Mineral Resources
Consultative Committee

Mineral Dossier No 22

Common Clay and Shale

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PREFACE

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

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

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

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

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SUMMARY

Clays and shales are argillaceous sedimentary rocks consisting of fine particles of clay and other minerals, the type and abundance of which are determined by source area rocks and climate, as well as depositional environment and diagenesis.

Such rocks outcrop over wide areas of the United Kingdom and are represented in practically all geological periods. The structural clay products industry is the largest user of clay and shale in the United Kingdom, but although a very wide variety of horizons and lithological types are utilized, some deposits are unsuitable e.g. many Lower Palaeozoic rocks, or sediments containing unacceptable amounts of impurities. Other deposits may be sterilized by development or there may be environmental pressures militating against extraction.

Brickmaking, in one form or another, has been known since at least 8000 B.C. In the United Kingdom today, common clays and shales are used for the production of building and engineering brick, floor and roofing tiles and agricultural field drains. They are also employed in the manufacture of vitrified clay pipe, lightweight aggregate and cement.

In 1978 the production of common clay and shale in the United Kingdom was 25.5 million tonnes, of which the heavy clay sector accounted for some 55%. The Oxford Clay remains pre-eminent as the major source horizon for building brick and field drain pipe clays (47% of UK brick pipe and tile production) while Carboniferous shales and the Triassic 'Keuper Marl'* are second and third in importance. The Etruria Marl has retained its traditional markets for top quality engineering bricks and floor and roofing tiles, as well as facing bricks.

The trend in the industry recently has been towards rationalization and larger production units, though some 200 works remain spread across Britain from Devon in the south to Grampian in the north. There has been a tendency towards better quality control and often complex blending of raw materials; the production of quality facing brick has greatly outstripped that of common brick, the latter having been largely replaced in internal walling by various dense and lightweight blocks.

* See page 42.

INTRODUCTION

This dossier aims to discuss those argillaceous rocks in the United Kingdom that are suitable for the manufacture of building and engineering bricks, tiles and agricultural land drains, as well as the technology, products and distribution of the structural clay products industry. Although a certain amount of this clay is used in the vitrified clay pipe, lightweight aggregate and cement industries, these sectors are more fully dealt with by other reports and a dossier in this series (for example Mineral Dossier No 23, Limestone and Dolomite).

Structural clay products are made from a wide variety of raw materials which are subjected to diverse production procedures, but in spite of the considerable technological advances which have taken place since the last World War, selection of the optimum parameters for the production of a given product remains largely empirical. Ultimately, firing tests remain the only certain method of determining whether or not a particular clay is suitable for the production of the particular product required, and how it will respond to different treatments. Much is known of the general properties which the raw material should possess, but because different clays vary so widely in mineralogy, texture, degree of lithification and crystallinity, each clay is to some extent unique and demands individual treatment. It is therefore difficult to approach the subject from a purely technical or academic standpoint. Such an approach might be practical if strength or durability were the main properties determining the saleability of the product. However, although certain minimum standards have to be met, the price is in large degree determined by the aesthetic properties of the fired material. Some bricks can be produced cheaply from particularly suitable raw materials, while other more expensive prestige bricks are produced that may be no more durable and often use clays that may be inherently less suitable from a purely technical standpoint. Because of this importance of appearance, minor differences in raw material composition may have a considerable impact in the facing brick and flooring tile sectors, and saleable products can be produced from apparently very diverse kinds of clay. Vitrified clay pipes and engineering bricks on the other hand tend to be made from a much smaller range of clays because technical specifications such as strength and permeability are of major importance.

Because potential source materials for building brick occur so widely, the choice of particular quarry sites is often an accident of history, of geography, or of fuel availability. The type of product and the techniques employed have then tended to evolve by trial and error to suit the raw material encountered. The resulting diversity is reflected in the wide-ranging treatment devoted by this study to each aspect of the production of structural clay products.

HISTORY

Brickmaking is one of the oldest crafts in the world. Some of the earliest bricks known come from excavated sections of ancient Jericho (8000 B.C.). These were sun-dried and it was not until the third millenium B.C. that kiln-firing for building bricks was introduced. Even today, more of the world's houses are built of unfired earth than of any other material. In the United Kingdom burnt bricks and tiles date from about the end of the 1st century B.C. and consequently the oldest bricks and tiles coincide with the beginning of the Roman occupation.

The Romans derived their art of brick and tile making from the Greek and Etruscan clay workers, but by 150 B.C. they had discovered how to produce a hydraulic pozzolan cement by mixing volcanic ash with lime. Concrete quickly replaced brick and tile as the major building medium in Rome, but even in those days the aesthetic qualities of fired clay were much appreciated, so old bricks and tiles were in demand for facing and cladding. Bricks were once more in production in Rome by the first century A.D. and at about this time fired clay drain pipes were in use in larger Roman houses, for example at the Roman Palace of Fishbourne in Sussex. Brick manufacture ceased with the departure of the Romans and it was not until the end of the 12th century that the English began making bricks by their own techniques and started a very stable industry which persists in modern times. The use of bricks was at first confined mostly to larger houses (though clay tiles were more widely used), and also to an area east of the Humber–Solent line where, apart from materials like flint and Kentish ragstone, there was a relative shortage of building stone. This area was also adjacent to the Netherlands and the Hanseatic towns of the North German Plains where there was already a long tradition of brick building. On the continent, the craft had not entirely ceased with the fall of Rome and had spread north from Italy to the Low Countries between the 5th and 8th centuries. Until the last quarter of the 17th century however, demand increased slowly.

The use of bricks for chimney shafts, and the use of roofing tiles in smaller houses, was practised from the 14th century onwards but it was not until the 15th Century that brick construction was used for smaller houses and became a common material over large areas of England. The popularity of brickwork continued with the building of such edifices as Hampton Court Palace in the reign of Henry VIII, and the Great Fire of London was largely responsible for transforming London from a wooden to a brick city, with other towns soon following suit.

Brick ceased to be simply a fashionable building medium at the beginning of the nineteenth century with the emergence of brick as the dominant structural material during the Industrial Revolution. Bricks were the main building medium of the Victorian and earlier 19th century engineers, and became the normal material for housing construction. Railway towns like Derby, Crewe and Swindon, not far from good building stone, were nevertheless built almost entirely of brick. So too were industrial buildings of all kinds and even such "prestige" structures as theatres, hotels, and other public buildings. Low cost and cheap labour were no doubt the principal reasons for this widespread use, but many Victorian architects came to prefer the use of brick.

In 1859 a steam-powered extrusion machine was invented and mechanisation of the industry advanced rapidly. In the same year a necessary complement to the brick machines, the Hoffman continuous kiln, was developed in Europe. Steam power also provided more powerful mineral extraction and dressing equipment so that grinding machinery for shales became available; this opened up large new reserves of raw material for use by the structural clay products industry. By 1875 steam presses and extrusion techniques had revolutionised the sewer pipe industry and superseded hand moulding for pipe production. Throughout the nineteenth century bricks were used in every kind of building and engineering structure including factories, canals, bridges and worker housing. A very important technological advance in the forming of extruded clay, introduced in 1932, was the incorporation of a vacuum chamber through which the plastic clay was forced before the shaping die to remove entrapped air. This resulted in increased product strength and improved uniformity and is now universally practised.

Since 1900 the brick industry has experienced a series of booms and slumps, reflecting changes in the nation's housing programme. The paving brick industry declined very rapidly in the 1920's with the introduction of concrete, and the brick industry as a whole moved away from the common brick market by greatly expanding the production of facing bricks. Competition from other building materials since the last World War has led to a trend towards decorative as well as functional brickwork in a variety of colours and textures.

Plain flat clay roofing tiles were probably in use in Britain before bricks. References to mediaeval tile-making are scarce but by 1300 many of the better homes in the southeast and east of the country had clay tiled roofs. By the nineteen-thirties Staffordshire and Shropshire had become important tile-making counties. The introduction of a brick tax in 1784 gave an incentive to the use of mathematical or brick tiles, so shaped that when fixed to a wall they resembled brickwork. In more recent years competition from other roofing materials has led to a severe decline in the clay tile-making industry. The 1784 tax also caused a setback in the land drain tile industry; the draining of land with clay pipes has been carried out for several centuries and with the removal of the general tax on clayware in 1850 land drains returned to popularity, although today they are partially replaced by PVC.

TERMINOLOGY AND CLASSIFICATION

The term 'ceramics' originally referred to products made from burnt clay, those articles used in the building and construction industries being classed as coarse ceramics or heavy clay ware. Today, ceramics also embraces glass and a variety of 'special' ceramics composed of a range of silicate and oxide components. 'Heavy Clay' is therefore an established, though scientifically rather misleading, term used in the industry to denote clays, shales, marls, mudstones, siltstones and brickearth used in the production of heavy clay ware. The term arose through the commercial description of the product rather than the raw material, but despite its colloquial usage there is no formal industrial definition of 'heavy clay'.

The clay products forming the subject of this study are fired, unglazed, structural clay ware. The finished goods are construction materials including bricks, roofing tiles, field drains, floor quarries and cable covers. The following types of clay are distinct commodities in their own right and are excluded: *i.* essentially kaolinitic clays, including the high grade china clays and specialised ball clays (Mineral Dossier No 11), *ii.* high grade smectitic clays such as bentonite and fuller's earth (Mineral Dossier No 3), and *iii.* fireclays for refractory and vitrified clay pipe uses. There is however a certain amount of overlap between the components of the various industrially used clays; some smectitic clays can, under the right conditions, be used in brick manufacture, while some bricks contain a significant proportion of fireclay. The terms 'brick clay' and 'common clay' are colloquially used to denote all clays and shales suitable for the production of structural clay products, lightweight aggregate and cement. The definition of 'clay' is itself perhaps less ambiguous than that of heavy clay, though there is still some confusion. In the ceramic industry 'clay' is a material which, when mixed with a suitable amount of water, can be shaped as required and will retain that shape during drying and firing. To an engineer the term 'clay' signifies a rock consisting of more than 50% particles of diameter less than $^{1}/_{256}$mm, while a mineralogist may describe any member of the several groups of naturally-occurring crystalline substances possessing a certain layer-lattice structure as a clay mineral. In fact most of the terms available (clay, mud, mudstone, etc) are defined by texture, although they generally apply to sediments containing substantial amounts of clay minerals. Both texture and mineralogy give rise to the industrially important property of plasticity. Clay has also been defined as a natural plastic earth composed of hydrous aluminium silicates, but this is inaccurate since the clay minerals may constitute less than 20% of the rock. It is perhaps better to use the qualifier 'argillaceous' to denote fine-grained rocks normally rich in clay minerals.

Numerous particle size boundaries between silt and clay have been adopted, and values proposed by most authors are in the range 0.0039mm (Udden-Wentworth grade scale) to 0.002 (Atterberg scale, U.S. Corps Eng. scale) (Figure 1). Material coarser than this, say 0.002 to 0.05 or 0.06mm is generally considered to be silt, which means that texturally many so-called brick 'clays' are in fact silts. According to Krumbein and Pettijohn (1938) a true clay is composed of grains at least 50% of which are less than $^{1}/_{256}$mm (4 μ) in size (diameter). The majority of these grains are clay minerals. These authors differentiate a silt from a clay in that more than 50% of the grains of a silt are between $^{1}/_{16}$ and $^{1}/_{256}$mm (625 and 4 μ) in size. Mud is a general term to include silt, clay and mixtures of the two; the suffix '——stone' refers to lithified sediments. 'Shale' implies a fissile mudrock, though it is frequently used *sensu lato* for all consolidated fine-grained sedimentary rocks that contain substantial quantities of clay minerals, (e.g. Coal Measures shales). Modern muds average approximately 15% sand, 45% silt and 40% clay (Picard 1971), but in ancient argillaceous rocks new clay minerals may form as a result of diagenesis, modifying the original composition.

Figure 1 Grain size scales relevant to brick making materials

Udden-Wentworth	*phi (ϕ) scale (ϕ = $-log_2d$)*	*USDA and Soil Sci. Soc. Amer.*	*U.S. Corps Eng., etc. (U.S. Standard Sieves)*
Very coarse sand		Very coarse sand	
——1mm——	0	——1mm——	Medium sand
Coarse sand		Coarse sand	
——0.5mm——	1	——0.5mm——	
			——40 mesh——
Medium sand		Medium sand	(= 0.42mm)
——0.25mm——	2	——0.25mm——	Fine sand
Fine sand		Fine sand	
——0.125mm——	3	——0.10mm——	
Very fine sand		Very fine sand	——200 mesh——
			(= 0.074mm)
——0.0625mm——	4	——0.05mm——	
Silt			Fines
——0.0039mm——		Silt	
	8	——0.002mm——	
Clay		Clay	

Suggested classification of mudrocks:

Ideal size definition	*Fissile mudrock*	*Nonfissile mudrock*
$^{2}/_{3}$ silt (particles 0.0039–0.0625mm size)	Silty-shale	Siltstone
$^{1}/_{3}$–$^{2}/_{3}$ silt (particles 0.0039–0.0625mm size)	Shale	Mudstone
$^{2}/_{3}$ clay (particles less than 0.0039mm size)	Clay-shale	Claystone

There are many colloquial terms describing clays and shales; an important term which has frequently been misused is 'brickearth'. The precise origin is in dispute but it has been traditionally applied to Quaternary ferruginous clay or silt, typical of Thames Valley and south-east England superficial deposits. These contain a high percentage of wind-blown, silt-sized grains or loess. In planning, civil engineering and trade terminology however, the term brickearth has wrongly come to be synonymous with 'brick clay', that is, any clay suitable for the production of bricks.

MINERALOGY AND PROPERTIES OF ARGILLACEOUS ROCKS

Argillaceous rocks exhibit various properties depending on the nature and quantities of the component minerals present. The mineralogy of a brick clay largely determines its properties in the wet and dry state, while its chemical composition influences its behaviour on firing. Clay rocks differ widely in chemical composition, but silica and alumina are by far the most abundant oxides because of the dominance of clays and quartz in the detrital fractions. Silica is present as part of the clay minerals and undecomposed silicates, and as free silica, usually quartz. Alumina occurs in the clay minerals and other silicates such as feldspar and micas. The abundances of other major oxides also derive from the mineralogy; ferric iron from haematite, potassium from mica (and illite), calcium from calcite, ferrous iron and magnesium from chlorite and dolomite, and sodium and potassium from plagioclase feldspar and montmorillonite. Iron also occurs in the sulphide pyrite, the carbonate siderite and the hydrated oxide goethite. Minor constituents may include titanium, manganese and phosphorus. Organic matter may be present in sufficient quantities to affect properties and energy requirements.

It is difficult to quantify the chemical composition of the typical or 'average' shale, though this has been attempted (Table 1). Extreme variations in composition exist; black shales commonly contain 5 to 10% organic carbon, lacustrine sediments often contain appreciable amounts of carbonates, many red sediments have high free iron oxide contents, argillaceous rocks containing authigenic felspar may contain as much as 10% potassium, and many mudrocks deposited in eugeosynclinal areas are high in sodium due to their content of volcanic detritus.

Clay rocks are thus composed essentially of two groups of constituents, clay minerals, which by their nature impart plasticity, and other 'non-clay' minerals such as quartz and accessories. For a complete understanding of the properties of clays, and the importance of these properties in the heavy clay ware industry, it is necessary to study the composition (Table 2) and crystal structure of clay minerals.

Clay minerals

Clay minerals have a number of common characteristics, most of them occurring as platy particles in fine-grained aggregates which when mixed with water yield materials of varying plasticity. The clay particles may be crystalline or amorphous, and though normally very small, may vary from colloid size to those easily resolved with an ordinary microscope. All clay minerals are hydrous silicates which on heating lose adsorbed water and water of crystallization. At high temperatures, the residual alumino-silicate material would provide a refractory product, but this is considerably modified by fluxes (alkalis and ferrous iron) which tend to form glassy phases of lower melting point.

The main groups of clay minerals and related sheet silicates may be listed as:

1. Kaolinite group, including kaolinite, and halloysite.
2. Mica group, including micas, illite (hydromica), glauconite etc.
3. Smectite group, including montmorillonite, hectorite, nontronite, saponite etc.
4. Hormite group, including attapulgite and sepiolite.
5. Chlorites.
6. Vermiculite.

Table 1 Average chemical composition of mudrocks *Wt. per cent*

	A	*B*	*C*	*D*	*E*	*F*
SiO_2	58.1	58.5	55.4	60.2	56.2	53.4
Al_2O_3	15.4	17.3	13.8	16.4	15.1	16.4
Fe_2O_3	4.0	3.0	4.0	4.0	3.4	3.4
FeO	2.4	4.4	1.7	2.9	2.3	2.8
MgO	2.4	2.6	2.7	2.3	2.1	2.4
CaO	3.1	1.3	6.0	1.4	4.4	5.8
Na_2O	1.3	1.2	1.8	1.0	1.1	1.1
K_2O	3.2	3.7	2.7	3.6	2.6	2.7
TiO_2	0.6	0.8	0.5	0.8	0.8	0.7
P_2O_5	0.2	0.1	0.2	0.2	0.1	0.2
MnO	tr	0.1	tr	tr	0.1	0.1
CO_2	2.6	1.2	4.6	1.5	3.3	4.3
SO_3	0.6	0.3	0.8	0.6	0.2	0.2
C	0.8	1.2	0.7	0.9	0.8	0.8
H_2O	5.0	3.9	5.6	4.7	5.0	4.5
Misc	—	1.2	0.1	tr	—	—
TOTAL	99.7	100.8	100.6	100.5	100.5	100.8

Notes:
A Average shale (78 samples): Clarke, 1924.
B Average slate (69 samples): Pettijohn, 1957.
C Average of Mesozoic and Cenozoic shales (27 samples, I analysis): Clarke, 1924.
D Average of Palaeozoic shales (51 samples, I analysis): Clarke, 1924.
E Mudrocks of Russian platform (relatively stable shelf area), Mesozoic to Cenozoic (4030 samples, 290 analyses): Ronov et al, 1966.
F Mudrocks of the Great Caucasus geosyncline, Mesozoic to Cenozoic (11,151 specimens, 455 analyses) Ronov et al, 1966.

Table 2 Chemical analyses of clay minerals *Wt. per cent*

	A	*B*	*C*	*D*	*E*	*F*
SiO_2	45.72	45.48	56.91	50.10	47.55	51.14
TiO_2	0.42	0.86	0.81	0.50	0.64	—
Al_2O_3	39.82	38.84	18.50	25.12	32.45	19.76
Fe_2O_3	0.10	0.19	4.99	5.12	0.76	0.83
FeO	—	—	0.26	1.52	1.85	—
MgO	—	0.17	2.07	3.93	1.70	3.22
CaO	—	0.24	1.59	0.35	0.06	1.62
Na_2O	0.16	0.24	0.43	0.05	1.05	0.11
K_2O	0.36	0.42	5.10	6.93	6.22	0.04
H_2O+	13.67	13.66	5.98	6.82	7.73	7.99
H_2O-	0.55	0.71	2.86	—	0.00	14.81
TOTAL	100.80	100.81	99.50	100.44	100.01	99.52

Notes:
A Kaolinite, Lewistown, Montana, containing 2.56% impurities (Kerr et al., 1950).
B Kaolinite, Murfreesboro, Arkansas, containing 2.81% impurities (Kerr et al., 1950).
C Illite, Fithian, Illinois (Kerr et al., 1950).
D Illitic material, Ordovician shale, near Gilead, Illinois (Grim et al., 1937).
E Hydromuscovite, average analysis of fine fractions from Coal Measure shales of South Wales (Nagelschmidt and Hicks, 1942).
F Pink montmorillonite, from shale, Montmorillon, France (Ross and Hendricks, 1945).

The first four groups comprise the important layered clay minerals; all these are sheet silicates, mostly hydrated alumino-silicates. Disordered kaolinite, illites, and, to a lesser extent, well-ordered kaolinites, mica, smectites and chlorite are the clay minerals normally found in brick making clays. The hormite group, rarely present in clays used to manufacture structural clay products, comprises clay minerals possessing a chain silicate structure. Because most brick clays are in fact composed of a mixture of clay minerals as well as other sheet silicates such as chlorites and micas, their physical properties are seldom attributable to those of a particular clay mineral.

The sheet silicate clays are built up from two characteristic types of layer. The basic unit of the first layer is a silica tetrahedron in which the silicon atom is surrounded by four oxygens (or hydroxl ions). Each of the three oxygens at the corners of the base of the tetrahedron is shared with an adjacent tetrahedron to build up a continuous sheet of composition $Si_4O_6\,(OH)_4$. The other layer comprises two sheets of close-packed oxygen and hydroxl ions in which aluminium, magnesium or iron cations are embedded in octahedral co-ordination with the anions. When aluminium is present, only two-thirds of the cation sites are filled, producing a gibbsitic layer, whereas with magnesium all the available sites are filled to balance the charge of the structure. Although the former applies only to free $Al(OH)_3$ – the gibbsite in bauxite – and not to the gibbsitic layer in silicates, a high gibbsite content will produce excessive cracking due to high water loss especially in fired thin shapes such as tiles (Cole 1959). In kaolinite, each unit contains a single silica tetrahedral layer bonded to a single alumina octahedral layer. This structural unit with the composition $Si_4Al_4O_{10}\,(OH)_8$ is the structure of kaolinite and contains 39.5% alumina, by far the highest alumina content of any sheet silicate clay (Table 2).

A poorly crystallised form of kaolinite is called disordered kaolinite. There is some randomness in the stacking and the ionic composition deviates slightly from the norm, there being substitution of Mg and possibly Fe^{2+} for Al in the octahedral layer. This results in a negative charge which is balanced by some other ion, commonly Ca^{2+}, and accounts for the slightly higher cation exchange capacity of disordered kaolinite. Clays characterised by disordered kaolinite, e.g. Devon and Dorset ball clays, and Etruria Marl, tend to be fairly refractory, of high plasticity and possess a long vitrification range. Well-ordered kaolinite is relatively poorly plastic. Kaolinite is a very important mineral to the ceramic industry since it occurs in, or may be added to, the raw material. In the structural clay products industry however, it is the disordered variety that is most commonly used, normally in amounts subordinate to illite. The two polymorphic forms of kaolinite, nacrite and dickite, are of little concern to industry. Halloysite contains the same type of silicate layer structure as kaolinite but in this case double layers of water molecules are present between the silicate layers. Slight dimensional imbalance between the octahedral and tetrahedral layers causes the structure to curl into a cylindrical shape instead of a flat layer as in kaolin. A high content of halloysite may lower the plasticity of a clay sufficiently to produce a brick with a poor bond. However, this mineral is of virtually no importance in British sediments used to manufacture heavy clay products.

Illites, smectites and vermiculites are all clay minerals which are structurally related to the micas, but closest similarity to the micas is shown by the illite group. In both illite and smectites the unit cell has an octahedral layer sandwiched between two tetrahedral layers. In illite, characteristic of, for example, the London and Gault clays, about one sixth of the Si^{4+} ions are replaced by Al^{3+}. The unit sheet therefore has an overall negative charge which is balanced by positively charged potassium ions that lie between successive sheets and bond them together. Substitution of up to 15% of the Si^{4+} by Al^{3+} is also found in smectites. In this case part of the resulting charge imbalance may be compensated for by the infilling of some of the vacant cation sites in the octahedral layer and by the partial replacement of oxygens by hydroxyl in the tetrahedral layer. The remaining imbalance is compensated for by exchangeable interlayer cations especially sodium and calcium. These cations are generally accompanied by one or two layers of water molecules between each unit sheet. Swelling of the structure is accompanied by an increase in the number of these layers of water molecules.

Illite is intermediate in many of its properties and burns to a satisfactory product at relatively low temperatures (900°–1000°C), so a clay composed dominantly of illite should theoretically be suitable for use in the heavy clay industry. The red-firing mineral illite is possibly the most widely distributed clay mineral in the world and many heavy clay products are made from raw materials in which illite is the dominant clay mineral. Marine clays such as the Lower Lias, Oxford Clay, Gault and London Clay are dominantly illitic and many contain a fairly high proportion of fine-grained mica. They are more plastic and less refractory than, for example, disordered-kaolinitic, deltaic Coal Measures shales. Deposits such as the 'Keuper Marl' (Mercia Mudstone Group) laid down in inland drainage basins are often characterised by illite, with high fine-grained mica and carbonate contents. The latter acts as a flux which reduces the refractoriness and vitrification range.

Smectites are the most plastic and possibly the least refractory of clay minerals (Grim 1940); they have high drying shrinkages, because of the high proportion of water needed to make them workable. They are therefore not common constituents of clays used for brick manufacture, but are sometimes important in individual deposits such as some of the Reading Beds where, with an admixture of sand, they produce good facing bricks. However, some clays may contain over 70% clay minerals with montmorillonite predominating, e.g. Clay-with-flints from the Yorkshire and Lincolnshire Wolds and some London Clay beds. This highly plastic material is poorly suited to brick manufacture. The structure of vermiculite is similar to that of smectite. All of the cation sites in the octahedral layer are filled with magnesium and divalent iron, and substitutions tend to be confined to the silica tetrahedral layers. Vermiculite is sometimes a very minor constituent of the common clays and shales used by the industry, and may be present in mixed-layer assemblages. Mixed-layer clay minerals result from the interstratification of different clay minerals, especially different three-layer clay minerals, within a single clay particle. Such interstratification may show a regular alternation of two minerals, or may exhibit a completely random arrangement. Some are known which consist of units of mica, chlorite and vermiculite; in others, hydrous-mica and montmorillonite layers may be included.

Mica group minerals are common constituents of brick clays, occurring in such deposits as the 'Keuper Marl', Lias clays and London Clay. They are also characterised by a platy shape with a perfect basal cleavage and possess a basic structure of a composite sheet in which a layer of octahedrally co-ordinated cations is sandwiched between two identical layers of linked silica tetrahedra. Varying amounts of micas are found in argillaceous sedimentary rocks, though much of the fine-grained material which was previously thought to be muscovite has proved to consist of mixed-layer structures of muscovite and montmorillonite, pyrophyllite, kaolinite or illite.

Chlorites are a group of sheet silicate minerals which physically resemble micas. They are often found in red-firing clays and shales used by the industry, sometimes in major quantities, and can have important effects on the properties of the end product. There are many mineral names in this group, but they are all part of substitutional solid solutions of a basic structure. In chlorite, illite-type sheets with the general composition $(Si,Al)_8\,(Mg,Fe)_6O_2(OH)_4$ alternate with brucite-like octahedral layers $(Mg,Al)_6(OH)_{12}$. The negative charge on the illite layer resulting from the substitution of Al^{3+} for Si^{4+} is compensated for by the substitution of Al^{3+} for Mg^{2+} in the brucite layer. Where the brucite layer is discontinuous the chlorite may exhibit swelling properties. Such swelling or expanding chlorites are found for example in the 'Keuper Marl'. High proportions of sheet silicates that bloat on firing, such as chlorites, are detrimental to brick, pipe and tile-making and an upper limit of 10% chlorite in clays for hollow ware is considered reasonable. Septechlorites are two-layer sheet silicates with the same structure as kaolinites. Chemically, however, they contain more magnesium and/or iron, and less silicon and aluminium than kaolinite, as a result of cation substitution in both layers of the structure. The only septechlorite which may be of importance to heavy clay manufacturers is the hydrated magnesium iron aluminium silicate, chamosite.

Because of the relative weakness of the bonds between structural units in sheet silicates it is easy for percolating waters to remove interlayer ions and to add cations during weathering and diagenesis, and clays with less than stoichiometric amounts of these ions are termed 'degraded'. Most natural illites and montmorillonites in sediments are degraded, as are many chlorites, biotites and muscovites. Montmorillonite contains three times as much sodium and calcium as illite but the $FeO + Fe_2O_3 + MgO : K_2O$ ratio is about the same in the two minerals (Fig. 2). The large amount of potassium in the montmorillonites probably reflects their origin as degraded illites retaining some pottassium. Kaolinite, consisting as it does of only a tetrahedral layer and a gibbsite layer, is nearly devoid of metallic cations other than aluminium and silicon.

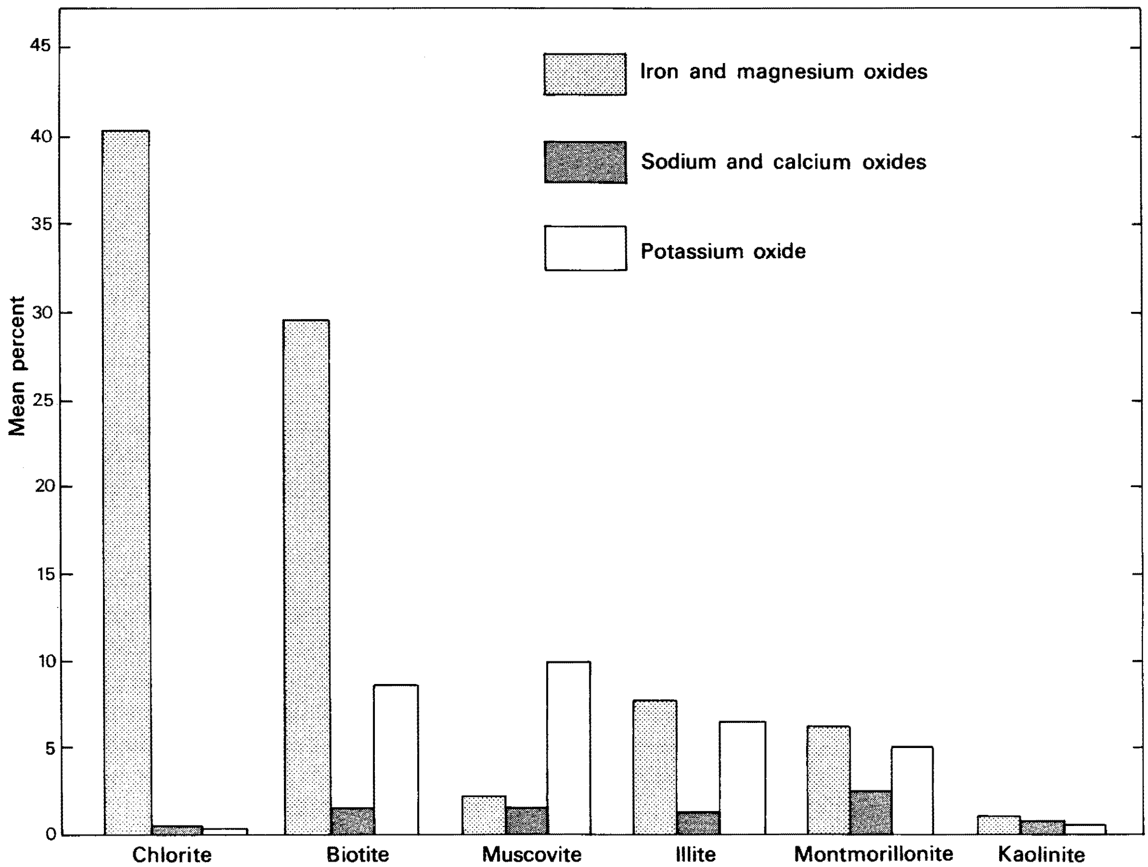


Figure 2 Average amounts of metallic cations (except aluminium) in the most common micas and clay minerals (after Blatt, Middleton and Murray, 1972)

Most clays and shales contain other minerals that are not essential for the manufacture of heavy clay products, but which nevertheless have to be considered during production. Some of these constituents may be beneficial, others detrimental. In general, any inhomogeneity in the raw material is to be avoided, but the economics of the industry are such that very little beneficiation is possible. Impurities may be chemical or physical; the latter are often avoided during winning or removed early in processing, for example important lenses and beds of sand or sandstone which reduce plasticity and strength of the product, or pebbles which cause drying and firing problems due to localized differential thermal expansion and contraction.

Quartz and feldspar

Fine-grained quartz, which is necessary as a filler in structural clay products, is ubiquitous and is normally the commonest mineral in brick clays and shales. The size and shape of the grains is determined by their origin and method of transport and deposition; much of the material is less than 20 μ (0.02mm) in size. Some tiny grains of flint are occasionally present in post-Cretaceous formations e.g. London Clay, Brickearth etc. A high ratio of quartz to clay minerals in a clay or shale will cause poor plasticity and a low-strength product. The 1 per cent volume changes that accompany the alpha- to beta-quartz inversion during firing and cooling tend to weaken the body still further. However, during the vitrification period quartz combines with the basic oxides of the fluxes to form a glass which is responsible for the strength of fired ware.

The small to trace amounts of feldspars that occur in most brick-making clays act as inert fillers throughout the manufacture of red-firing products, but can act as fluxes in the higher temperature fireclay raw materials. Alkali feldspars however, are strong fluxes across most of the brick firing temperature range.

Carbonates

Carbonate minerals are frequently present in small quantities in brickmaking clays. They may occur as calcite (calcium carbonate) dolomite and magnesite (magnesium carbonates) and siderite or ankerite (iron carbonates). They are particularly common in clays associated with evaporite sequences, such as the 'Keuper Marl', and in some glacial clays (Till) and marine clays (Gault, Jurassic etc). Calcite is the commonest carbonate which may occur in limestone bands, lenses, veins, nodules, fossils and as cement in many clays and shales. Dolomite is commonly found in the 'Keuper Marl' and in certain Palaeozoic periods such as the Devonian.

The term marl has frequently been used to denote certain limey clays or muddy limestones. Only a clay containing more than 25% of carbonate minerals should be described as a marl and the so-called 'marls' used by the brick and tile industry in this country rarely contain enough carbonate to fit this definition. In most clays and shales used to manufacture structural clay products the total calcium and magnesium oxides present as determined by chemical analysis rarely exceed 15%. The Etruria Marl, as used, normally contains from 0.2% to 0.5% CaO or about 2% in the calcareous horizons. The 'Keuper Marl' contains more, from 2.5% to as much as 14%. The effect of carbonate in clays used in brickmaking varies depending on how intimately the clay and carbonate are mixed. Lime and magnesia are important fluxes which form low viscosity silicate liquids abruptly during firing, reducing the vitrification temperature and shortening the vitrification range. This gives rise to critical firing conditions which must be carefully controlled. Although excessive amounts of calcite and dolomite result in a completely unstable product, calcareous shales and clays with low proportions of these carbonates can be successfully used in the industry provided special care is taken to ensure that carbonate is evenly and finely distributed throughout the product. In the Weald Clay of southern England, operators avoid horizons containing calcareous microfossils, but up to 10% finely disseminated carbonate is tolerable. The Gault Clay, with up to 19% CaO, has been successfully used for many years.

On heating to 900°C, carbonate minerals decompose with the evolution of carbon dioxide and leave behind very reactive oxides. The presence of free or unreacted oxides in the fired product is detrimental since they will hydrate (or slake) on exposure to the atmosphere and convert back to the carbonate form by reaction with moisture and carbon dioxide. This results in expansion with emission of heat and rapid disintegration of the product. The phenomenon of lime-blowing or bursting commonly occurs when clays containing nodules and patches of calcium carbonate or calcareous fossils are fired. Such raw materials, or those clays interbedded with limestone or dolomite horizons, must therefore be ground to 20 mesh or finer in order to prevent lime bursting.

More than 5% localised calcium carbonate, with the exception of the Gault Clay, can cause serious shrinkage and slumping of the product during firing. Expulsion of carbon dioxide from clays with a carbonate content in excess of 15% may produce bricks with too high a porosity, depending upon the amount of void filling produced by vitrification. As the strength of a brick depends largely on its lack of porosity and hence on the carbon dioxide emission and degree of vitrification, it is often difficult to produce a really strong brick from calcareous or carbonate-rich raw materials.

Typical porosities may be as follows:

Type of brick	*Bulk Density kg/cm²*	*Porosity % vol.*
Low-grade commons	1.2	55
Medium-grade commons	1.6	41
Low-grade facade wall brick	1.8	33
Better quality facade wall brick	2.0	26
High-grade external brick	2.3	15
Grade B engineering brick	2.5	7.5
Grade A engineering brick	2.6	3.7

Engineering bricks are required to have great mechanical strength so they must be as dense and non-porous as possible. The clays from which they are made therefore have a low carbonate content and possess a higher proportion of such fluxes as iron and manganese compounds. They may be fired to temperatures well above normal brick making temperatures.

Siderite may occur alone or with other carbonates, especially in clay ironstone bands, concretions and nodules. It can cause lime-blowing and iron spotting as well as brown staining of structural clay products.

Sulphates

Various sulphate minerals present in brick-making clays and shales are detrimental because they cause scumming and efflorescence. Calcium sulphate occurs in the anhydrous form as anhydrite and more commonly in the hydrated form as gypsum. Occasionally the magnesium sulphate epsomite is encountered. Clays noted for the presence of sulphates are the Etruria Marl, 'Keuper Marl', Weald Clay and London Clay. The clear crystalline form of gypsum, selenite, is common in the weathered zones of the London and Oxford Clays. Calcium sulphate can form by the reaction of calcium carbonate with pyrite or with sulphur dioxide from the fuel used during firing.

The reaction between calcium sulphate and the aluminosilicates and silica in clays is important to the heavy clay industry since it is related to the problem of efflorescence. Calcium sulphate does not decompose by itself in the temperature ranges of most structural clay ware. If even a trace remains it will cause efflorescence when the product is exposed to moisture, due to the solubility of this salt. The effect is normally unsightly rather than harmful, but as little as 0.05% magnesium sulphate produces efflorescence which can cause severe decay. Sulphates in solution may also react with the tricalcium aluminate of Portland cement to cause expansion of mortar joints and resultant disintegration. Drying scum due to soluble salts can be minimised by the addition of a specific amount of barium carbonate, which then precipitates barium sulphate and calcium carbonate. Harder firing techniques may also help by removing sulphur dioxide and decomposing the sulphates. Indeed the most effective way of minimising soluble salts in the product is to fire to as high a temperature as the clay will permit. However, since no chemical treatment is wholly effective against efflorescence it is important that the salts content of the clay feed is kept within certain manageable limits.

Sulphides

The more typical sulphide minerals found in clays are the iron disulphides, pyrite and marcasite. Pyrite is usually found in clays which were deposited or altered during diagenesis, in a reducing environment, and occurs associated with organic matter, being a by-product of the bacterial breakdown of organic matter and reduction of sulphates. It may be present as disseminated tiny grains in, for example, Lias clays. On firing in the presence of moisture this produces sulphuric acid vapours that may attack metal-work and chimney tops. Pyrite may also occur as distinct yellow cubes or in a nodular or fibrous habit. Radiating needle clusters of marcasite in a clay are easily oxidised to ferrous sulphate on weathering to produce a white scum. Iron sulphides are common in Coal Measures fireclays and shales and are avoided if possible as they produce black spots if grinding has not been fine enough; otherwise they form masses of fused slag.

Pyrite decomposes on heating to produce ferric oxide and sulphur dioxide. Incomplete oxidation (e.g. in the presence of organic matter) yields ferrous compounds which flux with silica to form black glassy phases – the origin of 'black coring' in some bricks. If the vitrified material forms an envelope arround ferrous sulphate in the core, and the body is heated until this decomposes (before finishing temperature), gases cannot escape and bloating and distortion occur. Bricks have to be fired, therefore, at a rate such that the gases evolve before vitrification begins. The addition of small quantities of ammonium chloride sometimes helps to assist the decomposition of pyrite.

Carbon and organic matter

Many clays contain a proportion of carbonaceous matter which can be either detrimental or advantageous in the production of structural clay ware. Organic matter may be disseminated throughout the clay or may occur as seams or lenses. In the latter case it is troublesome, since complete homogenization of the clay feed becomes difficult and unless complete oxidisation of the carbon is achieved during firing, black coring and bloating may result. Even minute quantities of organic constituents can produce black coring in dense-fired ceramic products if they are not burned out during the heating-up period. The rate of burning out is governed by the density of the body, the atmosphere during firing, and the amount of organic matter contained in the body. Highly bituminous clays have to be fired with care to avoid over-vitrification, and the ease and speed of temperature control within the kiln are very important.

However, the organic content of the raw material may be particularly helpful when uniformly distributed throughout the clay as it can considerably reduce the need for conventional fuel during firing. Finely ground coke breeze is added to clamp-fired bricks and provides sufficient heat on controlled burning to fire the bricks completely without the need for additional fuel. The addition of about 5% of coal in small lumps to the clay feed produces localised reducing conditions and a pleasing mottled appearance to facing bricks.

Carboniferous Coal Measures shales and the Lower Oxford Clay both contain above average amounts of carbonaceous matter which is used to advantage by industry in their firing. A certain proportion of 'firey' organic-rich shale is incorporated in the Scottish Coal Measures raw material and the additional fuel requirement is greatly reduced. However pyrite is also common and black coring frequently occurs.

The organic content of clays has been used to advantage most effectively in the fletton industry, as the high carbonaceous content of the Lower Oxford Clay acts as a built-in fuel having a calorific value equivalent to almost 5% organic material. Conventional fuel need only be added to start the firing and to maintain a constant temperature, the bricks reaching full firing temperature of 1000°C by virtue of their organic content alone. Most other clays used in the heavy clay ware industry, however, are chosen to contain less than 2% carbon in order to make control of the firing easier.

Iron oxides and the effect of raw material composition on fired colour

Iron oxides including hematite, goethite and magnetite occur in brickmaking clays and shales in amounts from 1% to 8%. Clays whose depositional or diagenetic environment has been oxidising, tend to contain iron oxides as their colouring agents. Goethite (hydrated iron oxide) imparts a yellow colour, while hematite produces a deep red colour. The colour resulting from the presence of hematite is temperature dependent; at low temperatures it is almost orange but as the temperature rises darker reds are produced until at 1316°C the colour is almost black. The black colour is produced by reduction of Fe_2O_3 to Fe_3O_4. The development of colour control is dependent upon the highest temperature reached by the product, and reduction of iron oxide at high temperatures can be used to produce a brown or tan brick (Table 3).

Although the fired colour of brick clays is due chiefly to oxides of iron, it can be appreciably modified by the type of clay mineral, by the presence of other constituents such as lime, and by the kiln atmosphere. Calcium, magnesium and aluminium oxides reduce the colouring effect of iron, while the presence of titanium oxide enhances it. Buff to white-burning clays may produce pale colours on firing for different reasons; fireclay may be buff-firing since kaolinite is the predominant clay mineral and total iron oxide content is relatively low, while a grey shale or blue clay may be buff-firing because of a high calcite content. Normally red-burning clays will burn yellow if a proportion of finely-divided lime is added to the mix; this is a common practice in, for example, the manufacture of yellow stock bricks from brickearth. If calcium carbonate is present, the very reactive calcium oxide remaining on evolution of carbon dioxide combines with the decomposed clay to form crystalline calcium alumino-silicates which take up iron in the lattice and prevent the formation of free iron oxides, the usual red pigment in fired clay. If the $CaO : Fe_2O_3$ content is greater than 2:1 as in Gault Clay, cream and pale yellow colours are produced. A ratio of 1.5 to 1.8 forms yellow in reducing conditions, but can form pinks or reds in oxidising conditions. The bleaching effect of the carbonate is inhibited if sulphur dioxide (from the kiln) is present, since the calcium oxide then converts to calcium sulphate. The buff-fired colour of low grade fireclays may be due to the ability of Fe^{3+} ions to enter the mullite crystals by substitutional solid solution. This solid solution reaction (between mullite and Fe_2O_3) removes the red hematite phase from the body when enough mullite has been developed to accommodate all the iron oxide present, thereby eliminating its characteristic red

Table 3 Physical Properties of some Brick Clays

Deposit/ Horizon	*Particle size (% smaller than 2 μ diameter)*		*Working moisture content (% dry basis)*		*Linear firing shrinkage (%) at different temperatures*		*Fired colour for different temperatures*	
	Range	*Average*	*Range*	*Average*	*Temperature (°C)*	*Range*	*Temperature (°C)*	*Colour obtained*
Coal Measures shale (outcrop)	*16–78*	*34*	*15.1–31.2*	*19.5*	*1050°*	*0.2–7.7*	*1050°*	*Light salmon, red pink, light cream*
					1180°	*2.0–9.7*	*1180°*	*Green-grey, dark brown, chocolate brown, greenish-yellow*
Coal Measures shale (from coal seams)	*14–43*	*26*	*15.0–25.1*	*17.8*	*1000°*	*0.4–5.1*	*1000°*	*Salmon pink, pale pink, buff, white*
					1180°	*0.7–7.7*	*1180°*	*Green-grey, light-grey, cream*
Etruria Marl	*24–74*	*47*	*15.2–30.2*	*23.6*	*1180°*	*0.6–12.1*	*1000°*	*Light buff, pink buff, light red, light brown, light-chocolate brown, pink cream*
							1180°	*Dull brown, red brown, purple brown, medium red, stone, greyish buff*
Weald Clay	*15–85*	*47*	*23.8–42.2*	*30.9*	*900°*	*0–3.4*	*850°*	*Salmon pink, light red-brown, buff*
					1100°	*1.5–8.6*	*1200°*	*Dark red-brown*
Boulder clays	*30–60*	*47*	*17.1–39.6*	*28.8*	*900°*	*0.1–4.3*	*880°*	*Salmon pink, light brown*
					1070°	*2.5–9.4*	*1070°*	*Light chocolate-brown, light brown*

(from W. E. Worrall 1964)

colour (Brownell 1958). A clay with 5–9% iron oxide, 10–22% alumina and little or no calcium oxide content will fire in various shades of red. A higher alumina clay, containing say 25% alumina and only 1%–3% iron oxide will fire to a buff colour.

Illitic clays and shales generally mature at lower temperatures than fireclays. The fired colour is always red on oxidation since they do not develop a sufficiently large mullite phase to accommodate all the ferric iron in solid solution; since Fe_2O_3 is unreactive at these temperatures, it remains, giving its red colour to the products. When red-firing clays are heated, light shades of pink appear at first. In an oxidising atmosphere a deep red colour is produced. When alternating oxidising and reducing conditions of firing are used, buff-firing clays give yellow and brown colours, while red-firing clays turn dark brown. Browns can also be induced by overburning normal reds or by adding small quantities of manganese dioxide to the mix.

A process often carried out in the floor tile sector of the heavy clay ware industry is 'flashing'. This involves manipulation of the valence state of iron oxide to produce special effects. Various shades of tan, brown and black can be produced from normally red-firing clays by reduction of iron oxides at the top temperature. A particularly pleasing mottled effect can be achieved by alternating reducing and oxidising conditions. Reoxidation during cooling of the tiles tends to turn parts of the surfaces back from brown to shades of red. Blue bricks can be produced by completing the firing in a reducing atmosphere; this causes the ferric iron compounds to convert to ferrous compounds resulting in blue or black colours.

Thus, the content of iron oxide in a clay determines its fired colour though this is modified by aluminium, magnesium and calcium oxides. The colour is darkened by increasing the firing temperature and variations can be achieved by controlling the oxidation-reduction conditions in the kiln. Varieties of colours can also be achieved by adding a stain to the mix or by varying the position of the bricks in the kiln. Bricks composed of normally red-firing clay can be made to fire multi-coloured if placed at the centre of a clamp or setting where air flow is restricted.

A slightly unusual method of producing a buff-fired brick is carried out at one works utilizing glacial lake clays. Here, one particular horizon is composed of extremely fine-grained disordered kaolinite which, during blending and mixing with other clays, coats coarser red-firing particles and causes their red-fired colour to be masked. Thus by blending only one-third buff-firing clay with two-thirds red-firing clay a buff-bodied brick can be economically produced.

Water

Clays naturally contain a large amount of water which may be present in several different forms, including pore water and water chemically bound into the structure. Pore water or free water is that which is not combined in any way with the minerals and which is drawn into the clay by capillary action. Moisture content depends on the porosity of the clay and therefore depends to a considerable extent on its grain size. Clays containing a high proportion of grains greater than $2\,\mu$ diameter tend to have a high porosity and water content. Specific surface area is important, as well as the amount of interlayer absorption of water (e.g. the swelling clays). When sufficient free water is present to cause partial separation of the grains, 'stickiness' is developed and deformation is easy. Too much water in a clay is undesirable since control of the moisture content in the clay feed is then difficult to achieve. Excess water may also cause high and irregular shrinkage during drying. The Lower Oxford Clay has a natural water content of 17.5–19% by weight and water addition or removal is not generally required, the clay being used at the moisture content as dug, although not for plastic forming.

Combined water in clays is an integral part of the crystal lattice and is liberated only at comparatively high temperatures when the mineral decomposes during firing (above 450°C). Absorbed water is that which is taken up within the crystal lattice from the atmosphere. This water is related to the swelling of clay minerals and montmorillonite for example, can absorb moisture between the layers of the crystal so that the lattice expands. Adsorbed water is related to the exposed surface area of the mineral and is thus different from absorbed water which enters the crystal lattice. The amount of adsorbed water is controlled by the specific surface area and charge on the surface of the clay mineral and therefore by the degree of fineness of the grains in a clay. It is important to remove all water at as low a temperature as possible in the production of structural clay ware, in order that the water vapour formed should not interfere with the oxidation reactions that must occur to remove certain impurities.

The basic requirements of a raw material for the heavy clay industry, then, are clay to provide plasticity, a fluxing material (commonly the alkali elements sodium and potassium), and a filler to control shrinkage and warping of the body. These ingredients normally occur naturally in the clays and shales used by the industry; where they do not, the raw material may have to be modified by additives. The common red-burning clays of the industry are predominantly illitic and essentially contain their own flux, as illite contains both potassium and magnesium. The inert filler material is provided by the fine-grained quartz present in such clays. Fireclays used as additives to produce buff-firing bodies contain kaolinite as the major mineral, but also contain minor amounts of illite which again act as a flux.

Technologically important properties

Plasticity is the ability of a clay to take up water and for the clay-water mass at its optimum consistency to be shaped and to hold that shape after the forming forces are removed. A clay's plasticity is affected by mineralogical composition, particle size, shape and distribution, cation exchange capacity, nature of cations, pH, and water content. To achieve plasticity the clay mineral particles must have an irregular shape, there must be strong surface forces on the particles due to incompletely co-ordinated small cations with large charge, and there must be a rigid water structure surrounding the clay mineral particles. Such factors as the type of cations adsorbed on the particles, the small particle size, the presence of non-clay particles and the temperature of the clay-water system are not vital to the development of plasticity but can markedly alter its magnitude.

The actual plasticity of a clay rock is the plasticity it exhibits as found (in situ or in hand specimen). Its potential plasticity is the maximum plasticity which can be developed by mixing with a suitable quantity of water. Many natural clays and shales require the addition of water to develop their plasticity. Grinding, vacuum treatment and weathering (souring) can also increase plasticity. Other clays are too plastic or sticky to be used in their natural state and must be treated or blended to reduce their plasticity. Plasticity and workability can be imparted to weak clays by the addition of calcium or ammonium-based sulphite lye.

Clay minerals that impart high plasticity usually have high moisture adsorption values, and those that are not very plastic, such as well-ordered kaolinite, have low moisture adsorption values (MA) (see Figure 9). The MA value thus gives an indication of the plasticity of a clay, since one with a high proportion of non-plastic clay mineral and one with a low proportion of very plastic mineral will both have a low MA value, whereas a clay with a high content of highly plastic clay mineral will have a high MA value. Moisture adsorption is a factor determined by the absorption of water molecules onto the surface of clay crystals and is proportional to the specific surface area of the mineral. Ignition loss is the result of the driving off of combined water of the clay crystal when allowance has been made for carbonates, carbon, sulphates etc., which also contribute to the total loss.

Well-ordered kaolinite is only moderately plastic but the disordered varieties, which are common in ball clays, fireclays and some brick clays are much more plastic. The ratio of ignition loss to moisture adsorption broadly separates clays into kaolinites, illites and smectites, i.e. into species of increasing complexity, disorder, plasticity and affinity for water (Fig 9). At one extreme of the scale difficulties in extrusion will be encountered, at the other extreme excessive plasticity occurs leading to severe shrinkage. To improve the workability of a schistose clay or shale a high-swelling and low viscosity sodium bentonite can be added. This alters the clay's green and dried properties sufficiently to enable easy working.

Green strength is the ability of a clay, after it has been rendered plastic by the addition of water and has been shaped, to retain that shape till it is dried. It must be adequate to allow the ware to be handled without damage. Very small variations in the water content of clays can greatly affect their green strength which increases with increasing water content up to a point and then decreases. The values quoted below (Table 4) for certain clay minerals were obtained at moisture contents giving maximum strength.
(Hofmann. U, 1954).

Table 4 Green strength (kg/cm^2)

Kaolinite	0.34–3.2
Illite	3.2
Calcium montmorillonite	5.0

In most clay minerals the particle size, degree of crystallinity and orientation of clay particles to each other also cause variations from the generally accepted norm. Poorly ordered kaolinitic, chloritic and illitic clay tends to have greater green strength than similar clays with better ordered clay minerals. The green strengths of montmorillonites tend to be greater by a factor of two or more than that of the above minerals, and the calcium-rich varieties will have greater green strength than those carrying sodium cations. This is partly due to their small particle size and their pronounced ability to hold water in a well-ordered condition.

The presence of large amounts of non-clay minerals reduces green strength, but small amounts of quartz actually increase the green strength if they are evenly distributed because they permit the development of a more uniform clay body. Normally a significant reduction in green strength occurs only when more than 25% non clay minerals are present, but with montmorillonitic clays the figure is 50% or more. A high content of well-sorted fine silt imparts a very low green strength to clays so that handling without damage is difficult. These clays may look plastic but they contain too much material of low water-adsorbing capacity and too little clay mineral. A reasonable green strength is perhaps even more important in pipe and tile manufacture than in brick manufacture since the formed body is much thinner and some manual handling still forms part of most tile making processes.

Dry strength, the resistance a clay offers to a load, is expressed in terms of the modulus of rupture and is much greater than the green strength. Values of the dry strength of individual species are shown below in Table 5.

Table 5 Dry strength (kg/cm^2)

Kaolinite	0.7–49.4 (occasionally up to 75 e.g. for ball clay)
Illite, chlorite	15.2–75.7
Montmorillonite	19.3–58.4 (occasionally up to 100)
Attapulgite	45.7

From this it will be seen that the range of dry strengths overlap considerably for kaolinite, illite, montmorillonite, chlorite and attapulgite, suggesting that the clay mineral itself is not the major factor in determining this property of clays.

The most important factors affecting dry strength are the grain size, moisture content, area of contact between adjacent particles, abundance of non-clay minerals, texture and the production method used. Non-clay components present in large amounts tend to reduce dry strength, particularly if the particles are well sorted. However, small amounts of poorly sorted non-clay minerals or organic matter can increase dry strength. Clays with small sized clay mineral particles tend to have higher dry strengths than those with large clay crystals and it has been shown that in kaolins the fraction finer than 0.25 μ has about 30 times the dry strength of the fraction over 1 μ. High values given by montmorillonites are a consequence of their ability to break down to a very fine grain size. Clays composed of poorly ordered clay minerals or mixed-layer assemblages show higher dry strength than clays composed of well-ordered or single layer types. Dry strength is sometimes also increased with the substitution of sodium for other cations, since its dispersing effect increases the fineness of the clay mineral particles.

Texture is also important; too lean a mixture or a mix in which the clay particles do not come into contact with each other results in low dry strength. Thus careful blending and mixing of clays is very important in the heavy clay industry, especially where sand is added to impart body, to ensure an even distribution of the clay minerals. The attitude of flake-shaped or elongate particles can be important since certain arrangements may produce interlocking and hence increase strength. Lastly, the denser packing of particles achieved by de-airing ensures a higher dry strength in the product.

Drying shrinkage is the reduction in size of a mass of shaped clay when pore and adsorbed water are driven off by drying and is normally expressed as per cent reduction in size.

Table 6 Linear drying shrinkage of clay minerals (after White 1947).

Kaolinite	3–10%
Illite	4–11%
Montmorillonite	12–23%
Attapulgite	15%
Halloysite	7–15%

The amount of drying shrinkage is usually related to the water of plasticity value (the amount of water required to develop optimum plasticity in a clay). It increases as the water of plasticity increases and, for a given clay mineral, as the particle size decreases. Drying shrinkage also varies with the degree of crystallinity of the clay mineral (mixed-layer and poorly ordered clays producing high values), and the shape of the clay minerals; elongate and fibrous clays tend to have large shrinkage values because of their looser packing. Non-clay minerals reduce drying shrinkage by amounts varying with their shape, particle size distribution and abundance. The presence of about 20% sand in a clay is generally desirable to reduce the shrinkage of the body. This amount does not adversely affect other ceramic properties and it is common practice to mix sand with certain very plastic clays such as montmorillonitic types from the Reading Beds. Drying becomes increasingly difficult as the particle size and amount of non-clay mineral decrease. In clays carrying cations other than sodium, the ease of drying is increased as the water of plasticity decreases. When sodium cations are present a large proportion of the water is adsorbed on the clay mineral surfaces and little pore water is available to escape easily. Thus, because of their water adsorption and dispersion properties, and because an impermeable layer is formed on the surface of the body during drying, sodium montmorillonite is more difficult to dry than other clays. Finally, because satisfactory drying also depends on uniformity of texture throughout the clay body, drying problems can often be traced back to the clay preparation and forming processes.

In general, kaolinitic clays are fairly easy to dry, while illitic and smectitic clays are difficult; clays between these two extremes, including disordered kaolinite or mixtures of kaolinite and illite with intermediate properties, tend to show cracking which is very detrimental in, for example, tile making. The nature of the clay minerals present thus have a crucial role in determining the drying properties of clays and may be more important than either the particle size of the material or the proportion of clay minerals present.

Notes on the properties of raw material for lightweight clay aggregate and vitrified clay pipe.

The most widely occurring materials that can be used to produce lightweight aggregates are common clays and shales. When certain clays, shales and colliery wastes are heated to incipient fusion, they expand or bloat, due to the rapid generation of gases within the material. The cellular structure is retained on cooling producing a lightweight material suitable for use as an aggregate. To reduce energy costs the clay should soften at a fairly low temperature and should contain minerals which emit gas at this temperature. The glass formed on heating the clay or shale must be of such a viscosity as to entrap the gases formed.

This bloating phenomenon has been of interest for many years, although to brick manufacturers it is an undesirable property. Riley (1951) plotted the chemical compositions of a large number of clays on a triaxial diagram and found that bloating clays fall within a limited area. Many brick clays and shales are suitable, especially if their chemical composition falls within the limits:

SiO_2	5–60%
Al_2O_3	10–25%
Alkaline earth fluxes	7–25%

Riley considered that this area bounded the composition limits from which a sufficiently viscous glass would be formed on heating. However, this composition does not necessarily imply a bloating clay as the viscosity of a glass depends on the clay minerals present and on the combination and ratios of the fluxes. The rate of heating or firing cycle can also be important. Silica and alumina increase the viscosity of the glass, soda and potash widen the vitrification range,and calcium, magnesium and ferrous oxides decrease the viscosity and shorten the vitrification range. The alumina-rich kaolinite minerals do not bloat because a glassy phase is not formed until they are heated to 1400°C, while illites, smectites and chlorites bloat because their high content of alkali or alkaline earth elements promotes the formation of a glassy phase at 950°C–1050°C.

The bloating gases may be one or a combination of the gases carbon dioxide, sulphur dioxide, oxygen and water. These gases can be formed from included carbonates, organic matter, sulphates, sulphides, clay minerals or ferric oxide. Bloating can be enhanced or activated by careful additions of such substances as, for example, lignosulphonates, sodium carbonate and fuel oil.

Full details of raw materials for *vitrified clay pipe* manufacture are available in the document on fireclay in this series (Highley[1]); but it is pertinent to note here that with the introduction, after the Second World War, of tunnel kilns, allowing much better temperature control, and high pressure extrusion equipment, clays

[1] In the press.

with lower and shorter vitrification ranges came into use and the need for a refractory clay diminished; thus a much wider range of raw materials became available to the pipe manufacturer.

Raw materials are currently required to vitrify between 1000° and 1100°C to produce a pipe with a final porosity between 2 and 7%. Firing shrinkage must be predictable and constant and, because of tight dimensional tolerances, an adequate vitrification range is still essential to offset any temperature differences within the kiln. More than 40%–45% quartz of coarse silt size is unacceptable since this would reduce the plasticity and green/dry strength of the clay. Deleterious impurities include carbon and sulphur, since they cause bloating, so that less than 1.5% carbon should be present with even lower levels of sulphur. A high lime content is also undesirable as it induces very short vitrification ranges, lack of firing control and produces porous ware susceptible to attack by acids.

The raw material requirements for vitrified clay pipes are similar to those for engineering bricks, where a dense, well-vitrified, high-strength body of accurate shape and dimensions is called for.

Although a large amount of fireclay is used in vitrified clay pipe manufacture, shales and mudstones with suitable compositions are also blended, notably from the Lower Coal Measures.

To summarise, although the permissible range of composition of brick clays tends to be wide, the uniformity of the chemical, mineralogical and particle size composition of the raw material is of increasing importance to meet physical standards and aesthetic qualities. Any variation in feed tends to complicate the generally highly automated manufacturing processes of the industry. The economics of the industry are such that the amount of beneficiation tolerable is minimal. Although lime, dolomite, soluble sulphates, sulphides, halides and, in some cases, iron oxides must be low, some clays containing a substantial proportion of one or more of these can be worked with due care. The process may be specially adjusted to cope with particular clays, or impurities may be rendered harmless. Despite the heterogeneous nature of the clays and shales used by the heavy clay industry, efficient clay preparation and mixing minimise the risk of large localized impurities, and careful control of firing can help towards the production of the most durable product obtainable from a particular raw material.

ORIGIN AND OCCURRENCE OF ARGILLACEOUS ROCKS

Origin

When silicates of primary crystalline rocks are decomposed by weathering, the products include hydrated aluminium or magnesium silicates (clay minerals). The relationship is illustrated by Table 7 (Keeling 1963) which shows that the average composition of the earth's crust, the average composition of glacial clay and the composition of a typical English 'Keuper Marl' are strikingly similar.

Table 7 Chemical analyses of the earth's crust compared with a 'Keuper Marl'.

	A	*B*	*C*
SiO_2	60.18	59.12	56.73
TiO_2	1.06	0.79	0.98
Al_2O_3	15.61	15.82	16.09
Fe_2O_3	3.14	6.99	6.27
FeO	3.88		
MgO	3.56	3.30	4.31
CaO	5.17	3.07	3.60
Na_2O	3.91	2.05	1.11
K_2O	3.19	3.93	4.03
P_2O_5	0.30	0.22	n.d.
		H_2O 3.02	Loss 7.04
TOTAL	100.00	98.31	100.16

Notes:

A Average composition of the crust from more than 5000 analyses from different parts of the world. Clarke and Washington (1924).

B Average composition of 77 analyses of different samples of a glacial clay from Norway. Goldschmidt (1934).

C Typical English 'Keuper Marl'. Keeling (1963).

The products of the breakdown of igneous rocks in the earth's crust may occur as residual clays which remain in situ, or more commonly they may be transported and deposited as sediment. They may also be altered, either in the environment of deposition or after burial (early and late diagenesis). The heavy clay industry in the United Kingdom does not utilise residual clays.

A study of the origins and modes of occurrence, as well as the modern distribution of clay minerals, leads to a better understanding of their distribution in ancient sediments.

The type of clay mineral assemblage produced by weathering is controlled by climate and by the lithology of the source area. The most extreme influence of climate occurs in wet tropical environments with the development of lateritic and bauxitic clays. These clays, rich in hydrated iron or aluminium oxides, owe their existence to the rapid decay of profuse tropical vegetation. The organic acids thus released mobilise all of the silica in the soil profile, leaving behind an insoluble lateritic crust, the pisolitic texture of which is produced by mobilisation and reprecipitation of iron.

Acid tropical soils, within which leaching is only slightly less intense, are characterised by kaolinite, the least siliceous of the silicate clays and the one with the simplest structure and smallest unit cell. Kaolinite is also a dominant constituent in many of the soils of warm temperate climates with a rainfall of more than 635mm (25 inches) per year.

Montmorillonite is usually formed under neutral or alkaline conditions and is a common constituent of chestnut and prairie soils. Desert and tundra soils usually contain a mixture of smectites and illite, while illite is found in many temperate soils, including podzols, that have undergone only limited leaching. Chlorite occurs in the soils of cold and arid regions, while sepiolite and attapulgite may form in the temporary playa lakes of desert basins.

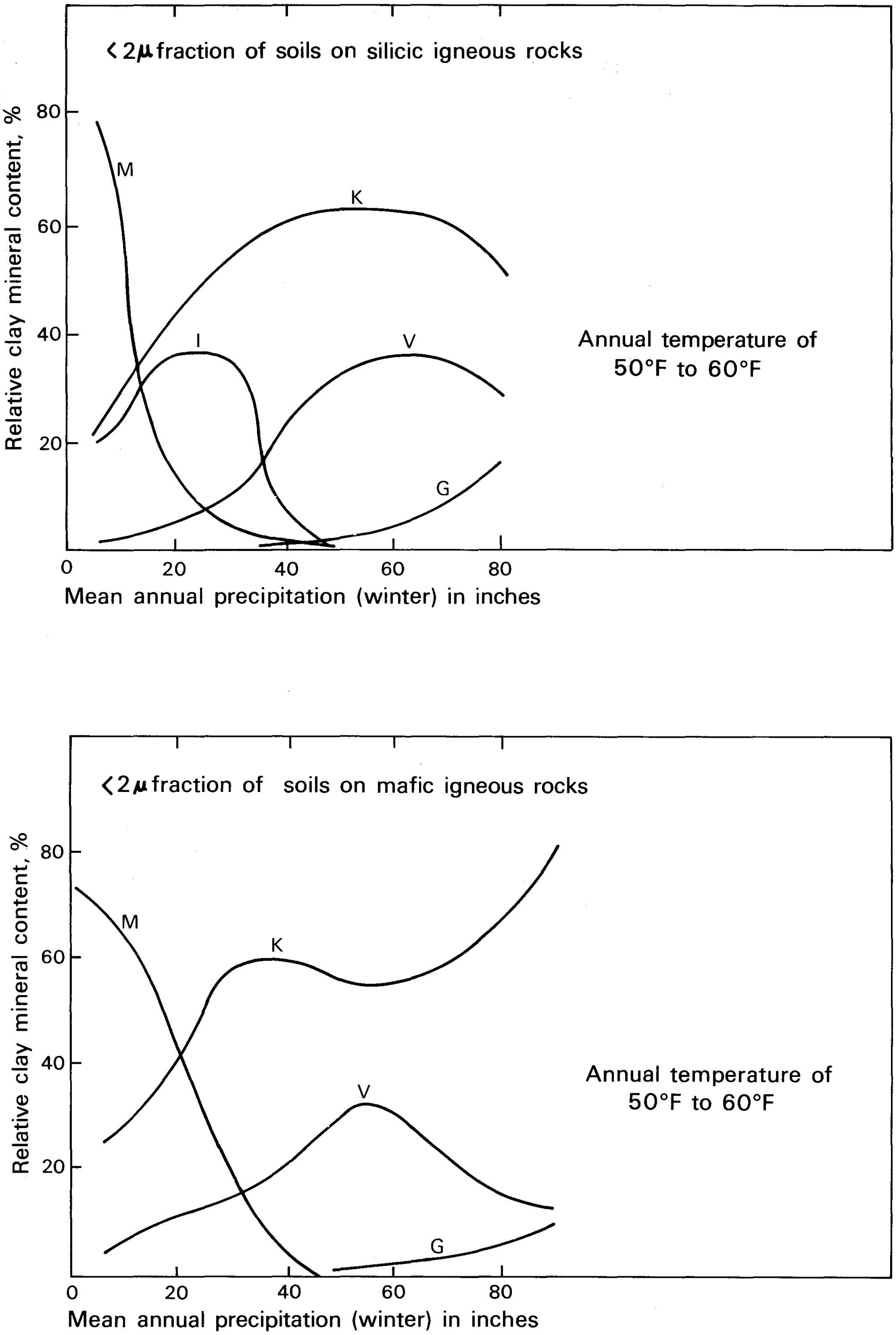
An elegant demonstration of the influence of rainfall and lithology on clay mineral assemblages is provided by Barshad (1966). His results (Fig. 3) show that while montmorillonite is the dominant clay mineral produced when either the silicic or mafic igneous rocks of California undergo weathering in an arid or semi-arid climate, it does not occur in wet areas. Kaolinite preponderates where the rainfall exceeds 500mm. Vermiculite abundance is greatest (30%) where the mean annual rainfall is around 1.38m. Gibbsite becomes important only in areas with a high rainfall, and its abundance increases with increasing rainfall; for any given rainfall more is produced from silicic than from mafic rocks. Illite is produced predominantly by weathering of acid rocks with their relatively high potassium content, and mostly in areas with a moderate rainfall. In arid and semi-arid environments, evaporation of ground water and changes in partial pressure of CO_2 lead to the development of carbonate in the soil profile.

Occurrence

It has been estimated that the upper ten miles of the earth's crust consist of 95% igneous rock, 4% clay or shale, 0.75% sandstone, and 0.25% limestone (Clarke & Washington 1924). Thick beds of mudstone and shale form predominantly in aqueous environments where current velocity, which determines the grain size of the deposit, is low and decreasing. They are therefore a characteristic feature of river floodbasins, lakes, delta tops, estuaries, lagoons, continental shelves and ocean basins. Slow, steady, uniform flows such as may occur in oceanic or continental shelf environments give rise to extensive, homogeneous, fine-grained clays such as the Oxford Clay; whereas unsteady flows of the type found in lakes, floodbasins, and tidal estuaries produce lenticular beds of laminated silt and clay, as found in many of the formations of the Coal Measures. Such lamination is usually preserved in areas where the bottom waters are stagnant, hypersaline or otherwise unsuited to the development of an extensive benthonic fauna. In well oxygenated marine environments, on the other hand, burrowing organisms bioturbate the sediment to produce a mottled or homogeneous texture. Where rivers discharge suspended sediment into saline environments, flocculation of clay particles is another important mechanism leading to the deposition and accumulation of muds.

The relative abundance of argillaceous sediments within any sequence is determined primarily by the tectonic setting and climate of the drainage basin. Optimum conditions occur where basins flanked by slowly rising shield areas and drained by mature rivers are situated in an area of high rainfall and high mean annual temperature. The clay minerals develop by the breakdown of other silicates in the thick weathering profiles that mantle such shield areas. Because erosion of more rapidly rising source areas, e.g. old mountain belts, generates considerable amounts of sand and gravel in addition to clay, coarser grained sediments tend to predominate in neighbouring basins. However, since most of this coarser bed-load sediment may be trapped and deposited fairly close to the source area, while fine suspended sediment moves freely downstream, thick sequences of silt and clay may develop at the same time in more distal parts of the basin.

Shoreline processes tend to trap nearly all the bed-load material brought down by rivers or produced by coastal erosion. Although some of this material may subsequently be carried down into ocean basins by turbidity flows, active clastic



M—Montmorillonite; K—Kaolinite; I—Illite; V—Vermiculite; G—Gibbsite

Figure 3 Variation in clay mineralogy of soils with mean annual precipitation (Californian example; after Barshad 1966)

sedimentation on the continental shelves gives rise mainly to fine silt and clay. Since active shelf sedimentation is encouraged by rising sea level, thick clays are often associated with periods of marine transgression e.g. Weald Clay, Gault, London Clay, Oxford Clay, whereas periods of regression or stability tend to produce scour and reworking with the development of sands and shell beds, e.g. Folkestone Sand and Bagshot Sand etc.

Where the climate is warm and little detritus is being brought to the sea by rivers, either because of geographic factors or as a result of low rainfall, clays become subordinate to limestone in shallow marine environments. The clays themselves contain a variable and usually high carbonate content. In open water environments the carbonate minerals are usually aragonite and calcite but in lagoons and other littoral environments where salinity and the magnesium/calcium ratio are unusually high, dolomite is often the main carbonate phase.

The type of clay minerals deposited in non-marine environments depends mainly on the type of clays being derived by weathering of the source areas. There may be some slight tendency for kaolinite to form at the expense of other clay minerals in lakes with a low pH, but otherwise the amount of alteration is negligible.

The influence of source area is equally important in many marine environments. Kaolinite, for example, comprises more than 25% of the total clay content of modern oceanic sediments only around Australia and those parts of the central Atlantic fed by the tropical rivers of Africa and South America. Much of Australia is mantled by thick kaolinitic soils as a result of tropical weathering during the Miocene. Chlorite, on the other hand, forms more than 25% of the total only in high latitudes in waters adjacent to glaciated continental areas. Because illite is associated with temperate weathering, it is abundant (>50%) in the North Atlantic and North Pacific around 40°N, supplied by rivers draining Eurasia and North America. Montmorillonite is the most abundant clay mineral in areas remote from major influxes of continental detritus. It is therefore characteristic of the south and central Pacific. This distribution may reflect the smaller grain size and therefore the greater ease of transport of montmorillonite in comparison to kaolinite or illite.

In ancient sediments, the clay mineral assemblage was similarly affected by geographic and climatic factors but has suffered some post-depositional (or diagenetic) alteration as a result of changes in temperature, overburden pressure and pore water chemistry. Kaolinite may form in this way in continental sediments but not in marine sediments, where the abundant potassium ion content of the pore water favours the development of illite. At depths below 3050m, corresponding on average to a temperature of just over 100°C, kaolinite and montmorillonite are replaced by illite and chlorite; in the Coal Measures, this change occurs under the same conditions as those that convert semi-anthracite to anthracite. The transformations occur under slightly different conditions in different host rocks. Thus, in Carboniferous sequences, the shales may be dominantly illitic and chloritic while kaolinite is still preserved in the interbedded sandstones. The transformation of montmorillonite to chlorite on the other hand may occur in sandstones before the associated shales are affected.

As a result of these changes the average illite content of all muds and shales increases with time from an average of 25% in modern sediments to 80% in early Carboniferous sediments (Figure 4). There is a corresponding decrease in smectites and other expandable clays from the present 60% to 5%. Twice as much chlorite (10%) is present in early Carboniferous clays as in modern ones. The decrease in overall kaolin content from 24% in the Cretaceous to 12% in recent deposits reflects the climatic deterioration that culminated in the Pleistocene glaciation. The scarcity of kaolinite in pre-Carboniferous clays (< 5%) is partly the result of deep burial, but also reflects the absence of widespread vegetation in pre-Carboniferous times which in turn affected the weathering process. The relative abundances of major clay mineral groups in British sediments as a function of time are shown in Figure 5.

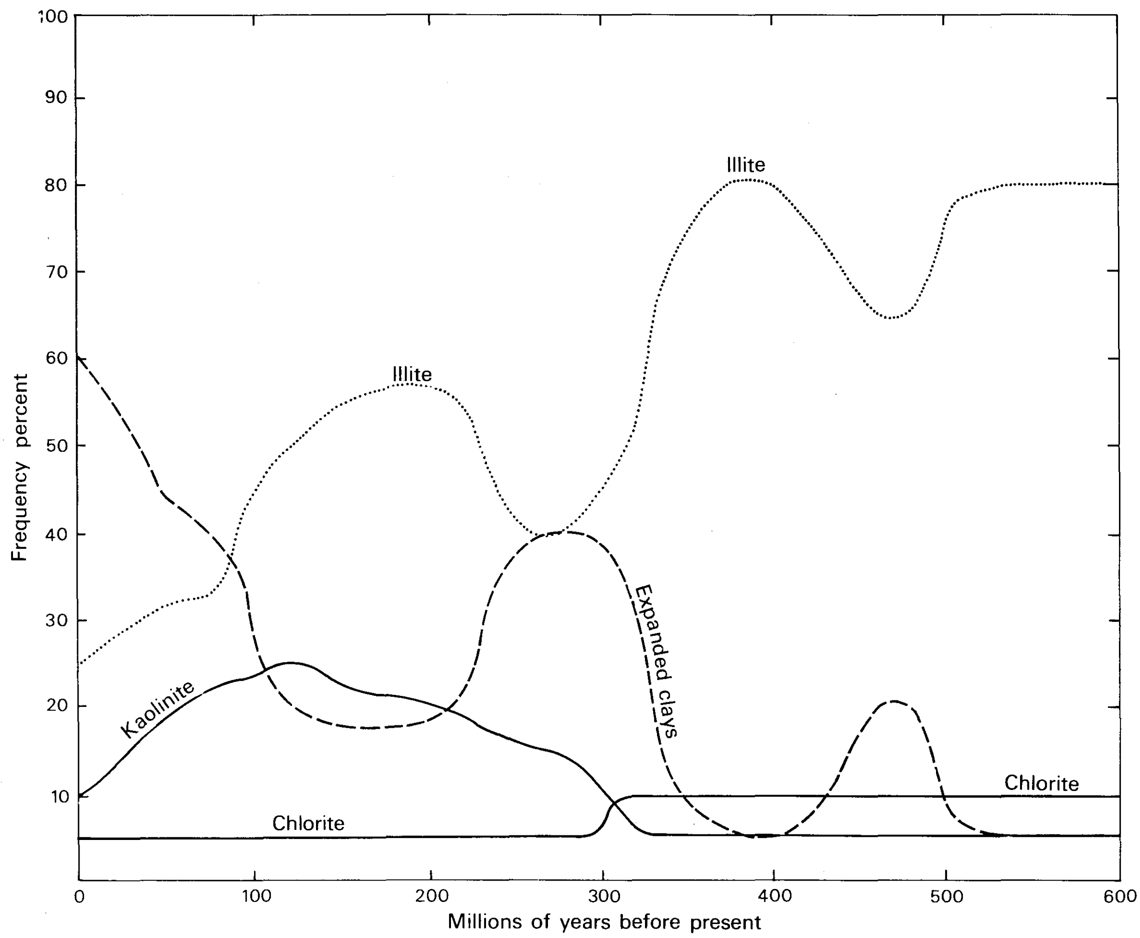


Figure 4 Relative abundances of major clay mineral groups in US shales, as a function of time (after Weaver 1967)

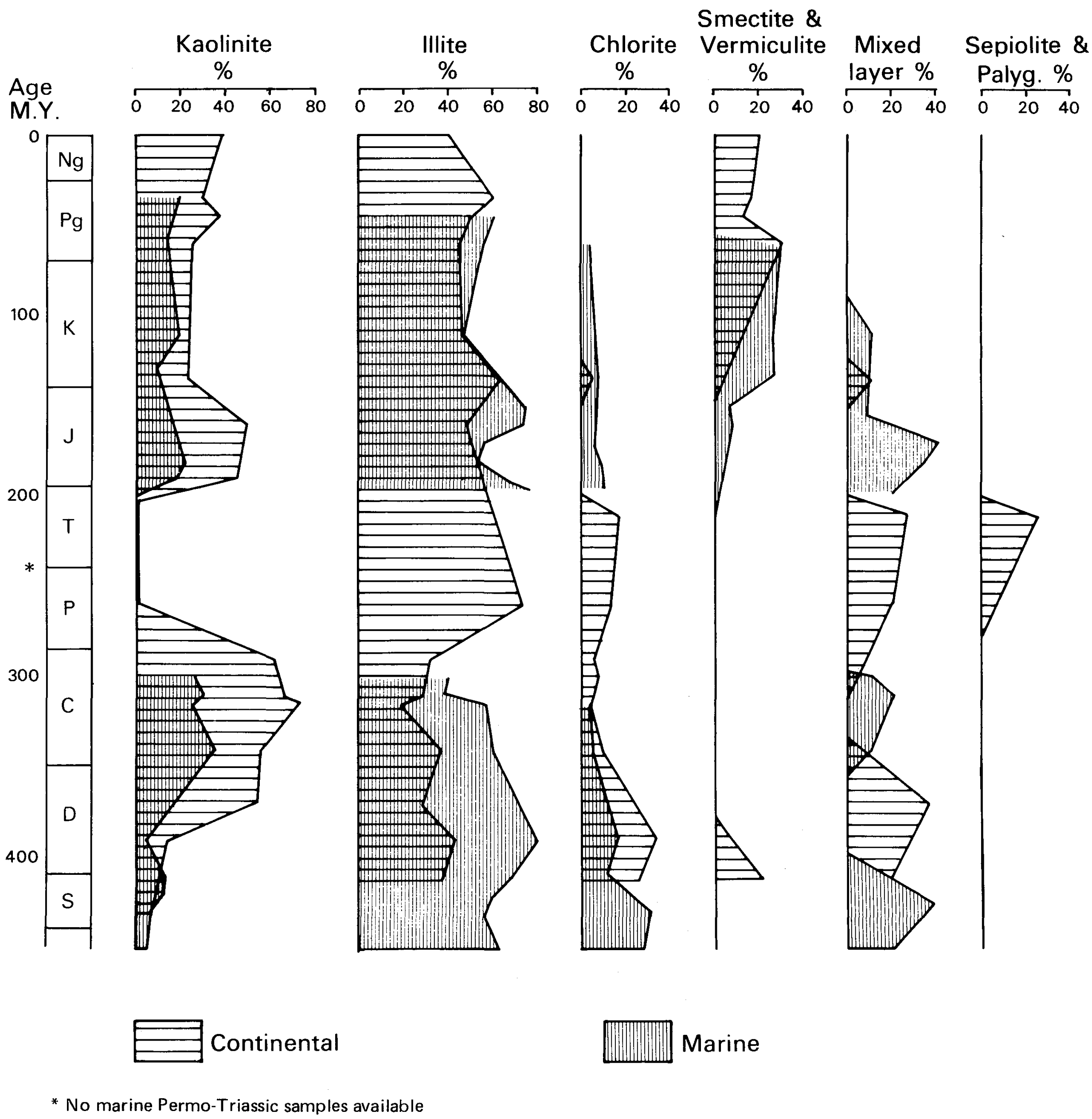


Figure 5 Variation in abundances of clay mineral species with time: British sediments (data mainly from Perrin 1971)

RESOURCES

Introduction

United Kingdom resources of material suitable for the production of structural clay products are extremely large, but it would be unrealistic to attempt a quantitative estimate as the required parameters of a structural clay are not acurately defined. Furthermore, changing aesthetic requirements and technological advances have meant that some previously 'unsuitable' clays have become viable, while others are no longer utilized for a variety of reasons. Even in the case of favourable deposits such as the 'Keuper Marl', Etruria Marl, Coal Measures etc., only a small and variable proportion can currently be used. For example, the presence of interdigitating channel sands in a supposedly homogeneous deposit can at best sterilize part of a quarry face, or at worst render uneconomic the working of shales which in themselves are eminently suitable for the manufacture of heavy clay ware.

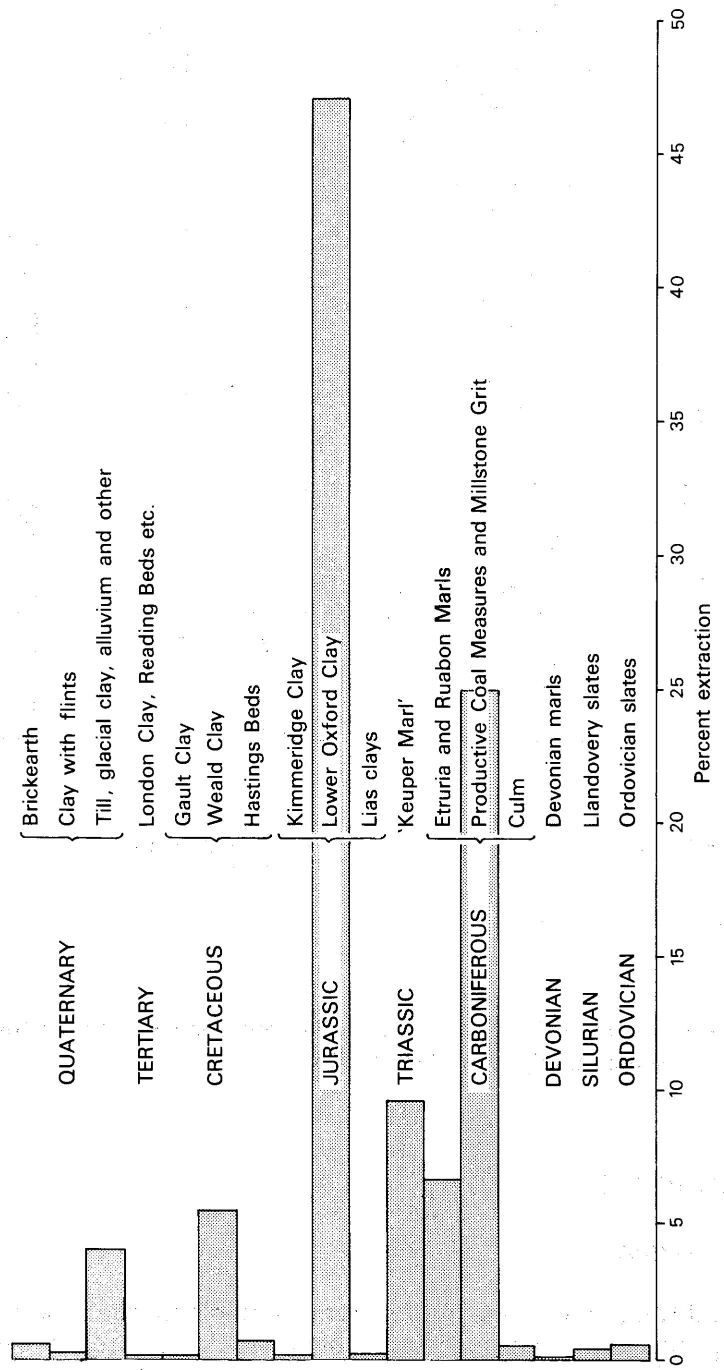


Figure 6 Relative importance of UK geological formations in brick, pipe and tile manufacture.

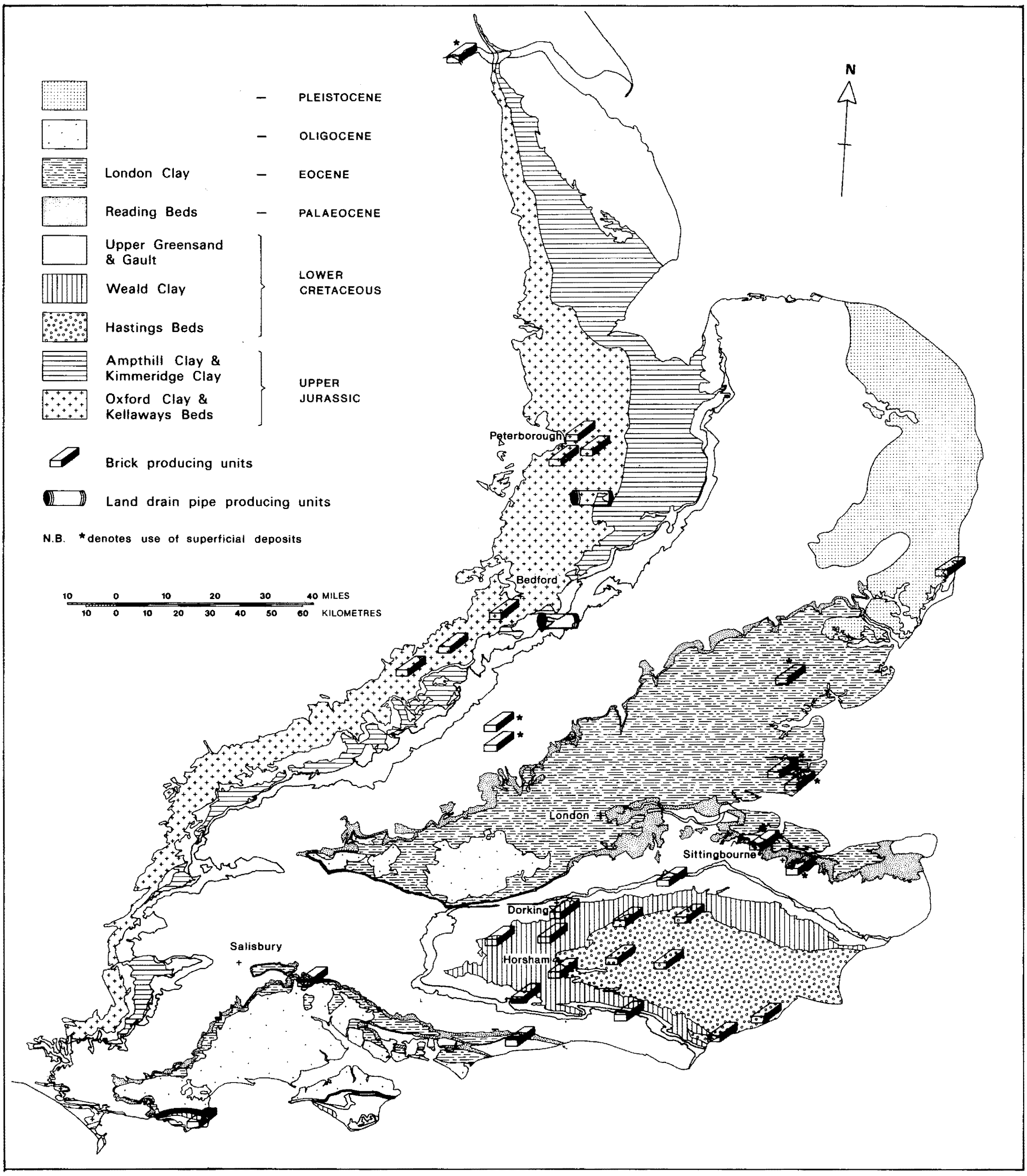


Figure 7 Sketch map of geological horizons in eastern England used for heavy clay ware manufacture

Deposits of argillaceous sediments including clay, shale, mudstone and fine silt occur over wide areas of Britain and in all geological periods except perhaps the Precambrian (Table 8; Figures 7 and 8). The resources include in-situ deposits, drift deposits and the waste products from other bulk mineral industries. Production from systems older than the Carboniferous is limited to less than 1% of total output and the main producing horizon is the Lower Oxford Clay accounting for about 50% of the total (Table 9 and Figure 6).

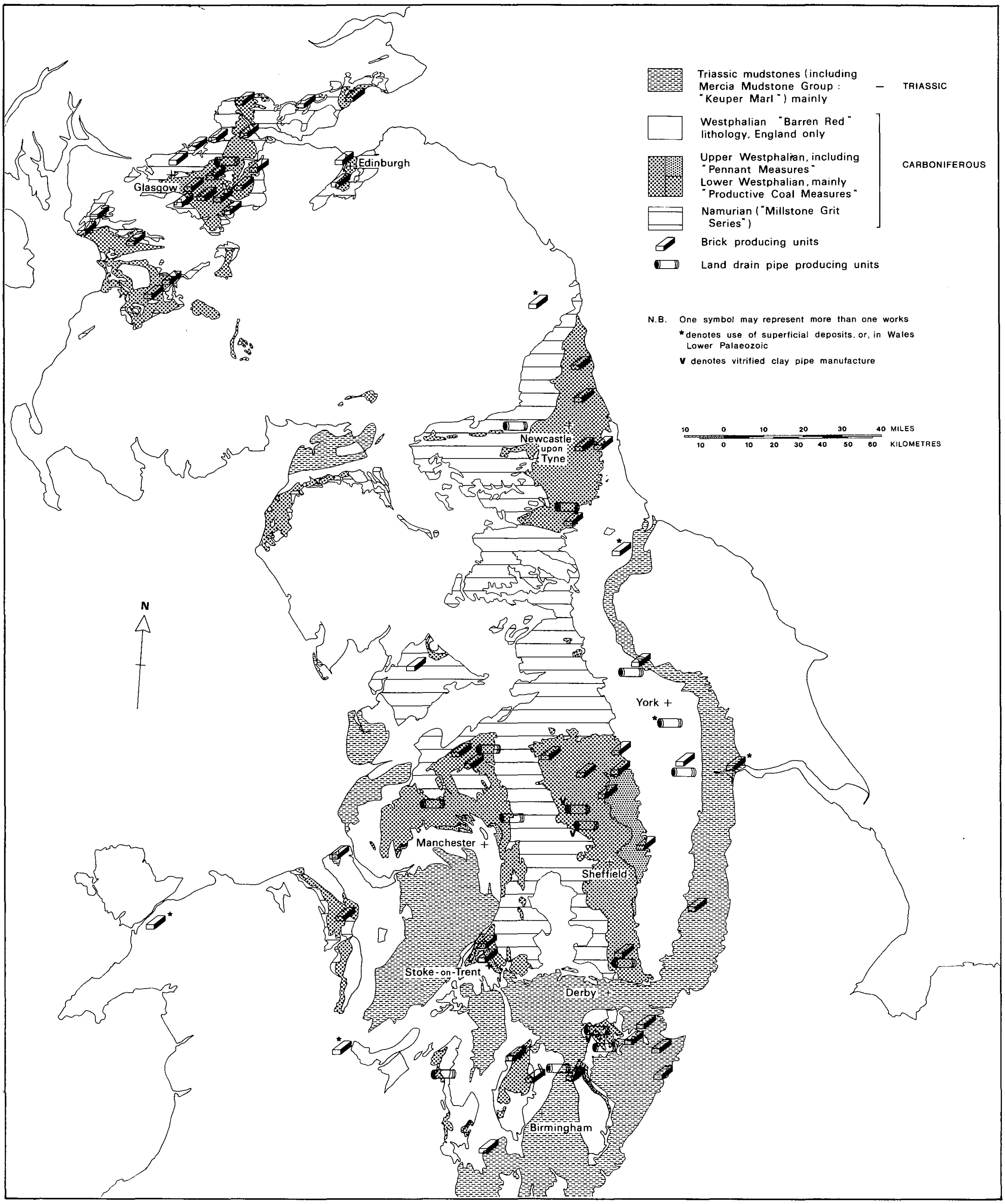


Figure 8 Sketch map of geological horizons in central and northern Britain used for heavy clay ware manufacture

Precambrian and Lower Palaeozoic

Because of the great age of Precambrian rocks their outcrops tend to be fragmentary or show highly complex deformation and they are represented mainly by the roots of mountain chains in which all the rocks are metamorphosed; in unmetamorphosed areas the rocks are dominantly arenaceous. Argillaceous slaty facies do occur, notably the Ballachulish Slates, but they are too well indurated and pyritiferous to be of any use in brick making.

Table 8 Geological formations and geographical distribution of brick, pipe and tile clays in the United Kingdom

Quaternary and Recent (superficial)	
Alluvial Clays	Severn Valley aluvium Humber Estuary and Lincolnshire coast Vale of York—Lacustrine clays Somerset Levels—Bridgwater area
Raised beach clays	Coastal Aberdeenshire, Banffshire, Angus, Morayshire, Ayrshire, Glasgow district and Midlothian
Brickearths	Lower Thames area—North Kent and South Essex Lea Valley (Enfield) Hampshire (Portsmouth to Littlehampton) East Anglia (scattered—Norwich, Sudbury, Bury St. Edmunds, Colchester) Thames Valley (Marlow, Iver, Hayes)
Clay-with-flints (and associated loams)	Chiltern dipslope between High Wycombe and Luton (Chesham area and around Berkhamsted) Widespread former small scale workings all over Chalk areas of Southern England
Interglacial and glacial clays	Laminated Clays in Northumberland, North Humberside and Co. Durham. Langholme (S. Scotland) Ayreshire, the Lothians and Aberdeenshire coast Clays and Loams in East Anglia Boulder Clay (widespread):– Viz: North East England (Northumberland Durham and Cleveland) Carlisle area South Lancashire and North Cheshire, including Wirral and East Flintshire Fylde (Preston and Blackpool) East Anglia Hertfordshire (Vale of St. Albans) Scattered isolated works in Midlands Londonderry and Co. Down (N. Ireland) Aberdeenshire, Fife, Central Coalfield
Tertiary	
Pliocene	
Chillesford Clay	Aldeburgh, Suffolk
Oligocene	
Bovey Tracey Beds	Devonshire
Hamstead Beds	Isle of Wight
Eocene	
Barton Clay	Hampshire
Bracklesham Beds	Hampshire–Surrey border Southampton

Bagshot Beds	Ringwood area (Hampshire) Hampshire–Surrey border (alone or with London Clay)
Claygate Beds	Surrey (Claygate–Cobham) Essex (Brentwood)
London Clay (often used with Reading Beds)	Suffolk (Sudbury, Ipswich) Essex Berkshire (Bracknell) Surrey Dorset–Wiltshire–Hampshire (Wimborne, Fordingbridge, Southampton, Winchester)
Reading Beds (see above)	Outliers on Chiltern dipslope Reading area (extending west to Newbury and east to Maidenhead) Hampshire (Fareham) Surrey (Epsom)
Cretaceous	
Gault Clay	Hampshire–Sussex (at foot of South Downs, esp. Petersfield) Isle of Wight Wiltshire (Devizes) Kent (at foot of North Downs: Sevenoaks–Maidstone–Ashford–Folkestone) Oxfordshire–Buckinghamshire–Bedfordshire–Cambridgeshire (at foot of Chilterns) Surrey (Farnham and Albury)
Weald Clay	Surrey (south of Greensand scarp, esp. south of Dorking, Reigate and Redhill) Kent (Edenbridge, Ashford) Sussex (Pulborough, Horsham, Warnham, Burgess Hill, Plumpton, Hailsham) Isle of Wight (Sandown)
Grinstead Clay	Locally, in central Weald (East Grinstead, Uckfield)
Wadhurst Clay	Kent (Tonbridge–Tunbridge Wells) Sussex (West Hoathly, Uckfield, Bexhill)
Ashdown Sand (clay beds in)	Locally in Sussex (Crowborough, Heathfield)
Fairlight Clay	Sussex (Hastings)
Upper Jurassic	
Ampthill Clay	Kirbymoorside
Kimmeridge Clay	Dorset (Gillingham) Oxford area Fenlands Kirby, North Yorks.
Oxford Clay	Buckinghamshire–Bedfordshire Peterborough Whittlesey, Eye Dorset (Weymouth, Bridport) Wiltshire (Trowbridge, Malmesbury) Brora, Sutherland
Middle Jurassic	
Estuarine Clays	Estuarine Series of Yorkshire (Grosmont) Lincolnshire (Stamford, Little Bytham)
Lower Jurassic	
Upper Lias	Northamptonshire Lincoln

Lower Lias	Somerset (Ilminster, Bath, Glastonbury) Gloucestershire (below Cotswold scarp, e.g. Stonehouse, Cheltenham, Moreton-in-Marsh)
Triassic	
Mercia Mudstone Group (formerly 'Keuper Marl')	East and West Midlands: Nottinghamshire (Nottingham; Newark and Gainsborough areas) Derbyshire (Derby area) Leicestershire, (Soar valley, Leicester to Loughborough; Ibstock) Warwickshire (Birmingham area) Staffordshire (Stafford, Rugeley, Lichfield) Worcestershire West of England: Devon (Otter valley) Somerset (Taunton, Wellington) Gloucestershire (Bristol area) South Wales: Cardiff area
Sherwood Sandstone (formerly 'Keuper Sandstone')	Leicestershire (Ibstock) Staffordshire (Lichfield)
Permian	
Permian Marls	Doncaster and Nottinghamshire Devon (Exeter–Exmouth area)
Carboniferous (England and Wales)	
Upper Coal Measures:	
Erbistock Beds	Denbighshire (Wrexham), Salop (Hanwood)
Enville Beds	Staffordshire (edges of Black Country)
Keele Beds	Coventry
Coalport Beds	Salop (Ironbridge Coalfield)
Etruria Marl	Stoke-on-Trent South Staffordshire (Walsall) Warwickshire (Tamworth, Nuneaton)
Ruabon Marl	Denbighshire (Ruabon–Wrexham)
Old Hill Marl	South Staffordshire (Black Country)
Blackband Group	Stoke-on-Trent
Middle and Lower Coal Measures:	All exposed coalfields, in greater or less degree: Northumberland (esp. Newcastle area) Durham West Cumberland Lancashire (esp. Accrington, St. Helens, Upholland, Wigan, Bolton, Manchester area) Flint (esp. Buckley) Denbigh (esp. Wrexham) Yorkshire (esp. area bounded by Leeds–Bradford–Huddersfield–Wakefield–Pontefract, also Barnsley and Sheffield area) Derbyshire (e.g. Ripley), and S. Derbyshire–Pottery Clays Formation Nottinghamshire (Eastwood, and a few collieries in 'concealed' field) Leicestershire Warwickshire (esp. Tamworth) North Staffordshire (Potteries area) South Staffordshire and Worcestershire (Black Country and Stourbridge)

	Gloucestershire and Avon (Cinderford and Bristol)
	South Wales (e.g. North-east area using old shale dumps)
Culm Measures	Devon (Exeter area)
Millstone Grit	Lancashire
(shales in)	Co. Tyrone (N. Ireland).
Lower Carboniferous	Northumberland (Scremerston)
Carboniferous (Scotland)	
Upper (Barren) Red Coal Measures	Central Coalfield and Midlothian Coalfield (Dalkeith area)
Middle and Lower Coal Measures	Waste blaes from all coalfields, plus in situ blaes
Passage Group	Some shale horizons used, e.g. in Ayrshire
Limestone Coal Group	Ayrshire and Midlothian, plus waste blaes from coalfields
Lower Limestone Group	Glasgow district, some shale horizons used
Calciferous Sandstone Measures	Upper Oil-Shale Group shales in Midlothian Coalfield and Red Marls in Carluke and Cleghorn areas
Devonian	
Old Red Marl	(Sometimes mixed with Coal Measure shales) South Wales (Pontypool–Newport–Cardiff)
Devonian slates (Shillet) and Lower Devonian Shales	Plymouth and Torquay areas, Cornwall, Herefordshire, South Wales, West Midlands
Silurian	Central Wales and formerly in Gloucestershire
Ordovician	W. Wales (Fishguard) Caernarvon area

(Adapted from Keeling 1954).
Note: Old style Scottish county names used where more specific

Much of the Lower Palaeozoic in Britain is represented by great thicknesses of geosynclinal deposits, chiefly of marine origin. The geosynclines were elongate regions of downwarped crust and the deposits that filled them have invariably been subsequently folded.

After a period of erosion, the Cambrian marked the beginning of a long period of marine transgression over much of Britain. Lower Cambrian strata are mainly arenaceous, while those of the Middle and Upper Cambrian contain mudstones, slates and dark argillites. The Ordovician is characterised by thick cleaved mudstones and shales. Despite a widespread break in sedimentation at the end of the Ordovician Period, similar conditions existed during the Silurian, and deep water graptolitic shales, greywackes and marginal facies prevailed. Reserves of low carbon, lime-free, Lower Palaeozoic shales and mudstones are extensive in Wales, Anglesey, the Lake District, the Welsh Borders and the Southern Uplands of Scotland, but they tend to be very variable in lithology, are often metamorphosed and highly folded or cleaved, and contain impurities. Clay rocks of this age tend to be extremely well indurated and it is not easy to render them sufficiently plastic for brick manufacture, although this has been done at Askam-in-Furness (Skiddaw Slates) in the past.

Clay mineralogy in the Lower Palaeozoic tends to be relatively independent of lithology and because of very long periods of diagenesis and depths of burial mica and illite are dominant with subordinate chlorite. Chemical analyses of Lower Palaeozoic brick-making shales indicate a fairly high alumina content (about 25%), a high percentage of iron oxide and generally a low lime content (Appendix 1).

Table 9

Estimated current geological distribution of clay and shale extraction in the United Kingdom for building brick, pipe and tile manufacture, 1979.

	Estimated proportion of production Per cent
Horizon	
Quaternary and Recent (supersicial clays):	
Brickearth	<1
Clay with flints	<0.5
Other (fluvio-glacial clays, alluvium etc)	4.0
Tertiary:	
Reading Beds and London Clay	<0.5
Cretaceous:	
Weald Clay	5.6
Gault Clay	<0.5
Hastings Beds	<I
Jurassic:	
Kimmeridge Clay	<0.5
Lias	<0.5
Oxford Clay	47.0
Triassic:	
'Keuper Marl'	9.5
Permian:	
Carboniferous:	
Etruria and Ruabon marls	6.7
Productive Coal Measures	25.0
Culm	0.5
Devonian:	<0.5
Silurian:	
Llandovery	<0.5
Ordovician:	0.5

Ordovician slates were formerly used for brickmaking in west Wales (Fishguard) and Cumbria, and are successfully dug today at Caernarfon, while the Silurian is utilized in central Wales and was formerly dug at Tortworth in Gloucestershire. Other works operate in Lower Palaeozoic shales near Welshpool, Clwyd; Ulverston, Cumbria; and in the Isle of Man.

The pre-war regional distribution of brickmaking capacities by geological formation indicates that 21.5 million bricks per year were produced from Pre-Devonian rocks in north-west England and 5.5 million per year from south Wales. These together represented about 0.35% of the total for England and Wales. Curiously enough, production from the Lower Palaeozoic today comprises about 0.9% and at present about 35 million bricks per year are made from pre-Devonian rocks in Wales.

Bonnell and Butterworth (1950) carried out tests on an Ordovician shale from Gwynydd and on Cambrian Manx slates which were being used to produce common bricks. The bricks were fairly dense with moderate or fairly high compressive strengths and low drying shrinkages. Modern wire-cut facing bricks made from Ordovician shales at Caernarfon have a compressive strength of 668kg/cm^2 (9500 p.s.i.) and low water absorption; normal works firing temperature is in the 950°C region.

Devonian

At the end of the Silurian Period the greater part of Britain became part of the Old Red Sandstone continent which included much of northern Europe. South of this landmass marine sedimentation continued in the Devonian geosyncline and Devonian rocks of marine facies are thus found in south-west England, while continental red beds, the Old Red Sandstone facies, are found in the rest of Britain. The Old Red Sandstone marl from Pontypool, Newport and Cardiff has been used in the past for brick and tile manufacture, and the fact that such marls from south Wales and Shropshire are not more widely used may be in part due to the absence of large centres of population on some parts of their outcrop. Red roofing tiles produced from this horizon were of good quality and low water absorption.

In south Devon and Cornwall marine slates occur with grits, limestones and volcanic horizons. The succession becomes more argillaceous westwards and the structure is often complex. In the north Devon–Somerset area volcanicity was less pronounced, limestones are rare and some of the succession is of non-marine origin. Devonian slates, called "shillet", are of local importance to the brickmaking industry in the Plymouth and Torquay areas, and in Cornwall and Herefordshire. Devonian shales were also used in south Wales before the last war, where 55.5 million bricks per year were produced; 50.5 million were produced in south-west England and there was a very small output in the West Midlands. Today the Devonian accounts for about 0.45% of total building brick production divided between Devon and south Wales.

Upper Devonian marl was until recently mixed with Coal Measures shale for the wire-cut production of about 19 million red engineering and facing bricks per year at Caerleon in south Wales.

Mineralogically, Devonian brick-making shales tend to be similar to Lower Palaeozoic varieties, being dominated by illite-mica with subsidiary chlorite. Their chemical analyses indicate silica contents in the range 54–60%, a high percentage of iron and a low, though variable, content of lime (Appendix 1).

Bonnell and Butterworth (1950) studied Devonian shale and slate from Devon, where common bricks were being produced by stiff plastic and semi-dry processes; their results prompted much the same conclusions as for the Lower Palaeozoic samples. At a firing temperature of 1040°C, the modern wire-cut production line at Caerleon in south Wales produces bricks of a very low water absorption and high compressive strength ($703 kg/m^3$), from the Upper Devonian.

The Devonian shale currently used for wire-cut facing brick manufacture at Steerpoint, Devon, is not plastic enough on its own so a percentage of ball clay and sulphite lye binder is added.

Carboniferous

At the beginning of the Carboniferous Period warm shallow seas spread northwards from the geosyncline which persisted in south-west England. In the area extending from the Bristol Channel to Derbyshire the Carboniferous Limestone facies, which contains little material suitable for brick production, was deposited. In the north Pennines and north-east England the deposits contain shales which have been worked from time to time.

The early Carboniferous sediments in the Midland Valley of Scotland, which are predominantly non-marine, also contain thick shales, particularly in the Oil-

Shale Group of the Calciferous Sandstone Measures to the west of Edinburgh. Two major sub-divisions of the Oil-Shale Group can be recognised in the Lothians; a dominantly argillaceous upper sub-division which contains most of the valuable oil shales and an arenaceous lower sub-division which includes the important Pumpherston Shales. The Burdiehouse Limestone divides the two sub-divisions. Some of these lagoonal shales are too bituminous for brickmaking, while others are too calcareous. None of them has therefore been used extensively for this purpose. However, upper Oil-Shale Group shales were formerly dug for brickmaking north-east of Straiton in the Midlothian coalfield, and until recently the waste shales from the oil-shale mines and from the processing plants have been used to produce shale-lime bricks. The use of waste blaes in Scottish brickmaking will be dealt with in the section on secondary raw materials because of the particular qualities of this raw material and the products manufactured.

Other horizons within the Calciferous Sandstone Measures have been dug for brick manufacture; for example, a red marl was quarried at Nellfield Brick and Tile works in the Carluke area, and at Lanark and Glasgow, for red facing bricks, blue 'flashed' bricks, chimney ears and ornamental tiles. The succeeding Lower Limestone Group shales were used for bricks west and northwest of Glasgow and in Fife. Seatearths from the Limestone Coal Group (Namurian) have been used for brickmaking in the past, though largely for fire bricks. Limestone Coal Group shales rather than seatearths were also used from Prestongrange, Newbattle and Arniston collieries.

Rhythmic deposition of deltaic sediments with marine intercalations persisted in Northern Ireland and Scotland during the Namurian. In County Tyrone some of the shaly horizons provide material for bricks, pipes, and flue liners, while in the Midland Valley of Scotland the Passage Group provides the most important source of Scotland's refractory clays. However, none of the Scottish Namurian shales either in the Passage Group or in the Upper Limestone Group and Limestone Coal Group has been extensively used for brickmaking, despite the fact that many of those in the latter group are lithologically similar to Coal Measures shales.

In northern and central England the Millstone Grit is more sandy; in the north the sands are mainly fluvial and deltaic but in the Central Pennine trough turbidites are also present. Numerous shales are interbedded with the sandstones but most beds are too thin to be of interest while the thick marine Edale Shales at the base of the sequence are too bituminous and pyritic. In the past, a few of the shales were used locally on the Lancashire–Yorkshire borders. The Namurian sediments of South Wales include thick potentially useful shales, especially in the Gower Peninsula, but they have rarely been exploited.

In south-west England the geosynclinal *Culm* facies is predominantly argillaceous but also contains innumerable thin greywackes and siltstones of turbidite origin. Cherts and muddy limestones are common in the Lower Culm, while the Upper Culm also contains thick deltaic sediments of Pennant type. In the absence of more suitable material some of the more shaly members of the Culm have long been used for brickmaking and are still exploited in the Exeter area where a complex folded and faulted geosynclinal facies occurs. The Culm shales improve if allowed to weather for a few months in a stockpile and best facing bricks are produced by stiff plastic extrusion or hand-moulding. For engineering bricks the only requirements are that the shales be more finely ground and the bricks have a longer 'soak' period in the kiln.

The Coal Measures provide the bulk of Carboniferous brick and pipe clays. They are worked in all the major coalfields and some of the material is won in conjunction with opencast coal mining. In Scotland where about 90% of brick production comes from the Carboniferous, the vast majority of shales are retrieved from old colliery bings (spoil heaps); production is thus dominated by waste materials, (see "Secondary Raw Materials" section). In England and Wales, colliery spoil material is rarely used for brickmaking, the vast majority of the shales being dug from quarries, even where waste shales are locally abundant.

The abundance of brickworks in coalfield areas was historically related to the local availability of fuel and to the great need for bricks in the industrial conurbations which spread rapidly in the coalfields after the Industrial Revolution. In 1939, one-third of all clay pits were located in the coalfields; by the 1950's only a quarter of national brick production was coming from Carboniferous sediments. At present, approximately 32% of clay building bricks are produced from Carboniferous deposits as a whole (including Coal Measure shales and fireclays 25%, Etruria and Ruabon marls 6% and Culm Measures 1%).

The Coal Measures were laid down in extensive deltas that were occasionally flooded by shallow seas. Most of the detritus was derived from the north and north-east e.g. from the Scottish Highlands, although in Middle and Upper Coal Measures times in the south of England and South Wales an increasing amount of sediment was derived from rising Hercynian uplands to the south. Shales predominate in most coalfields but thick sandstones are also common especially in Scotland, northern England and South Wales. The shales exhibit considerable lithological variation; many are very fissile or sandy while others, e.g. the Accrington Mudstone, are finer grained and more homogeneous.

In some parts of the sequence, for example in the Blackband Group of north Staffordshire, the value of the shales is adversely affected by the occurrence of nodules and layers of sideritic ironstone. As variation in carbonaceous content of the shales affects the firing characteristics and mechanical properties of bricks, shales from different quarries are often blended to maintain a satisfactory feed. Normally, however, for common and engineering brick manufacture, for which the shales are well suited, and for facing brick production, vertical cutting of the quarry face to maintain a consistent feed is adequate.

Because of the deltaic nature of the depositional environment, Coal Measures sequences exhibit considerable local facies variation with the appearance of channel sands and silts, coaly swamp deposits and ferruginous lake deposits. This variability increases the difficulty and costs of working Coal Measures shales. Sedimentological understanding of the causes of this variability and its relationship to such factors as thickness of the sequence and position within the depositional basin has increased considerably in the last twenty-five years. Thicker, more homogeneous shales occur in less rapidly subsiding and more distal parts of a typical coal basin. Many Coal Measures claypits are not located in the more geologically suitable parts of the basin. In some cases this is inevitable, e.g. when the shale is being won as a by-product of coal-mining, but more careful siting of future virgin clay pits could reduce the production difficulties currently experienced by some manufacturers.

Examples of the use of Coal Measures shales in modern brick production are numerous e.g. works at Ripley, Derbyshire, where a typical sequence of hard blue-grey mudstones, shales and siltstones includes several thin coal seams. Impurities such as sideritic and calcareous nodules can be rendered harmless by dispersal if the raw material is ground down to at least ⅛ inch. A stockpile composed of layers of different shales in the correct proportions ensures continuity of feed to the wirecut production line for tunnel kiln-fired red engineering and facing bricks.

One works of a major non-Fletton producer at Kidsgrove in Staffordshire is situated within the area of a large old coal tip and demolished coking plant, but despite the large amount of waste shales present, the raw material is dug from a quarry behind the works to ensure quality control. Shales from the typical Coal Measures sequence are incorporated into a well-planned stockpile and thin indigenous coal seam material is blended to bring the carbon content up to 6½% to aid firing. Wire-cut 'commons' and facings, or fair-faced commons, are produced using Hoffmann kilns.

A large user of Coal Measures shales among other deposits in England is the Ibstock Group whose wire-cut extrusion lines and tunnel kilns at several factories produce a variety of facing bricks. At St. Helens, in Merseyside, Upper Coal Measures shales, mudstones and fireclays are dug, while at Almondsbury, Bristol, the quarry is situtated in an inlier of highly folded and faulted Middle Coal Measures shales, mudstones and fireclays. The only problems encountered are the variable carbon content of the strata and occasional calcite veining; barium carbonate is normally added to counteract the effects of soluble salts.

Disordered kaolinite and quartz are both abundant in Coal Measures shales, with variable amounts of illite, chlorite, organic matter, iron oxides and sulphides. In some cases, such as the Accrington Mudstone, illite is the dominant clay mineral. Sufficient flux, often in the form of chlorite, is usually present, even in the very kaolinitic shales, to lower the optimum firing temperature and ensure a hard burnt product. Tests carried out on bricks made from a variety of Carboniferous deposits have shown that there is great variation in such properties as compressive strength, porosity and soluble salts content (Bonnell and Butterworth 1950). Black coring can occur in Coal Measures shale bricks if the carbon is not fully burnt out.

Composition bricks have been made in Scotland in the past by extracting virgin blaes (in situ shales and mudstones), usually from the Coal Measures, and superficial boulder clays together. When blended they made good quality bricks at a number of places including Foulshiels and Fauldhouse in the Central Coalfield. At present this practice is only carried on in Fife.

The apparently anomalous situation where seatearths, often rich in alumina, are being used to produce facing bricks, arose essentially from the increasing demand for a buff-firing body, and the expansion of opencast coal mining activities in parts of England previously restricted to producing red-firing bricks. Several brick manufacturers extract fireclay with the shales in their own pits, e.g. in West Yorkshire, Avon, Merseyside, County Durham, Northumberland, Staffordshire, Clwyd and Mid Glamorgan; while others, notably in Northumberland, buy in fireclays extracted as a by-product of NCB Opencast Executive operations. The relatively high price of some top quality facing bricks enables the manufacturers to pay more for the raw material. Because fireclays are being used either blended with shales or on their own, firing temperatures in the kilns have to be somewhat higher, thus increasing energy costs. Although fireclays are abundant in Scotland they are not used there in the production of building bricks because colour is of less importance in an area where brickwork is still largely rendered, and because these high quality fireclays, dug in underground mines, would be too expensive for this end use. Buff bricks have been produced for years in England and Wales although demand has increased greatly in recent years not solely due to the availability of fireclay from opencast coal sites. The special case of fireclay usage is dealt with fully in a dossier on Fireclay in this series.

The productive (grey) Coal Measures are succeeded by a variable series of sediments, the Upper (Barren or Red) Coal Measures, which "young" progressively southwards from Scotland. In most of the coalfield areas these begin with multi-coloured clays and marls with sandstones, grouped under various names but mainly known as the *Etruria Marl.* The Etruria Marl (from Etruria in north Staffordshire) is of great importance for facing and engineering brick, and floor and roof tile making. It is followed in places by a recurrence of grey sediments, the sandstones and clays of, for example, the Halesowen Group (from Halesowen in south Staffordshire). A thick series of red beds generally succeeds, grouped as the Keele Formation, Enville Formation and the Clent Formation in the south Staffordshire Coalfield. These beds attain a thickness of 915m in South Staffordshire and 1,525m in Warwickshire. The Etruria Marl, the most important brickmaking deposit in Staffordshire, is 395m thick, but thins to 45m in south Derbyshire. It contributes about 5% of current clay building brick production in the United Kingdom, and floor tile production is concentrated on Etruria Marl in the Stoke-on-Trent area.

Rhythmic sedimentation occurs throughout the Etruria facies, which consists of red sandy floodplain mudstones or marls intercalated with lenticular bands of green and yellow channel sands. These so-called "espleys" are thicker and more numerous in the southern parts of the outcrop and also increase in abundance and become more conglomeratic towards the top of the succession; they are unsuitable for brickmaking and are often discarded or avoided in the quarries.

The clay mineral suite of the Etruria Marl is dominated by kaolinite with lesser amounts of illite, and the clays are moderately refractory with firing temperatures of the order of 1100°C. Holdridge (1959) found that about half the fifty or so samples of Etruria Marl he analysed had silica contents between 55 and 65%, and alumina contents varying between 18 and 24% (see Appendix I). It is relatively free from carbonate and is thus erroneously referred to as 'marl'; it normally fires to a red colour but contains some buff-burning horizons eagerly sought after by brickmakers in view of the increasing demand for buff bricks. Quarrying is thus fairly selective at, for example, the Staffordshire works of one of the larger clay brick and tile companies in the UK. A layered stockpile is constructed to ensure that correct proportions of various horizons constitute the raw material feed. Up to 12m of Newcastle Beds overburden consisting of grey sandstones and shales with thin coal seams and thin muddy limestones is removed at a quarry near Newcastle to expose a dug 18m of upper Etruria Marl used in brick and roofing tile production. Mottled red mudstones and shales occur together with thin silty bands, lenticular cross-bedded sandstones and fairly common ironstone nodules. Faulting can cause problems when it brings in, or repeats, undesirable sandstone beds. Similar sediments are present in a large pit at Stoke-on-Trent in the lower Etruria Marl, where there are good red and pink-burning clays as well as a grey facies which fires buff; these mudstones are used for both facing and 'blue' engineering brick manufacture.

In North Wales the Upper Coal Measures are traceable from the Dee estuary southwards to Oswestry; they are most typically represented in the Denbighshire and west Shropshire part of the coalfield. The lower *Ruabon Marl* has been, and still is a well known tile clay, while the upper part of the sequence, the Erbistock Beds, were formerly used for brickmaking near Wrexham and Hanwood (Salop). These horizons are separated by the calcareous sandstones, marls and limestones of the Coed-yr-allt Beds. A similar Barren Red sequence occurs in Anglesey but does not outcrop.

At Ruabon, near Wrexham in north Wales, high quality quarry and flooring tiles are manufactured from the *Ruabon Marl.* Below boulder clay overburden there are about 10m of red-firing, red coloured, brickmaking marls, underlain by approximately 12m of so-called 'blue-clay', the beds currently used to produce tiles. Lower still there are at least 40m of red-firing marls which are suitable for brick manufacture. The lowest coal marker horizon in the pit is the Half-yard

Coal. The 'blue clay' mudstones clay mineral suite is dominated by disordered kaolinite with about half as much degraded or disordered potassium-deficient illite in addition; it fires satisfactorily at 1120° or 1130°C to produce a strong, well-vitrified tile. Iron oxide content varies considerably from bed to bed and mixing produces the brindled and varied fired colours of the product. Total alumina content of the 'blue clay' is high (23%) and carbonate content is low (see Appendix I). There are no problems with impurities, though careful grinding and even re-grinding is necessary.

The lower red-firing mudstones, which are suitable for brick manufacture, contain dominant well-ordered kaolinite with lesser well-crystallised potassium-rich muscovite as their clay minerals. Despite the predominance of normally pale-firing kaolinite, these beds fire red because of the high (7–8%) hematite content.

Accessible reserves of good quality Ruabon Marl for tile making are becoming limited (15–20 years in this area) due to pressures from road building, land ownership and planning, as well as the dip of the 'blue clay' beneath thickening overburden. Reserves of red-firing mudstones suitable for brick manufacture are adequate for the foreseeable future. Reserves of the equivalent Etruria Marl beds in Staffordshire are now severely limited due to sterilization by urban expansion and, to a much lesser extent, by intercalated thick sandstone lenses.

Marls, fireclays and shales from the Scottish Upper (Barren) Coal Measures were once used for the manufacture of building products, for example wire-cut bricks in the Central Coalfield and in the Dalkeith area of the Midlothian Coalfield, where mottled marls and mudstones produced a strong engineering type of brick.

Note on clays used in the clay pipe industry

Historically most clay pipe works have been situated in the coalfields, the availability of cheap fuel being an important factor. The low impurity, plastic, refractory fireclays found in association with the coal seams were easily shaped with the low powered equipment then available. The black carbonaceous Coal Measure shales were not suitable since they were less plastic and tended to bloat on firing. A few pipe works were situated outside the coalfields but they tended to use special clays such as the Tertiary ball clays in Devon.

Prior to the Second World War the South Derbyshire Coalfield was the major centre of salt-glazed pipe production, the high alumina Derby Fireclay and the underlying and more siliceous Derby Bottle Clay being the main raw materials. Today, lower quality Coal Measures shales and fireclays with moderate vitrification temperatures and ranges are used for vitrified clay pipe manufacture and complex blending of different beds or clays from different quarries is necessary. Various beds are dug to maintain a balance between more kaolinitic and illitic sediments, thus ensuring the desired vitrification properties of the final blend. The industry is now almost entirely based on fireclays in the Pottery Clays Formation of the Middle Coal Measures in the South Derbyshire Coalfield and several mudstones in the Lower Coal Measures of the Penistone area. Up to 24m of overburden consisting of black carbonaceous shales may be stripped away to extract 3m or so of 23% alumina illitic mudstone around Penistone. There appear to be adequate reserves of raw material for vitrified clay pipe manufacture at current production rates. The future use of even more sophisticated blending, fine-grinding and pre-calcination to reduce carbon and sulphur levels, may allow a wider range of raw materials to be used in vitrified clay pipe manufacture.

Permian

At the end of the Carboniferous, Variscan mountain building profoundly affected the geography of Europe; Britain became part of the Hercynian Continent and strata of continental facies were once more deposited over wide areas during the succeeding Permian and Triassic periods.

The early Permian rocks were laid down in Britain in tectonic basins or cuvettes, and Permian sediments are preserved in north-east, north-west and south-west England, as well as in the Midlands and in Scotland. However, limestone predominates between the Tyne and Nottingham, and the clays and marls are not generally thick enough to be of commercial interest. The Marl Slate for example, a bituminous silty shale, is mostly too calcareous (2–20% $CaCO_3$) and seldom exceeds one metre in thickness. The Permian Lower Marl is also rather limey and the Manchester Marls include fossiliferous, calcareous bands detrimental to brickmaking.

The Permian of south-west England includes the Watcombe Clays locally developed in the Torquay area and thicker, more extensive, red marls at the top of the Permian. A typical average mineralogical analysis from Permian red beds in south-west England is as follows:

Illite	49%
Kaolinite	1%
Chlorite	3%
Montmorillonite	0.5%
Mixed-layers	2.5%
Total clay	56%

Representative chemical analyses are shown in Appendix I.
The Permian marls have been used in the Exeter-Exmouth area for brickmaking and also in the Doncaster area and in Nottinghamshire.

Test carried out on bricks made from Permian clays from Devon and Yorkshire, using handmade,wire-cut, pressed wire-cut and semi-dry press processess, (Bonnell and Butterworth 1950) showed that their physical properties were broadly similar to those made from lower 'Keuper Marl'.

Triassic

Although the Triassic is composed largely of continental rocks, including dune sands, conglomerates and sandstones as well as muds, it contains one of the more important sources of brick-making material in Britain, the *'Keuper Marl'.* The rocks formerly described as Keuper Marl are now included in the *Mercia Mudstone Group* and the term should no longer be used. It is, however, retained in this dossier as it is still widely used by industry, but this informal usage is acknowledge by use of quotation marks throughout. Thirty or so years ago it afforded about 6% of total U.K. clay brick output; today the figure is nearer 9%.

Triassic rocks outcrop extensively in the Midlands of England and extend north-westwards and north-eastwards on each side of the Pennines as well as south-westwards into Devon. The Upper Triassic is divisible into the Sherwood Sandstone below and the Mercia Mudstone Group or 'Keuper Marl' above. There is no sharp boundary between the two, and bands of marl occur in the Sandstone while sandy beds are common especially in the lower parts of the Marl. Argillaceous beds within the 'Keuper Sandstone' have been used at Lichfield and in Leicestershire for brick manufacture.

The 'Keuper Marl' is a thick widespread series which overlaps earlier beds and covers considerable areas of Worcestershire, Warwickshire, Leicestershire, Cheshire, Nottinghamshire and South Yorkshire. In Cheshire, possibly the centre of a Triassic basin, it attains a thickness of over 1,370m while in Lincolnshire where it rests directly on the Pre-Cambrian, it attains a maximum thickness of 198m, thinning to only 30m in south-east Durham. Many of the brick pits are relatively shallow (a maximum of 15m deep) since reserves are laterally extensive (the beds are flat-lying in the Midlands) and extraction is not badly restricted by planning. However, in some quarries the main reason for extending horizontally rather than vertically is the downward incursion into the Waterstones strata which contain an unacceptable proportion of green sandstone beds. While a proportion of these sandy skerry bands can be incorporated in the feed along with more clayey deposits it has not yet been found necessary to use them. Where such beds are thickly developed they are avoided or dumped.

The 'Keuper Marl' represents the semi-arid weathering products of the Carboniferous which were deposited as mud in the shallow saline water of large inland lakes. The intercalated sandstones and siltstones represent channel deposits or aeolian accumulations. The absence of free drainage coupled with high evaporation rates led to increasing salinity and the development of halite, gypsum and anhydrite. The 'Keuper Marl' is seldom a true "marl" since its carbonate content is not generally high enough, but it may be described as a calcareous, argillaceous deposit composed of red and chocolate-coloured mudstones with silty mudstones and beds of sandstone and shale. A cyclic pattern of sedimentation is apparent and dolomitic cement is almost ubiquitous. The commonest lithology comprises clay minerals associated with a high proportion of fine silica of wind blown desert origin and magnesia in the form of dolomite. Illite is the dominant clay mineral with kaolinite, expanding chlorites and sepiolite present in small amounts. Chemical analyses of 'Keuper Marl' samples are shown in Appendix I. Iron, magnesia and carbonate contents are generally high while the alumina content is often only 11–13%.

At Ibstock in Leicestershire the 'Keuper Marl' contains between 4 and 34% dolomite with up to 40% illite mica which imparts plasticity.

The 'Keuper Marl' produces a variety of fired colours. In any one quarry there may be beds which, when fired, produce a buff body colour, while others are red-burning or cream-burning. It is thought that variations in both iron oxide and carbonate contents cause differences in the fired colour. The dolomite content of the 'marl' varies considerably and as the $MgO + CaO:Fe_2O_3$ ratio increases the material becomes progressively paler-burning. Most 'Keuper Marl' brickworks tend to extract the deposit selectively, since, having carried out fired colour tests on sample horizons, they are able to produce a variety of body colours from one pit by judicious blending or by using one bed or group of beds alone. In some cases there is a shortage of red-burning marl and operators are willing to dig down through buff-burning sequences which are discarded in order to obtain the red material.

Halite beds often of considerable thickness occur in the 'Keuper Marl', and two widespread gypsum bands, the Newark Gypsum and the Chellaston Gypsum, lie approximately 18.3m and 42.7m below the top of the 'Keuper Marl', (the former also occurs in Somerset). These beds are avoided by brickmakers. Thin stringers of gypsum are also common in some of the beds used for brickmaking, and are often difficult to separate out. Salt deposits in the 'marls' of Northern Ireland are a significant obstacle to brick manufacture.

The carbonate content of the 'Keuper Marl' varies widely but unlike some calcareous clays, it is present as finely disseminated dolomite crystals which, together with the high alkali content, helps to lower the vitrification temperature and avoid excessive shrinkage or distortion during firing. The vitrification range is short (1000°–1100°C) and firing temperatures of 980° to 1070°C are common, producing bricks with compressive strengths of 140–352 kg/cm^2 (2000–5000 p.s.i.), water absorptions of 15 to 20% and linear shrinkages of 15–5.5.%.

Bricks made from Triassic deposits tend to have a rather low bulk density, though the lower beds produce slightly less porous, denser bricks. It is possible to use deposits with low soluble salts contents but bricks made from the middle and upper parts of the 'Keuper Marl' do not withstand severe exposure well. Shrinkage due to loss of carbon dioxide at about 800°C is very variable due to the varying carbonate contents of the beds, but true bloating is rarely a problem. In some areas the 'Keuper Marl' presents difficulties for brickmaking because of its content of carbonate, which if not ground fine enough may result in surface 'blowing' of the brick. Also, when in high concentration, for example 24% CaO in one quarry, it causes the bricks to be almost refractory.

Much of the 'Keuper Marl' outcrop is obscurred by drift, especially boulder clay, and it is the thickness of this overburden which largely determines the availability of brick clay in this deposit. The boulder clay itself was worked for brick manufacture in a small way in the past but is now discarded. The thickness of contained sandstone beds can also affect the suitability of particular sequences for brick clay and may sterilize the clays below them. However, within the constraints of planning permissions reserves of 'Keuper Marl' would appear to be adequate for the foreseeable future.

The passage from the Triassic to the Jurassic is marked by up to 30m of Rhaetic beds which contain grey marls, black shales with bone beds and fossiliferous and pyritiferous limestone horizons. The variability and fossiliferous nature of much of the Rhaetic makes its clays unsuitable for brickmaking.

Jurassic

Jurassic strata outcrop in a broad expanse extending from the south coast of England to the Yorkshire coast; minor outcrops occur in Scotland and Northern Ireland.

Lower and Middle Jurassic

The Lower Jurassic (Lias) mostly comprises clays, shales and thin muddy limestones. Deposition in interconnected marine basins separated by submarine ridges led to lateral facies and thickness variations. Thick sequences of clays were deposited in the basins, e.g. Northamptonshire–Lincolnshire (over 330m thick), while the swells were the sites of thin calcareous and sandy deposits.

The Lias outcrops in Northamptonshire and Lincolnshire, over the Vale of Evesham and southwards to Gloucestershire and Dorset. Liassic remnants containing variable amounts of shaley beds are widespread in Somerset, south Wales, south Cheshire, west of Carlisle and in Scotland.

Despite the often appreciable amounts of carbonaceous matter and lime, the main brick clays of the Lower Jurassic occur in the Lower Lias. They are usually fossiliferous blue clays with limestone bands, and various horizons have been used extensively in the past for brick, tile and pipe manufacture. The decline in their use in recent years is largely due to the availability of economically more workable clays at higher horizons of the Jurassic. Impurities in the dominantly illitic Lower Lias clays include marcasite, pyrite and glauconite, while carbonaceous material and fossil remains may cause lime-blowing.

The Lower Lias clays were, and to a limited extent continue to be, worked at Glastonbury, Illminster and Bath (Somerset) and Blockley, Stonehouse, Cheltenham and Moreton-in-Marsh (Gloucestershire). In South Glamorgan, at

Rhoose and Aberthaw, and in the Rugby–Leamington area, the Lower Lias is worked for cement manufacture.

Lower, Middle and Upper Lias clays were until recently used for brickmaking near Lincoln and were dug for cement manufacture at Kirton, north Lincolnshire. The Lower and Middle Lias clays of south Warwickshire were used in tile production, while the Upper Lias of Northamptonshire has been worked in the past. The upper Lower Lias and lower Middle Lias clays, formerly worked at Waddington pit, 8 km south of Lincoln, vary considerably in composition and contain a rich fauna as well as pieces of fossil wood. The moisture content is about 15% and the sulphur content is high in places. Common and engineering bricks were made by semi-dry pressing the Lower Lias shales, while wire-cut facing bricks were made by extruding the micaceous blue-yellow Middle Lias.

North of the Moreton and Market Weighton axes the Middle Jurassic is largely non-marine. The deltaic facies of Yorkshire resembles the Carboniferous Coal Measures, with thin coal seams and seatearths, and significant shale/mudstone bands in the Estuarine Series. Chemical analyses of clays from the Upper Estuarine Series of Lincolnshire used to produce facing bricks are shown in Appendix I. The main Middle Jurassic clays in southern England are the Fuller's Earth Clay and Bradford Clay.

Tests carried out on bricks made from Lower and Middle Jurassic clays (Bonnell and Butterworth 1950) showed them to be generally of medium density and water absorption; compressive strengths were usually high and drying shrinkage tended to be small. There was, however, a wide variation in their saturation coefficients, soluble salt contents and durability. The iron content is usually high in the Lias clays, which produce body of good colour and average strength, though bloating at high temperatures can be a problem with Middle Lias material.

Upper Jurassic

Several important clays occur in the Upper Jurassic, the lowest of which is the Kellaways Clay. The Kellaways Beds, a predominantly sandy series extending from Dorset to the Humber and beyond, are lithologically variable, representing a transition from the Cornbrash to the Oxford Clay, and comprise ferruginous sandy shales, siltstones, sandstones and sandy clays. The Kellaways Clay is a green, grey or blue plastic clay 3 to 4m thick in Wiltshire and Hampshire.

The succeeding *Oxford Clay* , a formation remarkably uniform in character and thickness, is by far the most important brickmaking deposit in Britain. Fletton bricks made from the Lower Oxford Clay account for nearly 50% of total United Kingdom building brick production.

The outcrop, which varies in width from about twenty miles to as little as three miles, follows a diagonal course across England from Scarborough in Yorkshire, through Lincolnshire, Peterborough, Oxford and Wiltshire to Weymouth in Dorset. It occupies a large area of flat country in the counties of Bedfordshire and Cambridgeshire and, although largely obscured by recent deposits in much of the Fenland, comes to the surface in places (Whittlesey, Eye etc) to exhibit a relatively marked sub-fen topography. The eastern limit of the outcrop is often difficult to define in East Anglia due to its patchy covering by Chalky Boulder Clay drift. Drift or alluvium also masks much of the Lincolnshire and Vale of Ancholme outcrop.

The main brick-producing centres on the Oxford Clay lie between the Bletchley area and the Peterborough area (Calvert, Bletchely, Bedford and Peterborough –Whittlesey) where the clay presently supports fourteen brickworks. Stewartby, in the Bedford complex, is currently the largest brickworks in the world and even the other Oxford Clay works have production capacities as great as the largest non-fletton works in Great Britain. The Lower Oxford Clay has also been worked for brick manufacture near Weymouth, where shaley clays occur with ammonites and septarian nodules.

Lithologically the Oxford Clay comprises blue-grey bituminous clayey shales and mudstones in the lowest 20m or so, followed by more plastic, homogenous, paler clays above. Muddy limestones, bands of limestone concretions, and a variety of fossils are common throughout the succession; pyrite nodules and selenite cyrstals also occur. A threefold lithological division has been identified in the Oxford Clay. The bituminous lower division is the most favoured and is extensively worked by the Fletton brick industry. The commercial brick clays are largely confined to the *Kosmoceras jason* and *Erymnoceras coronatum* zones of the Middle Callovian Stage (Callomon 1962). The *Lower Oxford Clay* is 13.5-23m thick and is moderately high in lime and rich in carbonaceous matter. The Middle Oxford Clay comprises 15m of calcareous mudstones, while the Upper Oxford Clay is 30m thick and is composed of calcareous mudstones and thin siltstones. The Oxford Clay is often covered by gravel or superficial clay (callow) overburden which varies in the Fletton areas from 3.1–3.7m thick and represents the weathered profile of the clay. This material is nowadays rejected along with any non-carbonaceous Middle or Upper Oxford Clay although before introduction of the semi-dry Fletton process the plastic callow was used for brickmaking. Overburden shifted in the Bedfordshire area in order to reach the Lower Oxford Clay may be as much as 11m thick and averages about 7m.

It is the high carbonaceous content of the Lower Oxford Clay which has given it an inherent cost advantage over other brick clays and which has largely led to its expanding use ever since the Fletton process was developed in the 1880's. The clay contains an average of 18% moisture; it therefore requires no pugging before pressing, and is easier to work by the semi-dry pressing technique than other harder clays (containing 4–13% moisture) which use this process (Searle 1956). It is also physically well suited to dry grinding. However, firing of extruded pieces made from the Lower Oxford Clay is difficult compared with other British carbonaceous clays and shales. The bituminous content is in the form of fine (mostly less than 2 μ size) algal matter which forms an impermeable skin on the surface of the extruded column. The result is that at 380°C in the kiln, hot gases cannot easily escape the structure and severe spalling occurs, but it has been found possible to extrude and fire lower quality products such as field drain pipes from finely ground Lower Oxford Clay. The carbonaceous content of the clay is between 5 and 7% by weight, representing a calorific value of 200 to 900 cals/g (Duff 1972). The amount of fuel required to fire the bricks is thus considerably reduced. About 1¼ cwts (or 50–100kg) of low grade coal dust (55,560Kcal/kg or 100,000 BTU per lb.) are needed to assist firing of 1,000 Fletton bricks, whereas 4–7 cwts (200–360kg) are needed for Coal Measure shale bricks. Thus the apparent disadvantage of the absence of local fuel in the Fletton area compared with Coal Measures shale areas is more than offset by the reduced fuel requirement.

A further advantage to brickmaking plants based on the Lower Oxford Clay is that they are situated midway between London and the urban areas of the Midlands. The sediments in the main areas of exploitation are thick and laterally extensive as well as being lithologically and mineralogically fairly homogeneous, so that modern large-scale extraction methods have been more easily applied to the Oxford Clay than to any other brick clay horizon. While the Lower Oxford Clay is superficially homogeneous there is variability within comparatively small thicknesses but this is smoothed out by the method of winning carried out in all pits. Clay from the whole quarry face is dug vertically at right angles to the bedding by a shale-planer or by a walking dragline excavator. The limited zone of workings is thus due to the thickness, structure and superficial cover of the clay, the proximity of good communications, and the lower bitumen content in other parts of the outcrop.

The main clay mineral present is of illite-mica type with lesser amounts of kaolinite and traces of chlorites, smectites and vermiculite. Calcium carbonate is the dominant impurity and increases markedly with sampling height above the formation base. These variations tend to influence the firing shrinkage and fired properties of the Fletton clay (Freeman 1956). The levels of calorific value remain more or less stable in the lowest parts of the succession, but higher up the values fall below useful levels. These trends are similar in different areas of the outcrop though accumulation of organic-rich sediment is thickest in Bedfordshire. Representative chemical analyses of the Oxford Clay are shown in Appendix I.

Maximum firing temperature is between 980°C and 1050°C, and each brick loses about 0.95kg in weight and 7½% approximate linear shrinkage. There are no serious impurities, though careful screening and regrinding is necessary to reduce the size of calcareous nodules and fossils. Barytes and gypsum can be troublesome if not very finely divided.

The results of physical tests on Fletton bricks show that they usually have a fairly low bulk density with high water absorption and saturation coefficients. Linear drying shrinkages are small and on firing some contraction occurs between 850° and 900°C; subsequent contraction takes place more slowly until fusion develops at about 1100°C. Soluble salt contents of Fletton bricks are fairly high but the more soluble sulphates of magnesium and the alkalis are rarer.

Approximately five square miles of Lower Oxford Clay-bearing ground are currently owned by London Brick Company. Various sources have estimated that from 180 km sq to 600 km sq of Fletton clay suitable for extraction occurs in Great Britain as a whole. At current rates of production London Brick Company consider that they have assured reserves for another 60 years, and these amount to only a small fraction of the total amount of Lower Oxford Clay ultimately available.

The use of the Upper Oxford Clay as a source of heavy clay ware raw material had dwindled in recent years, due largely to the dominance of the contiguous Lower Oxford Clay. However London Brick Company continue to extract Upper Oxford Clay from their quarry at Warboys. Here they produce extruded hollow clay floor and wall blocks and field drains from the more plastic, lower carbonaceous content clays.

Marked geographical changes took place at the end of the Oxford Clay, and there followed deposition of Corallian arenaceous and reefal calcareous facies in parts of Britain. However in East Anglia the Corallian is represented by marls and limestones with some clays very similar to those of the Oxford Clay. North of the Oxford Axis the Corallian gives way to a deepwater clay facies, the Ampthill Clay, which, so far as is known, has only rarely been worked for tiles and drain pipes near, for example, Kirbymoorside. It is a dark, gypsiferous clay up to 60m thick in Lincolnshire and traceable northwards from Oxford to the Market Weighton Axis. At Kirbymoorside about 6m of grey-brown, shaley, calcareous clay with bands of calcareous septarian nodules and an ammonite fauna were extracted.

The Kimmeridgian marked a return to dominantly clay deposition due to gradual subsidence, and closely resembles conditions prevailing in the Oxford Clay. The *Kimmeridge Clay* comprises thick, dark blue-grey clays and shales with cementstone bands and abundant fossils. It exhibits great variations in thickness, thinning northwards from 488m at Kimmeridge in Dorset to 91m in Oxfordshire and Lincolnshire and no more than 36m in the Fenland, where it is overstepped by later strata. In East Anglia the outcrop is discontinuous; it is absent due to erosion in Bedfordshire, but emerges from below Lower Greensand cover west of Cambridge and extends towards the Wash in a widening outcrop underlying the eastern Fens. North of the Market Weighton Axis the Kimmeridge Clay thickens up to 152m and floors the Vale of Pickering where it is obscured by thick drift.

The Kimmeridge Clay is worked for cement manufacture near Westbury, Wiltshire, but production of bricks and tiles from this clay in the Fenlands is now negligible. This is partly because the highest beds are too bituminous for this purpose but mainly as a result of competition from the contiguous Oxford Clay. It is still worked, however, in the Vale of Pickering. Approximately 145,000 facing bricks a week were until recently manufactured from the Kimmeridge Clay at Kirby, North Yorkshire, where iron and carbonate contents are high (Appendix I). Similar argillaceous beds of Upper Jurassic age have been used for brickmaking at Brora, Sutherland; the deposit comprised at least 13m of dark grey, soft, rather sandy, shaley clays with a 3 to 8m thick overburden of glacial gravel.

Cretaceous

After a long period of limestone sedimentation at the end of the Jurassic period, uplift in central England initiated a change to clastic deposition in southern England. All the argillaceous beds of the Lower Cretaceous *Wealden Beds* have been or are used in brick manufacture. The Ashdown Beds, Wadhurst Clay, Tunbridge Wells Sand and Grinstead Clay are collectively known as the *Hastings Beds Group* and are followed by an important brickmaking deposit, the *Weald Clay*. The most typical development of these beds is in the Weald which was a subsiding graben with coastal alluvial mud plain, lagoonal and river facies (P. Allen 1975). Variable salinites existed during Hastings Beds deposition and brackish phases are recognisable in the Weald Clay. The Hastings Beds have a compact outcrop in Kent and Sussex extending to the northwest into Surrey. The lowermost division, the *Ashdown Beds* consists of deltaic fine-grained sandstones and siltstones which outcrop in the cores of two anticlines, in the Ashdown Forest and in the area between Uckfield and Winchelsea, as well as in numerous smaller areas. The Ashdown Beds are 183 to 213m thick at Crowborough but pass into the lacustrine Fairlight Clay near Hastings. These beds are about 122m thick at Fairlight and thin rapidly to the north and west. The Fairlight Clay has been used near Hastings for brick manufacture and pale grey silts with clayey lenses in the Ashdown Beds are used in Sussex (Crowborough) and Tonbridge.

The succeeding lacustrine *Wadhurst Clay* averages about 46m in thickness and comprises rhythmically alternating grey-blue clays, shales and mudstones with subordinate calcareous siltstones, sandstones and clay ironstones; freshwater bivalve and ostracod horizons may be common and are avoided in brickmaking. The Wadhurst Clay outcrop is roughly horseshoe-shaped running from Rye to Wadhurst, East Grinstead, Uckfield and Hastings, and generally thickens westwards to 70m at Cuckfield. This clay is worked in the central Weald for facing brick production e.g. Godalming, Lingfield and Tonbridge in Surrey, and at Lewes in Sussex. Suitable deposits also occur at Tunbridge Wells in Kent and at West Hoathly, Uckfield and Bexhill in Sussex. The Wadhurst Clay was formerly worked for bricks and tiles at many other places in the central Weald.

The Tunbridge Wells Sand represents a return to deltaic conditions with deposition of fine silts and sands. Except in the eastern Weald it includes the *Grinstead Clay,* a local development of blue and grey shaley clay possibly representing a temporary return to lacustrine conditions. This deposit was used at East Grinstead and Uckfield, while clayey lenses in the Tunbridge Wells Sand are dug for brickmaking near Bexhill, Sussex.

Representative chemical analyses of Hastings Beds clays are shown in Appendix I. Mineralogically the Wealden clays as a whole are variable, but normally contain nearly equal proportions of illite mica, a poorly crystallised kaolinite and a third clay mineral of the expanding chlorite or vermiculite type. Smaller quantities of silica, calcite, iron hydroxides, and gypsum may also be present. The illite has been modified by the development of expansile layers, resulting in a mixed-layer structure (R. W. Tank 1962).

Results of tests carried out in 1948 on various bricks and clays from the Hastings Beds (Butterworth and Honeyborne) show that they vary widely in their physical properties depending upon raw material used and method of production. Most of the facing bricks were of medium bulk density with medium or high water absorptions, while the engineering bricks had a high bulk density and low water absorption; saturation coefficients were generally low or very low. Great variation was also shown in compressive strengths, from below 70.3 kg/cm^2 to over 1054.7 kg/cm^2 for engineering bricks made from mixed Tunbridge Wells Sand and Wadhurst Clay; most of the facing bricks were of medium strength. Soluble salt contents were generally less than 0.5% and liability to efflorescence was negligible, though the Wadhurst Clay contains soluble salts and gives rise to some efflorescence. To some extent the variations in water absorption and compressive strength are due to different methods of production. Because the clays all contain appreciable amounts of kaolinite they tend to be fairly refractory and have long vitrification ranges.

Above the Upper Tunbridge Wells Sands lies a more argillaceous deposit, the *Weald Clay,* consisting essentially of green, grey, blue, brown and red clays or mudstones with subordinate siltstones, sandstones, shelly limestones and clay ironstones. It is poorly exposed in south-east England but gives rise to an extensive area of low-lying ground surrounding the "High Weald" of the Hastings Beds. Small inliers of Weald Clay occur in the Lower Greensand outcrop near Guildford, Dorking and Maidstone. Westwards it thickens from 122m at Hythe and 244m south of Maidstone to 457m near Guildford. Impurities in the Weald Clay include calcite, siderite, pyrite and gypsum, as well as ostracod-bearing horizons.

The Weald Clay of Kent, Surrey and Sussex is very important for the manufacture of facing and engineering bricks, accounting for some 80% of estimated brick production from the Wealden area. Brickworks are scattered over the outcrop but are more important between Dorking and Horsham, and near Nutfield and Cranleigh (Horsham, Godalming, Lingfield, Lewes, Dorking, Nutbourne). In the past, the clay was dug south of the Lower Greensand scarp especially south of Dorking, Reigate and Redhill, Surrey, at Edenbridge and Ashford in Kent, and Pulborough, Horsham, Burgess Hill, Plumpton and Hailsham in Sussex. Some use was made of the Weald Clay at Sandown on the Isle of Wight.

Chemical analyses of Weald Clay samples are shown in Appendix I; analyses of bricks made from the Weald Clay show that they contain appreciable amounts of ferrous iron, but the carbonate content is generally low. The results of tests on Weald Clay bricks made by different processes vary widely, (Bonnell and Butterworth 1958). Some of the handmade bricks showed low bulk densities;

drying shrinkage was normally very low in all bricks, and compressive strength was usually high in machine made types.

Late in the deposition of the Weald Clay there was a transition through brackish conditions to marine conditions as sea level rose. The succeeding Lower Greensand marked the end of a long phase of non-marine sedimentation, and comprises up to 244m of arenaceous glauconitic deposits, laid down in near-shore marine environments. The London–Belgian Ridge separated southern and northern basins of deposition for much of the time. The Lower Greensand contains some argillaceous beds, such as the *Atherfield Clay* (shales and mudstones with iron concretions and occasional sandy beds), which forms the lowest division in the southern basin of deposition. This clay is highly fossiliferous and grades up into sandier beds; it has been used in the past as a mix with the Weald Clay for brick manufacture.

Regional submergence at the end of the Lower Greensand allowed marine transgression over the whole of southern England and deposition of the highly fossiliferous *Gault Clay* and Upper Greensand which spread far beyond the confines of the Lower Greensand. The Gault in eastern Kent is entirely argillaceous, but westwards siltstones and sandstones become more important, and in the western Weald they constitute the whole of the Upper Gault. Known as the Upper Greensand, they are a sandy facies of the Gault and the two divisions are lithological variants of a single sequence spanning the Middle and Upper Albian. Between the two divisions siliceous and calcareous sandstones known as the Malmstone are often developed. The Gault comprises dark, blue-grey to pale grey, soft mudstones and silty mudstones sometimes with a rich marine fauna, weathering to yellow and brown clays. Glauconitic and calcareous bands occur as well as phosphatic nodule beds, notably in the middle of the formation. It generally produces low-lying ground between the escarpments of the Chalk and Lower Greensand and shows common variation in local thickness with a general westwards thickening across the outcrop. In the Isle of Wight and Dorset it is sandier, whereas west of the Chilterns it is characteristically a stiff dark clay up to 92m thick.

Gault bricks are only produced at Sevenoaks and Selbourne in the Wealden area, but the formation was formally utilized in Wiltshire near Devizes, Burwell in Cambridgeshire, the Isle of Wight, Oxfordshire, Buckinghamshire, Bedfordshire, Kent (Maidstone, Ashford, Folkestone) and Hants–Sussex (Petersfield). It is quarried for cement manufacture near Steyning, Sussex, Halling and Snodland in the Medway Valley. Suitable resources remain in all these areas. In Cambridgeshire tough blue or grey Gault clays and marls with phosphatic nodules cross the county in an outcrop up to 10 km wide, but drift obscures much of it and only the upper, less phosphatic and fossil-free clays were dug for bricks near e.g. Shefford, Gamlingay etc. London Brick Company currently produces large diameter field drain pipes from Gault Clay at Arlesey in Bedfordshire. Gault bricks are usually cream coloured due to the carbonate content (e.g. Kent, Cambridgeshire) though in some places they are red or multi-colour. Chemical analyses of Gault samples are shown in Appendix I. The white-burning clays contain carbonate which occurs in a finely divided form so that there is little trouble with lime-blowing. Where silica content is low, sand is sometimes added to the feed. Red-burning Gault clays from, for example, Hampshire, tend to be almost free of carbonate and have a higher silica content.

Results of various physical tests on Gault bricks showed that their bulk densities were all low due to their high porosity caused to some extent by the high carbonate content imparting an extremely short vitrification range. Compressive strengths were generally fairly low while soluble salts contents may be high.

The Cenomanian marine transgression inundated the greater part of Britain and the Upper Cretaceous is synonymous with the unusually constant limestone sequence of the Chalk in England. The Weald is surrounded by the Chalk Downs and the proximity of pure chalk to suitable clay resources such as the Gault Clay, London Clay, or alluvial muds, has led to the siting of cement works in the area.

Tertiary

The close of the Cretaceous Period was marked by regression of the Chalk sea from northern Europe, and a long period of erosion followed prior to deposition of the earliest Tertiary beds.

Cyclic marine Palaeogene beds are preserved in the London and Hampshire Basins in Britain. A wide variety of lithologies is represented, although limestones are rare. Deposition of the Eocene in the London Basin commenced with glauconitic sands and silts of the Thanet Beds, followed by the Woolwich and Reading Beds. These are a variable group of sands and clays, the Woolwich Beds being marine in the east of the basin, grading westwards into estuarine or brackish beds, and, further west still, into the fluviatile and deltaic *Reading Beds* facies. In the Hampshire Basin the westward gradation is also seen, but much of the area is composed of Reading Beds, the lithology of which varies from mottled, plastic clays to silts and cross-bedded sands. The mottled clay represents lagoonal or salt marsh sediments while the sands and pipe clays may have been deposited by rivers flowing into this low-lying swampy region. At Alum and Whitecliff Bays on the Isle of Wight the Reading Beds contain illite and kaolinite as major constituents with only minor amounts of montmorillonite and rare chlorite. Some sections such as those at Studland Bay, contain beds unusually rich in montmorillonite, and at Bishops Waltham and Otterbourne montmorillonite and illite are the major components. Many of the mottled clays from the London Basin are also highly montmorillonitic with lesser amounts of illite and kaolinite. Thickness variations are complex but the Woolwich and Reading Beds attain a maximum west of London and near Chichester. The mottled plastic clays and light sands of these beds were formerly extensively worked for bricks in the Thames Valley, around Bracknell, near Hemel Hempstead, Epsom and Ewell for brick and tile.

Montmorillonitic, plastic, mottled Reading Beds clays are dug at Michelmersh near Romsey, Hampshire, where sand and anthracite dust are mixed with the clay to produce hand-thrown and soft-mud pressed facing bricks and fireplace briquettes. Some clays are suitable for floor and roofing tiles. The Reading Beds were frequently mixed with the London Clay and suitable resources occur around Reading (west to Newbury and east beyond Maidenhead), Farnham in Hampshire, Epsom, and in outliers on the Chiltern dip-slope.

The succeeding marine *London Clay* is typically a stiff blue clay, weathering brown, relatively uniform in lithology, though it becomes sandier westwards. The sandy upper beds which occur both in Essex and west of London, are called the Claygate Beds, which in Surrey consist of rapid alternations of sand and clay. Up to 182m thick in the eastern part of the London Basin, the London Clay thins to some 90m at Windsor and less to the west. In the Hampshire Basin it thins from 90m in the Isle of Wight to 24m in Purbeck. The relatively uniform lithology of the London Clay is accompanied by an almost constant clay mineralogy, montmorillonite and illite being the major components with lesser amounts of kaolinite and traces of chlorite. In common with other Tertiary marine sediments it often contains abundant glauconite both in the form of pellets and as finely dispersed pigment.

The London Clay has never been greatly favoured as a brickmaking clay largely because pyrite occurs throughout, ranging from minute cubes and micro-concretions to irregular nodules, and also because it was too plastic to be used on its own. Selenite crystals also occur typically to a depth of 3m below the weathered zone, and calcareous concretions (septarian nodules) occur at intervals. However the London Clay was formerly an important source of brickmaking material in Middlesex and Essex, and, mixed with Reading Beds, in Surrey and Hampshire. There were many brickworks producing bricks, pipes, tiles and pots around London e.g. at Chessington, Tolworth, Worcester Park, Sutton, Norbury, Thornton Heath, Selhurst, South Norwood, Crystal Palace and New Malden, and the clay was often mixed with chalk to produce white stocks. It is now only locally dug for brick-making in Essex, Hampshire, Berkshire and Dorset although it is used in cement manufacture along Thames-side and to produce expanded clay aggregate in Essex. The London Clay was the most important brick clay of the Windsor-Chertsey area before the First World War and chemical analyses of two clays from the old Down Mill Brick Company's pit at Bracknell show very low alumina contents:

	Red Clay %	*Blue Clay* %
SiO_2	73.40	71.0
Al_2O_3	5.94	10.8
Fe_2O_3	6.35	3.7
CaO	13.80	9.8
H_2O Alkalis etc.	0.50	5.7

In the Hampshire Basin, sandy beds overlying the London Clay are well developed, for example in the Isle of Wight, where they are known as the Bagshot Sands. In the Bournemouth area the sands are deltaic or estuarine and contain interbedded clays; these 'pipe-clays' are also known from Parkstone and Poole. Bagshot Beds clays were used for brickmaking in these areas as well as the Ringwood area (Hants) and on the Hants-Surrey border, sometimes mixed with London Clay. The Bagshot Beds on the east of the Isle of Wight have a very variable mineralogy with illite-kaolinite predominant in the sands and occasional thin, highly montmorillonitic pipe clay horizons. The uppermost and lowermost horizons of the beds are generally rich in montmorillonite but at Alum Bay, Bournemouth, and in Dorset the only clay minerals are invariably illite and kaolinite in about equal proportions.

The sea that existed in the east of the Hampshire Basin during the deposition of the Bagshot Beds gradually spread over the whole area to produce a series of estuarine and marine deposits, the Bracklesham Beds, some 200m of clays and glauconitic sands. Montmorillonite and illite are generally the major clay minerals of the clay facies with lesser amounts of kaolin and traces of chlorite. The Bracklesham Beds were dug for brickmaking in Surrey near Ascot and Woking, and near Southampton.

A marine transgression followed the deposition of the Bracklesham Beds and fine marine sands and clays of the Barton Beds were deposited in a shallow sea which extended further to the west. The lower division of the Barton Beds, known as the *Barton Clay,* has montmorillonite, illite and kaolinite as the major components with small amounts of chlorite. The clays have been used in the past for brickmaking in Hampshire.

The Barton, Bracklesham and Bagshot Beds were thus exploited mainly in Hampshire, especially near Southampton and Bournemouth, with some production from Surrey. The lower quality ball clays of Wareham Heath and neighbouring areas have also been used for bricks, pipes and tiles.

Chemical analyses of clays from the Eocene are shown in Appendix I. As regards firing characteristics, the high montmorillonite content in many of the clays may explain the physical behaviour. The London Clay is highly plastic and has an unusual capacity for absorbing water and non-plastic additives. A high drying shrinkage results from the high moisture content and this can cause excessive cracking in the drying stage, a tendency which can be reduced by adding large amounts of grog (inert filler). The clay is of very low refractoriness and is often prone to bloating if the temperature is raised too rapidly. Bulk density and water absorption are generally moderate, but soluble salts can cause problems and the presence of magnesium sulphate can cause efflorescence especially if the bricks are fired at too low a temperature. Many Eocene clays are variable in their magnesium sulphate or carbonate contents, and thin lenses or pockets of clay containing these impurities are often not distinguishable in the quarry face.

Oligocene lagoonal and lacustrine argillaceous sediments are present in the Hampshire Basin (Isle of Wight and Dorset) and in the Bovey Tracey outlier in Devonshire. Bricks were produced from the Hamstead Beds on the Isle of Wight, while the Bovey Tracey Beds are famous for their ball clays, lower qualities of which were used for pipe manufacture around Newton Abbot.

Quaternary

Marine deposition of Pliocene (Tertiary) and Lower Pleistocene sediments occurred mainly in East Anglia, and rare clayey deposits such as the micaceous Chillesford Clay at Aldeburgh are still dug for brick manufacture in a small way.

During the Pleistocene, parts of the British Isles were affected by repeated glaciations and, at their maximum extent, the ice sheets covered almost the whole of Britain as far south as the Bristol Channel and Essex. Each of the advances and retreats of the glaciers was marked by particular deposits, and the lowlands were the recipients of ice-borne debris known collectively as "drift", often over 30m thick. There are many types of Pleistocene and Recent clays potentially useful to the brick industry, including till (boulder clay) glacial lake clays, periglacial clays, interglacial clays, clay-with-flints, brickearth, raised beach clays and alluvial clays.

The most characteristic deposit is *till (boulder clay)* which can vary from a plastic pebbly clay to an almost clayey gravel or sand. Till has been used in many areas for brickmaking especially in the north-east of England, in Scotland and in Northern Ireland. The suitability of a particular till deposit for brick manufacture depends to some extent upon the rocks traversed by the glaciers from which it was deposited. Thus limey clays, which are troublesome if the lime is not finely dispersed, may result from Carboniferous Limestone or Chalk bedrocks. Grain size varies considerably, and Northumberland-Durham boulder clays, which are often very plastic and fine grained, have higher drying and firing shrinkages and require lower firing temperatures than coarser grained clays from, for example, Lancashire and Lincolnshire. Till covers much of Cheshire and south Lancashire and was formerly utilized here and on the Welsh coast near Llanelly and Swansea. It was also used for brickmaking near Londonderry in Northern Ireland but the material was found to be too stony; red, sandy boulder clay has also been tried in County Down. Bonnell and Butterworths' studies (1958) of boulder clay bricks suggest that, used on their own, the clays are often too plastic and rich in clay minerals. This gives rise to cracking and excessive drying and firing shrinkages, as well as a very short vitrification range. When mixed with a proportion of sandy material excellent bricks can be produced, though of variable physical properties; soluble salts content is generally low. Till has been extensively used in the past to produce "composition bricks" with Coal Measures shales in Scotland.

As well as till, *Pleistocene periglacial and interglacial clays, silts, sands* and *gravels* occur in Britain. These were deposited in ice-dammed lakes, by sub-glacial drainage, by fluvio-glacial meltwaters, or by ice. Glacial lake clays were used for brickmaking in various areas e.g. near Langholm (southern Scotland), on the Aberdeenshire coast and in the Vale of York, but today are mostly dug locally on a small scale in for example Essex, or more extensively in the northeast of England. An interglacial deposit is currently worked for bricks near Colchester, the clay fraction being composed of kaolinite, illite and slightly lesser proportions of smectite. The deposit consists of thinly bedded, dark, grey-blue, alternating silts and clays which exhibit graded bedding and contain seams of plant fragments and lignite. A lignite band near the top of the pit is avoided, as is also an upper sandy layer which is carbonate-rich and causes lime blowing in the fired brick. The basal 6m or so of the pit are dug and blended for brick manufacture, and 25% sand is added to the clay feed as a filler. The deposit is ascribed to the Hoxnian interglacial; it produces good quality, handmade facing bricks which, due to the relatively high proportion of lignitic material dispersed throughout the sequence, are virtually self firing. The clay has been tried for tile making but did not possess sufficient strength, and tended to crack when fired.

One of the larger heavy clay ware companies in Britain utilizes several superficial clays at its north of England factories. Very extensive Pleistocene glacial and interglacial clays and silts occur in North Humberside, including a high quality glacial lake clay indispensable for the production of high class interlocking clay roofing tiles at Broomfleet. The deposit is of wide extent, stretching from Easingwold, across the Humber, to Selby. At Broomfleet a three-fold sequence exists with red-firing clays near the top used for brick manufacture, white- or buff-firing pale glacial lake clays in the centre, also used for brick manufacture, and a red-firing basal black glacial clay from which the tiles are produced. The Broomfleet tile clay is a very 'fat' clay and requires the addition of 11–13% sand for strength. A higher firing temperature can thus be used which results in enhanced vitrification, higher strength and better frost resistance. The pale brick clay is composed of extremely fine-grained kaolinite which when blended with other clays coats coarser red-firing particles and causes them to fire to a buff colour. Hence by using only one-third white clay to two-thirds red clay, the works can produce a buff-bodied facing brick. A laminated, relatively pebble-free, superficial clay which may be till or interglacial clay, is also worked at Eaglescliffe, Cleveland. Even with a period of souring it is very sandy, and lacks green strength, but reserves of this clay are very large and stockpile blending of variable beds is by-passed by vertical scything of the whole quarry face. Quality facing bricks are produced by extrusion from the 19% moisture content clay.

Recent *alluvium* and *alluvial clays* deposited in river valleys have been used in brickmaking but, because they are highly plastic, drying shrinkages tend to be high. Important, formerly worked, deposits occur on the banks of the Humber and in north Lincolnshire as well as in the Vale of York, and in Norfolk and Suffolk. In the Bridgewater area of Somerset alluvial clays were used in brick and single-lap tile manufacture, and they have also been used at Llandudno in Wales. Variable amounts of impurities including pyrite, fossils and calcareous nodules can be troublesome but the fine grain size of many of the deposits, in common with glacial lake deposits, makes them particularly suitable for tile manufacture. Both glacial lake clays and alluvial clays were more often than not mixed with clays from older formations.

Scotland possesses a variety of superficial clays which were extensively used in the past for brick, pipe and tile manufacture, but have remained untested and largely underused today. Sources include *till, glaciolacustrine* and *fluvioglacial deposits, raised beach, marine* and *estuarine deposits* and *alluvium.* In 1946 such reserves were considered to be 'probably ample' for the then demand, but production dwindled by comparison with the production of Coal Measures blaes bricks. A study of these superficial clays during the last World War pronounced them to be of variable quality and on average rather poor, although suitable for drainage pipes, tiles and bricks of moderate strength (Bonnell and Butterworth, 1946).

Superficial deposits have been worked in widespread areas of coastal Aberdeenshire, Banffshire and Morayshire. These are mainly glaciolacustrine and glaciomarine (raised beach) clays occurring along or near to the coast of north-east Scotland at various levels at or below the 30.5m contour. The deposits vary from good quality clays, through fine sand, to coarse gravel. They may be up to 20m thick and, though locally variable, some are stone-free. Shells are normally rare but where abundant can render a particular clay unsuitable for brickmaking; when mixed with sand several of these clays can be used for producing bricks suitable for severe exposure. Raised beach clays were formerly worked at many localities between Aberdeen and Fraserburgh and near Banff, Cullen and Elgin.

Glaciolacustrine clay is currently worked in the Grampian Region at Tipperty, near Ellon, Aberdeenshire. The Tipperty pit works part of the extensive red glacial drift of the eastern coast of Aberdeenshire consisting of red till (boulder clay) and interbedded derived lacustrine silt and clay. The thickest of the latter clays and those that constitute the main brick clay spreads are located below the 30.5m contour and are separated from the till below by a thin gravel. The lacustrine clay contains about 56% clay minerals and has a clay mineralogy of predominant dioctahedral illite (70–80%) with subordinate kaolinite (15%). The composition of the underlying till is similar but comprises in addition, 5% vermiculite (Glentworth, Mitchell and Mitchell 1964).

In Fife, one company near Methil produces composition bricks by blending virgin blaes and boulder clay. In the south of Scotland there were workings in raised beach clays near Newton Stewart used to make agricultural drain pipes, and near Langholm small glacial pond clays were dug. Deposits of lacustrine and boulder clays suitable for tile production are known and are currently worked by one company at Newton Stewart in Ayrshire.

In the Central Coalfield area of Glasgow, Coatbridge and Airdrie, tough boulder clay was dug at, for example, Robroyston quarry and was mixed with ground blaes from coal and ironstone pits at Souterhouse, Garturk and Rawyards for the manufacture of composition bricks. South of Drumpark, a small tract of stoneless laminated brick clay was also used. Good quality facing bricks were produced from the plastic blue and brown brick clays of the Clyde Valley late-raised beach deposits, but this formerly fairly widespread industry declined under competition from English facing brick, planning restrictions and quality control problems. Red sewer-pipe bricks were produced at Belvidere north of the Clyde.

In the Bathgate, Wilsontown and Shotts areas of the coalfield, till was used with colliery blaes for composition bricks near Foulshiels colliery and at the Braehead and Eastfield quarries in the Fauldhouse district. Clays at the top of the Armadale quarry have also been used in composition bricks. Stoneless superficial brickclays are associated with the sands and gravels to the west and north-west of Bathgate and were used at Nethermains and Westfield for bricks and tiles. A large area of these clays occurs to the south-west of Broompark.

In the Rutherglen, Hamilton and Wishaw areas of the coalfield, boulder clay dug as a by-product of sandstone quarrying was extensively used for brickmaking at Auchinlea and Bellside quarries, while composition bricks were made using colliery blaes and till near Carfin colliery.

On both sides of the Clyde there are thick interbedded brick clays, sands and gravels overlying the boulder clay. These were dug at Bothwell Park quarry and the old Birdsfield Tile Works, near Stonefield, as well as to the west of Caldergrove. There is thus a fairly wide spread of superficial brickmaking clays between Uddingston and Motherwell, and on the south bank between Hallside and Hamilton. However, sterilization of resources by urbanization has been extensive. Laminated, stoneless, plastic glacial lake clays occupying hollows in the till were worked at many places in the Carluke, Strathaven, Larkhall area for bricks and tiles, e.g. Newmains, Morningside, Hallcraig, Whiteshaw, Milton, Braidwood, Auchenheath and Blackwood. Hallcraig and Milton also produced composition bricks using superficial clays with ground ironstone waste blaes.

In eastern Stirlingshire late-glacial ('100 foot') raised beach clays were worked for bricks, floor, roofing and drainage tiles, and chimney pots at Blackness over one hundred years ago. In the Midlothian coalfield similar, but thicker, fluvioglacial and raised beach clays were dug until more recently at Smeaton and Portobello. Eskbank and Newtongrange also had quarries in the sub-boulder clay laminated, stoneless, glacial clays. Many of the resources of superficial clays in Scotland have become sterilized by development in the last fifty years and little appraisal work has been carried out.

Clay-with-flints

Clay-with-flints is a pebbly clay deposit found in dissected patches on the higher parts of the Chalk Downs and in other parts of England such as the Yorkshire and Lincolnshire Wolds. Its origin is still in dispute but it may represent the weathered remains of Tertiary material. The clay mineralogy is variable, with kaolinite often predominating over lesser smectite and illite (e.g. Chesham area), though sometimes the proportion of smectite greatly exceeds that of the other clay mineral types. The clay is a sticky, relatively stoneless, mottled orange-buff-grey deposit; flint/chert pebbles and small ferruginous nodules are avoided during digging and a blend of 'strong' and 'weak' clays is normally produced to which sand is added for body. There are no important chemical impurities in the clay and, were it not for the pebbly stringers and the patchy nature of the deposits, the clay-with-flints would be a useful source of brickmaking material. It has never contributed a significant proportion of total UK brick production because of its poor lateral and in-depth continuity, though a few works, e.g. near Chesham and Cholesbury, maintain a small but profitable turnover by supplying a very local market with hand-made facings and specials. Bricks made from the clay-with-flints tend to have low compressive strengths but are resistant to severe exposure. The Buckinghamshire–Hertfordshire material may represent the weathered profile of the Reading Beds and a gravel overburden of a few feet has generally to be removed at the onset of digging. After the addition of sand for body, it is suitable for hand-moulding and firing at up to 1300°C. Mineralogically the clay contains disordered kaolinite as the major clay mineral with variable amounts of smectite (1–5%) and illite (1–4%). It produces a variable quality but aesthetically pleasing facing brick characteristic of the area. Because temperature regulation in the batch kilns is poor, a variety of colours and qualities is obtained. Red bricks have a compressive strength of 2,000 p.s.i., and brown bricks of 4,000 p.s.i.

Brickearth

The term brickearth has been applied to superficial buff, brown or red deposits which are composed of fine sands and silts with some clay, and are so called because they have long been used for making bricks. The formation of the same name occurs mantling Mesozoic and Tertiary strata or other drift deposits and is mainly of late Pleistocene age.

The light sandy-coloured loam, normally about two metres thick, occurs principally in North Kent and South Essex but is traceable into Hertfordshire, Middlesex (Hayes), Surrey, Sussex, Berkshire, Hampshire (Portsmouth to Littlehampton), Buckinghamshire (Marlow, Iver) and East Anglia (Norwich, Sudbury, Bury, Colchester). The Sittingbourne–Faversham area was the centre of the North Kent brickearth industry (Rainham eastwards to Clay Hill, and Swale/Medway southwards to Rodmersham). The areas of Essex in which brickearth chiefly occurs are around Romford, Southend-on-Sea and in the eastern part of the county.

The precise origin of brickearth is not clear but it contains a high percentage of wind-blown silt-sized quartz grains and is thought to be a Quaternary, loess-type, ferruginous clayey or silty loam. It is also thought that 'head brickearth' was formed as a result of solifluxion. In south Essex, complex deposits of 'head brickearth' up to 8m thick consist of brown, stiff, clayey silts, yellow-brown silty sands and sandy silts, with coarse sand lenses and scattered flints. This type of deposit can be seen at Milton Hall (Southend) Brick Company's Cherry Orchard Lane works near Rochford, Essex, and is probably a soliflucted loess deposit or the reworked upper silty facies of buried channel deposits.

Thick loess is rare in Britain apart from the small patches of brickearth which bear some relation to the loess deposits that stretch across central Europe and Asia. However, the English brickearths are essentially of local origin, in contrast to loess in Europe where powerful wind action operated over vast regions. The laminated variant seen in some sections in England probably represents deposition in small patches of standing water, e.g. laminated silts in the Eastwood brick pit, Essex.

Deposits of buff-coloured, structureless loam occurring in the Weald have been called brickearth, and appear to be partly post-glacial aeolian accumulations and partly due to sheet-flooding (alluviation). In east Kent they occur from sea level to about 91m above sea level, and in Surrey they form patches on the higher parts of the Lower Greensand outcrop. Fine grained brickearth near Hove has been explained as wash material from the Downs, which was decalcified during long periods of exposure. Brickearth occurs up to 200m above sea level on the Chilterns near Luton, where it includes Palaeolithic artefacts indicating its recent nature.

The clay mineral suite of brickearth is normally a mixture of illite and lesser kaolinite. In many cases the brickearth clay mineralogy closely resembles that of the underlying solid formations. For example, in the Foulness area of Essex the only difference between brickearth and London Clay mineralogy is the sporadic abundance of calcite in the former. As a rule the brickearths have a lower average montmorillonite content than the solid deposits on which they rest, while the quartz and carbonate content is higher. However, in South Essex montmorillonite and illite are dominant and some are surprisingly rich in montmorillonite with only 5 to 10% kaolinite and a small amount of mixed layer clay. Brickearth from north Kent often contains approximately equal proportions of kaolinite, illite and smectites with 6% or so of calcite. Calcium carbonate content generally varies according to the abundance of calcareous nodules. Dispersed iron oxide is normally included in the clay fraction and finely divided calcite is often present, while glauconite is common in the medium-fine sand fraction of some brickearths.

Brickearths may be red or buff firing depending on their relative proportions of iron oxides and carbonate, and upon their origins. Buff firing types are probably less abundant, though brickearths can commonly be made to fire yellow by the addition of chalk slurry.

Extensive spreads of brickearth have been mapped overlying gravels along the south coast between Hove and Portsmouth. Formerly this area supported numerous brickworks but is now almost totally built over so that large resources have been sterilized. It is possible however that sufficient material remains to establish a small brick industry.

The north Kent deposits, though less extensive, have not as yet experienced such great pressures from development, and support a vigorous stock brick industry. In the Sittingbourne–Faversham area brickearth has been worked over several thousand acres. In 1955 it was estimated that there were about 8,510 hectares of brickearth left in Kent, with about 810–1215 hectares sterilized by development.

The Milton area of Sittingbourne was traditionally the main centre for brickearth working but the deposits have long since been worked out. Before 1930 there were forty brickearth works in Kent; at present there are four, situated at Conyer, Otterham, Funton and Murston (the first is on a care and maintenance basis). The first three together use 66,300 cubic metres of brickearth per year. About 2.8 to 3.3 hectares of brickearth are dug each year during the summer months in north Kent, and poorer quality 'strong' types containing up to 25% clay mineral are now being used (previously a content of 18 to 22% clay mineral was most sought after).

Various factors influence the working of brickearths in Kent. Reinstatement of the land is very rapid and is carried out so successfully that almost no trace of extraction is visible. Most farmers co-operate willingly with the brick manufacturer who reimburses them for the inconvenience as well as for the brickearth and the cost of lost agricultural production. If the deposits occur on arable land extraction can be carried out without difficulty, but if the area is covered by orchard, extraction may have to wait several years before the owner is willing to uproot all his trees. Much of the north Kent brickearth is covered by orchards, some of which have up to a 60 year life before replanting is necessary. Thus sites are most intensively studied with a view to extraction where they are arable or covered by senile orchards.

Today, due to development, worked out areas and refusals of planning permission, there are not enough reserves to ensure a minimum 20 years of working for the industry in north Kent. If firms are allowed to work only the areas already permitted, production will tend to fall. If production is to be maintained it will be necessary to make provision for the future working of new areas including perhaps the deposits of brickearth in other parts of Kent. There are extensive spreads of brickearths in the Hoo area, east of Faversham, in the south of the Isle of Thanet and in a broad zone between Canterbury and Sandwich. Though these deposits have not been seriously evaluated for composition, thickness, and other factors, they may be workable in the future.

Secondary raw materials

Sources of argillaceous raw material, in some cases suitable for the production of heavy clay ware, occur as the waste products of certain mining operations in the United Kingdom. By far the most important of these is colliery spoil, particularly in Scotland.

Colliery Spoil

Waste produced from the mining of Carboniferous coaley materials in Scotland includes colliery spoil and spent oil shale. Spoil heaps, known locally as 'bings', are scattered across the whole of the Midland Valley of central Scotland. The main areas of coal exploitation have been, or are, Fife, Clackmannanshire, the Lothians, east Stirlingshire, the Central and Douglas fields of Lanarkshire, Midlothian and Ayrshire. There continue to be large resources in the Fife, Central and Ayrshire coalfields and it is from the modern mines in these areas that most colliery spoil will accrue. Apart from large mines, some of which have an output of 1 million tonnes per annum, there is now significant open-cast working in Fife and elsewhere in central Scotland including the largest open-cast mine in the UK at Westfield. There is a stockpile of about 138 million tonnes of blaes in Scottish NCB-controlled tips and current production is adding to this at the rate of 4.5 million tonnes per year (Lawson and Nixon 1978). Much of the colliery waste tipped in the past has become wholly or partially burnt as a result of loose tipping. This allows air to penetrate into the heaps so that spontaneous combustion may take place, although in some places burning may have been started by tipping of hot ashes. Modern bings are better controlled and compacted in layers with earth-moving vehicles, so there is less chance of burning.

The spoil heaps consist of shales, mudstones, siltstones, and sandstones together with associated fireclay, ironstone, limestone and dolomite. In addition there may be colliery washery tailings slurried into silt ponds in the centre of tips. The Productive Coal Measures blaes and Limestone Coal Group blaes which form the bulk of tips are hard, laminated, blue-grey shales which weather rapidly on exposure. The composition of colliery waste tips is very variable and considerable amounts of combustible materials are often present; these can spontaneously ignite to produce a red burnt shale, or in the case of black unburnt shale can be profitably used as a self-firing agent in brickmaking. Burnt red blaes are a harder more stable material, but normally contain a higher proportion of soluble sulphates than un-burnt shales. Burnt shale bings are thus of little use to the brick industry.

The main disadvantage to the use of colliery spoil arises from the fact that the contents of the tips are unpredictable. The blaes have a high carbonaceous content, but vary from one tip to the next and within the same tip. The quantities available are statistically sub-divided into 'burnt', 'part burnt' and 'unburnt' although quantities in different categories are sometimes difficult to assess. The largest quantity of unburnt spoil in disused bings in Scotland occurs in the Lothians, while in active tips the greatest unburnt amounts are in Ayrshire. In England and Wales the greatest amounts of unburnt spoil are found in east Wales, west Wales and north Yorkshire. The current rate of tipping on land is greatest in Nottinghamshire, south Yorkshire, north Derbyshire, Barnsley, east Wales and the Midland Valley of Scotland, in that order. From this it will be seen that there is, and will continue to be, a greater amount of spoil available in England and Wales than in Scotland. Despite this, the use of colliery spoil in brickmaking is a predominantly Scottish phenomenon due partly to the traditional building methods employed there and partly to the scarcity of other suitable brickmaking materials. About 80% of building brick production in Scotland is based on the use of waste blaes to manufacture common bricks, although in many cases a mix of bing material and opencast 'virgin' blaes is used to obtain the necessary blend.

Up to 1978, the brick industry in Scotland was using about 750,000 tonnes a year of tipped shale from bings and in addition about 100,000 tonnes of current waste (colliery washery slurry) from active collieries in Fife and the Lothians (Lawson and Nixon 1978).

The waste shales normally contain about 5% of carbonaceous material though the so called 'firey' bings contain pockets of coal or anthracite. Fairly complex blending is normally carried out by the brick manufacturers who, for example, mix 'firey' carbonaceous blaes with 'dour' low carbon-content blaes. In this way they achieve the most acceptable average carbon content designed to reduce firing costs and yet minimize firing problems such as black coring. Most of the bricks produced in this way are almost self-firing; however the 'firey bings' are rapidly being used up and very few remain in the east of Scotland. Non-Carboniferous bricks fired in Scottish kilns normally require double to over twenty times the amount of fuel needed by blaes bricks.

The production line of a brick factory depends upon continuity of supply and quality control; variations, even very small ones, in the type of blaes coming from the tips can thus disrupt production. With improved methods of sorting and building of tips in layers, newer bings look more attractive to prospective users. However, mining methods in the past involved the tipping of a large proportion of coaly material on the bings, whereas today, with modern mining technology, most of this material is recovered and a higher proportion of 'dour' low grade shale is present. Thus, the older bings tend to produce the self-firing blaes which are such a feature of the Scottish common brick industry. In future, it may become more difficult to obtain enough of the 'firey' material.

Because of the hardness of waste Carboniferous shales and their inability to develop good plasticity easily, the stiff plastic press method of forming is employed. This process is also used in the many factories that use virgin dug Coal Measures shales, though these shales can now be successfully extruded. It is a fairly general concept that in order to produce good quality facing bricks it is more desirable to extract Coal Measures shales opencast, rather than use old tipped shale where quality control is much more difficult. Thus recent expansion into the facing brick market by Scotland's largest colliery blaes brick company involved the utilization of opencast virgin shales and wire-cut extrusion forming. Similarly, in England there are brickworks, situated adjacent to large colliery spoil heaps, which prefer to extract their raw material open-cast.

Tests on samples of Scottish common bricks made from waste blaes carried out over twenty years by the Building Research Establishment's Scottish Laboratory have shown that the bricks have variable properties, but they generally have low soluble salt contents and medium to moderately high compressive strength. However, their liability to efflorescence was often marked despite the overall low salts content. Their main problems were lime-blowing due to over-burnt calcerous nodules and the liability of iron staining. Because of their general use as common bricks the staining does not normally constitute a serious problem though staining of internal finishes can be troublesome. The presence of black coring is largely a feature of the speed of firing in the Scottish continuous kilns and is not a serious defect. Reduction in throughput to eliminate black coring would add about 10% to the cost of the brick.

A large amount of waste blaes from the former oil shale industry occurs in Scotland. Reference has been made to the fact that little use has been made of Oil-Shale Group shales for brickmaking, but the estimated 170 million tonnes of waste from mining and processing of this Group for oil is a significant waste resource. The oil shale bings are confined to a relatively small area within West Lothian and Midlothian. About 125 million tonnes of the waste is spent shale from the oil processing, while the rest is mining waste dumped in 'dirt' bings.

At present the oil shale waste is used only to manufacture autoclaved shale-lime (calcium silicate) bricks. Its potential as a clay building brick raw material on its own has not been greatly studied due to the large amount of Coal Measures blaes available locally. Analysis of spent shale from the oil retorts (Appendix 1) shows that iron oxide, lime and salt contents are higher than in burnt colliery blaes, although a useful 2–3% free carbon is present. There would probably be more potential for the use of the mined waste in the 'dirt' bings for brickmaking.

Waste Coal Measures and Limestone Coal Group shales also originate from old ironstone workings in Scotland and Wales. Thinly bedded sideritic ironstones, often oxidised to limonite, occur within shales above coal seams. When these relatively poor seams were dug for iron ore in the past a large amount of shaly waste was produced. Apart from a slightly higher percentage of illite in these predominantly marine shales, the ironstone bing wastes are essentially similar to the more widespread colliery wastes. Waste shales from ironstone workings are used at Merthyr Tydfil in Wales mixed with fireclay to produce buff facing bricks. The shales are very hard and non-plastic, and in order to impart some strength to them, sulphite-lye is added to the blend; extrusion is then possible.

In most coal mining areas the emphasis is on reclaiming and reinstating land covered by coal tips; the Scottish Development Agency is trying to remove some tips and is thus promoting a search in the Lothians for virgin blaes. The National Coal Board has set up a 'Minestone Executive' to market colliery spoil for such uses as construction and motorway fill, and so remove unsightly tips. Since early 1968 more than 25 million tonnes of this material has been used in the UK for this purpose, though recently such usage has been decreasing.

In Scotland, although current consumption of waste blaes is small compared with the total amount available, it is important to note that only about 5 million tonnes of bing material contains the desirable combination of 'clean' shale and pockets of 'firey' material for fuel. Rehabilitation with consequent sterilization of such bings has already begun and supplies of suitable waste blaes might be difficult to obtain in the future. However, because of the increasing demand for high quality facing bricks in Scotland, the quantity of colliery waste used in the production of bricks is likely to continue to decline.

The introduction of highly mechanised mining techniques has increased the production of colliery waste in tips and more coal is being obtained by opencast extraction. Thus, in addition to obtaining brick making material from spoil heaps, a large tonnage could be obtained from the Opencast Executive of NCB. Where opencast working is on a large and increasing scale, such as in Northumberland and Durham, vast tonnages of overburden including shales, mudstones and fireclays are shifted annually. Normally only fireclays generally warrant the transport costs to existing brickworks (although small quantities of brick making shales are derived from NCB opencast sites in the north-east of England) and the focus is on reinstatement of the land by progressive replacement of the shales after the coal has been worked out. The area is normally reinstated over a short time, perhaps 2 to 8 years, and arrangements between clay users and the National Coal Board's agents have to be made rapidly. It may be particularly desirable to encourage this type of operation both to avoid sterilizing clay resources and to reduce the level of extraction in other areas, but there are amenity problems in transporting large quantities of shale over long distances to brickworks and in stockpiling the shale for future use.

There are other waste materials which contain a significant proportion of clay or clay-like minerals and which could be used in the production of construction materials should the need arise.

Slate waste

The various uses of slate waste have been dealt with in Mineral Dossier No. 12 – Slate. Approximately 500 million tonnes of slate waste are present in old Welsh tips, 20 million tonnes in the Lake District and 15 million tonnes in Cornwall. Some 70 million tonnes of waste are estimated to have been produced in Scotland (Lawson and Nixon 1978).

Slate, a fissile, argillaceous, low grade metamorphic rock, is mineralogically composed of a fine aggregate of chlorite, sericite, quartz and haematite with rutile, calcite and pyrite accessories. This material has little or no plasticity and even when crushed is apparently unsuitable for moulding even by modern brick forming methods. However, if the slate is allowed to weather thoroughly and certain additives are used it can be used as brickmaking material (Rural Industries Bureau Report of Investigation September 1954). The Building Research Station (now Building Research Establishment) has carried out research which shows that the most favourable outlet for slate waste in the brick industry lies in the production of calcium silicate bricks. Bricks of adequate strength can be made by autoclaving mixtures of crushed slate and lime. However, the bricks have a high drying shrinkage which would preclude their use other than as a Class B brick, and they tend to be susceptible to frost damage in severe conditions. The utilization of slate waste from different areas in the production of expanded aggregate has been well researched and successful lightweight slate aggregate has been manufactured for use in lightweight concrete. Slate waste has also been used in the past to produce concrete bricks and cement, and small amounts are used as construction fill.

China Clay waste

On average the production of one tonne of china clay gives rise to 9 tonnes of waste, of which a little under one tonne is fine micaceous residue, the rest being coarser sandy material. At present only calcium-silicate bricks and concrete blocks are made from the sand fraction of the waste. The ECLP Group have undertaken extensive research on ways of utilizing the vast amount of waste produced by the industry (12 million tonnes per annum). The present utilization of this material is small, but in the future it may be possible to use the micaceous fraction as an additive in clay brick manufacture.

Red Mud waste

At Burntisland, Fife, about 70,000 tonnes of red mud are produced annually as a waste byproduct of the processing of bauxite by the Bayer process. The residue consists mainly of iron oxide, insoluble alumino-silicates and 35 to 40% moisture. Tens of thousands of tonnes of red mud have also been tipped at Newport, South Wales where bauxite was formerly processed. The mud is mostly disposed of in ponds, and while little use is made of it at present, research in Australia suggests that it could be used in a blend with shales to produce clay bricks.

Recycling of Bricks

Large quantities of building materials are made available by housing redevelopment and industrial demolition; approximately 60 tonnes of bricks per dwelling house or 3 million tonnes of brick per 50,000 dwellings (Willis 1946). In 1974 about 50,000 dwellings were demolished in Great Britain and this figure could be greater in the future.

The demolition of obsolete buildings has provided a convenient source of materials for the construction industry throughout history (parts of St Albans Cathedral were built with bricks salvaged from the Roman City of Verulamium). During and after the last World War demolition materials were extensively used in new buildings. However, although there should have been an economic advantage in recovering material, the cost differential between used and new bricks was too low to make the exercise profitable. In 1946 new and secondhand bricks were very similar in price: £6.20 per 1,000 and £5 per 1,000 respectively for first hard Stocks. Sharp rises in the price of new bricks have sometimes prompted consideration of demolition material where previously it would have been rejected. In 1970 1,000 first hard Stocks cost £26.70 new and £7 secondhand; by 1976 the figures were £83.55 new and £25 secondhand (prices from "Building" 1946, 1970 and 1976).

The material that has the greatest advantage is that which is available within, or close to, large cities or in an area where alternative natural materials are scarce. However, it is in big cities that economic and planning constraints restricting the recovery of demolished material are greatest. It is still only economic to recover bricks for which there may be a significant secondhand demand (e.g., yellow stocks in the London area, and Staffordshire Blue engineering bricks in south Wales) or where the textural or handthrown quality of the bricks is particularly attractive and new alternatives are in short supply. Lime mortar is easily separated from bricks, but where cement-containing mortar has been used it is very difficult to remove without damaging the bricks. This influences the economics, so that only high value bricks are recovered; others under normal circumstances will be used only as fill or hard core.

Additives

A variety of non-clay raw materials are used as additives in the brick industry, one of the most important being sand. Many brick clays, especially those of more recent geological age, are too plastic to be used on their own. This is often because of their unusual clay mineral content (e.g. montmorillonitic Reading Beds clays or glacial lake clays) and a variable amount of sand must be added, often more than 20% to reduce drying and firing shrinkage and to impart 'body' to the brick.

Another additive is chalk slurry in brickearth stock brick production; this less than 100 micron material is a by-product of nearby cement manufacture and is used to impart a characteristic pale yellow colour to the bricks. About 6,560 tonnes per year is used in the Kent area and enough is added to the brickearth to bring the total calcium carbonate content to about 6 or 8% in the final mix.

Various materials are mixed in with the clay in many brickworks to aid firing or reduce firing times or temperatures. One of the commonest additives to low-carbon clays is colliery washery slurry bought from the National Coal Board, which can make a brick 55% self burning. Anthracite dust evenly distributed in the clay feed achieves a similar reduction in fuel costs and is also widely used. Town ash (burnt town waste) is also sometimes obtained by arrangement with various councils. In Kent, for example, town ash provides 90% of the firing material in one clamp-fired works, but its calorific value of 4,500 Btu per lb. is lower than that of colliery washery slurry (6,500 Btu per lb.) and its use is declining.

Some brickworks have to contend with the problem of 'scumming' where calcium sulphate in the clay (for example the 'Keuper Marl' and the Wadhurst Clay) produces unsightly white discolourations on the surface of the fired brick. To avoid this, 0.25 to 0.5% of barium carbonate is added. The barium carbonate combines with the calcium sulphate to produce calcium carbonate and fixes the scum. This barium carbonate is largely imported, and though domestic crude witherite has been tried it was not found to be as efficacious.

Comments on Resources of Raw Material

Almost all argillaceous formations capable of producing bricks in the United Kingdom have been utilised although many served only local demand. There are extensive areas underlain by rocks which are possibly physically and chemically suitable, although relatively little testing and assessment has been undertaken, but which are not worked as there is little demand due to sparse population of the surrounding area or because they cannot compete with established sources.

No area in the United Kingdom with a continuous high demand for clay products lacks suitable raw materials. Some regions may lack certain types of clay suitable for specific purposes e.g. for producing engineering bricks, or special quality facing bricks. However, the number of areas with large, geologically undisturbed, reserves of good clay, close to markets and lacking surface development is limited. Also, resources available in some sparsely populated areas, such as parts of Scotland north of the Highland Boundary fault and parts of Wales and Cumbria are not always easily worked so that normal production methods may require some modification. In other parts of Europe and in the USA clay is frequently transported from its source to works some distance away, but this practice is seldom followed in the U.K. Brickworks have generally been situated close to major markets; hence there are now no works in the Lake District, in west and most of central Wales, and in southeastern and most northern areas of Scotland. There is also a marked absence of works in a belt surrounding the Fletton area e.g., in Oxfordshire and Rutland, on account of competition from that industry, although recently some attention has been focused on the outcrops of Lower Oxford Clay to the west of the main workings.

The Lower Oxford Clay is a particularly important formation on account of its special properties. With this in mind the National Board for Prices and Incomes (1967 and 1970) proposed that "the Oxford Clay should be exploited as fully as economic considerations justify", to produce Fletton bricks and allow brick prices to remain competitive. While competition from, for example, the Fletton sector, outdated plant and distance from conurbations are the main reasons for most of the closures in the last 40 years or so, it has been estimated that approximately 150 million bricks capacity is lost each year through exhaustion or deterioration of clay reserves. For example, in the Newport-Cwmbran area of Gwent pits operating in Devonian red marls encountered calcareous nodules or cornstones which are difficult to remove and detrimental to the mix. The Belfast brick industry contracted considerably in the last 35 years because of the poor quality of bricks produced from the 'Keuper Marl' in the area, and competition from concrete and sand-lime bricks. Individual deposits are particularly prone to sterilisation by general building development as many works dating from the early 1900's are now surrounded by the towns which they originally served, e.g. local sterilisation of very limited high-grade clays by building is a serious problem in Co Tyrone. As brick kilns themselves usually cover a larger acreage than the ancillary buildings of other quarrying operations the incidence of sterilisation by poor works planning is marked, although London Brick Company's policy for past and future new works is to construct manufacturing plant on the floor of worked-out pits, thereby avoiding sterilisation of clay reserves and producing as little impact on the environment as possible.

Although large areas of the sea bed around the British Isles are composed of clay (Till and Tertiary clays in the North Sea, Tertiary clays in the Solent, and Jurassic clays to the south of Weymouth), it is unlikely that production from these sources would be economically feasible in the foreseeable future. Material dredged from the Thames estuary was formerly used as a 10% additive in the manufacture of Kent brickearth stocks, but such muds are now used only in cement production.

The estuarine clays underlying the 'levels' fringing parts of the Bristol Channel have not been examined as a source of brickmaking materials although some of these clays intercalated with thin silts and peats may range up to 100 feet in vertical thickness. Similar clays exist in several coastal areas of south-east England, e.g. Romney Marsh, Pevensey Level etc.

Although it is possible to use lower grade clays, such as colliery waste shales, the increasing use of more efficient processes and in some cases the availability of higher grade materials make the working of low grade clays unattractive. For example, callow (weathered Oxford Clay and Till lying above the exploited Oxford Clay horizons) was once used for brick making, but cannot be employed in the pressed brick process. Attempts have been made to pass 5% of this clay through with the Fletton clay, but quality control proved difficult and the practice was discontinued.

In Scotland there is a search for virgin (in situ) blaes; bing material is still the main source, though it is short term, and derelict land is being actively reclaimed by the Scottish Development Agency. A case for restricting other development can be made where clays have special properties, for example, where the products may be highly resistant to frost or acid attack, or may be capable of bearing heavy loads. There is also a case for safeguarding reserves of brick and pipe making clays where their physical and chemical properties are well documented and where there are known to be very satisfactory raw materials for existing works. The capital cost of putting down a new works is such that the most must be made of reserves such as those outlined above. The Etruria Marl is perhaps in the greatest danger as far as sterilization of reserves is concerned.

In an industry as large and varied as that under discussion there is obviously scope for deeper workings at some pits. The advantages and disadvantages applicable to most open-pit operations are relevant here. It is not possible to extend many workings in the direction of dip owing to increasing overburden ratios; these must be low as the end product is relatively low priced. Maintenance of low pit-to-plant transport costs and of dry workings by pumping are important in deep pits. Slope stability is very important in the larger pits. Safety factors are determined by reference to the height of the slope, dip of the beds, cohesion, porosity, percentage saturation and other factors. Most wall collapses in the Oxford Clay are related to inflow of water either from the base of the drift or surface water. The major problem of deeper workings is that of use after working has been completed; acquisition of suitable fill and stability of slopes are often the deciding factors.

Resource Evaluation, Research and Testing

The ideal raw material for heavy clay products should have at least moderate plasticity, with good workability, high dry strength, a long vitrification range, total shrinkage of less than 10% and a fired colour to suit the market. Since many raw materials are not ideal in all respects, it is often necessary for the manufacturer to develop blends fitted to his process and product. In other parts of the ceramic industry, clays are to some degree blended or standardized by the clay producing companies, but in the heavy clay ware sector the raw materials and the products are so diverse that it is the manufacturing company that controls the quality and consistency of the clay. Because of increasing automation of manufacture and reduced handling in the brick, pipe and tile industries, consistency of raw material has become increasingly important, and unexpected changes in raw material composition can be adverse. Traditionally, common bricks were the main product of older brickworks, where the lack of good quality control was not of great importance. The emphasis is now on the production of facing bricks which require careful control procedures. The testing of argillaceous raw materials for the production of structural clay products can be divided into examination of the natural unfired characteristics, the firing characteristics and behaviour and the properties of the fired product.

Few totally new plants have been established in the United Kingdom recently due to the depressed state of the market, so testing normally involves quality control of a clay in or near established pits where the general characteristics are already known; however, even in established pits it is essential to have adequate reserves to ensure production over many years before any sort of modernisation of plant can be warranted. Hence evaluation of new clay deposits or extension of existing ones should involve an estimation of the reserves available to the manufacturer by means of large scale geological mapping in three dimensions. Most currently used building clay deposits were recognised at outcrop or often identified by chance during excavations for other purposes. Most of the areas in which commercial clay deposits are worked are now covered by maps produced by the Geological Survey at various scales up to 1/10,000 and there is considerable published data available on many aspects of argillaceous horizons in Great Britain. Shallow drilling will provide a good measure of the thickness, attitude and content of the strata concerned. Very few naturally-occurring deposits are homogenous and the manufacturer must know whether undesirable horizons remain constant, thin out, or thicken up in any particular direction. He should also know whether disseminated constituents such as pyrite, gypsum, microfossils or carbonaceous matter change in abundance, and whether there are any tectonic or sedimentary disturbances or discontinuities in the sequence that are likely to affect the quality or quantity of clay available. Many of the larger companies have an on-going drilling and reserve evaluation sampling programme in their pits. Normally large pits are planned on the basis of results from preliminary drilling often at very close intervals e.g., London Brick Company pits. However, in the industry as a whole there has often been a general lack of awareness of the value of careful research and long-term assessment work, and many smaller or old works rely almost entirely on the experience of the personnel. This factor has forced a few works to close prematurely or to incur high transport charges in obtaining raw material. Evaluation of the economic potential of British clay deposits has therefore mostly been carried out by individual large companies and on a trial and error basis by smaller ones. There is a general view in the industry that some form of up-to-date economic assessment of clays in certain areas would be desirable, especially from the point of view of reducing sterilisation of valuable reserves.

No national surveys have been carried out, although the MHLG conducted a series of conferences in the 1950's related to planning, and structure plans for individual counties tend to include a section on existing usage of clays where appropriate. Information has been derived from IGS surveys for Milton Keynes and Peterborough which may lead to a closer definition of the horizon in the Lower Oxford Clay which is worked for Fletton bricks. Drilling in the Hastings Beds by the IGS has also provided valuable information on brickclays.

Very little work has been done to assess the suitability of resources for various end products, although useful information from a number of surveys of run-of-kiln bricks was collated and published by the National Brick Advisory Council in 1950 (Bonnell and Butterworth).

Some form of preliminary testing to broadly define the types of products possible is usually carried out on new deposits. Such properties of the unfired material as particle size distribution, colour, water of plasticity, workability, green strength, drying shrinkage and dry strength can be ascertained, together with data on the mineralogy and chemistry. Important characteristics of the fired material such as fired colour, total shrinkage, hardness, absorption, porosity, bulk density and bloating tendency can be determined by judicious firing tests.

Some companies have established small quality control laboratories for clay appraisal and regular product assessment, but technological research is not given high priority especially in regard to the chemical nature of the raw materials. Many of the larger producers of special-purpose clays provide customer research facilities whereby the consumer's particular needs can be catered for, but the heavy clay ware producer usually relies on his own experience and expertise or sends representative samples to the British Ceramic Research Association for testing. While the manufacturer cannot help but benefit from knowing as much as possible about the composition (mineralogy and chemistry) of his raw materials, upon which most of its properties depend, some producers are reluctant to improve technology and firmly believe that experience is all important. No one can predict exactly how a particular clay will behave until it has been run through a production line or at least subjected to pilot plant firing tests.

In most ceramic testing laboratories there are generally accepted test procedures from which the suitability of a clay for various end-products can be deduced. Mineralogy, which influences forming, drying and especially firing, can be quickly and efficiently determined, the method used depending on the desired degree of accuracy. Clay mineral composition can be determined by X-ray diffraction, thermal reactions on heating, optical properties, infra red adsorption spectra and staining reactions.

X-ray diffraction is probably the most popular method for qualitatively determining both clay and non-clay minerals, and experienced operators can produce reasonably comparable quantitative results (Schultz 1964). Differential thermal analysis can be used to determine clay minerals, although results may be masked by impurities. However, used in conjunction with thermogravimetric analysis (T.G.A.), the resultant derivative thermogravimetric analysis (D.T.G.) can be more accurate and quantitative, and can lend an insight into the degree of crystallinity, particle size and state of hydration of the clay minerals.

The composition of clay minerals can also be determined by plotting the ignition loss of a clay against its moisture adsorption. This method, known as the IL/MA method, was developed at the British Ceramic Research Association (Keeling 1958, 1961, 1963, 1966, 1968, 1969), and results are plotted on a reference graph indicating the fields—ordered kaolinite, disordered kaolinite illites, mixed layer clays and smectites. Figure 9 shows examples of MA values for various types of clay mineral and IL/MA plots for some British clays. The MA characterises the type of clay mineral present while the IL indicates the quantity present.

The plastic limit of a clay (the water absorbed by it before it becomes plastic) and the liquid limit (the water absorbed by a clay before it becomes a liquid) are called Atterberg Limits and are standard tests in soil mechanics, where they are a method of evaluating plasticity. These limits have not been used as practical tests in the heavy clay ware industry, but it has been shown that they can be adapted to increase their use in ceramic problems (Rieke 1923), and the composition of clays can be deduced from a study of their plastic limit and plasticity index (range of moisture content through which a clay is plastic). A graph believed to be suitable for interpreting the composition of clays from their PL and PI values has been produced, although such factors as particle size can artificially increase or decrease the Atterberg Limits of clays. There are other tests that can be performed to determine the plasticity of a clay (Pfefferkorn test, cyclic stressing of plastic clay bars in torsion etc) but they are rarely used.

Particle size distribution is an important factor relating to plasticity and drying properties. It can be determined by several methods including the Andreason pipette, wet-sieving of coarser fractions and flocculation with elutriation of finer grain sizes or microscopic examination. Scanning electron microscope examination of clay minerals clearly reveals their character and size, while x-ray fluorescence techniques enable the rapid determination of mineralogical and chemical composition. Reflected light microscopy is used to study fired clay specimens to determine various properties including porosity and degree of vitrification.

Although chemical analysis can contribute to clay mineral identification, for example a high K_2O value may indicate the presence of illite, its main use is in the analysis of ancillary non-clay minerals. Indeed chemical analysis of clays can often be misleading. They are not indicative of physical properties and reactions, and cannot be regarded as a substitute for firing tests. Most manufacturers have chemical analyses of their raw materials though only the largest companies carry out any form of regular monitoring of total chemical compositions. More frequently the clay is tested for specific chemical impurities. For example, if a deposit contains significant amounts of migratory and variable compounds, such as soluble salts likely to cause scumming, it should be analysed frequently to determine the amount of barium carbonate to be added. Similarly, significant variables in the vitrified clay pipe industry are carbon and sulphur contents and the largest manufacturer in this field regularly monitors these values.

Routine quality control of raw material in even the largest heavy clay ware companies, then, is normally restricted to examination of moisture content at appropriate points in the production line (stockpile, mills, extrusion point etc), quantitative analysis of specially pertinent chemicals or minerals (carbon, lime, impurities etc) and grain size monitoring.

Quality control of made ware from drying and firing stages is very important. There are various methods of determining volumetric and linear drying shrinkage of test pieces and production line samples, this property being of great importance since uneven or undue shrinkage at this stage can have serious effects on strength and dimensions of the end product. Other drying tests which may be carried out especially in tile manufacture, include testing made-up samples for drying cracking. This property depends largely on the type, quantity and distribution of clay minerals in the mix and cracking tendency tests can help isolate particularly unfavourable raw material horizons or areas.

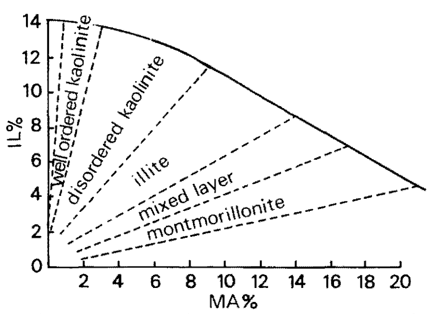
The degree of firing shrinkage is one of the most important factors during firing of heavy clay products and accurate measurement of temperature within the kiln is vital. In the late 18th century Josiah Wedgwood made use of a device based on the fact that clay contracts when heated and that the amount of contraction can be measured against a simple linear scale. A century later the German ceramist Seger invented pyrometric cones made of different ceramic compositions, which are still widely used today. Seger cones or Staffordshire cones, graded to distort or slump over at specific temperatures, are a visual guide to kiln temperature and the effects of temperature with time on the ware in the kiln. The risk of cracking is increased in modern fast firing and cooling continuous tunnel kilns and the necessary precision temperature control is achieved with thermocouples. Placed strategically throughout the kiln they enable the drawing of a firing curve graph which is essentially the firing schedule for a particular type of ware.

Firing shrinkage is measured linearly, or when warping is suspected volumetrically on run-of-the-kiln samples or on laboratory specimens. Shrinkage under load is also an important test carried out periodically on structural clay products. The tendency for ware to distort during firing depends on the clay from which it is made, upon firing temperature and upon the weight of the setting. Some shrinkage is necessary for the product to develop adequate strength but laboratory tests are carried out to produce shrinkage-under-load curves (Figure 13) which indicate safe firing ranges, tendency to shrink at certain temperatures and the suitability of the clay for particular products.

Product testing in the industry is concerned primarily with dimensional variations, strength and water absorption, the specifications for which are discussed later. Strength depends largely on the degree of vitrification and the manufacturing process employed, and compressive strength testing is normally carried out on a number of bricks each carefully centred between the plates of a crushing machine. Load is applied axially until failure occurs. The compressive strength of each brick is taken as the maximum load at failure divided by the area of the brick, and results are averaged out.

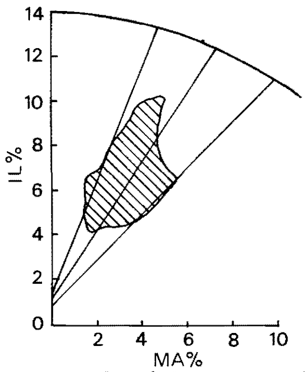
MA range %	Type of clay mineral	Examples of deposits
0.5-2.5	Well ordered kaolinite	China clay
2.5-9	Disordered kaolinite	Ball clay, Fireclays, Coal Measures shales, Etruria Marl
9-14	Illite	'Keuper Marl', London Clay, Oxford clay
14-17	Mixed layer	various e.g. Namurian shales
17-21	Montmorillonite	some Reading Beds, some Clay-with-flints

Fig.9a



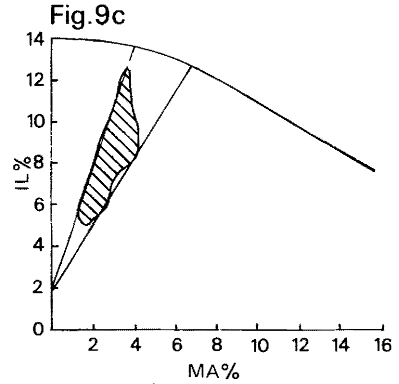
IL/MA zones for different varieties of clay mineral

Fig.9b



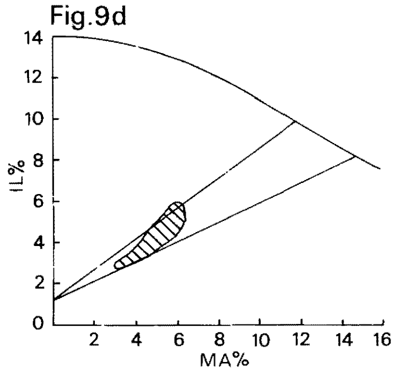
Zone of IL/MA values for Etruria Marl samples, Keele, Staffs

Fig.9c



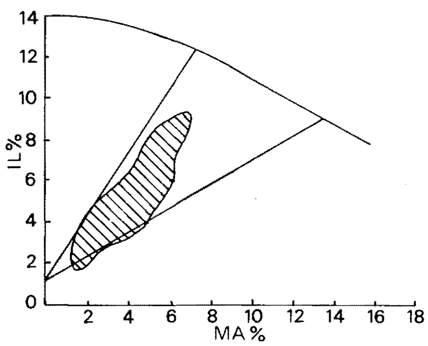
Zone of IL/MA values for Coal Measures fireclay samples

Fig.9d



Zone of IL/MA values for London Clay samples

Fig.9e



Zone of IL/MA values for Weald Clay samples

Adapted from Keeling 1963,1968

Figure 9 Approximate moisture adsorption ranges, with type of clay mineral, and IL/MA values

The five-hour boil test for water absorption is specified in B.S. 3921, as is the crushing strength test.

Soluble salts testing of fired ware is important especially in connection with the liability of bricks to contribute to sulphate failure in brickwork. Wet chemical techniques are normally employed to determine the amount and nature of these salts remaining in the products. Liability to efflorescence can be measured by allowing test bricks to absorb water over a set period of time, allowing them to dry and comparing any efflorescence against a simple index of susceptibility. The actual soluble salt content as determined in B.S. 3921 does not relate directly to the tendency for efflorescence.

Additional specialised tests may be carried out on specific products, for example, tests for acid resistance on certain types of bricks and tiles required to resist corrosive acid attack. Roofing tiles are normally tested for transverse strength rather than compressive strength but, as with bricks, testing for water absorption is very important.

The most authoritative body concerned with ceramic research in Britain is the British Ceramic Research Association based at Stoke-on-Trent. It is a cooperative industrial research organization, one of a number of similar Research Associations set up under D.S.I.R. and as such received a Government grant based on the monies levied on members. It still receives income from member companies but Government funding is now in the form of contracts for specific projects of interest, and additional income now comes from extensive contract research and testing for both members and non-members worldwide. The BCRA carries out research of general interest to the industry in the fields of raw materials, process technology (including energy utilization and conservation), new product development and new research particularly into the performance of the products. A substantial part of the activities of the Heavy Clay Division is now devoted to the safe, efficient and economical use of masonry, and their new Structural Testing Laboratory, which is capable of testing full-size buildings up to 3-storeys high, is the most extensive clay masonry research facility in the world.

LAND USE AND THE ENVIRONMENT

The most economical method of working low value bulk materials such as clay and shale is by surface quarrying. This involves at least the temporary interruption of an existing use of the site or, at worst, permanent change in the use of the land.

Land Use

In terms of current production by weight, clays and shales ranked fifth after coal, sand and gravel, limestone and igneous rock in 1978. Compared with the amount of land already used for mineral extraction in the United Kingdom, that dug for clay and shale ranks about fourth after that of sand and gravel, coal and limestone.

The Survey of Derelict and Despoiled Land in England, 1974, compiled by the Department of the Environment, identified a total of 11,875 ha of land covered by permissions for the working of clay and shale (including fireclay, ball clay and potters clay) of which 6,458 ha had not yet been affected. In 1974 the counties with the largest areas of permissions pertaining to building clays were Bedfordshire, Cambridgeshire and Staffordshire, in that order. The survey has not been extended to Scotland and Wales; however, the total loss of land in these two areas caused by clay working has been low, (probably amounting to less than 320 ha in Wales) due to the depth of some workings and the appreciable amounts of waste shale used. Land occupied by current and abandoned clay workings in Northern Ireland amounts to about 80 ha.

In 1966, it was estimated that some 200 ha in England and Wales were consumed annually for clay, shale and fireclay extraction. The total rate of extraction and encroachment on land in any area depends not only on the production required but also on the depth of workable clay. In the Coal Measures or Oxford Clay, where the deposits are normally worked up to 30m in depth, only 0.8 ha of clay would be necessary to produce 100 million bricks. In contrast, in the Brickearth areas of Kent and Essex, where the thickness of clay averages less than 3m, 10 ha may be needed for the same output. The most reliable estimates of land usage for structural clay workings are found in recent County Structure Plans. As an example, the annual take of land in the Fletton brickfield as a whole is about 30 ha.

Environmental Impact

Brick clay workings in common with other opencast workings have some basic environmental effects on the surrounding area. Firstly, there are visual and other impacts of both clay extraction and processing; secondly, they may interrupt existing land uses and may pose difficult restoration problems if permanent change in land use is to be avoided; and thirdly, there can be air pollution problems from the manufacturing process.

Quarrying inevitably disturbs the land surface and may affect visual amenity especially in areas of outstanding natural beauty. However the majority of clay and shale formations by their nature form areas of relatively monotonous low relief, eg Keuper and Jurassic clay vales, so workings seldom conflict with areas of high landscape value. On the other hand, in these flat areas, large deep quarries can cause a substantial visual impact unless they are screened by amenity banks and/or vegetation.

Existing works in some counties demonstrate that clay extraction can be relatively unobtrusive if located on low-lying sites with good tree cover. When new sites or extensions to existing sites are permitted this is normally conditional on tree planting and other screening measures such as earth moulding and landscaping.

Structures ancillary to the pit itself may also be detrimental to the visual environment of the area. Workings may have to be planned to accommodate tips of clay, overburden or soil on either worked or unworked land. The clay may need to stand in tips for weathering, and soil and overburden may need to be stacked until the progress of operations allows them to be returned to the pit in the course of restoration. If these are to remain for a prolonged period it is preferable that they be located and planted in such a way as to screen other operations within the pit.

The unsighly methods for the disposal of callow in the Fletton brickfields have now been replaced by new methods involving dryfilling and the use of overburden for landscaping purposes. The main use of the overburden surplus to requirements for immediate use as cover material in landfill restoration sites is for screen banking along sensitive margins of clay excavations.

Brickworks themselves, which are often substantial buildings, can have a pronounced visual impact on the surrounding area. In Bedfordshire, for example, there were until recently over one hundred brick chimneys dominating a relatively flat and featureless landscape. Recapitalisation and the replacement of old works with new ones using modern techniques is planned to allow a drastic reduction in the number of chimneys, though this is accompanied by an increase in the height of those which remain to promote greater dispersion of smoke and gases. Outstanding examples of minimising the visual impact of brickmaking plants are the new Kings Dyke works and the New Saxon works of London Brick Company near Peterborough. These were constructed on the floors of existing worked quarries and the buildings, except for the chimneys, are virtually invisible from the surrounding countryside.

Another good example is the newly rebuilt Cattybrook works of Ibstock Building Products at Almondsbury, near Bristol. This consists of a blend of existing and new plant covering over 13,935m^2 situated in a particularly pleasant wooded hollow. The works is built to a low profile and numerous trees have been planted, so that it is barely visible although having a capacity three times as great as the pre-existing works.

Ground movement associated with heavy clay workings is limited to landslipping but this can be controlled by regrading the sides of excavations. Adequate safety margins must be left where roads, railways etc. are sited close to pits, and pit profiles are prepared, for example, in the Fletton area, in accordance with planning consent stipulations and engineering requirements.

Landslipping is more likely in water-filled pits; the working of clay often necessitates the realignment of natural drainage channels, and pumping is used to dispose of water which collects as a result of rainfall and the interruption of land drains. In some cases, working to the bottom of the clay may expose underlying permeable beds, such as the Kellaways beds below the Oxford Clay. Lowering of the water table has been attributed to brick clay working in some non-Fletton areas.

Because of the relative softness of many brickclays, blasting is very seldom used, although there may be some noise from dump trucks within the quarry, particularly on inclined haul roads. As with other industries, large brickmaking complexes generate a great deal of heavy traffic on surrounding roads, especially where the quarry is some distance from the factory, and this traffic may have to be specially routed to avoid residential areas.

Agriculture is the commonest use of the land which may give way to clay working. The agricultural quality of the soils overlying clay formations varies but is normally average or below average. Important exceptions are the brickearth areas of Kent and Essex which contain some of the highest quality agricultural land in Great Britain. For this reason, the Brickearth Conference, convened by the Ministry of Housing and Local Government in 1953 proposed that land allocations in the Kent and Essex brickearth areas should allow the stock brick industry a life of only 40 years from 1956 at a production rate of 150 million bricks a year. In the event, this production has not been attained and the potential life of reserve allocations now extends beyond 1996. Negotiations are continuing between the industry and central and local government as to whether working should be allowed beyond that date and if so whether there should be some adjustment of land allocations.

All existing clay workings are subject to permission under the various Town and Country Planning Acts. Many quarries opened before the introduction of planning control have no restoration conditions and many of the early permissions have conditions which are vague or inadequate in the light of present-day standards. For this reason, the Government intends to introduce legislation enabling local planning authorities to review conditions imposed on planning permissions subject to reasonable compensation provisions. This will allow the older workings to be brought into line with more modern permissions which normally require a satisfactory scheme of working and a plan for restoration of the land to a condition suitable for an acceptable after-use. Land taken from agricultural use shall normally be restored to that use. This presents few problems when dealing with land of lower agricultural quality, but is more difficult to achieve on higher grades of land.

Restoration

Restoration or after-treatment of clay workings depends largely on the scale of working, the availability of suitable fill and the most desirable after-use as well as available finance and planning permission. With some workings, particularly shallow deposits and some deeper deposits excavated into hillsides, any overburden and/or topsoil can be returned to the pit so that the resultant surface may be capable of agricultural or other use provided certain precautions are taken, eg stabilisation of back-slopes if present. Good examples of such relatively rapid restoration are the brickearth workings of Kent and Essex, where topsoil and subsoil are progressively stripped and restored after excavation of 2m or so of brickearth. Even here, however, restoration seldom produces agricultural land of the uniquely high quality that existed before working. Similar shallow deposits where progressive restoration is so readily attained are rare. Small workings near to urban areas may readily be filled with urban refuse, hardcore, etc and the land restored to agriculture or used as building sites. However, many workings are on a large scale and are excavated to considerable depth. The ratio of clay won to clay and overburden rejected is usually very high so the volume of filling material required is immense, and restoration is a major operation in itself, although today appropriately scaled schemes have been developed.

The relative impermeability of most brickmaking horizons makes the excavations left by quarrying very suitable for the disposal of a variety of wastes. Restoration may be achieved by filling with natural materials, e.g. quarry wastes and colliery spoil etc. or, provided proper precautions are taken to control and treat site water, with artificial fill such as domestic and industrial refuse.

Colliery spoil is a particularly attractive fill for large brick pits, as it seems sensible to fill the holes left by one extractive industry with the waste produced by another. Very large tonnages are available in large unsightly spoil heaps within a reasonable distance of brickpits in the coalfields. Although some derelict land reclamation schemes have been able to take advantage of this proximity, particularly in Stoke-on-Trent, the costs and impact of transporting the waste have prevented large-scale adoption of this practice. The Fletton brickpits of Bedfordshire are of sufficient size and London Brick Landfill in conjunction with Bedfordshire County Council have put forward outline proposals for the remote disposal of spoil from the Belvoir colliery, which are currently being investigated. A similar scheme proposed in 1968, for the disposal of colliery spoil from Nottinghamshire by transporting it by rail to the Fletton pits proved unworkable owing to the British Rail quoted cost of haulage. The cost of transport is likely to be a major factor in determining the adoption of such a scheme for Belvoir, as well as the dual environmental benefit to be obtained in preserving agricultural land (and amenity) in Leicestershire and restoring quarried land in Bedfordshire.

The proximity of many pits to urban areas enables domestic and trade refuse to be used as filling material. The shortage of tipping sites near to some urban areas has also made the transport of domestic refuse economical and there are a number of schemes involving rail transport of urban refuse, particularly from Greater London to Bedfordshire and Buckinghamshire.

London Brick Company's subsidiary, London Brick Landfill, operate a particularly successful scheme whereby compacted domestic refuse from several London boroughs is transferred by rail to the Company's Stewartby and Calvert landfill sites in specially-designed enclosed containers. The off-loaded refuse is levelled and compacted by specialized wheeled compaction machines into the pre-designated areas in 2m layers and is covered by 15–20cm of soil almost immediately to prevent wind blowing of refuse and possible vermin problems. This proceedure is continuous and when the planned final levels are reached within the site a capping layer of clay is deposited and a reclamation programme is activated by cultivation and sowing in the top soil.

A considerable amount of capital expenditure as well as sophisticated planning and monitoring is involved in schemes such as this, which can only be justified if long-term contracts are achieved and large areas are available for filling. Industrial and domestic waste is received by road at other landfill sites operated by the Company at Bletchley, Anlesey near Hitchin, and Dogsthorpe near Peterborough.

The first pits at both Bletchley and Peterborough have now been filled, drained, topsoiled and fenced, and will subsequently be farmed.

Industrial wastes, including toxic materials, may also be safely tipped in many clay pits, either with or without treatment. At Aldridge in Staffordshire, Polymeric Treatments Ltd use a disused clay pit to dispose of the 'Sealosafe' polymer resulting from their toxic waste treatment plant. There are proposals for similar plants at clay pits in other industrial conurbations. A certain proportion of the fill in London Brick Landfill's site in Bedfordshire is industrial waste including some notifiable waste. The disposal of these involves their correct deposit in permitted areas within the landfill site, the control and treatment of site water and monitoring of hydro security in underlying aquifers via bore holes.

Refuse from local authorities and industry, small amounts of colliery shale, waste from British Rail and rejected brick and pottery are currently being used to fill clay and shale pits. There are several other schemes in operation which can return the land to acceptable agricultural standards. In 1963, London Brick Company signed an agreement with the CEGB involving a considerable restoration programme. Pulverised fuel ash is transported by rail from coal-fired power stations in the East Midlands to Peterborough where it is re-slurried and pumped into disused clay pits. Top-soiling of the filled pits uses soil washed off sugar beet at a local factory in addition to topsoil saved during continuing brickclay excavation.

Frequently, deep disused pits are allowed to fill up with water or, less commonly, have water pumped into them. Such pits may be used for water storage purposes (for domestic water supply, industrial process water or power station cooling water) if the banks are carefully stabilized, though many have proved to be unsuitable. Other projects which have been proposed include hovercraft testing and air-sea rescue training. Filling old pits with water purely for amenity purposes is an attractive proposition where suitable filling material is not economically available. An example is Stewartby Lake (100 ha), which LBC rents to Bedfordshire County Council at a 'peppercorn' rent as a water sports amenity area.

Although there are local concentrations of land despoiled by clay working elsewhere, particularly in the coalfields, a major restoration scheme is that of the Lower Oxford Caly workings for Fletton brick manufacture and particularly those of Bedfordshire. The examples cited above of pulverised fuel ash filling at Peterborough, transport of GLC refuse to Bedfordshire, and Stewartby Lake illustrate that there have been some successes and in one year an excess of

600,000 tonnes of fill material have been used in addition to about one million tonnes for the CEGB scheme. These quantities are increasing each year and further increases are planned with the pace of filling increasing rapidly. However, the worked out pits are steep-sided and deep. The capacity of existing pits available for back-filling in Bedfordshire alone is more than 80 million m^3 and the annual increase in void space is of the order of 3 million m^3. The workings are concentrated in a relatively small area of Bedfordshire, and are quite remote from major urban concentrations, although conveniently situated on a major rail link (as the London domestic refuse disposal schemes have shown). Many of the excavated areas were worked out before the introduction of planning control or under Ministerial permissions which were vague as to restoration conditions, typically containing a requirement to fill 'having regard to the availability of suitable filling materials at suitable times, on reasonable terms' (letter from MHLG to LBC, 1952). Local authorities are therefore keen that most pits should be refilled completely to provide a surface, at approximately the original ground level, which might be put to further use. It was recognised that companies should not have to pay an inordinate price for filling materials nor that the cost of tipping to other parties should be unreasonably high. London Brick Landfill seeks solutions to, and fulfills the joint objectives of, offering a service to Local Government while restoring large areas of land. However, the local planning authority in Bedfordshire is still concerned about the problem of restoration (and air pollution, see below) and it has stated that 'new applications will only be granted if further workings would lead to rationalisation of existing workings or to an improvement in the environment' (Bedfordshire Minerals, Appraisal and Issues, 1978). London Brick Company's New Works proposals for Bedfordshire embody these principles and will result in considerable improvements. The value to the country as a whole of a very economically produced building product which is used to build one in three houses in Britain as well as many schools and other buildings has to be set against the disruption caused by quarrying in the relatively small area affected by Fletton brick production.

Air Pollution

Air pollution associated with brick manufacture may be in the form of dust generated during the handling and loading of bricks or gas produced in the kilns and emitted to atmosphere via chimneys.

Heavy clay processing works are registered under the Alkali and Works Regulation Act 1906 as extended by the Alkali and Works Orders 1966 and 1971 and the Control of Pollution Act 1974. The present list of scheduled ceramic works comprises works in which:

(a) pottery products (including domestic earthenware and china, sanitary ware, electrical porcelain, glazed tiles and teapots) are made in intermittent kilns fired by coal or oil;
    or
(b) heavy clay or refractory goods are fired by coal or oil in
    (i) intermittent kilns
    (ii) continuous grate-fired kilns, not being tunnel kilns
    (iii) any kiln in which a reducing atmosphere is essential
    (iv) salt glazing of any earthernware or clay material is carried on.

For certain processes it is considered that the more difficult technical problems have been solved and there is no longer a need for special control by a central inspectorate. As a result it is intended to amend the list of scheduled ceramic works to comprise works in which:

(a) a reducing atmosphere is essential to the firing of any heavy clay or refractory material in any form of kiln.
    or

(b) salt glazing of any earthenware or clay material is carried on.

This revision would result in the handing back of about 100 ceramic works to local authority control, under the Public Health and Clean Air Acts and the Control of Pollution Act 1974, with retention on a scheduled basis of about 40 works where there are special problems. The works descheduled would constitute installations previously having smoke control problems which were now largely overcome. The case for retaining the scheduling of certain ceramic processes in order to control dust emissions is considered to be indeterminate and rather doubtful.

Scheduled works are required to use the "best practical means" to prevent or render harmless the emission of noxious and offensive gases, smoke, grit and dust. Standards of emission are laid down by the Chief Alkali and Clean Air Inspector from time to time. Local authorities must be satisfied both under environmental health legislation and as a consideration in determining planning applications, that chimneys will be high enough to prevent smoke, grit, dust and gases from becoming prejudicial to health or from being otherwise objectionable. In the heavy clay industry, codes of practice have been formulated and manufacturers are required to provide data on emissions as supporting evidence for the chimney height they recommend. The dust problem is now less important than hitherto because of improved dust catchment from stock gases and highly mechanised brick handling methods as well as the increasing use of polythene shrink-wrapping, which effectively seals off the fired products until they are required on site. Because of the moisture content of brickmaking materials, dust is seldom a problem during quarrying. Smoke emission is now a problem only in blue brick manufacture.

During the firing of clay bricks, pipes and tiles, all the volatile components such as water, organics, carbon dioxide and halogens are released. Pollution due to the use of coal in the firing of kilns is no longer so important as cleaner fuels such as natural gas, oil and liquefied petroleum gas are increasingly used. However, there must be some doubt as to whether this trend will continue in the light of rising world oil prices. The 'rubbery' odour which characterises many brickmaking areas is caused by mercaptans. Although the emission of odours may be offensive and causes some problems, it does not appear to have any effects on health, and can be mitigated by the degree of dispersion achieved by modern high chimneys.

Ceramic firing processes liberate fluorine bound in the crystal lattices of rock-forming minerals. The quantity of fluorine thus emitted depends on the mineralogical composition of the raw materials as well as on the top temperature of the kiln. The fluoride contents of many green pressed bricks range from 500 to 700 ppm, while those of fired bricks range from 90 to 300 ppm (Troll and Farzaneh 1978). Although fluorine compounds are emitted whenever clay is fired, they are of consequence only in certain areas where local problems of fluorosis in cattle have been reported. The major part of Fletton works emissions is sulphur dioxide, and both this and fluorine compounds have been studied in various reports on the area, whose results were generally inconclusive. A report by the County Medical Officer of Health on Atmospheric Pollution in the Brickworks Valley 1960, indicated air pollution from the chimneys to a distance of at least 3 km, though results about health hazards were inconclusive. The Alkali Inspectorate concluded that the ground level concentrations of sulphur and fluorine compounds are satisfactorily low and there is no public health hazard. The Ministry of Agriculture, Fisheries and Food investigated the farming hazards and found fluorosis severe enough to cause economic loss to a number of farmers in the area (Fluorosis in cattle—Animal disease survey, Report No2, 1964–1965). However, in their Fenton Manor Farm experiment they considered that no danger exists if normal methods of good husbandry are used.

At the present time no single abatement technique exists to remove all the materials from the stack gases and pending a solution to these problems dispersion by tall chimneys is considered by the Alkali Inspectorate to be the 'best practicable means'. In 1974 the Fletton Brickworks Liaison Committee was formed to review the environmental aspects of emissions from the industry and the principal body which has carried out research on the subject has been London Brick Company itself. The Department of the Environment was asked to produce a comprehensive review on what, if any, conclusions could be drawn from existing information on emissions and their effects on the local environment (Air pollution in the Bedfordshire Brickfields, 1980, DOE). This reported no positive correlation between the air pollution concentrations in the Bedfordshire area and health effects. The incidence of fluorosis in cattle appears to be much reduced since 1957, and research on the effect of air pollution on crops is inconclusive. Although there is some enhanced deterioration of building and structural materials in the Bedfordshire area due to the elevated levels of SO_2 and fluoride, the problem is not specific to Bedfordshire.

TECHNOLOGY

Extraction

The raw materials for heavy clay ware manufacture are normally available at or near the surface and are extracted by opencast quarrying. However, the waste products of some underground coal mining operations are also used.

The methods of winning depend firstly upon the physical and chemical properties of the clay itself when dry, wet or weathered and, secondly, on whether the material needs selective extraction or can be utilised *en masse.* If certain seams are to be avoided, a benched or terraced quarry profile is adopted; where the clay is almost homogeneous and free from undesirable impure bands it is advantageous to mix the strata, and hence to cut a deep and steeply angled quarry face.

The depth to which clay is dug may depend upon the continuity of its physical and chemical properties with depth and on the stability and natural angle of repose of the material in the quarry slopes. Some homogeneous clay and shale sequences can be quite safely dug to depths in excess of 20m without benching eg. Oxford Clay, while others with inherent mineralogical and physical inhomogeneities may require careful management. Other factors such as water seepage, dip of the beds, the quantities of material to be dug, and the condition in which the raw material must be delivered to the plant, also affect the choice of excavation methods. The *in situ* moisture content of the deposit worked is important in the continuity of feed to the works, and the height of the local water table may influence the method of winning and the ultimate pit depth.

The uniformity of many brick clay sequences makes them well suited to mechanised methods which are now ubiquitous. Hand digging has the advantage that impurities can be easily avoided, but not even the smallest pits use this method today. Various modern mechanical excavators are employed according to the properties and requirements of the clay dug; they include front-end loaders, bulldozers, tractors with scrapers, face shovels, draglines, multi-bucket excavators, and planers. Face shovels and draglines are the most widely used excavators in the heavy clay industry, the positive action of the former being effective even with hard shales, so that blasting is not normally necessary.

The dragline-type of single-bucket excavator scrapes over a large radius and excavates below the level on which it is set; it is therefore useful for a sloping cut and in pits where water seepage is a problem or where the clays are relatively soft. The multi-bucket endless chain excavator is used for relatively plastic, homogeneous clays where the whole of the exposed face is dug by the buckets as they travel along the lower side of jib-mounted 'ladders'. It can be adapted to the shape of the face, may be situated above or below the face, and with modifications can even be used under water. Its disadvantages are that it is non-selective, is not suitable for uneven terrain, and operates over a fixed traverse on rails or caterpillar tracks.

The shale planer is similar to the multi-bucket excavator and was designed about fifty years ago specifically for digging shales for the heavy clay ware industry. The electrically driven steel cutting chain operates at an angle of between 68° and 90° and moves automatically across the face in semi-circular sweeps. It is suitable only for digging uniformly hard, friable material with a steep natural angle of respose. The machine works from the bottom of the face with its jib almost vertical and rotating through an arc to make a semi-circular cut. In the Oxford Clay brick pits near Peterborough, the clay is dug from a 22m face using a Ruston shale planer. The machine is ideal for this consistency of clay and produces a perfect blend of clays from the whole worked face. The size of the material produced is ideally suited to crushing in the Incla grinding mills.

The overburden and a thin layer of weathered clay are normally stripped by mechanical scrapers, skimmers or bulldozers and stockpiled pending reinstatement, or may be used to build up the floor of the existing pit to the correct level to create room for stock or equipment. Overburden thickness is of prime importance in the working of a relatively low cost commodity. The economically permissible ratio of overburden to useful mineral, the stripping ratio, decreases with decreasing value of the raw material; hence large thicknesses of overburden can effectively sterilise underlying clay seams of good quality. In clay excavations, therefore, overburden thickness is generally only two or three metres.

Where blending of different clays is required, several faces may be opened up and the materials subsequently mixed, or a number of quarries containing clays of differing properties are worked separately and the materials layered horizontally in stockpiles close to the works. The required mix is obtained by removing the material in the stockpile in a series of cuts across the layers.

The clay is transported from the excavation to the plant by various haulage systems: aerial cableways, band conveyors or most commonly by trucks. The condition of the dug clay and the proximity of the works to the pit, as well as the necessity to cross roads, railways or uneven ground, largely determines the type of transport adopted. Brick works are often constructed at, or very near, the working pit, as the low price of the product cannot justify transport of the raw material over long distances. Occasionally some works can be conveniently sited on the floor of an existing pit when the working face has receded somewhat.

Winched or counter-weighted tramway wagons are useful to transport soft clays, dug by shovel or single bucket, though the use of fixed haulage systems or tramways is now very rare. Suitably protected permanent or moveable band conveyors can however be very efficient. Free-ranging haulage systems are widely used in the heavy clay industry and include tipping trucks, dumpers, and bulldozers, front-end loaders and excavators supplying hoppers and feeders at the plant. Large dump trucks or tipping lorries are extensively used where clay must be hauled from quarry to works on public roads or in large adequately drained benched quarries. Following extraction from a quarry or from a waste shale tip, the raw materials used in the heavy clay industry normally pass through a series of production line stages, which for ease are designated: preparation, shaping, drying and firing. A typical process route is displayed in Figure 10.

Clay Preparation

An increasingly important part of the manufacture of structural clay products is clay preparation. Before the raw material can be moulded or extruded into the desired body shape it must undergo a series of preparatory processes which may include pre-treatment, blending, primary crushing, grinding and screening, milling, and mixing. Souring or weathering of the raw material is carried out at plants where clays of one or several types are dug seasonally and placed in large stockpiles. For some very plastic, moisture-rich clays weathering is avoided, but the majority of shaley raw materials undergo some form of souring even if only by leaving a freshly exposed quarry face to weather for a few weeks. Weathering is also said to leach soluble salts from the clays, though because of their relatively impervious nature stockpiles are likely to benefit in this way only in their surface layers. The reasons for stockpiling include the working of extensive shallow deposits, lack of manoeuvrability during wet winter months, and consistent blending of different types of clay. Clay is normally taken straight from the stockpile to the primary crushing stage via hoppers, boxfeeders and conveyors, but in some plants it may be stored in silos or in covered conditioning areas for some time. Bulk blending of crushed clay in roofed stores is not common in the United Kingdom although it can even out stratal variations in clay properties.

Crushing and grinding are carried out to reduce the grain size of the as-dug raw material, and in most cases part of the water necessary to make the clay plastic is added by control equipment. The type of equipment and method of preparation differs according to the final shaping process used and the physical state of the clay at its normal moisture content. Primary crushers are normally required for hard, indurated shales while secondary crushers such as crushing rolls, hammer mills, pan mills and gyratory or jaw crushers are widely used for most clays and shales. Soft clays are sometimes passed through a clay shredder which produces small slabs of clay up to half an inch thick.

Wet or dry grinding is designed to reduce the lumps of clay to the desired final grain size. Clays with up to 12% moisture content are normally dry ground in pan mills, the grid hole diameter of which determines the size of material leaving the pan. Wet-pan mills, in which breakdown is mostly by plastic deformation, are used for grinding fairly moist plastic clays. After dry grinding the clay passes to screens which determine the upper size limit suitable for particular applications. In the heavy clay industry the commonest screen size allows the passage of particles about 3mm diameter and smaller.

Despite crushing, grinding and screening the physical properties of the raw material are still not uniform and it must be mixed and blended with the correct amount of water for the forming process employed. This process is called 'tempering' and may involve the mixing of various grain sizes or of 'fat' and 'lean' clays, as well as the addition of water. At some works it is claimed that tempering with steam eases extrusion and later aids drying. Additions of various materials may be made, for example, sand or grog (crushed brick) to modify plasticity, wetting agents (soaps etc), body stains such as manganese dioxide, deflocculants (eg. sodium carbonate) and barium carbonate. The main function of tempering is to ensure uniform grain size distribution, water content and mineral composition, and to develop the plasticity of the clay.

Shaping

Nearly all structural clay products are formed from clay materials in the plastic state and are very rarely made by slip casting. Bricks may be shaped by one of several processes, including hand-moulding, soft-mud moulding, wire-cut extrusion, stiff plastic pressing and semi-dry pressing. The particular method chosen depends on the physical properties of the raw material, its ability to develop good plasticity and on the type and strength of product required.

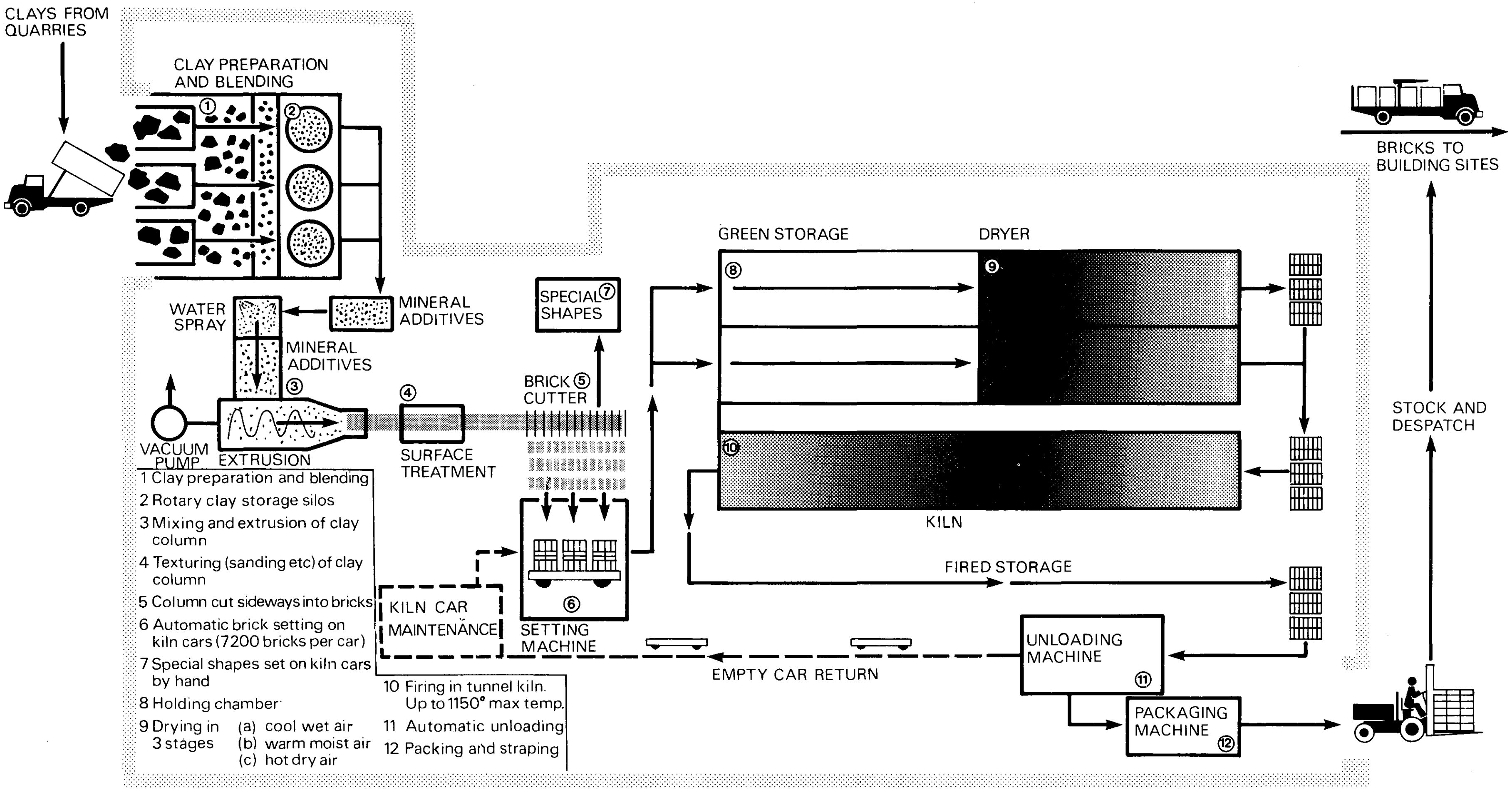


Figure 10 Typical process route at a modern fully automated clay brick plant (by courtesy of Gibbons Northern Brick Ltd.)

From earliest times and until comparatively recently nearly all bricks were shaped by hand. Despite the introduction of highly mechanised shaping systems since the last World War, *hand-moulding* or *hand-throwing* has continued for the production of best quality facing bricks. Indeed, in the last few years their production has increased in response to an upturn in demand for bricks with an aesthetically pleasing finish or texture. Some large mechanised works have reintroduced a small hand-throwing team to cater for this specialized market. In addition certain specials or complicated shapes are most easily produced by hand-moulding, and many small works especially in the south and south-east of England hand mould some or all of their bricks.

Hand-throwing of bricks is a highly skilled operation which can produce bricks of better quality than many mechanised methods. The moisture content required for hand moulding is normally higher than for most other shaping methods, say 20% to 30%, but the clay must still be firm enough for the brick to retain its shape when turned out. Traditionally the throwers are supplied with a slow stream of raw material via a pug mill; a hollow wooden mould is lined with sand, laid on a frogged stock and filled with a clot of clay. The way in which the clot of clay is kneaded and then thrown into the mould determines the quality and texture of the fired brick. Excess clay is scraped off the mould and the shaped brick is tapped out onto a wooden pallet. The method is termed slop-moulding when water is used to lubricate the mould and sand moulding when sand is used. The sand is usually of fine grain size and consistent quality since it will affect the appearance of the fired brick, though its main purpose is to aid release of the clay from the mould.

In the mechanised *soft-mud* or *slop moulded* process the clay mix is extruded from a pug into banks of sanded wooden moulds, surplus clay is scraped off and the mould is inverted to turn out the green bricks. The clay may be slopped into the moulds (slop-moulded process) or alternatively pressed into the moulds (pressed soft-mud process). These processes were used extensively in the south-east and eastern counties of England and continue to be used by the stock brick and Wealden brick industry. The consistency of the clay used varies, but it is often in the form of a slurry comprising clay, water and various additives, for example, fuel in stock bricks. In this case plasticity is not as important a factor as workability and consistency, and the clay must be able to flow easily into the shape of the mould with low-pressure packing. The bricks cannot be stacked in the wet condition and so the moulds are emptied onto pallets where the bricks remain until dried. The range of water content required in the clay for the soft-mud process is from about 24% to 27% (though it may be as high as 32% to 33%) and is sometimes almost on the way to a slip condition. Careful grinding of the raw material is not as important for this process and it is often used for fine grained, superficial clays such as brickearth.

There are various soft-mud brickmaking machines which extrude the clay into composite moulds. The operation can be made fully automatic when used with a pallet ascender. Machines of various outputs from 1000 to 15,000 bricks per hour are available, for example the well known Berry machine and the Dutch Aberson machine. Because of the recent increase in demand for hand-thrown bricks there has been an attempt to introduce fully automated, simulated hand-thrown production lines in some works, using machines capable of imitating the particularly attractive appearance of hand-thrown bricks.

The *stiff-mud* or *extrusion process,* which utilizes the inherent or induced plasticity of the clay and involves forcing a clay-water paste through a suitable die, is perhaps the most advanced and widely used forming process in modern brickworks. It can be applied to a variety of clays of different moisture contents to produce all kinds of heavy clay ware including solid, perforated and hollow types. The clay materials and additives are normally blended and mixed with water to the desired consistency in a pug mill, and extrusion is brought about by the propelling action of an auger or by expression rolls.

Extrusion should take place at the optimum water content for maximum plastic strength but a somewhat drier mixture is often used; for most raw materials the practical range is between 22% and 25% for soft extrusion and 15% to 20% for de-aired stiff extrusion. It is often economically desirable to extrude in as dry a condition as possible despite sacrificing some plastic strength, since a harder product is more amenable to automatic handling, a lower water content means more efficient and cheaper drying, a better quality product is obtained and the bricks are strong enough to be stacked directly on top of one another. Lignosulphonate binders are sometimes added to increase product strength after drying, and water soluble internal lubricants aid extrusion; wetting agents, by their effect on water surface tension, reduce the need for added water and reduce the power necessary for extrusion. However, all these additives tend to affect plasticity adversely.

The screw extruder or auger machine is used for both soft and stiff extrusion; clay is forced along a cylindrical barrel and eventually through the constraint of the die by a close-fitting helix on a central shaft. Most structural clay products are made with a core in the die to produce hollow parts and perforations. Frictional resistance against the sides of the die is reduced by lubrication, oil, emulsion, or steam, depending upon the nature of the clay.

Because laminations produced in the clay column by parts of the auger can cause cracking failure and spalling in the end products, de-airing of the pugged clay is a common practice. Further, lean clays not suited to ordinary extrusion can often be extruded if de-aired; thus de-airing is particularly useful in the case of poorly plastic clays. The clay is subjected to a vacuum in the de-airing chamber. With full de-airing plasticity is increased, a denser stiff column is produced, the product is stronger and it has a low porosity. Partial de-airing is carried out on more plastic clays and where specific textures are to be applied (rustication). Steam treatment of clay in the pug to facilitate extrusion is also an important part of some production lines.

The extrusion method of forming is capable of producing first class common, facing and engineering bricks as well as hollow ware at a moderately low operating cost. Soft-extruded facings with 140.6 kg per cm^2 crushing strength, to stiff-extruded, de-aired engineering bricks with strengths almost ten times as great are possible. Almost all modern brick factories are equipped with stiff-extrusion production lines.

The extrusion process of shaping is also termed the *wire-cut process* since the continuously extruded clay column must be cut at regular intervals into product units of the correct size and this cutting is done by taut wires. A cutting table is part of all extrusion production lines. Although hand operated cutting machines and manual hacking survive in some works, automatic power operated reel or side cutters are almost ubiquitous for high outputs and stiff extrusion. In these cases the clay column operates a trip to set the cutting operation in motion. Tightly stretched wires cut through the clay column and synchronisation of the rates of travel of the column and cutter allows the cuts to be made straight and true. Some machines incorporate a guillotine to cut the column into 1.2m to 1.8m lengths, which are then pushed laterally through fixed cutting wires. Another automatic cutting device suitable for columns of slightly softer-consistency operates a single wire chopper which rapidly cuts off one brick at a time from the clay column.

Certain hard clays and shales are particularly suited to *plastic pressing*. The raw material must still be plastic but can afford to be of stiffer consistency than that required for other processes, and the moisture content of the prepared clay is usually between 9% and 15%. This method of forming has commonly been applied to Coal Measures shales in the Midlands, northern England and southern Scotland.

A clot of clay is extruded into a mould where it is roughly shaped and then passed to another mould for pressing, where plastic deformation occurs. The press mould is larger than the clot and the action of pressing squeezes it out to fill the mould. Ventholes allow excess clay to leave the mould. Normally, in an automated production line a number of clot moulds are set in a circular intermittently rotating table and pass in turn below the opening of a powerful vertical pugmill. Simultaneously, the already filled moulds are emptied and the clots pass automatically to the press. Lubrication of the clot is essential to correct pressing and the clots are sprayed finely with oil. Various types of press are used in conjunction with different clot-forming mechanisms. The press boxes are made of steel with renewable steel liners in the mould. The output for stiff-plastic production lines varies from about 1000 to over 2000 bricks per hour.

The *stiff-plastic process* is used extensively for the production of common bricks in, for example, Scotland; some bricks, especially facing and engineering bricks may require a second pressing (re-pressing) to produce a better finish or a denser brick. Occasionally, even wire-cut bricks may be re-pressed to produce a better surface texture.

The main advantage of the stiff-plastic process is that it makes a separate drying stage in brick production superfluous; the bricks can be set directly in the kiln after forming. The bricks produced are dense and strong, and top quality engineering bricks are possible. However, the typically machine-made appearance of the product militates against the use of this forming process for facing brick. Where small production units of up to only 100,000 bricks per week are required, and where the local raw material is particularly hard, stiff-plastic pressing still finds favour.

The forming process used in Fletton brick production, although not entirely restricted to the Fletton sector, is the *semi-dry pressing* method. The raw material is dry ground and the moisture content in the resultant dust is normally about 6% to 8% (although the Lower Oxford Clay generally has about 20 per cent in situ moisture). Grain size at this point must be 5mm or less. Various types of mechanical presses are available (crank, cam or toggle), but in all cases the mould is filled automatically with clay dust from a feed box. The bricks are shaped between two pistons and are given two impact pressures by a cam in double-mould machines capable of producing 1200 bricks per hour. The pressure applied during pressing is usually between 10 and 40 tonnes (a pressure of 100 bars is common) although total pressures of up to 600 tonnes can be applied by some machines. Re-presses are also available and the trade mark "Phorpres" of the London Brick Company indicates that four pressures have been applied.

It is important that air entrapped in the body of the brick should be allowed to escape during pressing, and the moulds are often de-aired by an automatic de-airing pause at a selected point of the compression stroke, or by applying a vacuum and causing entrapped air to escape through slots or holes in the mould liners.

Drying

The purpose of drying heavy clay ware before firing is to remove water, and in many cases to impart sufficient dry strength to the body so that it can be set in the kiln. Only stiff-plastic and semi-dry moulded ware can pass directly to the kiln without a drying stage. If moist green bricks, tiles or pipes were to be put straight into the kiln they would contract and shrink unevenly causing distortion and cracking. During drying most of the moisture between the clay particles evaporates and shrinkage occurs; when all particles are in contact, the "leather-hard" stage is reached. The moisture content at this point varies for different brick and tile clays but can be from less than 4% to as much as 14%. Dryer designs normally aim to achieve less than 4% moisture at completion of the drying cycle. The remainder of the moisture will be removed at the beginning of the firing cycle.

The rate at which products are dried is very important, and safe rates have to be worked out for particular clays at individual works to avoid cracking (Fig. 11).

Although the grain size of the raw material and the thickness of the body affects cracking tendency, the proportion and nature of the clay minerals present determine the drying properties of specific clays. Illitic clays are very difficult to dry effectively while well ordered kaolinitic clays are relatively easy; disordered kaolinite or admixtures of kaolinite and illite produce intermediate cracking tendencies. Hence the need for extremely efficient mixing when two or more clays or clay horizons are blended.

Drying may be carried out by a number of methods from the traditional process of allowing bricks to dry naturally in the open air to passing them through the most up-to-date tunnel dryers associated with tunnel kilns.

Until recently, in some older works, drying was accomplished in open air stacks or in temporarily roofed yards known as hackyards. Hot-floor drying (using under floor steam heating) was developed in the nineteenth century and was previously used extensively in Britain though drying rates on hot-floors can vary considerably. This method is now used only when the output is varied, as with refractory products, though some roofing-tiles are still dried on hot-floors. A number of types of chamber and tunnel dryers have been developed more recently having markedly higher thermal efficiencies than older methods. Chamber dryers usually operate in batteries; they are brick-built, and in the Keller system pallets of clay ware rest on brick ledges on the side walls. Hot air is admitted first to the chambers that contain already partially dried bricks. Chamber drying is a batch process and as drying rates differ in various parts of the chamber, drying times have to be increased to ensure that all bricks are dry. They are, however, easier to control by instrumentation than tunnel dryers. Intermittent drying involves stoppage of the air flow after a short period to allow built up stresses to be dissipated before the air flow is restored and the drying resumed.

Many heavy clay products are now set on kiln cars and drying is achieved in long tunnel dryers fitted throughout their length with temperature and humidity controls. Drying is frequently achieved economically by diverting spent hot air from the cooling zones of the kiln. Tunnel dryers provide a continuous process; the operation is carefully monitored and the circulating air is kept humid and only warm at the entrance to the dryer, becoming progressively hotter and dryer towards the exit. Movement of the kiln cars on rails through the dryer is automatically controlled and normally counter-current, i.e. the bricks travel in the opposite direction to the air flow. Drying may require only a few days or some weeks depending on the properties of the clay, the forming process and the end product required. The linear drying shrinkage of a particular clay mix is of great importance to manufacturers since size tolerances are very small for heavy clay ware. For example, in extruded ware, shrinkage parallel to the direction of extrusion is greater than that at right angles because of the alignment of the clay particles.

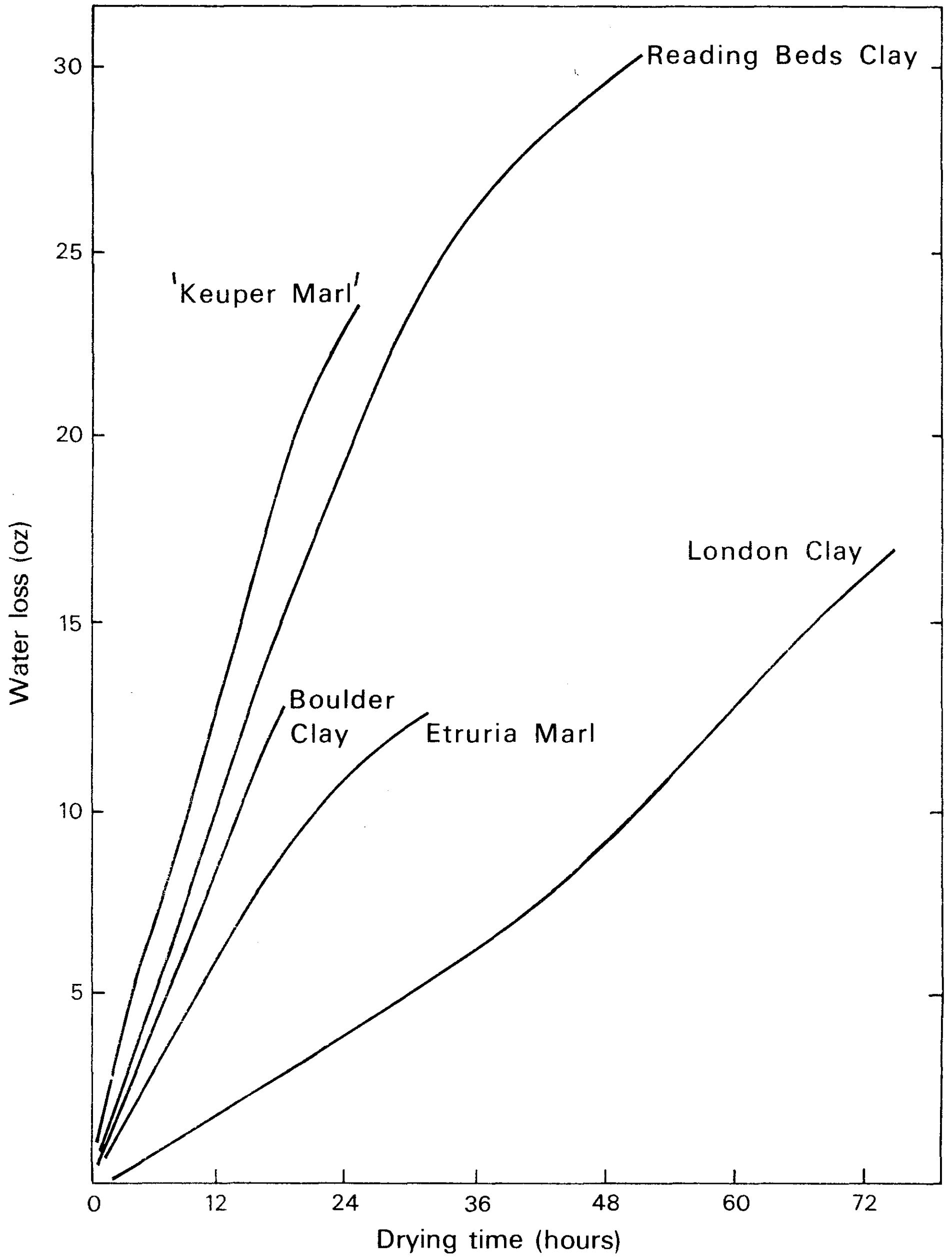


Figure 11 Maximum safe rates of drying for various types of clay (after Ford 1967)

Firing reactions

In order to withstand long term natural weathering and to develop the necessary strength, heavy clay ware must be heated up to temperatures where important physical and chemical changes take place in the clay. Above about 600°C the clay is no longer plastic and cannot be broken down in water. A minimum firing temperature of about 950°C is required for most clays and temperatures as high as 1100°C produce a very strong, low absorption product, provided the clay can tolerate them without distortion.

Porosity, strength, moisture absorption, thermal conductivity and hardness are determined by the nature and amount of the various minerals within the raw material and their reactions during firing. Mullite ($3Al_2O_32SiO_2$) is a hard, chemically resistant phase produced by heating clays to high temperatures. The presence of mullite in the product denotes a well-fired body and its elongated crystal structure provides great strength.

The type of clay mineral dominant in a particular clay determines its initial response to the firing process, although other mineral components such as fluxes have a pronounced effect. When a kaolinitic clay, say a low-grade fireclay, is fired, the first reaction is carbon burnout, followed by pyrite oxidation, dehydroxylation of clay minerals at about 600°C, and mullite nucleation from the spinel phase at about 970°C. The mullite does not, however, possess a stable composition until about 1300°C. The decrease in shrinkage over 1170°C indicates overfiring and ultimately bloating.

The sequence of events that occurs when a building clay is exposed to increasing heat is shown in figure 12.

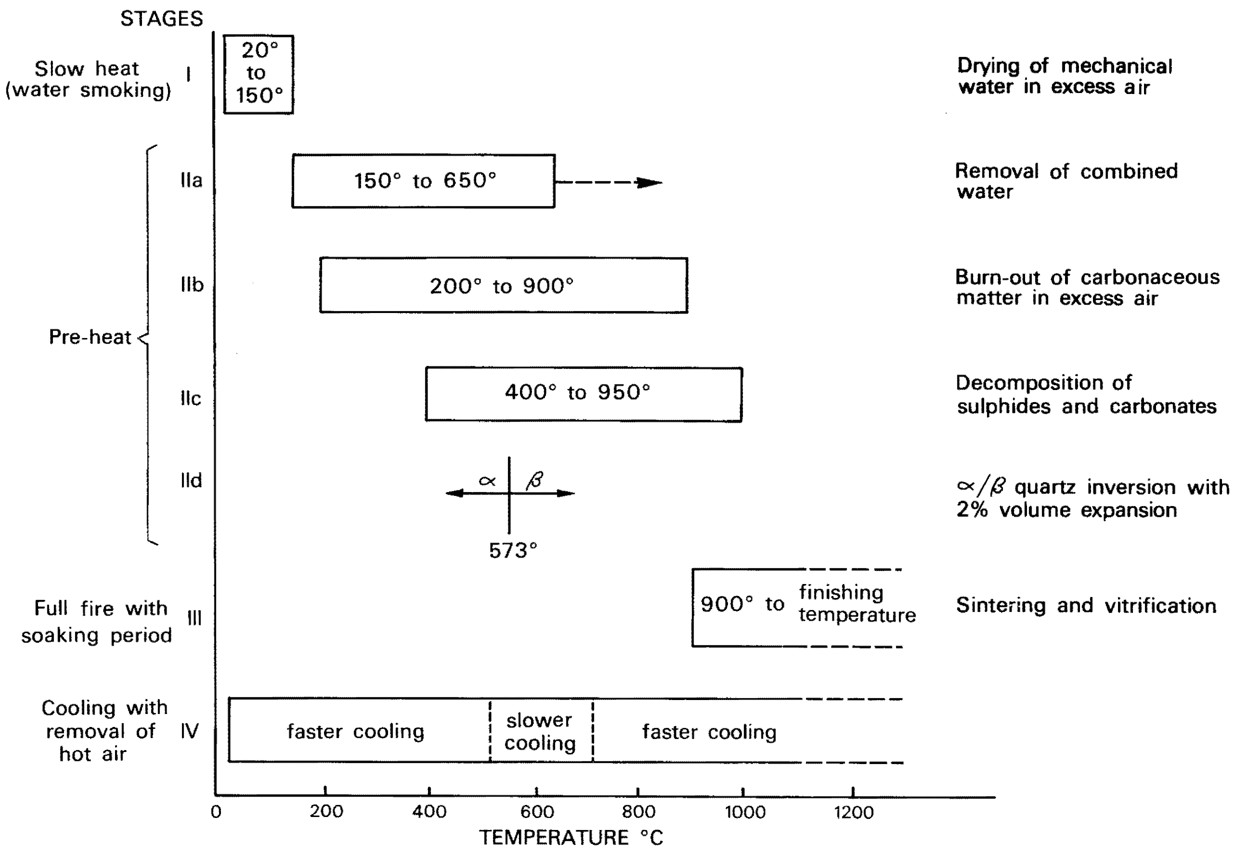


Figure 12 The action of heat on heavy clays during drying and firing (adapted from West 1969)

Proper firing of clays for structural clay ware involves balancing up the advantages of very low water absorption against the disadvantages of excessive shrinkage. When a brick is fired to about 1000°C a glassy bond begins to form and thereafter the pores in the brick are gradually eliminated, while shrinkage increases. As the temperature rises, more and more pores will be eliminated making the brick denser and stronger. This process is known as vitrification. Clay building products, except perhaps sanitary drainage pipes, should not be fully, but partially, vitrified, though if the firing temperature is too low the ware will be too porous, while too high a temperature will produce too dense a product. The best raw material compositions produce rather flat shrinkage and absorption curves over a range of temperatures where the values of these properties are satisfactory. This range of temperatures, between that which will produce just enough vitrification and that which will produce too much is known as the vitrification range (firing range). This varies with the chemical composition of the raw material but for practical considerations it is best to have a range as long as possible. A vitrification range spanning at least 100°C would give reasonable latitude during firing. During the firing of such products as dense drainage pipes where good vitrification is required, the firing range is that between the point at which almost full vitrification is achieved and that at which bloating begins.

Despite different phases being formed on the way towards a stable product, mullite is still the crystalline end-product of heating illite to high temperatures. The beginning of melting and the appearance of mullite occur at about 1050°C in illitic clays. They mature at much lower temperatures than kaolinitic clays and the rapid increase in shrinkage and decrease in absorption above 1090°C followed by bloating, is characteristic of illitic clays containing some chlorite. The vitrification range of such clays would be from about 1038°C to 1093°C.

When carbonate minerals are present in the raw material they tend to greatly alter the course of high temperature reactions. Dolomite and calcite in an illitic clay will cause it to be more refractory at low temperatures, more porous and to have a relatively narrow vitrification range.

The vitrification range for most heavy clay ware begins at about 900°C and extends up to the highest temperature the goods can withstand without serious distortion. At the higher end of the range more and more melting of the clay mass occurs and the glass so produced binds the crystalline solid particles together to form a strong product. Most building clays cannot be fired above 1100°C since at this temperature the amount of liquid produced is so high that loss of shape results.

The suitability of a clay for a particular product depends to a great extent on its mineralogical composition and consequently on its behaviour in the kiln. Products that must be strong and of accurate dimensions should be made from clays that vitrify gradually but appreciably. Thus engineering bricks, for example, must be as dense and nonporous as possible; the clays from which they are made often contain a higher proportion of such fluxes as iron and manganese compounds than the clays used for other types of brick. Figure 13 shows that a Coal Measures shale with a long range of steady shrinkage up to 1100°C, falling off between this temperature and 1200°C, possesses the kind of firing curve ideal for dense, well vitrified engineering bricks or vitrified clay pipes. The 'Keuper Marl' (Fig. 13) is less suitable since there is only slight contraction up to 1100°C and poor strength. Above 1100°C however, the increase in shrinkage and deformation are such as to make firing too difficult. Figure 13 indicates that this Liassic clay will bloat at 1150°C to 1200°C while the calcareous Gault clay has a safe firing range between 850°C and at least 950°C.

Firing

In pre-Roman times bricks were normally either simply sun-dried, or fired using solid fuel in the open air in 'clamps'. Kilns with the capability of firing to temperatures of about 1000°C were in use more than 4000 years ago in the Middle East, but it was the Romans who developed them and used them on a large scale. *Clamp firing,* formerly extensively used to fire bricks, is still carried out in the south-east of England where some of the production of brickearth stock bricks is produced in this way. The soft-mud moulded bricks, containing a proportion of colliery washery slurry or coke breeze, are set on a roofed, but otherwise open, floor in such a way that the fire can get to all parts of the clamp. The clamp of one million or more bricks is fired by the insertion of gas lances along specially designed flues. The lances are then removed, the flues sealed off and the clamp allowed to burn by itself for several weeks. The particularly pleasing yellow and multi-coloured hues achieved during clamp firing are produced by the random oxidising and reducing conditions within the clamp affecting the firing of the carbonate-rich bricks. The building of the clamp is

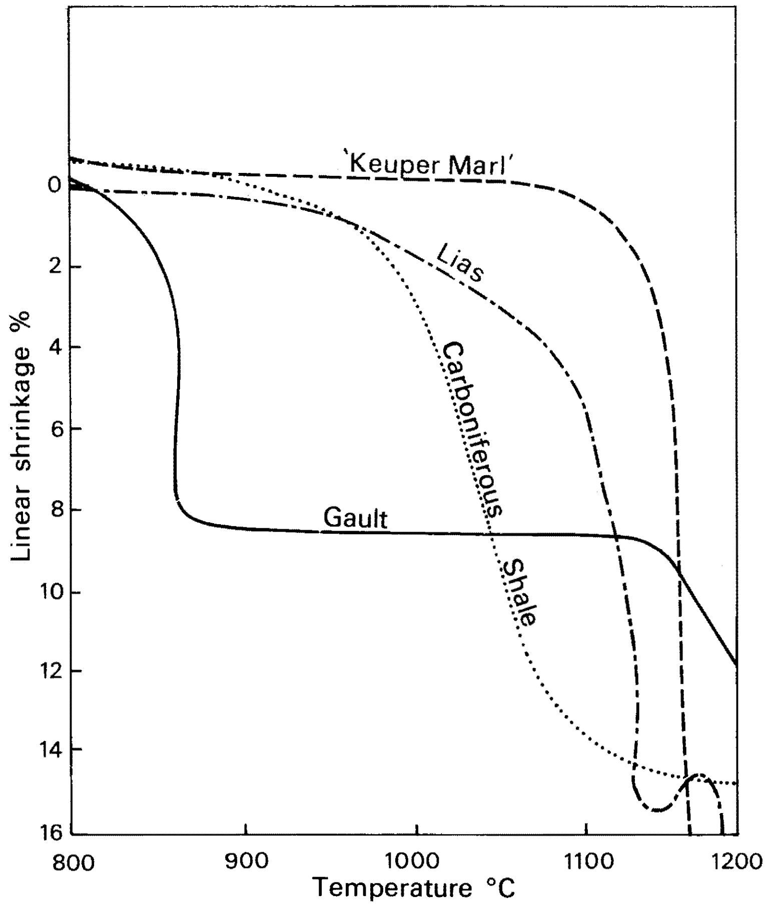


Figure 13 Typical shrinkage-under-load curves for some British brick clays (adapted from Clews 1969)

therefore a highly skilled art, though, even once lit, its unsheltered aspect means that firing can be greatly affected by the weather, especially the strength and direction of the wind.

Clamp firing has the advantage that there is very little capital outlay, and there is great flexibility in the rate of production, especially in times of slack demand. The main disadvantage is the low yield of good quality or 'first hard' stocks. Homogeneous temperature control is very difficult to achieve throughout the clamp and bricks around the edges and top tend to be underfired, while those near the centre may be overfired.

Many types of kiln have been devised for the better controlled firing of ceramic products, but they can be broadly divided into two categories, intermittent and continuous.

The basic feature of round or rectangular *intermittent kilns* is that the green bricks have to be placed in them before firing can commence and they have to be totally cooled down whenever bricks are to be drawn. Numerous design improvements have been made to intermittent kilns, some being equipped with updraught systems, some with downdraught. They have one basic drawback, however, which is loss of heat resulting from the periodic cooling of the kiln. Up to one third of the heat used in firing may go into reheating the cooled structure. Setting and drawing are labour intensive, and the labour must be skilled to avoid wastage. The use of ceramic fibre insulation has significantly improved the fuel consumption of shuttle kilns. One of the commonest intermittent-type kilns used widely in the industry until the last World War is the round or beehive down-draught kiln. It is still in use in certain of the smaller specialized works where its flexibility of firing schedule enables the production of a variety of ware and colours. Such kilns can normally accommodate from 10,000 to 100,000 bricks, or an equivalent number of roofing tiles, floor quarries or pipes. They are fired via a number of fire-holes in the side walls, and circulation of the hot gases, up to the crown and down through the setting, is achieved by a system of openings in the kiln floor, flues, and dampers before the stack. There are variations in size and design of these kilns and their settings, depending upon the type of ware to be fired, and considerable expertise is required in the control of the firing. Burning is normally carried out under pressure and both round and rectangular intermittent kilns have to be circled with steel bands to prevent distortion and cracking of the structure due to thermal expansion and contraction. Rectangular kilns are easier to set, but do not have such a good all-round temperature control as the beehive variety. Some saving on energy can be achieved if several intermittent kilns of similar design and capacity are linked in such a way as to enable the utilization of waste heat from a kiln on full fire to preheat another recently set kiln.

Most large heavy clay product works fire their ware in *continuous kilns,* where the process of firing is normally uninterrupted and heat losses are minimised, so reducing production costs. Continuous kilns are usually operated for long periods, often years, without damping down, and fuel consumption is only half to one quarter that needed to fire the same product in an intermittent kiln.

The principle of modern ring-type or annular continuous kilns is that the setting remains stationary while the fire-front (the position of maximum temperature) advances through it. In the continuous tunnel kiln the goods pass along the kiln on rail cars, encountering progressively hotter conditions up to the zone of maximum temperature (which is fixed in position) and then continue through zones of decreasing temperatures to exit at atmospheric temperature.

Various designs of moving-fire kilns are available, broadly distinguished as longitudinal (barrel) arch and transverse arch types. The most widely used are perhaps the *Hoffmann* top-fired barrel arch kiln and the Hoffmann transverse arch kiln, the latter can consist of up to eighty adjoining firing chambers arranged in a closed circuit. Some of the largest continuous chamber kilns are used in the fletton brick industry where the transverse arch Hoffmann-type kilns may be 260m long with eighty chambers each holding 76,000 bricks; there are five fires which follow each other around the kiln at the rate of about nine chambers a week. Communication between chambers is achieved via interrupting dampers and, while fired bricks are being drawn from one chamber, unfired bricks are being set in another and firing is taking place in others.

The firing of Fletton bricks is somewhat unusual in that they are virtually self-firing by virtue of the high carbonaceous content of the Lower Oxford Clay. Once shaped by the semi-dry press method, and still containing about 20% moisture, they are set in a warm chamber and dried, using heat recycled by the hot air flue system, for about five days. Initial drying is achieved using heat stored in the kiln structure, a benefit of its high thermal capacity, and then by hot air drawn from chambers which need to be cooled. Heat produced from the adjoining chamber at full fire is eventually sufficient to ignite the carbonaceous matter in the bricks and bring them up to the full firing temperature of 1050°C, without the addition of extra fuel. After some eight hours of firing the temperature drops and the bricks are allowed to 'soak' at 1000°C for a day, before cooling entirely.

Hoffmann kilns are simple and involve a relatively low capital outlay as well as having a low fuel consumption; however, an even temperature distribution is difficult to achieve especially in older designs and despite the introduction of mechanised setting using, for example, fork-lift trucks, the careful setting and drawing of the chambers can be time consuming. Nevertheless, Hoffmann-type kilns are suited to the production of the Fletton brick and are employed in the firing of well over half of present United Kingdom building brick production.

One of the principles of the continuous *tunnel kiln* is that ideally a steady supply of bricks set on rail cars moves automatically down the whole length of the kiln from entrance to exit. Various designs are available, for example the kilns may be top-fired or side-fired and may operate a continuous push system or the cars may advance forward half a car length at a time. The firing zone of a tunnel kiln, where most of the burners are situated, is at the middle, and cool air moves from the exit towards the firing zone; waste heat passes backwards towards the entrance to heat the green bricks on the way to the firing zone in a counter-current situation.

When the kiln has reached its correct temperature after ignition, it may operate continuously for years. The temperature requires only to be maintained, which means a considerable fuel economy. Further fuel saving may be effected by using some of the waste heat for drying green bricks. This may be done by installing an in-line dryer and tunnel kiln system or more commonly the waste heat is ducted to separate but adjacent tunnel dryers.

Most highly mechanised heavy clay ware production lines now incorporate a tunnel kiln; although the initial capital outlay is relatively high, there is a great improvement in labour conditions, an increase in, and total mechanisation of, output is possible, with more accurate temperature control. Modern low-profile tunnel kilns can be very efficient users of fuel, and structural deterioration is slight compared to intermittent or continuous chamber kilns, since the tunnel kiln is not subjected to thermal stress by being repeatedly heated and cooled. The modern tunnel kiln is, however, a complex piece of machinery and requires careful monitoring and control by competent staff. It is designed to fire ware rapidly on a particular inflexible schedule, thus the raw material supply must be constant and homogeneous. Although not suited to frequent firing schedule changes, modifications to suit particular products can be made, given several hours for stabilization at the new conditions.

Tile manufacture

Traditionally tiles have been made by hand using a variation of the hand-throwing process of brick shaping. Plain tiles and pantiles are still occasionally moulded by hand using a slightly stiffer clay mix than for brick moulding. Tile manufacture involves the same sequence of processes as brick manufacture but for roofing tiles normally includes both an extrusion and a pressed stage.

For modern clay roofing tile production the raw material must be very finely ground and is often re-ground several times to ensure a fine consistency; water is added to bring the moisture content up to about 15% (slightly lower than for bricks made from the same material). Blending is also very thorough before the clay mix passes to a de-airing auger used to extrude flat or ridge tiles. One of the most successful methods of tile production involves extruding the clay in thin ribbons that can be cut into lengths, subsequently to be made into roofing-tiles or floor quarries. Tile extrusion may be achieved by either a roller bat machine where moist clay dust passes between two rollers placed vertically above one another and is compressed in the gap of 1 cm or so; the clay mix may also be extruded via expression rolls. The stiff-plastic clay is delivered as a continuous ribbon of uniform thickness and is oiled before being automatically cut into tile-size pieces or 'bats'. Machines are available with outputs of between 4000 and 12,000 'bats' per hour. For roofing tile blanks the rotary drum cutter is often used. Knives mounted across the width of the drum are spaced at intervals equal to the desired length of the tile.

At this stage the tile bats are still fairly plastic and must be handled with care to avoid wastage. The tiles, or bats, are normally manually sorted and stacked for subsequent pressing. Hand-operated screw presses, or more commonly power presses, are used to shape tile bats prepared by roller bat-machines or expression rolls. For plain tiles, outputs of about 30 tiles per minute can be achieved using a power press fitted with double dies fed automatically from a magazine. For complex interlocking tiles and pantiles, plaster of paris moulds are used instead of the steel type used for plain tiles; the plaster of Paris absorbs moisture from the clay in immediate contact with it, thus making removal easy. Also, the bats or blanks are normally only very roughly tile shape and size and are much softer than those produced for pressing plain tiles.

The machine not only presses the tiles but inserts the nail holes, and moulds the anticapillary fluting and nibs. Automatic pressing machines can also form completely interlocking weather bars on tiles which give a roof optimum impermeability.

Sometimes, an auger machine with a continuous nib is used during extrusion. A slight camber is applied to 'flat' roofing tiles by stacking them on cambered firebrick pallets on kiln cars. Vacuum lifting devices are employed to lift complicated tiles carefully onto pallets while plain tiles may be manually stacked. The re-pressing of bats to make interlocking roofing tiles is now one of the most advanced techniques in heavy clay ware moulding.

Drying times for roofing tiles varies from twenty-four hours to fourteen days depending on their type and the mix used. This process has to be carried out very slowly and carefully since, if hurried, or if the tiles are not sufficiently dry before firing, cracking will occur. Loaded kiln cars are normally held in a heated holding room pending transfer into the tunnel kilns, because the tiles have an unusual capacity to absorb moisture from the atmosphere. If left in a cool place at this stage they can absorb up to 3% moisture. Before firing, their moisture content must be less than 1%.

In many modern works both bricks and tiles are produced in the same plant and cars of brick and tile are interchangeable in the kiln, though their firing schedules will vary. For flat tiles made from the Etruria Marl maximum firing temperature is 1160°C to 1170°C, and the time spent in the kiln is about 80–90 hours. Tiles are thus fired slowly and gently to ensure a sound product.

As an example, production of quarry tiles using, for example, Ruabon Marl at Ruabon in Wales, involves initial stockpiling and careful blending of up to 10 seams of a particular clay horizon to acquire the correct mix of fired colour. The raw material passes via a boxfeeder to kibbler rolls and is then tempered in a wet pan mill; at this point up to 12% moisture is added. The crushed clay passes through a double set of medium-speed rolls, then a double set of high-speed (finishing) rolls and on to mixers. Depending on grain size at this point, regrinding may well be necessary. The clay is conveyed to two extrusion lines incorporating de-airing extruding augers with continuous nibs and fluting capability. The clay column is cut into bats, and the bats are pushed sideways through a wire cutting table. The green tiles have very good green strength and are stacked directly on top of each other on pallets. On entry to the chamber dryers the tiles possess about 14% moisture and upon exit should have only 2.5%. A relative humidity of 95% is maintained for 24 hours and total drying times vary from 7 to 14 days depending on the size of the tile. The tiles shrink about 10% from green to fired, about half of which occurs during drying. Pressure firing is carried out in down-draught beehive periodic kilns with a top firing temperature of 1105°C. Ambient to finishing temperature takes 85 hours, with cooling a further 5 days. Intermittent oxidising and reducing conditions are applied repeatedly (flashing) to produce the desired colour effects.

The Ruabon plant also operates a dry or dust press production line with tunnel kiln firing for unglazed floor tiles. Local carefully selected marl and buff-firing Shropshire fireclay are milled and dried before mixing in various proportions and with manganese and iron pigments to produce different colour effects. The ground and dried clay must pass an 18 or 20 mesh sieve and has 5% moisture for automatic hydraulic ram pressing in metal moulds. The pressed tiles are set in refractory saggars, since they would be too delicate to stack to any height otherwise. Variations in colour can be achieved according to the position in the kiln. The red-firing clays have the lower vitrification range and so are set in the centre of the stack on the kiln cars; the buff-firing clays are set at the top and bottom of the cars since they have a higher vitrification range. The drying and firing processes are automatically controlled and continuous, with dryer and tunnel kiln arranged in-line.

Pipe Manufacture

Clay drainage pipes were moulded by hand until the 19th century when stoneware pipes came to be fashioned in short lengths on hand-operated machines. The need for longer units meant thicker walled and heavier pipes, and this prompted the installation of mechanical handling and automatic machines. Today all clay pipes, with the exception of complex fitments and shapes which have to be cast, hand moulded or assembled manually from parts, are shaped by extrusion. Clay pipe manufacture is one of the most highly mechanised sectors of the ceramics industry.

As with the extrusion of bricks, the forming of pipes and tiles by plastic extrusion requires that the raw material develop a high plasticity, since the ware must often withstand great compressive and shear loading in the unfired state. Although extruded sewer pipes are not stacked in courses on kiln cars like bricks or tiles, some of the larger ones exert their own compressive forces that tend to distort and crack the lower ends when sufficient plasticity is lacking.

Sewer pipes are made by either horizontal or vertical, auger or ram extrusion, which involves the use of a steam-heated, oil-lubricated, annular die from which the body is extruded to produce a cylinder of plastic material of required wall thickness and diameter for the main pipe length. After trimming and cutting the pipe passes to the dryers where most of the moisture is removed.

Vertically stacked pipes pass through modern tunnel kilns on kiln cars or are fired in chamber kilns. Firing time is determined by the type of clay used and the thickness of the body, and the process has to be carefully monitored. The firing cycle must comprise a gradual build up of temperature to a maximum of about 1100°C, with a 'soaking period' at this temperature, followed by a gradual reduction. Upon cooling a high density, very strong, substantially impervious clay body is produced.

PRODUCTS AND SPECIFICATIONS

Common clays are used primarily for the manufacture of (i) building bricks, (ii) permeable hollow ware such as field drains, (iii) almost non-permeable hollow ware such as sewers, drains, and electrical conduits, (iv) almost non-permeable roofing tiles, unglazed floor tiles and quarries etc, (v) cement, and (vi) lightweight expanded clay aggregate.

Bricks

Building bricks are made primarily from clay, shale or mudstone, though a small proportion is produced from calcium-silicate or concrete. There are three basic types of clay brick in current production, based on end use:

i Commons—which are suitable for general building purposes;
ii Facings—which are specially made for their attractive appearance, achieved by variations in colour and surface texture;
iii Engineering bricks—which have high strength and low absorption.

Specialised acid-resisting bricks are also available.

Bricks may also be classified according to the type of clay used to produce them, the forming process employed or the method of firing. Bricks made from the Lower Oxford Clay are termed 'Flettons' after a village near Peterborough where the process originated in 1881. Fletton bricks can be commons or facings, but because of the particular properties of the raw material none are of engineering quality. Other clay bricks made from a wide variety of geological formations may be referred to in this way e.g. 'Keuper Marl', but are more normally referred to collectively as non-Fletton bricks. No special designation is given, for example, to building bricks containing a significant proportion of low-grade fireclay. Bricks may also be referred to as 'clamp-fired' or 'kiln-fired', and 'mechanically moulded' or 'handthrown'; the latter are in great demand for certain applications because of their natural, rustic, and aesthetically pleasing texture. Their return to popularity is evidenced by the installation in some works of equipment capable of producing machine-moulded simulated 'handthrown' bricks, and by the inclusion in brand new works of a traditional handthrown forming line.

There are no British Standards relating to the raw material of the industry since traditionally tests are carried out on the products. The essential requirements are that, after being ground and prepared, the clays and shales are capable of taking a good shape, by one or other of the various forming methods, and that the shape should be retained without significant shrinkage, warping or cracking when the bricks are dried and fired under suitable conditions. Details, such as Atterberg limits, dry strength, drying shrinkage and amount of grog or sand to be added to the raw clay, are not generally available.

There are, however, British Standards for the finished structural clay product. Clay bricks are classified in B.S. 3921:1974 'Clay bricks and blocks', which defines varieties, qualities and types, formats and dimensions, strengths and absorptions, soluble salts content, liability to efflorescence, frost resistance, and quality of finish, and recommends testing procedures. Bricks are classified on the basis of quality as well as variety and type. 'Internal' quality bricks are suitable only for internal use, 'Ordinary' quality are normally durable in the external face of a building, and 'Special' quality bricks are durable in conditions of extreme exposure to water and freezing. Thus common bricks may be not only of 'internal quality', since some of 'special quality' are durable even when used in situations of extreme exposure. Common bricks produced from Coal Measures shales in Staffordshire are suitable for exterior use. The vast majority of common bricks produced from Coal Measures shales in Scotland are not of sufficient durability to withstand exposure without rendering and are thus of internal quality only. Similarly, facing bricks are not necessarily of special quality since some are less frost-resistant than some common bricks. Thus 'facing' means simply 'specially made or selected to give an attractive appearance'. In fact the methods of classification are all independent of each other. Very often the type, quality and variety of a brick depend not only on the method of production and firing but on the raw material it is manufactured from. Certain clays are more suited to engineering brick production, where a greater amount of flux is desirable to produce a stronger, more vitrified and impervious brick, while others may be suitable only for commons or facings.

B.S. 3921 requires physical standards to apply to varieties of bricks and blocks, and recommends tests and characteristics which are noted as being desirable. The minimum compressive strength of 5.2 MN/m^2 for bricks referred to in the British Standard is sufficient for the loadings in low-rise housing and other similar buildings, and ensures that the bricks are strong enough to be handled. It is the minimum figure laid down in the appropriate Schedule to the Building Regulations and applies only to structures built using the rules in that Schedule. Where CP 111 or BS 5628 are applied the 5.2 MN/m^2 value will not be high enough. Only for engineering and damp-proof course bricks can Table 10 be taken to be a definite specification. Table 10 gives a classification of bricks in terms of strength and absorption.

Table 10 Classification for strength and absorption

Designation	*Class*	*Average compressive strength not less than*		*Average absorption (boiling or vacuum) % wt, not greater than*
		MN/m²	*lb/in²*	
Engineering brick	*A*	*69.0*	*10,000*	*4.5*
	B	*48.0*	*7,000*	*7.0*
Load-bearing brick	*15*	*103.5*	*15,000*	*No specific*
	10	*69.0*	*10,000*	
	7	*48.5*	*7,000*	
	5	*34.5*	*5,000*	*requirements*
	4	*27.5*	*4,000*	
	3	*20.5*	*3,000*	
	2	*14.0*	*2,000*	
	1	*7.0*	*1,000*	
Bricks for damp-proof courses		*As required*	*As required*	*4.5*

Strength is not necessarily an index of durability and bricks of class 7 and upwards, though usually durable, may decay rapidly if exposed to freezing in wet conditions. Water absorption, while being a much used test, is not a general index of durability; only engineering and damp-proof course bricks have B.S. 3921 specific requirements, though low absorption (less than 7% by weight) usually does indicate a high resistance to freezing damage. Other important specified and non-specified properties of brickwork and bricks include fire resistance, sound, thermal and moisture properties, (C.P. 121: Part I: 1973, Schedule 8 of the Building Regulations, 1972) frost resistance, weight, soluble salts content and liability to efflorescence, (BS 3921). Reproducibility is essential in the production of bricks, which must comply with the British Standard

Requirements. B.S. 3921: Part 2: 1969 specifies brick size where tolerances are fixed by giving maximum and minimum dimensions on batches of 24 bricks chosen at random. Making size is adjusted to allow for shrinkage, enabling the required fired size to be achieved.

Bricks are usually shaped as rectangular prisms, but special shapes (defined in B.S. 4729), some of which are in such general use as to be known as 'standard specials', are produced as required. (However, note 'Special Quality' refers to a defined quality of brick in B.S. 3921). Dimensions for these special shaped bricks are given in B.S. 3921. Some companies have extended their special shape facility so that users can now achieve complex architectural features by the use of special shapes. Other firms produce special shapes by hand as and when required using a separate small kiln. Brick types are also defined in B.S. 3921; bricks may be (i) solid, with or without 'frogs'; (ii) perforated, where small holes may not exceed 25% of the total volume; (iii) hollow, where the total of the holes (small or large) may exceed 25% of the volume; and (iv) cellular, where holes closed at one end do not exceed 20% of the volume.

A number of tests are carried out on bricks, including those for porosity, dimensions, compressive, tensile and shear strengths, abrasion resistance, water absorption and tests for soluble salts and efflorescence. As part of its general research programme on heavy clay products, the Building Research Station at Garston, Watford, undertook for the National Brick Advisory Council an extensive survey of clay building bricks. Their report (Bonnel and Butterworth 1950) gave the results of tests on large numbers of bricks, which in turn provide indications of the types of clay used to produce them. In addition, a large number of recommendations for the proper use of bricks and blocks is available particularly in the correct use and selection of mortars, plasters and cements, and in minimizing sulphate attack, dampness and movement. One of the main properties of structural clay products is their ability to resist the rigors of climate and to function well in their intended purposes with negligible maintenance for a very long time. Their durability is normally expected to exceed that of other materials such as wood, metals and plastics, and this is evidenced by examples thousands of years old.

Common bricks are used in the external walls of buildings where appearance is not of prime importance, or are used as internal walling. Where additional bond is required, keyed commons are available, and where weight is to be kept to a minimum, cellular commons are used. For walls between 102.5mm (half brick) and 215mm (whole brick) Calculon common bricks of class 5, 7 or 10 can be obtained.

Facing bricks are specially made for their attractive appearance; a wide variety of colours and finishes now exists from black and purple, through red and brown, to buff and cream. Both surface and body colours are available as well as smooth, sandfaced, wirecut, handthrown, strawthatched, brushed, rustic and other textures. They may be in a solid colour or mottled, brindled or multicoloured. Aesthetic appeal is a very important aspect of facing bricks and the variety of colours and textures now offered allows architects wide scope in their building projects. Colours and textures are often selected to blend into the landscape or the brick may be required to look 'rustic' or 'antique', either to enhance new buildings or to match broken and deteriorated original brickwork in ancient buildings. Red, brown and mottled bricks tend to be used in areas where the creation of a 'warm' atmosphere is desired e.g. the cladding of living room walls; paler colours produce a clean 'fresh' look in hospitals, research facilities and food preparation areas.

Sometimes bricks for special purposes are used in situations where their special properties are not necessary; thus Staffordshire Blue engineering bricks are often used in a facing capacity because of their attractive colour. Progressively more ambitious designs are being undertaken in brick, often necessitating comprehensive series of specials and calling for highly skilled laying. Masonry panels composed of prefabricated sections of facing brickwork may be formed in the factory or at the building site. These panels can be reinforced both horizontally and vertically, and this, combined with the very full mortar penetration achievable, ensure that the resulting brickwork is of high strength. Some companies make brick-clad pre-cast panels formed to produce elaborate shapes.

Engineering bricks are specially made to withstand specific load-bearing conditions, and are normally of Special Quality. They have a high resistance to moisture penetration, to the attacks of acids and alkalis, to erosion, abrasion and impact stresses. Their great strength in compression endows extraordinary load-bearing properties and they are unaffected by extremes of climate. Engineering bricks are used in a wide variety of civil engineering works. Probably the best known variety is the Staffordshire Blue engineering brick, manufactured from the ideal and unique Etruria Marl. During firing the natural red colour of the clay is changed to blue. This blue colour penetrates about 5mm into the brick and covers the vitrified body. Staffordshire 'Blues' are among the strongest of bricks, perhaps second only to Accrington 'Noris' made from Lower Coal Measures Accrington Mudstone. Many brands of engineering brick are available with high compressive strength, low water absorption, excellent durability, and high resistance to frost and acid damage.

There is an increasing use of brickwork as a hard landscape material in gardens, patios and amenity areas, and there is a wide range of purpose-made paving bricks in different colours, textures and sizes. The colours are permanent and the pavers are extremely hard-wearing. Specifications for acid resisting bricks and tiles are given in B.S. 3679, and those for special shapes and sizes in B.S. 4729.

Bricks should ideally combine durability, and structural strength with attractive appearance. Their main advantages are that the raw material is indigenous and the product has low energy content, is durable, has negligible maintenance costs and is incombustible. Brickwork has some disadvantages such as the fact that it is labour intensive and can have low thermal insulation or problems of salt content and efflorescence. Modern construction methods have overcome low thermal resistance by insertion of highly insulating mineral wool, foam etc., in the cavities of cavity brick walls or as an insulant attached to the inner leaf.

Tiles

Roofing tiles are shaped to overlap and/or interlock on sloping surfaces and may also be used as wall cladding. Appearance as well as weatherability is an important factor in their production. They are closer-grained and denser of texture than bricks and selected local clays may be mixed with sand to obtain the right mix. High quality double interlocking clay pantiles are made by one company in the north of England. British Standard Specifications pertaining to clay tiles are:

B.S. 402 : Part 2 : 1970	'Clay plain roofing tiles and fittings—metric units'.
B.S. 1286	'Clay tiles for flooring'.
B.S. 3679 : 1963	'Acid-resisting bricks and tiles'.

These specify rates of sampling and methods, dimensions and shape tolerances, water absorption and apparent porosities, transverse strength (B.S. 402 only) and other requirements.

Plain clay roofing tiles are available either machine or handmade in several body colours and a wide variety of shapes, enabling the most complicated roof angle to be covered. They have excellent weathering properties and if anything their aesthetic appearance improves with age and exposure. Apart from standard specials, some manufacturers produce many specials of complex shape by hand. Flat clay tiles are also produced as ornamental cladding for vertical surfaces; these are designed in several body colours and end-patterns, and are commonly used in better housing developments as well as on some industrial buildings. Clay roofing tiles, especially handmade varieties, are often used to re-tile buildings of great age in the correct tradition, but are popular as an attractive roofing medium for more modern residential homes in Britain and the rest of Europe. It is important not to mix handmade and machine-made tiles on the same roof since, although they may superficially resemble each other, the handmade tile will mellow with age while the machine-made tile will remain essentially unaltered.

Unglazed floor tiles used in kitchens, yards, terraces and patios, are dense, fully vitrified coloured tiles with various finishes and high resistance to abrasion. They are expected to resist staining and never to require replacement or resurfacing, although they are often subjected to excessive dampness. There is an increasing interest in their use for decorative wall cladding in kitchens, while renewed interest has been generated for unglazed, specially shaped, small flooring tiles of natural hues. Only a small proportion of floor tiles are produced from brick clays. They are normally unglazed, relatively thin body, and do not usually exceed 15cm x 15cm in size, whereas floor 'quarries' are a heavy ceramic flooring material and are thicker, coarser textured and more resistant. Quarry tiles are normally made rectangular, square or hexagonal, up to 229mm in diameter and 29mm thick. They are highly resistant to acids, oil and frost and are very hard wearing.

Pipes

Two basic types of clay pipe are in current production in the United Kingdom: porous and vitrified. The porous pipes considered here can be butt-jointed, can withstand compression and low temperatures and are used as agricultural field drains; clayware land drains currently account for about 70% of land drain materials. They are available in various diameters, the 3 inch (75mm) internal diameter pipe being the most commonly used, and are designed to match the types of machines that will lay them in the ground. Vitrified clay pipes now account for a very large percentage of clay pipe production in the UK, and clay pipes and fittings altogether represent approximately one third of the total pipe market in Britain. Vitrified clay pipes are dealt with fully in the dossier on fireclay in this series.

Other heavy clay products

Hollow clay blocks are perforated lightweight clay products made by essentially the same method as some building bricks, though the raw material is more finely ground and normally of slightly better quality and consistency. They are shaped by the wire cut extrusion process using a complicated die. Drying and firing have to be carefully controlled to avoid cracking and shrinkage of the large surface area body. Specification for clay building blocks are embodied in B.S. 3921 as well as specifications for hollow clay floor blocks used as filler blocks in reinforced concrete flooring. Hollow clay blocks can be used in most building situations instead of conventional solid bricks or blocks, but their use is limited in the United Kingdom compared with other European countries where they form a large part of the clay building products market. Normal house building practice in France, for example, is to use hollow clay blocks faced with a bonding screed for external and internal walls as well as floors and ceilings. There are however a number of specialised products in the U.K. including hollow clay floor blocks.

The production of hollow blocks requires less raw material than conventional bricks, while load-bearing capacity can be maintained and thermal insulation is improved.

Conduits, cowls, flue liners, chimney pots (B.S. 1121 : 1961) and flower pots account for a very small part of total clay product output. Production of these is often concentrated in small areas where clays with special qualities occur or where there is a local demand or tradition. Clay and shale have been used extensively in fill for roadworks, although it is preferable for environmental reasons to use waste material, e.g. colliery waste, or to match the amount of material derived from cuttings with the fill required. Clay and shale are occasionally worked specifically for road projects.

New uses

Research into new outlets for clay has been aimed at modification of traditional building products. The main research body working in this field is the British Ceramic Research Association. The Brick Development Association also sponsors work at BCRA and at universities and polytechnics. Various clay blocks, planks and panels have undergone tests and have been designed mainly in an attempt to counter competition from other materials. The results of tests, mainly in Switzerland during the 1950s, suggested that UK safety standards were unrealistically high and led to the production of 'CP 111' : 1964 'Structural recommendations for loadbearing walls' (with subsequent amendments). In a connected field, the Ronan Point disaster (although this involved a non-brick building) led to work on the deformation of brickwork and other materials in gas explosions. The Building Research Station developed the 'V' brick, a brick which allowed a two-leaf cavity wall to be laid in one operation. However, it was never a success for building external walls and was subsequently modified for use in internal cross-walls, (the Calculon brick). The scope for research into new uses which would lessen the clay industry's reliance on the building industry seems limited, as the most promising products, for example fillers, would consume only relatively small amounts of clay in comparison with fired clay products. An exception would be in the alumina field if substantial advances were made. The possibility of using alumina-rich clays in the production of aluminium has been discussed from time to time but the exploitation of clays for this purpose is unlikely as long as alumina continues to be freely available from bauxites. Fireclays, certain alumina-rich shales in Coal Measures sequences (see Mineral Dossier No. 20. Bauxite, Alumina and Aluminium, in this series), and unburnt colliery spoil would probably be the most appropriate raw materials for this purpose.

SUBSTITUTES

Traditionally, bricks, tiles and pipes have been made from natural argillaceous materials such as clay, shale and mudstone, but they have been, and are, facing competition from other building products. Although there are no economically acceptable substitutes for clay as a raw material, there are numerous alternatives for clay building products, many of which are based on, or employ, cement at some stage, thus replacing only part of the clay formerly used. Clay-like properties may be given to non-clay minerals by organic reagents, but this has only been carried out on a laboratory scale. Traditional clay bricks may be replaced by clay blocks or by clay-free bricks and various lightweight or dense blocks.

The demand for increased speed of construction, and ease of laying, led to the production of building units larger than bricks, often manufactured from alternative materials. Many of these non-clay products are quicker to manufacture and in some cases cheaper than brick; however, in most applications their properties are only as good as, or less good than, those of equivalent clay products (viz. frost and fire resistance, sound and thermal insulation etc). In terms of health hazards and general questions of safety, brick is generally unsurpassed. Factors in the past leading to the use of substitutes included availability, proximity to major markets and the use of waste or semi-waste by-products of other industries. In some limited areas there had been difficulty in supplying completely uniform and reliable clay bricks in large quantities, and this led to a search for more stable building materials. Builders may have been induced to turn to alternative bricks as a result of fluctuations in brick deliveries which were delayed for several months during 'boom' periods, but seldom turn to substitute materials. It may be true though that because of their speed of manufacture non-clay bricks are better able to respond quickly to sharp up-turns in demand.

There are two main materials from which non-clay bricks are made: calcium silicate and concrete. Together they account for about 10% of total UK building brick production. Calcium silicate bricks may be 'sand-lime' or 'flint-lime' depending on whether they are composed of a mixture of lime and sand or lime and siliceous gravel or rock chips. They are mechanically pressed into shape and hardened in an autoclave by chemical action induced by steam under pressure. As with clay brick, calcium-silicate brick production can be limited by the availability of suitable raw materials. Production of calcium-silicate bricks started in the early part of this century and steadily increased, though it has never accounted for more than about 6% of total UK brick production. Waste from other industries is often used in their manufacture; until recently waste sand from the production of china clay was used in south-west England. Calcium silicate bricks are naturally light in colour (white, cream, pink), but suitable pigments can be added to produce facings of various colours including darker hues; textured facings are also available. The main advantages of calcium-silicate bricks are their good light reflectance in enclosed spaces, their lack of soluble salts and hence absence of efflorescence, and the accuracy and uniformity of their shape and size which makes them easy to lay and saves mortar. They undergo a certain amount of drying shrinkage if care is not taken in their storage and their regularity may not always be advantageous in facing brick markets; their range of colours and textures is often considered to be more limited than that of clay bricks. Calcium silicate bricks are cheaper than most high quality facing bricks, but they too have suffered in the recent general recession in the construction industry.

Amendments to the code of practice which permit the use of load-bearing concrete construction on a par with clay brickwork in multi-storey buildings, have resulted in some increased demand for high-strength blocks as alternatives to common bricks. High strength dense aggregate concrete blocks manufactured to B.S. 2028:1364:1968 are used in many public and private sector building and civil engineering applications. They can be made from selected hard Carboniferous limestone or sand and gravel aggregate and are available in standard or fair-faced finishes. However, dense blocks made of conventional concrete may present handling difficulties on site owing to their size and weight, so clay-based bricks and blocks or lightweight blocks made from clinker, foamed slag, sintered pulverised fuel ash, perlite, vermiculite, pumice and expanded clay aggregate are becoming increasingly popular. The main alternative to clay engineering bricks is in-situ or pre-cast concrete.

A wide range of materials can be used as substitutes for facing bricks including concrete, aggregate-faced panels, natural or reconstituted stone, slate, plastics, ceramics, glass, timber and metals. The competitiveness of these products with bricks and with each other depends on a variety of local and national factors, not least those of fashion. Many facing materials are used as panels which are light and induce higher productivity. However, when used as cladding most require some structural support and the total cost is often more per unit area than for facing bricks. Indoor partitioning is increasingly made from plasterboard, although various lightweight blocks have also extensively replaced bricks in the inner leaves of walls and internal walling in both the housing and industrial sectors. However, sound insulation and differential shrinkage have been a problem with lighweight blocks.

Continuously-laid, perforated plastic pipes are an increasingly used alternative to clay pipes for agricultural drainage; polythene has been tried but the commonest material now used is PVC. They are much lighter, easily handled, less liable to damage in transit and there is a considerable potential for mechanised laying. However, clay land drains are still functional after many decades, and clay pipes generally require less energy for their manufacture than pipes made of PVC, asbestos cement, pitchfibre and cast iron. To be economically competitive for field drainage plastic pipes have to be made smaller in diameter than clay pipes, and in practice after a number of years they are found to be less efficient due to silting and sometimes collapse. Their derivation from petrochemicals may affect both availability and economic competitiveness in the future. The present market share relationship between clay and plastic for field drains is 66% clay, 33% plastic and 1% other materials.

The demand for clay roofing tiles has declined over the years, and apart from very high quality, relatively expensive types with great aesthetic appeal, they have been largely superseded by concrete tiles coated with a pigment and sand mix. In 1976 concrete roofing tiles formed 27.5 million m^2 out of a total roofing tile market of 29 million m^2. The production of quarry tiles has been severely affected in recent years by the use of plastic, carpet, cork, wood block and concrete floorings, though some unusual styles and hardwearing finishes remain popular in amenity areas. It is also interesting to note that paving brick seems to be largely replacing quarry tile as an outdoor patio paving medium.

Research by such bodies as the British Ceramic Research Association, the Building Research Station, and the Cement and Concrete Association may lead to developments in building materials which could alter the balance of usage in favour of, or against, clay products. As well as substitute materials for brick manufacture, there are various extenders which have been shown to produce bricks of adequate density and strength, for example pulverized fuel ash, mine tailings and sawdust additives. A lightweight brick can be produced using a 2:1 mixture by bulk volume of clay and sawdust. When fired the sawdust is burnt off leaving a fairly porous body, less dense than conventional clay bricks but said to have adequate strength. At the present time in the United Kingdom a lightweight clay block is produced for improved insulation on the inner leaf of an external wall and this block is made by using expanded polystyrene in a similar fashion, as a burn-out material. As thermal insulation standards for external walls are improved such blocks may have advantages over dense concrete or clay bricks, but will not probably be sufficient to meet new standards being considered for the future. For such construction, highly insulating fibre and foam fills for cavities will no doubt be required.

It is unlikely that substitutes will significantly replace conventional heavy clay ware, and market penetration by alternatives has only been successful where the specific advantages of the substitute meet a particular need. No competitively priced alternative appears to be fully comparable with clay bricks and although their unit size is small they are more flexible for some uses and enable the production of a rich variety of visual effects. It would also appear that recent work and subsequent modification of standards on the load-bearing properties of bricks are reversing the trend to other materials in high rise structures.

STATISTICS : PRODUCTION, CONSUMPTION, TRADE.

Production

In 1784 a Brick Tax was imposed in Britain and subsequently increased in 1794 and again in 1803. Apart from checking the use of bricks, the excise duty also meant that their manufacture was placed under surveillance and standards could be introduced. For example, brick sizes were laid down by the Act 17 Geo. III c.42, prices were controlled and some record of manufacture was kept. The tax also gave a strong incentive to the use of brick tiles, since these were not subject to tax.

Hunt (1859) quotes numbers of bricks paying duty in the early part of the 19th Century as follows:

1821	899 178 510
1840	1677 811 134
1847	2193 829 491
1849	1462 767 154

With the exception of 1849, 'being the year when the oppressive nature of the duty on bricks was strongly urged and the repeal expected' with the result that the construction of many large buildings was delayed and the manufacture of bricks diminished, these figures illustrate the expansion of brick-making which came in the 19th Century with the rapid growth in urban population and industry.

The common clay and shale from which most of this material was manufactured are, as their description implies, of widespread occurrence. There is little or no record of the quantity of clay worked until almost the end of the 19th century. Most of it was worked by small enterprises, and often intermittently near construction sites as demanded and not, as later, in extensive pits and quarries. In 1858 Robert Hunt made his first and only attempt to collect returns from all clay works and quarries. In Part II of the Mineral Statistics of United Kingdom for that year output of bricks, tiles, and pipes produced is recorded together with considerable detail of the clay works and quarries from which these were produced, but no record of the amount of clay dug. (For example, see Figure 14.) It was not until the Quarries Act of 1894 that regular returns of the output of common clay and shale were collected and published. At first, these excluded all quarries and pits of less than 6m in depth, so that the earlier figures tend to understate output. This restriction was lifted by an amendment under the Factory Act of 1937 but between 1941 and 1944 quarries with an output of less than 1,000 tonnes per annum were omitted. The annual production of common clay and shale in the United Kingdom is summarised in Table 11.

Since 1895 nearly 1,600 million tonnes of common clay and shale have been dug in the United Kingdom and annual production increased from approximately 10 million tonnes to almost 38 million tonnes in 1968. Although output has fallen recently, it was still over 25 million tonnes in 1978. For much of the period before the Second World War the tonnages produced were larger than those for any other mineral apart from coal. Output of clay and shale has subsequently been overtaken by those of limestone, sand and gravel and igneous rock, but clay and shale remain the basis of an industry with sales of over £300 million per year.

Figure 14 Extract from "Memoirs of the Geological Survey of Great Britain, Mineral Statistics; Part II for 1858" Hunt, R. 1860.

SUSSEX

Estimated annual quantity of all kinds manufactured	Number, 77,550,000.
Estimated Value thereof	£85,305.

Name of Brickfield or kiln	Description of Clay or Brick earth	Nearest Town or Shipping Port	Name of Freeholder	Name of Manufacturer	Kind of Manufacture, Estimated Annual Make and General Remarks
Airsford	Chalky clay	Arundel	Sir John Anson		Bricks
Blendworth Common	Plastic clay	Havant			Bricks
Bosham	Plastic clay	Chichester			Bricks
Buxted		Uckfield	Earl of Liverpool		Bricks
Chilton Brick Works		Sudbury		Robson & Co.	Bricks and Tiles
Cowden		East Grinstead			Bricks
Crowhurst	Weald Clay	Hastings	Thomas Papillion		Bricks
Eastergate	Plastic clay	Chichester	R. W. Field	R. W. Field	Bricks
	Weald Clay	Hastings	B. L. Smith, Esq.		Bricks
East Grinstead		East Grinstead		Mr. Lynn	Bricks and pottery
Emsworth	Plastic clay	Havant			Bricks, 20,000
Ewhurst	Chalky clay	Guildford		Parks and Thampsitt	Bricks and tiles
Fishburn (several brick-fields)	Plastic clay	Chichester	Various	Several	Draining pipes for agriculture are made largely around Chichester and along the South Coast Railway; very good bricks, used for paving Brighton, Worthing, etc.
Hawkenbury	Sandy clay	Tunbridge Wells	Marquis of Camden	William Francis	Paving bricks, 100,000; kiln bricks, 100,000; clamp bricks, 60,000; socket pipes, 5,000; drain pipes, 30,000; tiles, 50,000.
Hurst Green			Morgan Thomas		Bricks, 90,000
Lewes	Weald Clay	Lewes			Bricks
Manor House Farm	Weald Clay	Burwash		Henry Heigham	Bricks
Petworth	Weald Clay	Petworth	Colonel Wyndham	Colonel Wyndham	Bricks
Regate	Weald Clay	Midhurst			Bricks and tiles

Table 11 United Kingdom[1] Production of common clay and shale[2] 1895–1980

Thousand tonnes

Year	*Quantity*	*Year*	*Quantity*	*Year*	*Quantity*	*Year*	*Quantity*
1895	6,768	1920	8,163	1940	16,689	1960	31,303
1896	8,108	1921	8,494	1941	16,609	1961	32,665
1897	9,275	1922	6,565	1942	12,438	1962	33,039
1898	11,292	1923	8,726	1943	10,381	1963	31,780
1899	11,366	1924	11,131	1944	7,978	1964	34,674
		1925	13,429	1945	7,555	1965	35,054
1900	10,364	1926	13,247	1946	12,998	1966	34,080
1901	10,580	1927	14,980	1947	18,324	1967	37,292
1902	11,478	1928	13,654	1948	19,931	1968	37,850
1903	12,260	1929	14,676	1949	23,556	1969	37,313
1904	11,911						
1905	11,227	1930	15,834	1950	23,956	1970	32,083
1906	11,176	1931	16,044	1951	24,945	1971	31,680
1907	10,782	1932	15,233	1952	26,826	1972	33,669
1908	10,416	1933	18,874	1953	28,570	1973	33,945
1909	10,235	1934	22,551	1954	29,411	1974	31,109
		1935	23,930	1955	29,775	1975	27,794
1910	10,248	1936	25,187	1956	29,857	1976	26,077
1911	10,013	1937	26,287	1957	28,848	1977	23,545
1912	9,090	1938	27,234	1958	26,404	1978	25,473[3]
1913	9,796	1939	24,726	1959	28,218	1979	21,644[3]
1914	9,793						
1915	6,342					1980	19,925[3]
1916	4,096						
1917	3,380						
1918	3,609						
1919	5,380						

(1) As at present constituted, i.e. including only the six counties of Northern Ireland throughout the period. Isle of Man is however excluded except for the years 1946 to 1948.
(2) Includes fuller's earth from 1939 to 1973 and "mica clay" up to 1920. The consequential increase in the figures is not however likely to be significant.
(3) Great Britain only.
Sources: 1897–1919 Mines and Quarries; General Report & Statistics, Home Office.
1920 Mines and Quarries; General Report & Statistics, Mines Dept., Board of Trade.
1921–1938 Annual Report of the Secretary of Mines; Mines Dept., Board of Trade.
1938–1949 Statistical Digest; Ministry of Fuel and Power.
1950–1980 United Kingdom Mineral Statistics, Institute of Geological Sciences.

Production by counties in England, Wales, Scotland and Northern Ireland, is shown in Table 12 for the years 1975 to 1980 (see also Figure 15). The predominance of the south-eastern region, arising from the brick operations of the London Brick Company, can be clearly seen. The table also illustrates the widespread occurrence of the building clays. In 1976, for example, only four counties and two Scottish regions are not represented as producers of clay and shale.

Figure 16 shows the end uses of common clay and shale in Great Britain for 1978. The manufacture of bricks, pipes and tiles predictably accounts for the major proportion of output, around 60% of the total, other uses including cement and lightweight aggregates about 15%, and other general constructional uses about 28% of the total.

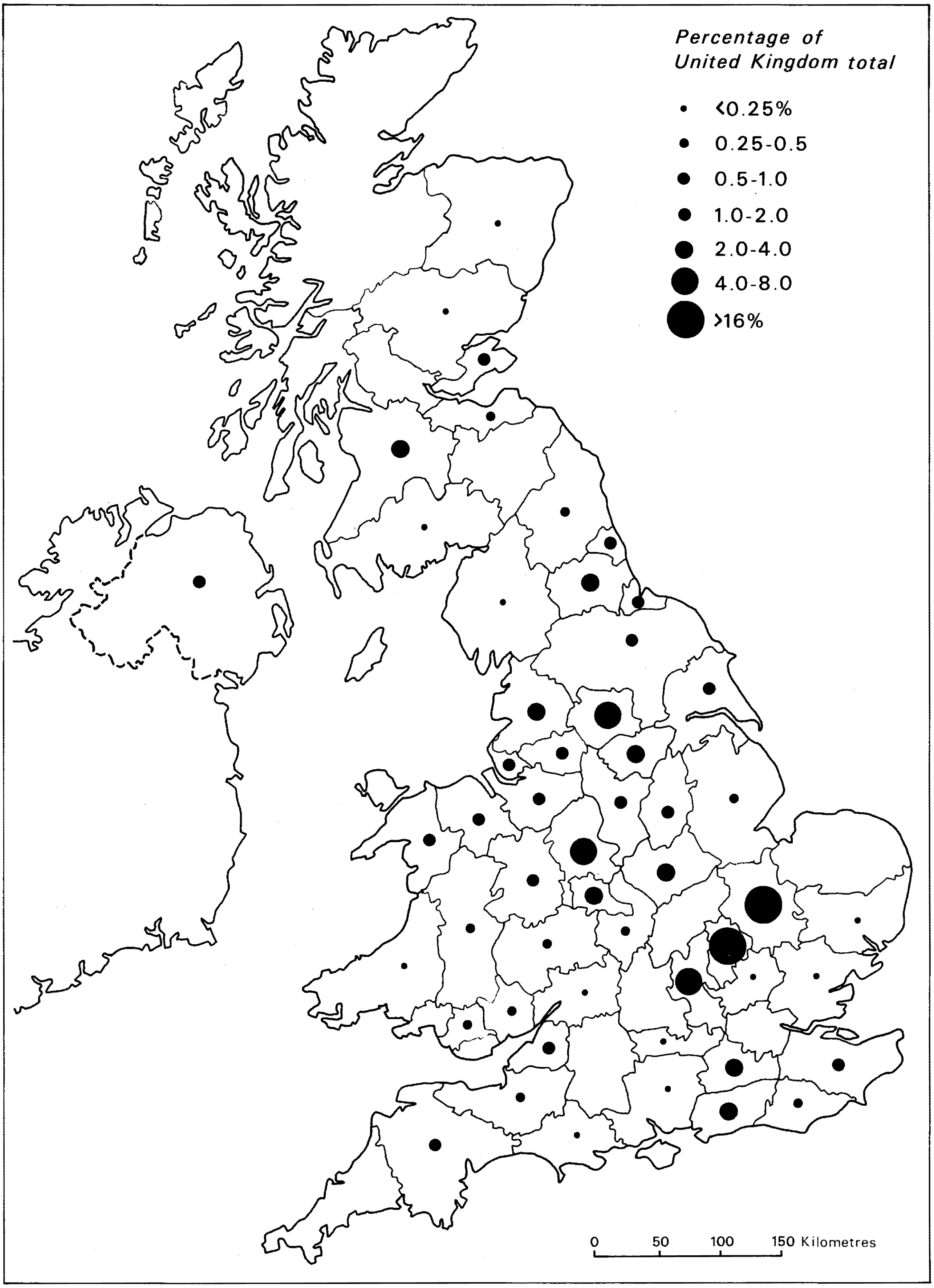


Figure 15 Importance of clay-shale extraction for brick, pipe and tile production in the United Kingdom, by county/Scottish region

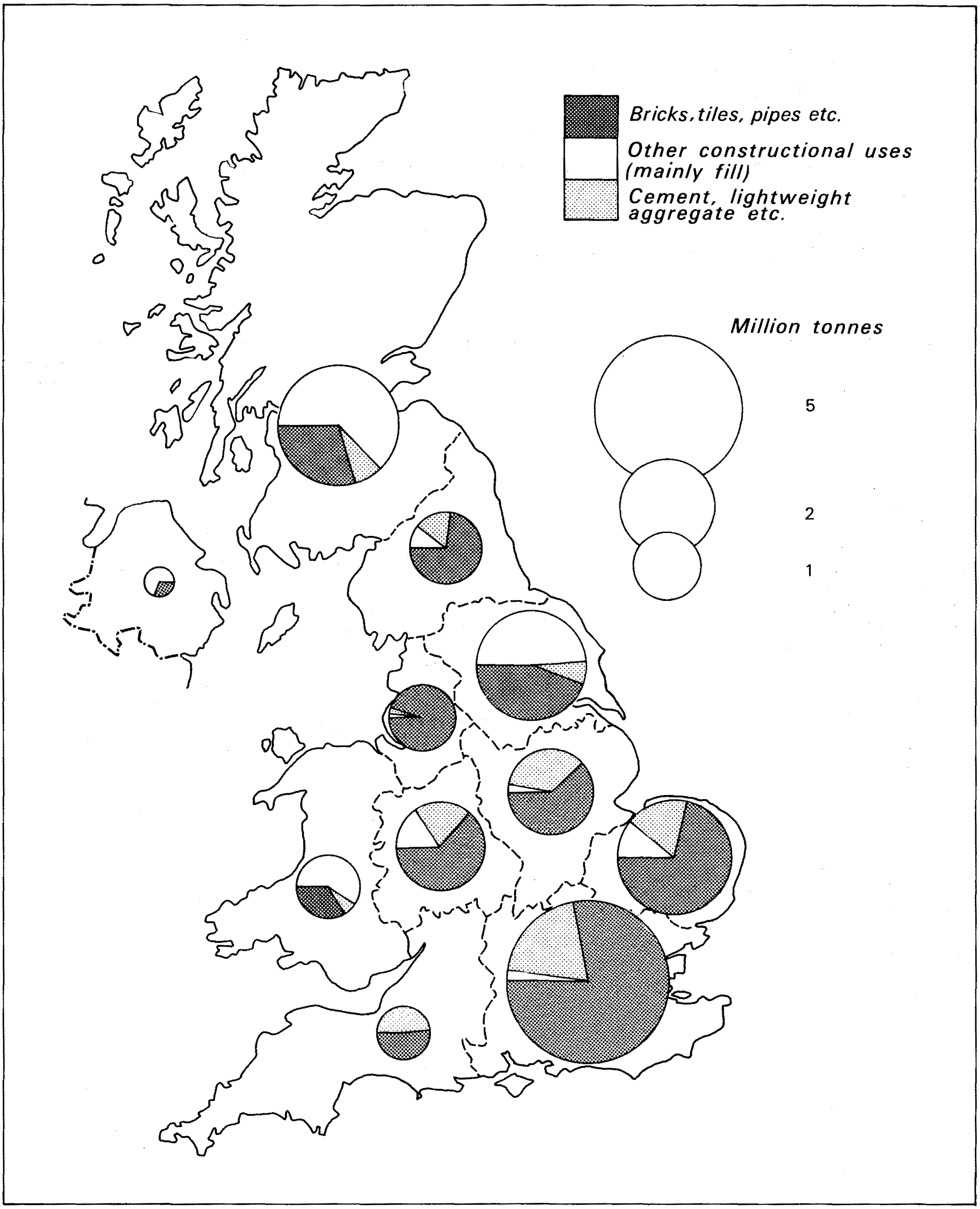


Figure 16 Production of common clay and shale by end use and by planning region

Production of clay products is shown in Tables 13 and 14. The regional distribution of production is illustrated in Table 15. The figures show *deliveries* of bricks by economic planning regions, but they are deliveries from brickworks situated in the region and not deliveries to consumers in each region. The percentage distribution in the regions has remained fairly static throughout the last 10 years.

Consumption

There are no official consumption statistics for heavy clays for Great Britain, but statistics for clay building bricks, tiles, pipes and other non-refractory clay products include home deliveries and stocks and provide a measure of consumption.

These are collected and published by the the Department of Environment in the following:

(i) Housing and Construction Statistics—Quarterly and Annual.
(ii) Monthly Statistics of Building Materials and Components.

Table 12 United Kingdom Production of common clay and shale by counties/Scottish regions. 1975–1979

Thousand tonnes

	1975	1976	1977	1978	1979
England					
Durham	986 (Durham, Cleveland)	844 (Durham, Cleveland)	613	614	540
Cleveland			162 (Cleveland, Cumbria)	149 (Cleveland, Cumbria)	172 (Cleveland, Cumbria)
Cumbria	130	21			
Northumberland	250	203	163	2,606 (Northumberland, Tyne and Wear)	59
Tyne and Wear	419	681	350		246
North Yorkshire	87	163	107	92	106
South Yorkshire	391	530	432	1,629	806
West Yorkshire	1,008	864	727	710	588
Humberside	295	360	1,598	236	238
Lincoln, Nottingham	357	385[1]	408	313	374[6]
Leicester	691	607	550	569	557
Derby	938	780	695	803	772
Greater Manchester	618 (Greater Manchester, Cheshire)	546 (Greater Manchester, Cheshire)	820 (Greater Manchester to Lancashire)	210 (Greater Manchester, Cheshire)	691 (Greater Manchester to Merseyside)
Cheshire					
Lancashire	361	504		560 (Lancashire, Merseyside)	
Merseyside	283	215	163		
Norfolk	—	—	—	—	—
Cambridge, Suffolk	3,116 (Cambridge, Suffolk, Kent)	3,518 (Cambridge, Suffolk, Kent)	3,174 (Cambridge, Suffolk, Kent)	3,155 (Cambridge, Suffolk, Kent)	2,382
Kent					753
Surrey	6,436 (Surrey to Berkshire)	7,353 (Surrey to West Sussex)	5,789[2] (Surrey to East Sussex)	313	296
Bedford, Buckingham				5,686[2] (Bedford to East Sussex)	5,431 (Bedford to East Sussex)
Hertford, Essex, Greater London					
Berkshire					
East Sussex	640 (East Sussex, West Sussex)				
West Sussex			568	591	555
Hampshire	12	16	18	18	11
Isle of Wight	—	—	—	—	—
Gloucester	46	591 (Gloucester, Avon, Wiltshire)	467 (Gloucester, Avon, Wiltshire)	45	38
Avon, Wiltshire	452			532[7] (Avon, Wiltshire to Devon, Dorset)	632[12] (Avon, Wiltshire to Devon, Dorset)
Somerset	234 (Somerset to Cornwall)	260 (Somerset, Devon, Dorset)	183 (Somerset, Devon, Dorset)		
Devon, Dorset					
Cornwall		—	—	—	—
Hereford and Worcester, Salop	135	136	168	161	429[13]
Stafford	1,481	1,199	946	999	939
Warwick	246	206	305	378	...[8]
West Midlands	991	438	413	396	346
Total	20,602	20,419	18,820	20,765	16,962
Wales					
Dyfed	1,359 (Dyfed to Clwyd)	189	327[3]	121[3]	52
Gwynedd		311 (Gwynedd, Clwyd)	424 (Gwynedd, Clwyd)	494[4] (Gwynedd, Clwyd)	489[3]
Clwyd					
Mid Glamorgan	1,227 (Mid Glamorgan to Gwent, Powys)	122	...	...	...(k)
West Glamorgan		680 (West Glamorgan, Gwent, Powys)	—	—	—
Gwent, Powys			169	...	139[9]
Total	2,586	1,302	920	615	680

Table 12 (cont'd) United Kingdom—Production of common clay and shale by counties/Scottish regions. 1975–1979

Thousand Tonnes

		1975	*1976*	*1977*	*1978*	*1979*
Scotland						
Grampian						11
Tayside		78	41	33	247[5]	...[10]
Central						270
Fife		221	210	253	246	315
Lothian		2,828	2,293	2,166	2,673	2,271[11]
Borders		—	—	—	...	
Strathclyde		1,229	1,547	1,057	927	1,056
Dumfries and Galloway						80
	Total	4,356	4,092	3,510	4,093	4,003
GREAT BRITAIN	Total	27,545	25,812	23,250	25,473	21,645
NORTHERN IRELAND	Total	249	265	295	...	...
UNITED KINGDOM	Total	27,794	26,077	23,545	...	...

Source: Business Statistics Office,

1 Excluding Lincoln
2 Excluding Greater London
3 Including Mid Glamorgan
4 Including Powys
5 Including Borders
6 Including Northampton
7 Of which 150,000 tonnes were produced in Avon
8 Included with Hereford and Worcester
9 Excluding Powys
10 Included with Lothian and Borders
11 Including Tayside
12 Of which 144,000 tonnes were produced in Avon
13 Excluding Shropshire

Table 13 Great Britain Production of bricks—all types 1960–1980

Millions

Year	*Total*	*of which*			*of which*		
	All types	*Commons*	*Facings*	*Engineering*	*Clay*	*Sand-lime*	*Concrete*
1960	7,283	4,659	2,321	302	6,902	223	158
1961	7,414	4,647	2,436	331	7,015	231	168
1962	7,289	4,595	2,397	297	6,923	207	159
1963	7,139	4,433	2,426	280	6,722	231	186
1964	7,954	4,641	2,989	324	7,358	320	275
1965	7,868	4,501	3,012	355	7,214	351	303
1966	7,072	4,087	2,649	337	6,519	288	265
1967	7,208	3,971	2,846	391	6,545	349	314
1968	7,465	4,074	3,010	381	6,799	346	319
1969	6,734	3,727	2,632	375	6,116	341	304
1970	6,062	3,127	2,554	381	5,515	283	263
1971	6,541	3,194	2,936	411	5,865	347	330
1972	6,938	3,242	3,282	414	6,121	407	413
1973	7,183	3,230	3,532	421	6,315	446	422
1974	5,575	2,753	2,452	388	4,975	316	284
1975	5,046	2,149	2,515	382	4,405	266	375
1976	5,406	2,119	2,877	411	4,740	271	389
1977	5,067	1,980	2,718	369	4,495	205	362
1978	4,842	1,816	2,689	336	4,253	204	383
1979	4,887	1,863	2,690	334	4,301	206	383
1980	4,562	1,591	2,605	366	4,107	151	304

Sources: 1960–1970 Annual Bulletin of Construction Statistics
1971–1980 Monthly Statistics of Building Materials and Components
Department of the Environment

Table 14 Great Britain Production of tiles, pipes and conduits 1960–1980

Year	*Roofing tiles*		*Unglazed tiles*		*Vitrified Clay Pipes and Conduits*	
	Clay	*Concrete*	*Quarry tiles*	*Other*	*Pipes*	*Conduits*
	Thousand square metres				*Thousand tonnes*	
1960	3,501	21,380	1,600	1,054	581	81
1961	3,145	21,853	1,570	993	601	118
1962	3,080	21,654	1,562	1,023	624	123
1963	2,916	20,228	1,502	939	620	99
1964	2,720	26,876	1,549	1,083	639	134
1965	1,810	27,521	1,545	1,130	670	139
1966	1,643	25,921	1,298	1,027	697	163
1967	1,551	27,446	1,356	1,023	779	147
1968	1,444	28,627	1,431	1,078	793	123
1969	1,132	25,867	1,616	1,263	727	103
1970	953	22,349	1,565	1,362	671	49
1971(a)	969	27,789	1,298	1,392	715	...
1972	1,151	30,144	1,259	1,528	750	...
1973	1,238	30,669	1,325	1,840	753	...
1974	1,195	27,359	1,241	1,096	...	...
1975	1,108	25,942	1,146	1,704	...	...
1976	1,170	29,839	1,019	1,769	...	...
1977	1,192	24,151	1,155	1,900	...	...
1978	1,207	27,899	1,273	2,025	...	...
1979	2,265	28,263	1,220	2,099	...	...
1980	2,420	28,813	1,230	...	...	...

Sources: Deptartment of the Environment 1960–1970
Business Statistics Office 1971–1980

(a) Inquiry on clay roofing tiles, quarry tiles and other unglazed tiles, vitrified clay pipes and conduits, was discontinued in mid 1971. All subsequent figures relate to sales of firms employing more than 25 persons as published in Business Monitor PQ 461.2 and Annual Abstract of Statistics.
... Not available.

They include details of the production, home deliveries and stocks of building bricks by raw material used i.e. clay, sandlime, concrete, by type of brick, i.e. commons, facings, and engineering bricks and similar details of production, home deliveries and stocks for roofing tiles, both clay and concrete, unglazed tiles and pipes and conduits.

The Business Monitors published by the Department of Industry, Business Statistics Office, also include quarterly and annual sales figures of clay products with details for building bricks, partition and flooring blocks, roofing tiles, and fittings, quarry tiles, field drain pipes and vitrified pipes and conduits, chimney terminals etc. The statistics relate to all establishments in Great Britain employing more than 25 persons classified to minimum list heading 461.2, 'Clay Building Bricks and other non-refractory goods'. The details from these sources are summarised in Tables 16 and 17.

Table 15 Great Britain: Deliveries of bricks from economic planning regions[1], 1969–1980

Millions

Economic Planning Region		*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*(2)(3)	*1976*	*1977*	*1978*	*1979*	*1980*
Northern		352	351	390	398	405	331	379	361	298	315	339	281
Yorkshire & Humberside		332	317	321	334	339	240	260	296	278	289	270	241
North West		556	502	563	618	600	384	395	418	391	398	379	315
East Midlands		381	414	445	438	422	306	414	375	326	374	364	311
West Midlands		445	438	441	409	409	331	349	335	299	281	313	307
East Anglia		914	882	959	999	1,048	766	757	777	646	773	737	510
South-east													
Greater London / Eastern counties		1,016	951	1,000	1,067	1,043	605	967	1,111	933	1,071	992	784
Southern counties		956	1,042	1,168	1,098	1,057	760	592	420	347	403	368	294
South east counties		414	424	499	515	485	374	409	442	398	390	392	371
South West		167	166	179	200	191	132	195	204	187	204	210	175
England	Total	5,533	5,487	5,964	6,078	5,999	4,229	4,722	4,739	4,166	4,498	4,364	3,589
Wales		228	231	243	252	259	192	196	167	149	172	156	133
Scotland		720	638	618	693	740	590	550	474	403	436	388	324
Great Britain	Total	6,481	6,356	6,825	7,023	6,998	5,011	5,468	5,380	4,718	5,107	4,909	4,046

(1) Deliveries of brickworks situated in each region.
(2) Figures from 1975 refer to the economic planning regions as defined by the Local authority reorganisation of 1st April 1974.
(3) Figures from 1975 include additional sites increasing figures of deliveries by:– Northern 6%, GLC & Eastern Counties 1%, South West 3%, West Midlands 3%, North West 2%, and Great Britain 1%.

Table 16 Great Britain Consumption (1) of bricks—all types 1960–1980

Millions

Year	*Total*	*of which*			*of which*		
	All types	*Commons*	*Facings*	*Engineering*	*Clay*	*Sand-lime*	*Concrete*
1960	7,232	4,623	2,307	302	6,857	222	153
1961	7,356	4,624	2,407	325	6,961	227	168
1962	7,075	4,483	2,309	284	6,720	202	153
1963	7,287	4,529	2,473	285	6,863	238	187
1964	8,098	4,706	3,055	337	7,500	320	278
1965	7,424	4,258	2,833	332	6,799	334	291
1966	6,729	3,943	2,467	318	6,184	274	271
1967	7,701	4,259	3,038	404	7,015	372	315
1968	7,221	3,958	2,886	377	6,572	334	315
1969	6,481	3,545	2,565	372	5,686	307	306
1970	6,356	3,334	2,631	391	5,784	299	274
1971	6,825	3,339	3,060	426	6,143	355	327
1972	7,022	3,275	3,330	419	6,210	408	407
1973	6,998	3,191	3,392	415	6,138	439	422
1974	5,011	2,406	2,256	350	4,432	296	283
1975	5,468	2,391	2,682	395	4,828	268	371
1976	5,380	2,138	2,836	406	4,716	276	388
1977	4,718	1,849	2,526	342	4,146	202	369
1978	5,107	1,957	2,799	351	4,512	207	389
1979	4,909	1,787	2,762	360	4,407	211	371
1980	4,046	1,423	2,299	324	3,599	149	299

Source: Department of the Environment
1960–1970 Annual Bulletin of Construction Statistics
1971–1980 Monthly Statistics of Building Materials and Components

(1) Home deliveries.

Consumption of heavy clays in the United Kingdom is almost entirely from domestic production; there is no known overseas trade in common clay and shale. Over the last 25 years, consumption has been between 20 and 40 million tonnes per annum with fluctuations in the annual total clearly reflecting the variable levels of activity in the construction industry, (See Figure 17). Production and consumption (home deliveries) of clay products also relates to the prosperity in the construction industry, though the general trend differs for some clay products. The steady decline in the use of clay roofing tiles in favour of cheaper and more durable concrete tiles has already been referred to. Similarly the output of common bricks has fallen from 4,335 million in 1950 to 1,591 million in 1980 with the increasing use of breeze block, plasterboard and other materials for internal walling. Total consumption of clay bricks has declined despite increasing use of facing and engineering bricks. The use of vitrified clay pipes and conduits has changed less markedly but production and home deliveries of quarry tiles have declined while the use of other unglazed tiles has increased. Stocks of bricks also fluctuate with demand from the construction industry, the increased stocks in 1966, 1969 and 1974 following sharp falls in the number of housing starts (Table 18 and Figure 17).

Table 17 Great Britain Consumption of tiles, pipes and conduits 1960–1980

Year	*Roofing Tiles*		*Unglazed Tiles*		*Vitrified Clay Pipes and Conduits*	
	Clay	*Concrete*	*Quarry*	*Other*	*Pipes*	*Conduits*
	Thousand square metres				*Thousand tonnes*	
1960	3,508	20,807	1,432	831	556	85
1961	3,297	21,698	1,390	806	584	114
1962	3,096	20,521	1,397	827	571	118
1963	2,654	20,601	1,277	767	576	100
1964	2,437	25,980	1,413	808	659	134
1965	2,005	26,006	1,344	825	638	144
1966	1,789	25,609	1,063	755	660	155
1967	1,596	27,345	1,115	798	782	150
1968	1,451	27,892	1,181	834	745	123
1969	1,307	24,584	1,219	911	646	101
1970	952	23,273	1,118	892	640	47
1971[1]	969	26,908	1,298	1,392	715	...
1972	1,151	28,255	1,259	1,528	750	...
1973	1,238	30,939	1,325	1,840	753	...
1974	1,195	25,214	1,241	1,906	...	...
1975	1,108	26,061	1,146	1,704	...	...
1976	1,170	27,454	1,019	1,769	...	...
1977	1,192	24,644	1,155	1,900	...	...
1978	1,207	26,868	1,273	2,025	...	...
1979	2,265	27,583	1,220	2,099	...	...
1980	2,420	25,921	1,230	...	...	...

Sources: Department of the Environment
Business Statistics Office

[1] Enquiry on clay roofing tiles, quarry and other unglazed tiles, vitrified clay pipes and conduits was discontinued in mid 1971. All subsequent figures relate to sales (including export sales) of firms employing more than 25 persons classified to SK. Minimum List Heading 461.2 Clay Building Bricks and other non-refractory goods.

... Not available.

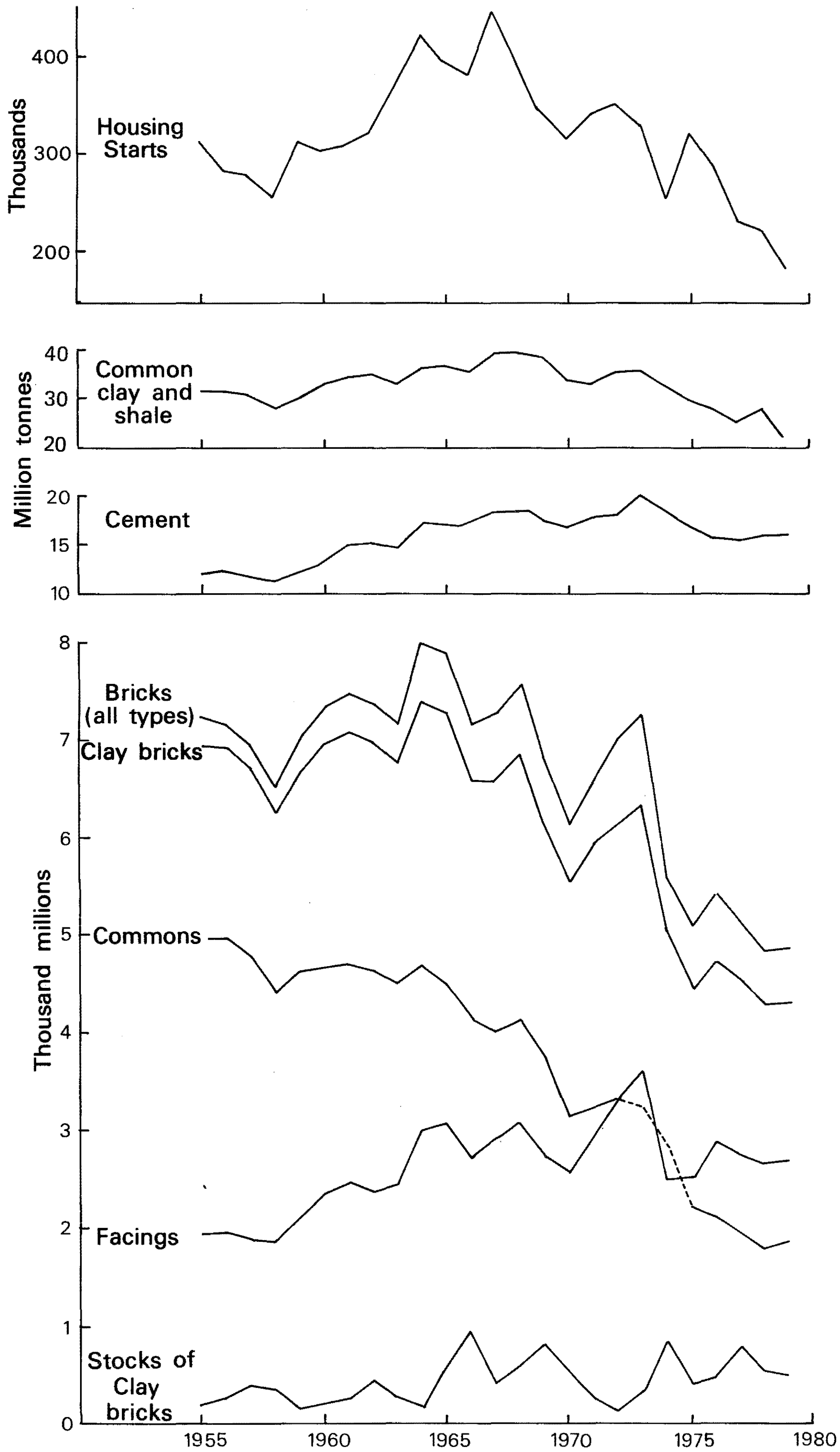


Figure 17 Production of clay and shale, bricks, cement and housing starts, 1955–1979

Table 18 Great Britain Stocks of bricks all types 1960–1980 *Millions*

Year	*Total all types*	*of which Commons*	*Facings*	*Engineering*	*of which Clay*	*Sand-lime*	*Concrete*
1960	160	97	54	8	141	3	16
1961	213	118	80	14	191	8	14
1962	422	230	169	23	396	13	13
1963	263	131	115	17	247	3	14
1964	115	63	48	4	100	3	12
1965	561	308	226	26	510	21	29
1966	905	455	407	44	846	36	24
1967	405	168	206	32	370	13	22
1968	635	290	310	36	583	25	27
1969	877	422	370	35	819	32	26
1970	575	271	279	26	540	19	16
1971	275	129	136	10	245	12	19
1972	180	90	84	6	143	12	25
1973	362	125	225	12	319	19	24
1974	925	452	423	51	861	40	24
1975	504	208	258	38	437	32	36
1976	528	188	295	46	460	26	43
1977	865	311	481	73	798	28	39
1978	588	172	359	57	535	25	28
1979	578	254	295	29	516	22	40
1980	1,075	437	582	56	1,015	15	45

Sources: Annual Bulletin of Construction Statistics
Monthly Statistics of Building Materials and Components

Overseas Trade

The United Kingdom trade in heavy clays, though not separately specified in the trade statistics, is believed to be minimal, and trade in clay products is not large, but in recent years there has been an export surplus, for example in 1979 exports earned some £15,061,000 (fob) compared with the cost of imports of £1,564,000 (cif). Exports of certain products such as quarry tiles and interlocking roofing tiles are increasing, namely to Belgium, Holland, West Germany and France.

The Standard International Trade Classification (SITC R2) and Customs Co-operation Council Nomenclature (CCCN) headings under which any United Kingdom trade in common clay and shale and clay products was recorded in 1979 are summarised below.

a. *Common clay and shale* is not separately specified in the UK trade classification, but any such material which is traded would be classified under the SITC (R2) heading 278.21: "Clay (for example kaolin and bentonite), and andalusite, kyanite and sillimanite, whether or not calcined, but not including expanded clays falling within 663.5; mullite; chamotte and dinas earths". Under this description common clay and shale would probably be classified into the CCCN code 2507. 8099.

b. Trade in unglazed clay products—bricks, tiles, pipes etc. is recorded under the SITC (R2) heading 662.4. The main subdivisions in the CCCN classification are:

   6904 Building bricks etc.
   6905 Roofing tiles, chimney pots, cowls, etc.
   6906 Ceramic piping, conduits and guttering.
   6907 Unglazed ceramic setts, flags and paving and wall tiles.

Table 19 Imports and Exports of clay building bricks and other non-refractory goods 1975–1979

Tonnes

Description	1975 Imports	1975 Exports	1976 Imports	1976 Exports	1977 Imports	1977 Exports	1978 Imports	1978 Exports	1979 Imports	1979 Exports
Building bricks:										
of common pottery	178	1,600	539	4,238	953	27,163	768	66,331	1,582	59,874
other	6,457	12,215	2,144	6,592	92	3,302	133	5,656	67	1,832
Roofing tiles:										
of common pottery	222	161	683	1,820	575	14,241	468	18,820	998	14,192
other	282	2,311	273	1,026	92*	245*	79*	133*	49^x	91*
Pipes, conduits and guttering:										
of common pottery	10	5,306	138	260	62	338	0	—	—	3
other	87	5,226	411	15,327	912	36,872	851	27,230	184	39,440
Unglazed setts, flags and tiles:										
of common pottery	392	13,301	261	6,992	188	181	101	—	—	—
other	5,070	21,353	3,881	32,964	4,169	45,562	3,803	52,699	5,532	48,960
Other constructional goods:	52	441	79	267	92*	245*	79*	133*	49*	91*
Total value £.stg.	£ 1,078,000	£ 4,496,000	£ 937,000	£ 6,094,000	£ 1,209,000	£ 11,655,000	£ 1,158,000	£ 13,522,000	£ 1,564,000	£ 15,061,000

(* categories grouped together)
Source: H.M. Customs & Excise

For full details of the UK classification, code numbers, and descriptions see 'Guide to the Classification for Overseas Trade Statistics 1980' and/or H.M. Customs and Excise 'Tariff & Overseas Trade Classification in the United Kingdom of Great Britain and Northern Ireland'.

Imports and exports of clay products for the years 1975 to 1979 are shown in Table 19. Imports are small, seldom exceeding £1–1.5 million in value and come predominantly from neighbouring EEC countries. Exports are larger but, despite signs of rising exports in the last three years seldom exceed 1% of domestic production. The exception is exports of unglazed setts, flags and tiles, which apparently exceed domestic consumption. The export headings however include items not included in the production inquiry, but clearly a substantial proportion of the production of unglazed quarry tiles, and other setts, flags etc. are exported, though the bulk of the exports is of tiles etc., other than of common pottery. The common market countries still take a major proportion of the exports of bricks, roofing tiles and other constructional goods, but Saudi Arabia and the Gulf States are the major markets for pipes and conduits, and over 60% of exports of unglazed setts, flags and tiles are destined for Australia, Canada and the USA.

INDUSTRY

The structural clay products industry in the United Kingdom comprises some 90 companies engaged in winning clays and shales for the production of brick and tile at about 200 works. About twenty companies manufacture clay roofing tiles or quarry tiles and at least twenty-five firms produce engineering bricks. A further twelve or so companies manufacture clay pipes (evenly split between those who produce porous land drains and those whose speciality is impermeable vitrified pipes).

As recently as 1939 there were 1,316 brickworks in Britain served by over 1300 clay pits; nearly one third of these used Coal Measures shales, one third used recent alluvial and brickearth material and most of the remainder Jurassic and Cretaceous clays. The production capacity of the Oxford Clay was 2,606 million out of a total of 8,429 million bricks per year, so the trend towards the dominance of this deposit was already well established. By 1971 the Oxford Clay brickworks contributed a large proportion of national output of bricks distributed throughout the country. The total number of works at the end of 1970 was 360, a drop of about 72% from 1939; 107 works closed in the three years ending December 1969. There was an overall diminishing demand for bricks in the late nineteen-sixties and early nineteen-seventies which, coupled with the particular cost advantages of the Oxford Clay, accelerated the reduction in the number of works. The trend recently has been towards fewer, larger, capital-intensive producing units, serving much larger market areas. Also, some companies have broadened their base by diversifying into various non-brick interests, such as concrete tiles, waste disposal and light and dense aggregate.

Today, the industry is still extremely diffuse and a wide variety of geological horizons and production methods are used. London Brick Company, however, accounts for about 40% of total brick production (clay, calcium-silicate and concrete) and another eleven companies each have between one and ten per cent of total production (Armitage, Butterley, Crossley, Downing, Steetley Brick, Ibstock, Ockley, Redland, Ryarsh (CS), Scottish Brick Corporation, West-brick). The twelve major companies between them account for 75% of total brick production, with the remaining eighty or so companies representing less than one per cent each.

The use of Carboniferous shales for brickmaking, often despite their poor suitability, arose partly from favourable supply and demand conditions in certain parts of the country. Traditionally, many brickmaking companies concentrated in the coal field areas; there was a relatively cheap and steady source of both raw material, either blaes, in-situ shales or fireclays, and energy (coal). The demand for both refractory and building bricks was great in these mining areas due to the concentration of heavy industry and the consequent influx of population during and since the Industrial Revolution.

London Brick Company, Britain's largest brick manufacturer, was incorporated in 1900. It currently operates fourteen Fletton and three non-Fletton works in the southeast of England producing about 50% of total United Kingdom clay brick production, as well as land drains and hollow clay blocks. Production capacity is about sixty million bricks—enough to build about 5,000 houses—per week, as well as 1.6 million land drains. The Stewartby complex near Bedford is currently the Company's largest plant with a capacity to produce some 13 million Fletton bricks per week. Other London Brick Company works are situated in Bedfordshire, Buckinghamshire, Cambridgeshire and Surrey.

The name Fletton derives from a village near Peterborough where this type of brick was first made in 1881; from its earliest days the Fletton brick was produced for national construction projects—the early Fletton brickworks were built along the Great Northern Railway, and were used primarily for what was then known as "the Metropolis". Upon the initiative of several smaller brick companies in the area (together representing about 30% of Fletton production) London Brick Company acquired further Fletton operations—the Marston Valley Brick Company Ltd in 1968, Redland Ltd's Fletton brickworks in 1971, and Whittlesea Central Brick Co Ltd in 1973. Thus by 1974, London Brick Company was the only producer of Fletton brick with 22 works in the Peterborough, Bedford and Bletchley areas. Eight of these works were however closed or put on a care and maintenance basis due to the severe reduction in demand experienced that year. The Monopolies and Mergers Commission decided in 1976 that the monopoly conditions prevailing in the United Kingdom with regard to the supply of building bricks were not against the public interest.

All but two of London Brick Company's works date from before the last World War, but major and continuing expenditure has been incurred since the end of the war on the modernisation and mechanisation of all existing and acquired Fletton brickworks. The 'new generation' works built since 1968 are the Kings Dyke works and the New Saxon works at Whittlesey, near Peterborough. The 'New Works' plan will result in the replacement of existing works representing about half of London Brick's current production capacity. All Fletton kilns are of the transverse arch Hoffmann continuous chamber type, built of about 11 million of the company's own bricks, although the Weald Clay works near Horsham, Sussex, has a modern tunnel kiln. The Hot Air System Hoffmann Kiln can be more energy efficient than the modern tunnel kiln, especially when Fletton clay is being fired, since this clay supplies substantial amounts of fuel. Brick distribution to all part of Britain is carried out either by the Company's fleet of lorries equipped with patented 'Strapack' unloading facilities or by private road hauliers. The bulk of rail dispatches are made up into 'Fletliner' trains for delivery to the Company's depots at King's Cross, Manchester and Liverpool. The Stewartby complex includes comprehensive research facilities where studies of the properties of clays from the company's deposits and of samples from overseas are carried out. The company has an important engineering and foundry division and much of the brickmaking machinery is designed and manufactured 'in house'. While brickmaking is its main concern, London Brick Company has diversified in an attempt to provide a hedge against the vagaries of house building fluctuation. Thus the London Brick Group includes waste disposal (London Brick Landfill Ltd) and domestic, industrial, garden and leisure construction subsidiaries (London Brick Buildings Ltd), as well as other companies involved in, for example, rubber and plastic household accessories and structural, sheet-metal or engineering work. The Group's overseas ventures include Ajor Iran Press in Iran, designed by LBC on the Kings Dyke and Saxon model to produce 145 million bricks per year. Otherwise, overseas involvement is concerned with the supply of construction and engineering products and services.

Redland Brick Ltd accounts for about 4% of clay building brick production and operates some fourteen brickworks in the southeast of England. The Surrey-Sussex works utilize a large amount of Weald Clay and also Tunbridge Wells Sand, Wadhurst Clay and Ashdown Beds material. The Kent stock brickworks use brickearth, and Redland is the largest user of this material for brick manufacture. A wide variety of quality facing and stock bricks are produced by various methods including soft-mud hand and machine moulding, wire-cut extrusion and pressing. Redland was the first company to introduce a fully mechanised 'hand-made' facing brick production line at its Beare Green works. The resultant brick is a simulated hand-thrown facing called 'Wealdmade'. Redland Brick Ltd is part of Redland Limited, a large organisation with a wide base providing materials and services to the construction industry in many countries of the world. The company has operations in the form of subsidiary companies in the Federal Republic of Germany, Netherlands, Belgium, Austria, Australasia and the USA and associate companies in France, Switzerland, Sweden, Italy and South Africa; these cover a wide range of fields, mainly in building products and engineering, and account for a substantial part of the organisation's turnover. Redland Limited's diverse interests include concrete and plastic pipes, aggregates, ready mixed concrete, road surfacing materials and services, concrete roofing tiles (they are responsible for the majority of UK concrete roofing and cladding tile output) and other building products as well as a waste disposal subsidiary. Redland Brick Limited's new works at Bexhill-on-Sea, produces multi-stock bricks at a rate of 25 million per year.

Butterley Building Materials Ltd, is one of Britain's major manufacturers of facing and engineering quality brick with a weekly output capacity in excess of 8 million at 13 production units in the Midlands and north and south Wales. Some of the works were originally operated by the National Coal Board, and most are thoroughly modernised. Tunnel kilns are used throughout and brickmaking technology, research and development are studied at comprehensive laboratories. Butterley's range of products includes quality facings of some 60 colours and textures, specials, pavoirs and engineering bricks, handmade briquettes and refractory shapes as well as Aglite lightweight clay aggregate and lightweight refractory aggregate. 45% of production is from the 'Keuper Marl', but Coal Measures shales are also widely used as well as some Devonian marl, and Ordovician and Silurian shales. Subtle shades are achieved by using north Wales fireclays, while cream bricks similar to the old Gault brick are produced from cream-firing 'Keuper Marl'. Coal Measure shales from old ironstone dumps are used with NCB fireclay in south Wales to produce buff bricks. Brick delivery is effected by the Company's fleet of lorries equipped with mechanical off-loading ('Stackpack' system). Butterley exports its products to many parts of mainland Europe, Ireland, the Middle East and South Africa.

Ibstock Building Products Ltd comprises seven brickmaking subsidiaries operating eleven factories in the Midlands, north of England, southeastern England and Avon areas. They produce some fifty colours and textures of facing and engineering brick, pavers and specials from the Coal Measures, the Etruria and 'Keuper' marls, Wadhurst Clay, Weald Clay and Gault Clay. The bricks are predominantly wire-cut, but a sizeable proportion of hand-thrown bricks is also manufactured, as well as soft-mud pressed clamp-fired bricks in the Weald.

Modern tunnel kilns are almost ubiquitous. Total brick production is in the order of 250 million per year with an additional 2 million pavers.

Crossley Building Products Ltd (Bowater Group) operate five brickworks, one of which also produces tiles, in the northeast of England. The company produces facing bricks in a variety of colours and textures, engineering bricks and high class, frost resistant, interlocking clay roofing tiles. Crossleys are the only manufacturer of these tiles in the UK and have considerable export outlets in Belgium, Holland, West Germany and Denmark. They are probably the biggest users of superficial clays in Britain (boulder clay, glacial lake clays etc.) and until recently operated the sole works in Kimmeridge Clay. Engineering bricks are manufactured from Coal Measures shales.

G. H. Downing and Co Ltd manufacture facing, engineering and common clay bricks as well as ridge tiles, flat roofing tiles, specials and refractories. They are the largest users of Etruria Marl in north Staffordshire though about one sixth of their production is from Coal Measures shales and fireclays.The five building brick and tile factories are situated in Staffordshire, and total production is currently about 86 million bricks and 45 million tiles per annum. Wirecut extrusion and tunnel or chambered kiln firing are employed.

The *Gibbons Dudley Group now Steetley Brick* comprises five brick manufacturing subsidiaries in its Building Products Division:

Gibbons Northern Brick Ltd., Newcastle-upon-Tyne,
Henry Foster Bricks Ltd., Bishop Auckland, Co. Durham,
Ravenhead Brick Co Ltd., Skelmersdale, Lancs.,
Wm. Thomas (Wellington Bricks) Ltd., Wellington, Somerset and
United Fireclay Products Ltd, at Armadale, Bathgate, Scotland.

Expansion into the building brick industry took place in 1971 with the acquisition of U.F.P. Ltd., and Gibbons Northern Brick from the National Coal Board in 1973, and then in 1974 Henry Foster Building Products Ltd. at Bishop Auckland. Gibbons Northern Brick operates 3 works, 2 adjacent works in Tyne & Wear using Coal Measure shales from various quarries, plus fireclay from NCB opencast sites. This company is probably the largest user of fireclay in the building brick industry and produces a comprehensive range of facing bricks, containing varying ratios of shale and fireclay. Henry Foster Bricks and Ravenhead also use Coal Measures shales and fireclays; Wm. Thomas uses 'Keuper Marl' and U.F.P. Ltd. uses colliery shale from old tips. One small works in Northumberland belonging to Gibbons Northern Brick and the works of the U.F.P. Ltd. makes Commons from waste colliery shale, but the majority of the brick production of Gibbons Dudley Ltd. are high quality facing and engineering Bricks made in modern tunnel kiln factories, by wirecut extrusion or stiff-plastic pressing. The annual production of all the works together is approximately 250 million bricks.

The *Scottish Brick Corporation Ltd.*, owned jointly by the National Coal Board and Tilling Construction, is the largest building brick producer in Scotland. Until comparatively recently the company operated about 25 brickworks, but closures in line with rationalization of the industry have reduced the number to 13 producing works. All these units are located within the Midland Valley of Scotland from east of Edinburgh to Ayrshire, and all are based on the use of Carboniferous blaes, either virgin or bing material. The use of virgin blaes is steadily increasing and to meet the demand for locally made facing bricks in Scotland, Scottish Brick opened a modern wirecut extrusion facing brick production line with new chambered continuous kilns just outside Glasgow. Other Corporation factories produce common and engineering bricks.

The remainder of the brick industry comprises a large number of small or moderately sized and mainly private companies serving more local requirements or providing specialist products. Approximately 80% of United Kingdom brick makers are members of the Brick Development Association which collates production data and generally promotes the products.

Calcium-silicate and concrete account for approximately 10% of current United Kingdom brick production, and the largest company concerned, having 4% of the market, is *Ryarsh Brick Co.* at West Malling, Kent.

There are approximately twelve companies which manufacture clayware land drains in the United Kingdom, from Aberdeenshire in the north to Cambridgeshire in the south. The majority also produce clay building bricks and are members of the *British Clayware Land Drain Industry,* which exists to promote and advise on its members' products. A variety of geological horizons are dug for clayware land drain manufacture, the commonest being superficial clays and Coal Measures shales in Scotland and the north of England, and Oxford Clay and Gault Clay in the south. London Brick Company is an important supplier of clayware land drains and plans to replace its existing plant at Arlesey, Bedfordshire with a new pipe works, having a capacity of 120,000 tonnes per annum. Larger diameter pipes are produced at the company's plant at Warboys, Cambridgeshire.

A major proportion of British vitrified clay pipe production is accounted for by the *Hepworth Group* of companies. The only significant other producer is *Naylor Brothers (Clayware) Ltd.* Important centres for these pipes exist in south and west Yorkshire, and in the Swadlingcote–Woodville area of the south Derbyshire coalfield. Starting as a brick producer at the turn of the century, Hepworth Iron Co Ltd is now the world's largest single producer of vitrified clay pipes and cable conduits. The Hepworth Iron name originated from the company's early interest in iron ore mining prior to brick production. Hepworth started producing cable conduits after the last world war and about 15 years ago went into sanitary pipes. Production today centres on three locations; at Hazlehead, near Sheffield, seven plants are grouped in one unit; five plants are situated within an eight km radius near Burton-upon-Trent and two are in Lancashire.

A number of medium sized firms produce clay floor (and sometimes wall) tiles from a variety of British common clays and shales; products include thick quarry tiles, thinner unglazed earthenware tiles and acid-resisting varieties. Some of the companies, e.g. *Hawkins Tiles (Cannock) Ltd,* combine floor tile production with roofing tile and brick manufacture, while others, e.g. *Dennis Ruabon Ltd,* concentrate on the floor sector. The vast majority of quarry tile and unglazed floor tile manufacturers are concentrated around the Stoke-on-Trent area where the Staffordshire Etruria Marl is used to produce a very dense, hard wearing and highly resistant flooring product. The equivalent Ruabon Marl is utilized by Dennis Ruabon Limited near Wrexham.

ECONOMIC FACTORS

Common clay and shale are used captively and are seldom traded on the open market; therefore, unlike ball clay or china clay, there are no market prices as such for this raw material. All the products of the heavy clay industry are value added products, that is to say, the cost of processing forms a far greater proportion of the final cost than does the mining of the raw material. The proportion of the price which is represented by the raw material increases only when higher quality material such as fireclay is added to the mix or when expensive body pigments and surface sandings are used. In the former case, even this additional cost can be reduced if the fireclay is obtained as a by-product of opencast coal mining as, for example, in Northumberland, where the National Coal Board agents' fee for fireclay was about £2 per tonne ex-site in 1977.

The 1979 cost of extraction of clay or shale was in the region of 60p per tonne and any additional raw material cost to the brick maker is largely for transport and perhaps the cost of stockpiling. In Scotland 60p per tonne for blaes transported 22 km or so was average.

As clay building products are made from a wide variety of clay materials by numerous production methods, production costs vary greatly and there is no agreed producer price for specific categories of product. However, the prices quoted by manufacturers employing similar methods and raw materials tend to fall within certain broad limits. The average works cost of producing 1,000 good quality wirecut facing bricks must include at least £16 fuel costs (1980); the ex-works price covers the works cost plus administration, sales, advertising, and other factors. The cost of the raw material, assuming it is dug from a pit adjacent to the works, is about £3 per 1,000 bricks, which represents only 5% to 6% of the works cost and 2% to 3% of the ex-works price. In Scotland the cost of producing 1000 common bricks in 1980 was about £30.

The other non-processing costs which may greatly affect product price are for transport. About 10p per tonne-mile is usual for short hauls. Haulage of more than 12 km or so from quarry to works is avoided where possible, although some companies, for example those using fireclay additives in their building bricks, are willing to transport this material greater distances. Longer haulage may also be involved when a company closes a works but continues to use the adjacent quarry, transporting the dug clay to an operational works some distance away.

The greatest part of the value-added cost of clay products is made up of energy costs (with the exception of Fletton production) and wages, with capital costs, depreciation of machinery, packaging and sales promotion adding a further proportion.

Energy costs refer only to energy consumed directly in the production process, but total combined energy costs for the industry as a whole would need to include figures for extraction (quarrying), transport and handling of the raw clay and of the end product. The largest proportion of energy used in the heavy clay industry is for drying and firing, and of the remainder the highest single item is electricity to power, for example, grinding and forming machinery. The amount of fuel needed to fire a brick depends on various factors not the least of which is the original fuel or carbonaceous content of the raw clay. The Fletton sector dry press Lower Oxford Clay which contains 75% of the total fuel requirement to fire the bricks; additional energy requirements are supplied by low grade coal, and therefore, the energy cost of the dry press Lower Oxford Clay bricks is low. In addition, they do not require separate drying and their bulk density after firing is less than that of other clay bricks. For example, there are approximately 400 Flettons per tonne compared to 320 to 390 non-Flettons, a factor contributing to lower transport costs for Flettons. Clays from other geological horizons have variable fuel contents, ranging from highly carbonaceous Coal Measures shales to low carbon-content oxidised marls. Only 18 therms of fuel are required per tonne of red commons made from Coal Measures shales or blaes, but 80 to 90 therms per tonne are required to fire buff, fireclay-based facing bricks. The type of kiln used also affects the amount of energy consumed. Tunnel or continuous kilns, for example, tend to give better energy utilization than intermittent kilns or clamp firing.

Until the 1950's coal was used as the main firing agent in the heavy clay ware industry, (in 1947 1.8 Mt of coal were used). Many of the brickworks were situated in or adjacent to coalfields and coal was relatively cheap. With the increasing availability of heavy fuel oil and increasing labour costs, the industry turned away from ash-producing solid fuel. The heavy clay sector's energy requirements are currently about 1.35 Mt coal equivalent per annum, of which 90% is used for drying and firing. The industry uses 17.5% of its energy as coal (equivalent to 235,000 tonnes per annum): natural gas supplies 31.4%, L.P.G. 43%, fuel oil 4.1% and electricity 4.0% (Tate 1979). Recently there has been a swing to L.P.G. (liquified petroleum gas, butane or propane) and natural gas from the North Sea. These fuels are clean, easily controlled, permit even greater firing precision and can be used to bring up the preheat. However, with continued increase in oil prices there may be a renewed interest in the direct or indirect use of coal as an energy source in the brick industry.

Modern automated brick factories now include tunnel kilns, top or side-fired by oil, LPG or natural gas. Dual fuel type burners using oil and LPG or oil and natural gas are also common, and all factories have backup fuel systems in the event of supply stoppages. Impulse burners are used with heavy fuel oil for top-fired tunnel kilns and side-fired kilns use atomizing high-velocity oil burners. The use of natural gas in top-fired kilns involves a ring main on the kiln top with air induction burners. Natural gas is also suited to intermittent kilns with one burner per fire-hole.

An interesting use of an indigenous and relatively cheap fuel supply in the ceramic industry is provided by the case of a quarry tile works in north Wales. Here, methane gas seeping naturally from the coal face of a nearby colliery, is drawn off and piped to the clay works, where it is used in the dryers and to fire both intermittent down-draft beehive kilns and a modern tunnel kiln. The supply has to be augmented by butane, since the methane has a low thermal value, but firing costs are kept low and the colliery benefits from increased revenue. Similar schemes using colliery methane to supply brickworks operate in the Stoke on Trent area and in Yorkshire.

The British Ceramic Research Association (West 1976) has carried out surveys which suggest that energy consumption in the heavy clay industry compares very favourably with other ceramic sectors and with other bulk mineral processing industries, and that the modern tunnel kiln plant can be very efficient as can the transverse arch Hoffman kiln used in the Fletton process with heat recycling from the cooling to the drying clay ware. Such procedures as reducing the amount of water in the making process, using 'waste heat' from the kiln to dry green bricks, better kiln insulation and speeding up kiln throughput all help to reduce energy consumption.

The finished products of the heavy clay industry are generally transported to the market areas by road; efficient self-loading lorries have been widely introduced which take full advantage of modern strapping, shrink-wrapping and handling methods. Despite the large increases in cost, the advantages of using road transport, particularly its flexibility, have led to a decline in the number of bricks carried by rail.

The economic market radius for the finished product varies considerably, generally with the scale of production, from a few tens of miles in the case of small non-mechanised brick yards to hundreds of miles for the largest producers. Most manufacturers have a scale of charges for brick transport and these reflect the cost of transport for a product with a high weight/value ratio. Sometimes the product may be in great demand or is sufficiently unusual to have a wider than normal market radius e.g. English facing bricks in Scotland, or fireplace brickettes in England whose greater profit margin enables them to be economically hauled further afield.

All the Fletton works are in close proximity to major railways, and are suitably located close to main roads, a factor which has helped their growth considerably. On the other hand the high cost of transport has enabled some smaller works in thinly populated areas to continue operating.

The popularity of bricks from the smaller works stems from their uniqueness and they are usually used locally where they blend well with existing buildings and preserve local character. However, architects sometimes specify bricks produced by small companies at some distance from the building site because of their particular appeal.

Up to date prices for a variety of construction materials including clay bricks, pipe, tile and block, are published each month in the 'current prices' section of the periodical "Building", or alternatively annually in Spon's Architect's and Builder's Price Book.

DEMAND TRENDS AND OUTLOOK

As most clay is used in the production of bricks and other building materials, output is directly related to construction activity. Apart from the two World Wars, when clay and shale production declined significantly, demand has been directly related to national economic growth, showing a general rise between 1900 and 1938.

The marked increase from 1946 to 1953 was largely attributable to large-scale house building, particularly in the public sector. Since 1946 increasing proportions of clay products have been used in house construction so that there has been a general tendency for house starts, clay brick production and clay and shale output to show similar fluctuations (Fig. 17). These may in turn be traced to the level of Government spending and its construction policies, bank rates, the availability of mortgages and credit and even weather conditions affecting clay extraction and building. Figures for cement production and clay output also show close correlation. In the medium and longer term, population trends, architectural preferences, changing building techniques and the use of alternative materials influence demand.

Since 1945 the pattern of brick production and demand has changed. There has been a steady increase in facing brick production, a rise in demand for engineering bricks, but a decline in commons. These facts have manifested themselves in the increased use of facing bricks on external walls and in a decreased use of commons in internal leaves and partitions.

There is a small but increasing use of lightweight aggregate blocks and panels, and although those produced from expanded clay are not differentiated in statistics, it is understood that output is rising in line with the general trend. Clay roofing tile manufacturers have experienced a marked decline in domestic demand over the past few decades, largely as result of competition from concrete, though exports to EEC countries have increased. There are now signs however of an increased demand generally. Unglazed vitrified clay pipe has largely replaced the salt-glazed variety and within certain diameter ranges demand is almost static. Electricity Board expenditures influence the number of clay cable conduit covers used.

There has always been some incentive in the construction industry to change from brick to less labour-intensive building units such as blocks and prefabricated concrete panels, and it was feared that demand for brick would not keep pace with other types of construction materials. However there has been a general return in recent years to rationalised traditional brick building as a result of revised safety factors, the increasing social resistance to high rise buildings, an improved knowledge of the load-bearing properties of bricks and the aesthetic appeal of the vast range of facings and specials now available. However, for inner leaf work and internal partitions common brick has been largely replaced by larger, lighter building blocks or lightweight panels.

Brickmakers in the United Kingdom, in common with other building material suppliers, have experienced a recession due to cutbacks in the building programme. This state of affairs has lasted for six years with little sign of improvement and the housing programme is now at its lowest ebb since the war. Inevitably this has led to a loss of brickmaking capacity. The cutback in housing is of particular significance to brickmakers since some two-thirds of their products go into housing and average brick deliveries have dropped from approximately 7,000 million bricks per annum to about 5,000 million.

On the other hand the industry has continued to invest in modern plant and machinery and its factories are now highly efficient. A large number of inefficient yards employing unproductive or labour-intensive equipment have closed in the last five to ten years, and production has concentrated at a smaller number of modern plants. The industry would therefore be able to accept a slow steady rise in trade but, like other material producers, would find it difficult to accept a sudden large surge in demand beyond current capacities and despite large stocks.

In any continuous process industry plant has to be run at or near full capacity. Whilst small changes of output are possible, long lead times are required to bring new works on stream. The whole construction industry is one that needs a strong steady demand, yet paradoxically it is one of those most affected by changes in policies. Wide fluctuation in construction activity inevitably causes problems of over or under supply for building material producers, and accurate forecasting of demand is essential.

There do not appear to have been any long term forecasts of the future demand for the raw materials of the brick and tile industry. Short term forecasts of brick demand are made by the Brick Development Association which also keeps up to date with production, deliveries, stock, production capacity and usage of bricks. These demand forecasts are related to forecasts of construction activity made by a number of bodies, chief amongst which are the National Council of Building Material Producers, the National Economic Development Office and the Department of the Environment.

It is clear that highly mechanised means of brick and tile production are essential if building costs are to be contained within reasonable limits, but there is evidence that there will always be a demand for the more individualistic appearance of hand-made bricks. The trend towards mechanisation of production of bricks with a handmade appearance shows signs of continuing, as will the decline in usage of rendered common bricks for exterior use in Scotland.

Appendix I

Representative Chemical Analyses
(Weight per cent basis)

The following selected chemical analyses have been taken, as far as possible, from samples of raw material used in the manufacture of certain heavy clay products. In many cases the analyses have been provided by manufacturers and are of representative grab samples; in some cases analyses of the blended clay fed to the production line are shown.

Ordovician

	1	2
SiO_2	56.27	49.66
Al_2O_3	22.29	26.90
Fe_2O_3	0.64	10.24
FeO	7.12	
MgO	2.11	1.88
CaO	0.39	0.26
Na_2O	0.79	0.76
K_2O	3.16	3.00
H_2O	5.60	
TiO_2	1.05	
P_2O_5	0.18	
MnO	0.23	
S	tr	
BaO	0.06	
C	0.27	

Sources:

1 Grey-green to blue-black Blake Fell Mudstones of the Skiddaw Slates in Cumbria (average).

2 Butterley Building Materials Ltd., Caernarvon works, Ordovician shale used to produce wirecut red facing bricks.

Devonian

	1	2	3
SiO_2	59.6	54.26	66.0
Al_2O_3	19.9	16.82	20.0
Fe_2O_3	11.4	7.54	5.0
TiO_2	1.2	0.32	1.0
CaO	0.2	2.46	n.d.
MgO	1.2	2.94	1.0
Na_2O	1.0	0.68	1.0
K_2O	4.2	3.50	5.0
SO_3	0.1	n.d.	n.d.
Loss on Ignition	0.5	11.46	n.d.

Sources:

1 W. E. Worrall 1964. Inst. of Ceramics Textbook Series, No. 1, Raw Materials.

2 Butterley Building Materials Ltd., Upper Devonian Marl, Caerleon works, Ponthir, nr. Newport, Gwent, S. Wales. Mixed with Coal Measure shales to produce wirecut red engineering and facing bricks.

3 Westbrick Ltd., Devonian shale, Steer Point works, Devon, (semi-quantitative only). Used to produce wirecut facing bricks.

Carboniferous

COAL MEASURES SHALES

	1	*2*	*3*	*4*	*5*
SiO_2	53.14	53.69	62.40	65.30	70.20
TiO_2		0.20	0.87		1.05
Al_2O_3	29.65	20.50	17.60	15.90	17.80
Fe_2O_3	4.04	7.81	6.70	6.36	1.33
CaO	0.22	0.30	0.40	1.66	0.16
MgO	0.31	2.41	1.50	1.46	0.71
K_2O	1.65	2.73	3.11	2.28	2.50
Na_2O	0.26	0.62	0.45	1.74	0.24
Loss on Ignition	10.70	11.14	6.25	5.33	5.83

Sources: Butterley Building Materials Ltd.

1 Catheralls works, Buckley, Clwyd, Wales. Shale/low grade fireclay used to manufacture buff refractory and facing bricks (pavoirs).

2 Merthyr works, Merthyr Tydfil, Mid. Glamorgan, Wales. Ironstone dump shales used to manufacture wirecut red facing bricks.

3 Thurcroft works, Rotherham, S. Yorks. Shales used to manufacture red engineering and facing bricks.

4 Waingroves works, Ripley, Derby. Shales used to manufacture wirecut red engineering and facing bricks.

5 George Armitage and Sons Ltd., seatearth to Middleton Little Coal from Oxbow Extension—Charcoal NCB opencast coal site used to produce buff facing brick.

Carboniferous

COAL MEASURES SHALES

	6	*7*	*8*	*9*	*10*	*11*
SiO_2	55.84	62.50	60.65	64.50	69.50	61.40
TiO_2	n.d.	1.15				
Al_2O_3	23.65	21.53	30.10	24.70	23.25	21.10
Fe_2O_3	4.53	7.40	2.68	3.03	2.35	3.00
CaO	n.d.	1.00				0.20
MgO	3.36	2.03				1.60
K_2O	2.77	2.90				} 4.70
Na_2O	2.83	0.77				
MnO_2	n.d.	0.09				
Loss on Ignition	7.00	8.20	12.40	10.23	10.90	7.00

Sources: Gibbons Northern Brick Ltd.

6 Crawcrook shale, Phoenix quarry (NZ 135628), Hutton and 5′ or 6′ seams.

7 Average of red burning samples from NCB Wardley Quarry, North Durham, used to produce common bricks.

8 Partial analyses: Average of white and cream burning fireclays from NCB Esh Winning opencast site, Durham, suitable for silver-grey facing bricks.

9 Partial analyses: Average of cream burning bastard fireclays from NCB Esh Winning opencast site, Durham, suitable for yellow, cream or buff bricks.

10 Partial analyses: Average of white burning bastard fireclays from former NCB Sisters opencast site, Northumberland.

11 Crossley Building Products Ltd. Coal Measures shale used at Eldon works Bishop Auckland, Durham, to produce stiff-plastic formed engineering bricks.

Carboniferous

COAL MEASURES AND MILLSTONE GRIT

	1	*2*	*3*	*4*	*5*
SiO_2	61.66	51.82	53.69	52.30	57.67
TiO_2	0.91	0.40	0.20	0.88	1.09
Al_2O_3	17.50	14.24	20.50	20.61	20.44
Fe_2O_3	3.33	0.57	6.95	2.29	1.84
Mn_2O_3				0.10	0.06
FeO	3.12	2.97	0.86	3.61	2.83
FeS_2		1.61	0.13	0.18	0.12
CaO	1.17	7.00	0.30	0.91	1.18
MgO	1.18	4.43	2.41	1.42	1.06
K_2O	2.52	2.10	2.73	3.26	1.92
Na_2O	1.17	0.52	0.62	0.41	0.27
SO_3	0.57	0.18	0.37	0.04	0.20
Loss of Ignition	6.60	14.08	11.14	14.02	11.38

Source: Bonnell and Butterworth, 'Clay Building Bricks', Ministry of Works, National Brick Advisory Council, Paper 5, 1950.

1 Lower Coal Measures shales, Lancs/Yorks.

2 Grey Weeton shales, Millstone Grit, Lancs/Yorks.

3 Red Weeton Shales, Millstone Grit, Lancs/Yorks.

4 Red-burning, Productive Coal Measures, colliery waste, Midlands/N. Wales.

5 Buff-firing bastard fireclays from Black Band Group and upper Productive Coal Measures (average), Midlands/N. Wales.

Carboniferous

COAL MEASURES AND LOWER LIMESTONE GROUP

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>SiO_2</td><td>59.21</td><td>56.1</td><td>50.77</td><td>47.81</td></tr>
<tr><td>TiO_2</td><td>0.98</td><td></td><td>1.00</td><td>0.84</td></tr>
<tr><td>Al_2O_3</td><td>18.62</td><td>24.1</td><td>24.10</td><td>18.03</td></tr>
<tr><td>Fe_2O_3</td><td>2.35</td><td rowspan="2">6.0</td><td rowspan="2">7.72</td><td rowspan="2">13.84</td></tr>
<tr><td>FeO</td><td>4.23</td></tr>
<tr><td>Mn_2O_3</td><td>0.12</td><td></td><td>0.08</td><td>0.11</td></tr>
<tr><td>CaO</td><td>0.56</td><td>0.7</td><td>0.49</td><td>2.6</td></tr>
<tr><td>MgO</td><td>2.01</td><td>3.0</td><td>1.38</td><td>1.58</td></tr>
<tr><td>K_2O</td><td>3.28</td><td rowspan="3">1.1</td><td>1.64</td><td>1.78</td></tr>
<tr><td>Na_2O</td><td>1.04</td><td>0.15</td><td>0.08</td></tr>
<tr><td>SO_3</td><td>0.14</td><td></td><td></td></tr>
<tr><td>CO_2</td><td>0.49</td><td></td><td></td><td></td></tr>
<tr><td>C</td><td>0.53</td><td></td><td></td><td></td></tr>
<tr><td>Loss on Ignition</td><td>7.46</td><td>9.0</td><td>12.36</td><td>12.96</td></tr>
</table>

Sources:

1 R. W. Nurse 1959 'The Relationship between the constitution of brickmaking clays and firing properties'. Clay Miner Bull. Accrington Mudstone.

2 A. B. Searle 'Clay, and what we get from it' London. 1925. Accrington Mudstone.

3 Scottish Brick Corporation; Lower Limestone Group blaes, Blairskaith quarry, for common brick manufacture.

4 Scottish Brick Corporation; Lower Coal Measures blaes, Drumshangie quarry, for facing and engineering brick manufacture.

Carboniferous

RUABON MARL

SiO_2	57.50
TiO_2	1.16
Al_2O_3	23.10
Fe_2O_3	7.26
CaO	0.33
MgO	0.87
K_2O	1.46
Na_2O	0.23
Loss on Ignition	7.50

Source: Dennis Ruabon Ltd. Colomendy quarry. Used in the production of unglazed floor quarries.

CALCIFEROUS SANDSTONE SERIES RED MARL

SiO_2	57.34
Al_2O_3	18.81
FeO	8.53
CaO	0.63
MgO	1.66
H_2O	9.65

Source: Terra-cotta clay formerly used for red firing bricks and tiles at Cleghorn brickworks, Glasgow.

CULM

SiO_2	62.00
TiO_2	0.94
Al_2O_3	18.70
Fe_2O_3	7.43
CaO	0.46
MgO	1.50
K_2O	3.69
Na_2O	0.86
P_2O_3	0.10
Mn_3O_4	0.11
Loss on Ignition	4.16

Source: Westbrick Ltd., Culm mudstones, Pinhoe works, Exeter, Devon; used to produce stiff-extruded facing and engineering bricks.

Carboniferous

ETRURIA MARL

	1	*2*	*3a*	*3b*	*4*	*5*
SiO_2	56.07	57.2–70.3	58.12	51.39	60.62	59.29
TiO_2	1.25	1.2– 1.5	1.35	1.27	1.22	1.27
Al_2O_3	20.85	13.7–21.8	22.40	23.10	20.62	20.09
Fe_2O_3	7.90	7.1– 9.9	7.55	10.02	7.4	8.43
Mn_2O_3	0.06	tr	n.d.	n.d.	0.03	0.25
CaO	0.50	tr– 0.2	0.40	2.00	0.28	0.76
MgO	1.13	0.6–1.0	1.28	0.96	0.73	0.72
K_2O	1.78	0.8–1.6	1.65	1.79	1.63	1.42
Na_2O	0.51	0.04–0.2	0.14	0.10	0.12	0.10
SO_3	0.04	n.d.	n.d.	n.d.	n.d.	n.d.
Loss on Ignition	10.42	5.1–7.1	7.40	9.09	7.59	7.37

Sources:

1 Bonnell and Butterworth. 'Clay Building Bricks', Ministry of Works, National Brick Advisory Council, Paper 5, 1950.

2 Range of Etruria Marls from Silverdale and Goldenvale areas, Staffs, after D. A. Holdridge, 'The Effect of firing on some physical properties of Etruria Marls', Clay. Miner. Bull, v.5, p.90–97, 1962.

3a Non-calcareous Etruria Marl, and *3b* Calcareous Etruria Marl, P. S. Keeling 'The Geology and Mineralogy of Brick Clays', B.D.A. 1963.

4 Average of 18 basal Etruria Marls from Goldendale Quarry North Staffs., after D. A. Holdridge, 'Compositional Variation in Etruria Marls', Trans. Brit. Ceram. Soc. 1959, v.58, no.5, p. 301–328.

5 Average of 20 middle Etruria Marls from Bradwell Wood Quarry, North Staffs., after D. A. Holdridge (as above).

Permian

	1	*2*
SiO_2	60.1	59.1
Al_2O_3	16.7	19.3
Fe_2O_3	5.8	7.1
TiO_2	0.5	0.9
CaO	6.5	2.1
MgO	4.2	1.7
Na_2O	1.2	0.6
K_2O	3.3	4.3
SO_3	0.9	1.1 (CO_2)
Loss on Ignition	0.3	4.6

Sources:

1 W. E. Worrall, Inst. of Ceramics Textbook Series, No 1, Raw Materials.

2 Red-bed mudstones from the Permian of southwest England, average major element chemistry. M. E. Cosgrove, Chem. Geol. v.11, 1973, p. 31–47.

'Keuper Marl' (Mercia mudstone group)

	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	48.70	46.20	65.30	42.74	49.54	61.14	41.38
TiO_2	0.69	0.65	0.74	0.95	0.80	0.77	0.63
Al_2O_3	13.30	12.80	14.00	16.32	13.70	13.16	12.57
Fe_2O_3	5.61	4.95	5.06	6.55	4.51	4.33	3.93
CaO	5.59	7.32	1.69	9.46	6.10	3.30	8.69
MgO	8.37	8.77	2.73	6.23	5.98	3.13	7.79
K_2O	5.07	5.00	5.03	3.57	3.98	4.72	3.62
Na_2O	0.09	0.08	0.53	0.83	0.62	0.41	0.50
Loss on Ignition	11.80	13.50	4.48	13.58	13.63	7.86	17.56

Sources: Butterley Building Materials Ltd.

1 Blaby works, Glen Parva, Leics. 'Keuper Marl' used for pink/buff handmade facing bricks.

2 Desford works, Bagworth, Leics. 'Keuper Marl' used for wirecut buff facing bricks.

3 Heather works, Ashby-de-la-Zouch, Leics. 'Keuper Marl' used for wirecut red facing bricks.

4 Kirton works, Newark, Notts. 'Keuper Marl' used for wirecut pink/buff facing bricks.

5 Average of six samples from top 92m of 'Keuper Marl' from Birmingham, Notts., Warwicks, and Leics areas after Bonnell and Butterworth 1950.

6 Average of four samples from basal 92m of 'Keuper Marl' from Leics. Notts, and Devon (after Bonnell and Butterworth 1950).

7 Average of two samples from middle 'Keuper Marl' from Northern Ireland (after Bonnell and Butterworth 1950).

Jurassic

MIDDLE LIAS

	1	*2*
SiO_2	57.8	62.96
Al_2O_3	23.2	23.68 (Al₂O₃ + Fe₂O₃)
Fe_2O_3	9.3	
TiO_2	1.2	n.d.
CaO	1.0	1.16
MgO	2.5	n.d.
Na_2O	0.9	4.74 (Na₂O + K₂O)
K_2O	2.9	
SO_3	0.3	0.33
Loss on Ignition	1.0	7.13

Sources:

1 W. E. Worrall 1964. Institute of Ceramics, Textbook Series, No. 1 Raw Materials. (analysis of fired brick).

2 Middle Lias 'brown clay', formerly used at Napton brickworks, Warwickshire, with the addition of lower 'blue clay' to produce red paving and kitchen flooring tiles.

Jurassic

LOWER OXFORD CLAY

	1	*2*	*3*
SiO_2	43.96	43.68	45.82
TiO_2	0.30	0.85	0.84
Al_2O_3	17.51	17.10	15.21
Fe_2O_3	2.76	2.08	3.12
FeS_2	2.60	2.35	1.83
CaO	8.14	10.55	10.10
MgO	1.59	1.57	2.21
K_2O	2.66	2.84	2.62
Na_2O	0.72	0.17	0.86
SO_3	1.30		2.01
F	0.05		
Loss on Ignition	18.46	18.10	15.00

Sources:

1 P. S. Keeling, 1963. The Geology and Mineralogy of Brick Clays, B.D.A.

2 London Brick Company Ltd, Saxon works, Whittlesea.

3 London Brick Company Ltd, Hicks No. 1 works, Fletton.

Jurassic

KIMMERIDGE CLAY

SiO_2	18.7
Al_2O_3	8.1
Fe_2O_3	10.6
TiO_2	0.3
CaO	27.3
MgO	4.0
K_2O&Na_2O	0.4
CO_2	24.1
H_2O	4.4
Carbon	2.1

Source: Crossley Building Products Ltd, Kirby works, Kirbymoorside, N. Yorks., used to produce facing bricks.

UPPER ESTUARINE CLAY

	1	*2*
SiO_2	79.03	73.98
Al_2O_3	10.97	13.53
Fe_2O_3	1.95	1.55
TiO_2	2.11	1.90
CaO	0.52	0.45
MgO	0.35	0.46
Na_2O	0.20	0.19
K_2O	0.26	0.61
Loss on Ignition	4.56	6.43
clay mineral (illite)	20%	29%
quartz	62%	45%
carbon	0.3%	1.7%

Source:

1 Williamson Cliff Ltd, white-burning 'fireclay' from Upper Estuarine Clay of Jurassic at Little Casterton, Lincolnshire, formerly used for facing bricks.

2 Brown-burning "fireclay" from Upper Estuarine Clay of Jurassic at Little Casterton, Lincolnshire, formerly used for facing bricks.

Cretaceous. Hastings Beds

ASHDOWN BEDS AND WADHURST CLAY

	1	*2*	*3a*	*3b*	*3c*	*3d*	*4a*	*4b*
SiO_2	78.16	91.84	63.33	65.23	72.16	74.31	55.25	49.81
TiO_2	0.96	0.65	1.44	1.36	1.32	1.24	0.98	1.00
Al_2O_3	8.88	3.22	17.46	19.05	15.36	13.20	19.20	14.16
Fe_2O_3	3.63	1.74	3.94	2.08	0.88	1.97	4.56	10.29
FeO	0.32	tr	2.74	0.65	0.72	1.40	0.68	1.40
Mn_2O_3	0.08	tr	0.02	0.02	0.01	0.01	0.05	0.39
CaO	0.37	0.33	0.36	0.20	0.27	0.26	1.90	0.35
MgO	0.70	0.11	0.64	0.64	0.46	0.50	1.51	1.25
K_2O	1.71	0.31	2.36	2.45	1.82	1.67	2.83	2.57
Na_2O	0.65	0.14	0.17	0.19	0.15	0.13	0.22	0.19
CO_2	0.08	n.a.	0.58	n.a.	0.14	n.a.	0.92	3.32
SO_3	0.01	0.01	0.12	0.02	0.31	0.04	0.02	0.06
Carbon			0.18					
Loss on Ignition	4.41	1.67	6.29	7.99	6.41	5.02	11.35	10.20

Source: B. Butterworth and D. B. Honeyborne, Bricks and Clays of the Hastings Beds; Trans. Brit. Ceram. Soc. 1952.

1 Representative sample of Ashdown Beds clay used to make hand made facing bricks.

2 Ashdown Beds clayey sand used mixed with Wadhurst Clay to make hand made and machine moulded facing bricks.

3 Wadhurst Clays used mixed with T.W.S. to make stiff-plastic and wirecut engineering and common bricks a) Red clay; b) White clay; c) Very dark clay; d) Buff clay.

4 Wadhurst Clays used to make hand made facing bricks.
a) Bluish yellow clay
b) Yellow plastic clay.

Cretaceous. Hastings Beds. (contd).

TUNBRIDGE WELLS SAND AND GRINSTEAD CLAY

	1	*2*	*3*	*4*	*5*
SiO_2	85.38	77.86	66.05	64.56	54.42
TiO_2	1.06	1.32	1.04	1.18	0.96
Al_2O_3	6.63	9.77	17.17	16.42	21.52
Fe_2O_3	2.44	4.05	4.10	6.59	6.35
FeO	0.14	0.46	0.36	0.17	0.58
Mn_2O_3	0.05	0.01	0.03	0.03	0.03
CaO	0.20	0.07	0.12	0.27	0.47
MgO	0.32	0.26	0.69	0.66	1.09
K_2O	0.87	1.16	1.95	2.37	2.47
Na_2O	0.13	0.18	0.20	0.12	0.24
CO_2	tr				0.15
SO_3	0.02	0.07	0.03	0.03	0.03
Carbon					0.34
Loss on Ignition	3.00	4.56	8.35	7.43	11.62

Source: B. Butterworth and D. B. Honeyborne, Bricks and Clays of the Hastings Beds; Trans. Brit. Ceram. Soc., 1952

1 Clayey Tunbridge Wells Sand used with Wadhurst Clay in the proportions 2:1 (commons), 1:2 (engineerings) and 1:1 (facings).

2 Clayey Tunbridge Wells Sand used with Wadhurst Clay for engineering and common bricks.

3 Grey plastic Grinstead Clay used for machine-moulded facing bricks.

4 Yellow Grinstead Clay used for machine-moulded facing bricks.

5 Yellow Grinstead Clay used with T.W.S. for machine-moulded facing bricks.

Cretaceous

WEALD CLAY AND GAULT CLAY

	1	*2*	*3*	*4a*	*4b*
SiO_2	58.27	52.50	54.98	48.26	35.44
Al_2O_3	22.16	22.37	18.43	19.86	13.77
Fe_2O_3	7.04	7.85 (FeO,0.43)	10.37	5.70	2.84
MgO	1.04	1.10	0.91	1.74	1.47
CaO	0.20	0.62	2.66	4.14	19.08
Na_2O	0.33	0.33	0.46	0.34	0.15
K_2O	2.67	2.72	3.25	2.89	2.35
TiO_2	1.05	0.90	1.01	0.90	0.67
P_2O_5	0.09	n.d.			
MnO	0.03	0.10 (Mn_2O_3)		0.02	0.06
CO_2	0.14	0.25	n.d.	2.88	14.42
SO_3	0.03	0.19	n.d.	1.24	0.57
Loss on Ignition	0.95	10.67	7.71	12.60	22.86
			Carbon	9.72	0.35
			FeO	2.29	1.01

Sources: Weald Clay:

1 Southwater works, nr. Horsham, Sussex. Redland Brick Ltd.

2 Pluckley Brick & Tile Co Ltd, Pluckley Works, nr. Ashford, Kent, used to make wire-cut multicoloured facings.

3 P. S. Keeling 'The Geology and Mineralogy of Brick Clays', B.D.A. 1963.

4 R. W. Nurse. 'The Relationship between the constitution of brickmaking clays and firing properties', Clay Miner. Bull. 19.
(a) Gault Clay (Dunton Green) used for incorporation with other clays.
(b) Gault Clay (Burwell) used to produce white brick.

Tertiary

	1	*2*	*3*	*4*	*5*
SiO_2	65.87	58.38	59.4	57.18	50.00
TiO_2	0.76	n.d.		1.08	n.a.
Al_2O_3	10.35	15.31	16.9	17.18	21.10
Fe_2O_3	3.94	7.00	7.5	7.98	11.30
FeO	0.83	n.d.	n.d.	n.d.	
Mn_2O_3	0.01	n.d.	n.d.	n.d.	
CaO	4.26	0.97	2.1 ($CaCO_3$)	2.41	4.10
MgO	1.58	2.72	6.3 ($MgCO_3$)	2.82	0.70
K_2O	1.93	2.86	3.2	3.27	} 12.80
Na_2O	0.37		0.3	0.27	
SO_3	0.23	1.80	n.d.	n.d.	
CO_2	2.61	n.d.	n.d.	2.10	
Carbon	n.d.	n.d.	n.d.	n.d.	
Loss on Ignition	9.67	8.20	n.d.	8.00	

Sources:

1 Eocene (Hammill). R. W. Nurse 'The relationship between the constitution of brickmaking clays and firing properties'. Clay Miner. Bull. 19 .

2 Typical analysis of London Clay, Tunnel Cement Co., Aveley quarry, Essex.

3 London Clay, Ockendon, supplying A.P.C.M. Ltd, Northfleet works, Dartford, Kent.

4 London Clay, P. S. Keeling, 'The Geology and Mineralogy of Brick Clays', B.D.A., 1963.

5 Reading Beds, Star works, Knowl Hill, Berkshire.

Quaternary

	1	2	3
SiO_2	51.74	67.7	52.36
TiO_2	0.86	n.d.	0.80
Al_2O_3	12.70	23.1	19.78
Fe_2O_3	5.64	2.6 (with FeO)	6.75
FeO	0.30		1.32
Mn_2O_3	0.06	n.d.	0.13
CaO	9.94	3.4	1.63
MgO	1.27	0.2	3.60
K_2O	1.76	2.4 (with Na_2O)	4.35
Na_2O	0.35		1.29
SO_3	0.02	n.d.	0.02
CO_2	7.16	n.d.	
C	n.d.	n.d.	
Loss on Ignition	15.35	0.6 ('H_2O etc')	8.66

Sources:

1 Boulder Clay, Garston, Herts., suitable for red hand-moulded bricks, R. W. Nurse, 'The Relationship between the constitution of brickmaking clays and firing properties'. Clay Miner. Bull. 19 .

2 Glacial brick clay (unspecified), A. B. Searle, 'Clay, and what we get from it', London, 1925

3 'Upper red clay', Tipperty pit, Ellon, Grampian (raised beach clay).

Waste Materials

	1	2	3	4	5	6	7
SiO_2	37.90	48.10	49.00	43.00	54.70	75–90	50.30
TiO_2	0.65	1.00	1.08	0.95	1.00	0.05–0.15	0.11
Al_2O_3	15.90	19.90	18.00	21.50	18.10	5–15	32.70
Fe_2O_3	2.70	1.80	2.80	0.60	1.70	0.50–1.20	2.37
FeO	2.70	3.30	5.60	3.70	5.40	n.d.	n.d.
P_2O_3	0.16	0.16	0.22	0.24	0.18	n.d.	n.d.
CaO	0.56	0.61	0.73	1.30	1.70	0.05–0.50	0.07
MgO	1.10	1.67	2.55	1.26	3.90	0.05–0.50	0.35
MnO	0.08	0.10	0.23	0.08	n.d.	n.d.	n.d.
Na_2O	0.30	0.39	0.64	0.14	1.50	0.02–0.75	0.24
K_2O	1.36	1.64	1.48	0.90	2.80	1.00–7.50	5.30
SO_3	2.05	2.32	0.34	0.46	0.40	n.d.	n.d.
Loss on Ignition to 950°C	35.06	19.05	16.81	25.47	6.70	1–2	8.30
					0.02 F		
					0.10 Mn_2O_3		
					0.53 S		

Source: R. J. Collins, 'A method for measuring the mineralogical variation of spoils from British Collieries'. Clay Miners. v.11, p.31–48. 1976 (weight %).

1 Unburnt colliery spoil, Morlais colliery, S. Wales.

2 Unburnt colliery spoil, Snowdown colliery, Kent.

3 Unburnt colliery spoil, Thorne colliery, Yorks.

4 Unburnt colliery spoil, Bedlay colliery, Scotland.

5 Average composition of four Scottish slate waste samples Building Research Establishment, Current Paper 19/74 (Gutt, Nixon, Smith, Harrison and Russell).

6 Composition range of waste china clay coarse sand fraction Ref. as above.

7 Composition of waste china clay fine micaceous residue. Ref. as above.

Waste Materials (cont'd)

	8
SiO_2	48.50
Al_2O_3	25.20
Fe_2O_3	12.10
CaO	5.30
MgO	2.20
SO_3	3.20
C	3.00
Chloride	trace
Alkalis	trace

Source:

8. Analysis of a typical spent shale (Oil Shale Group) as discharged from oil retorts, Scotland, (Building Research Establishment Current Paper 50/78.)

Appendix II

Producers

a. Clay brick, pipe and tile manufacturers
b. Calcium—Silicate brick manufacturers

N.B. Because of recurrent takeovers and closures it is accepted that some inaccuracies may be inherent in this compilation, but it was believed to be substantially correct at the time of going to press.

(a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Accrington Brick & Tile Co., Ltd (Geo. Armitage Group) Nori Works, Altham West Accrington, Lancs. No. 1 & 2 Works, Accrington. No. 3 Works, Whinney Hill, Accrington. No. 4 Enfield Works, Accrington. Deerplay Works, Accrington.	Lower Coal Measures shales 'Accrington Mudstone'	Facing bricks, acid-resisting bricks & blocks, acid-resisting tiles.
Afton Bricks Ltd Larbert, Stirlingshire.	Coal Measures or Millstone Grit shales	Common bricks.
Aldeburgh Brickworks Saxmundham Road, Aldeburgh, Suffolk.	Chillesford Clay	Facing bricks.
Alne Brick Co., Ltd 1. Forest Lane Works, Alne, North Yorks. 2. Hemingborough, nr Selby, Yorks.	Superficial clays	Bricks and various clay products.
Geo. Armitage & Sons Ltd Robin Hood, Wakefield, Yorks. 1. Howley Park Brick Factory (1 & 2) Woodkirk, nr Dewsbury, W. Yorks. 2. Thorpe Brick Factory, Thorpe, Wakefield, W. Yorks. 3. Swillington Brick Factory, Swillington, Leeds, W. Yorks.	Middle Coal Measures shales and fireclays	Comprehensive range of facing and engineering bricks.
Ashpark Brickyard Ltd Plaistow, W. Sussex.	Weald Clay	Facing bricks.
Baggeridge Brick Co., Ltd 1. Gospel End Works, Sedgley, Dudley, W. Midlands.	Etruria Marl	Facing and engineering bricks, and pavers.
2. Hartlebury Works, Kidderminster, Worcs.	Etruria Marl	
3. Kingsbury Works, Dosthill, nr Tamworth, Staffs.	Old Hill Marl	
Barker & Briscoe Ltd North Wirrall Brickworks, Carr Lane, Saughall Massie, Wirral, Cheshire.	'Keuper Marl'	Common and facing bricks, and air bricks.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Barnett & Beddows Ltd Atlas Brickworks, Aldridge, Walsall, Staffs.	Etruria Marl	Staffordshire Blue engineering and acid-resisting bricks, and pavers.
Belton Brick Co. Ltd (Innes Lee Industries), Belton Works.		Facing brick.
H. Birkby & Sons Ltd Storr Hill Brickworks, Wilson Road, Wyke, nr Bradford, W. Yorks.	Lower Coal Measures Shales or Millstone Grit shales	Brick.
Birtley Brick Co. Ltd Union Brickworks, Birtley, Tyne & Wear.	Superficial deposits	Slop-moulded facing bricks and pavers.
Blockleys Ltd Hadley, Telford, Salop.	Coalport Beds, Upper Coal Measures shales and fireclays	Facing bricks, briquettes and pavers.
Blue Circle Industries Ltd Brick Division, Sittingbourne Works, Murston, Kent.	Brickearth	Facing bricks (London Stocks).
Bovingdon Brickworks Ltd Hemel Hempstead, Herts.	Clay-with-flints	Facing bricks.
William Blyth, Hoe Hill, Barton-on-Humber, Lincs.	Marine alluvium	Clay roofing tiles and pan-tiles.
Blythe & Sons (Birtley) Ltd 1. Birtley Station Brickworks, Birtley, Tyne & Wear. 2. Washington Station Works, Washington, Tyne & Wear.	Coal Measures shales	Engineering and facing bricks.
S. T. Brown & Co. The Brickfields, Cholesbury, Tring, Herts.	Clay-with-flints	Facing bricks.
Bulmer Brick & Tile Co. Ltd The Brickfields, Bulmer, Sudbury, Suffolk.	London Clay	Facing bricks.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Butterley Building Materials Ltd		Comprehensive range of facing bricks, engineering bricks, handmade bricks and pavers.
1. Blaby Brickworks, Cork Lane, Glen Parva, Leics.	'Keuper Marl'	
2. Kirton Brickworks, New Ollerton, nr Newark, Notts.	'Keuper Marl'	
3. Thurcroft Brickworks, Thurcroft, Rotherham, Yorks.	Upper Coal Measures shales	
4. Waingroves Brickworks, Waingroves, nr Ripley, Derby.	Middle Coal Measures shales	
5. Buttington Brickworks, (Castle Brick Co.), nr Welshpool, Powys.	Llandovery shales	
6. Catheralls Brickworks, Buckley, Clwyd.	Coal Measures fireclays	
7. Hooton Brickworks, Hooton, Wirral, Cheshire.	Boulder Clay	Temporarily closed.
8. Heather Works, Heather, nr Ashby-de-la-Zouch, Leics.	'Keuper Marl'	
9. Desford Works, Heath Road, Bagworth, Leics.	'Keuper Marl' + imported Etruria Marl from Cannock	
10. Seiont Works, Caernarvon, Gwynedd.	Ordovician slates	
11. Lane End Works, Buckley, Clwyd.	Coal Measures shales	
12. Merthyr Works, Merthyr Tydfil, Mid. Glam.	Coal Measures shales (ironstone dumps) and fireclays	
13. Caerleon Works, Ponthir, nr Newport, Gwent.	Coal Measures shales and Devonian marl	
14. Aglite Works, Street Lane, Denby, Derbys.	Coal Measures shales	Lighweight aggregate and blocks.
John Caddick & Sons Spoutfield Tileries, Stoke-on-Trent, ST4 7BX	Etruria Marl	Quarry tiles.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Caledonian Brick Co. Ltd 1. Newmains Brickworks, Morningside Road, Newmains. 2. Mayfield Brickworks, Wilton Road, Carluke. 3. Hamilton Brickworks, Newpark Street, Hamilton. 4. Fife Brick Co. Ltd., Braehead-Lassodie, Kelty Fife.	Opencast and bing blaes (Coal Measures shales)	Common bricks
Campbell Brick Co (Innes Lee Industries Ltd.), Barrow Hill, Chesterfield, Derbys.		
Cannerton Brick Co. Ltd Banknock, Bonnybridge, Stirlingshire.	Coal Measures blaes	Common bricks.
Carlton Main Brickworks Ltd Grimethorpe, nr Barnsley, Yorks.	Middle Coal Measures shales	Common, facing and engineering bricks.
Carty Tile Works Newton Stewart, Ardrossan, Ayrshire.	Boulder clay	
Charnwood Forest Brick & Tile Works Ltd Shepshed, Lougborough, Leics.	'Keuper Marl'	Facing bricks.
Chellaston Brick Co. Ltd Derbyshire.	'Keuper Marl'	
Claughton Manor Brick Co. Ltd 1. West End Works, Claughton, Lancaster. 2. Manor Works, Claughton, Lancaster.	Namurian shales	Facing bricks.
Coalisland Brick Co. Ltd Coalisland, Dungannon, N. Ireland.	Coal Measures	Common, facing and engineering bricks, pipes, conduits and odd stuff.
Coleford Brick & Tile Co. Ltd Royal Forest of Dean Brickworks, Cinderford, Glos.	Coal Measures (using stockpiles)	Facing bricks.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
W. H. Collier Ltd Church Lane, Marks Tey, nr Colchester, Essex.	Glacial lake clays, (Hoxnian Interglacial silts)	Facing bricks and briquettes, handmade bricks.
Conways Tiles Ltd Globe Lane, Dukinfield.		Quarry tiles.
Cremer Whiting & Co. Ltd (W. T. Lamb & Sons Ltd.) Ospringe Brickworks, Faversham, Kent.	Brickearth	Facing bricks (London Stocks).
Crossley Building Products Ltd		Comprehensive range of facing, common and engineering bricks, and handmade bricks.
1. Coatham Stob Brickworks, Eaglescliffe, Cleveland.	Boulder clay and laminated clay	
2. Eldon Brickworks, Bishop Auckland, Durham.	Coal Measures shales	
3. Hetton Brickworks, Hetton-le-Hole, Tyne & Wear.	Boulder clay. Closed	
4. Kibblesworth Brickworks, Birtley, Tyne & Wear.	Boulder clay. Closed	
5. Hurworth Brickworks, Darlington, Durham.	Boulder clay. Closed	
6. Kirby Brickworks, Kirbymoorside, N. Yorks.	Kimmeridge Clay. Closed	
7. Broomfleet Brickworks, Brough, N. Humberside.	Glacial lake clays & interglacial clays	
8. Broomfleet Clay Tile Works, N. Humberside.	Glacial lake clays & interglacial clays	Double-interlocking roofing tiles and pantiles.
Cruden Bay Brick & Tile Co. Ltd Newark Tile Works, Tipperty, Ellon, Grampian.	Interglacial clays and boulder clay	Facing bricks.
Dennis Ruabon Ltd Hafod Tileries, Ruabon, nr Wrexham, N. Wales.	Ruabon Marl	Quarry tiles and bricks.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
G. H. Downing & Co. Ltd 1. Brownhills Works, Tunstall, Staffs. 2. Birchenwood Works, Kidsgrove, Staffs. 3. Keele Works, Madeley Heath, Newcastle, Staffs. 4. Chesterton Works, Newcastle, Staffs. 5. Knutton Tile Works.	Etruria Marl Middle Coal Measures shales Etruria Marl Etruria Marl & fireclays Etruria Marl	Comprehensive range of common and facing bricks, Staffordshire Blue engineering bricks, and clay roofing tiles.
Drury Brickworks Ltd Buckley, Clwyd.	Coal Measures fireclays & shales	
Dunton Bros. Ltd Meadhams Farm Brickworks, Ley Hill, Chesham, Bucks.	Clay-with-flints or weathered Reading Beds	Facing bricks.
Emlyn Brick Co. Ltd Penygroes, Llanelli, Dyfed.	Coal Measures	Common bricks.
Henry Foster Bricks Ltd (Steetley Brick), Todhills Works, Newfield, Bishop Auckland, Co. Durham.	Lower Coal Measures	Facing bricks, roofing tiles & field drains.
Freshfield Lane Brickworks Ltd Dane Hill, Haywards Heath, West Sussex.	Base of Upper Tunbridge Wells Sand + top of Wadhurst Clay	Facing and paving bricks, briquettes, and handmade bricks.
H. R. Gibbs & Son Ltd Steamhall Works, Bromyard, Herefordshire.	Devonian marl	Quarry tiles.
Gibbons Northern Brick Ltd Gibbons Dudley Group (Steetley Brick); 1. Ashington Works, Northumberland. 2. Cramlington Works, Northumberland. 3. Seghill Works, Northumberland. 4. Throckley Works, Tyne and Wear.	Coal Measures shales and fireclays	Comprehensive range of common, facing and engineering bricks, and pavers.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Glasgow Iron and Steel Co. Ltd Birkhill Brickworks, Boghall Road, Carluke.	Coal Measures shales	Common bricks.
Hammill Brick Eastry Ltd Kent.	Brickearth	Facing bricks (London Stocks).
Hastings Brickworks Ltd Fourteen Acre Lane, Guestling, nr Hastings, E. Sussex.	Hastings Beds	Facing bricks.
Haunchwood Lewis Brick & Tile Co. Ltd (Thomas Wragg & Sons Ltd Group), Rosemary Works, Cannock Staffs.	Etruria Marl	Staffordshire Blue engineering bricks; facing bricks, pavers and roofing tiles.
Hawkins Tiles (Cannock) Ltd Longhouse Works, Cannock Staffs.	Etruria Marl	Roofing tiles; quarry tiles, floor tiles, pavers, facing and engineering bricks.
Hemstocks Pottery Ltd Old North Road, Sutton-on-Trent, Newark, Notts.	'Keuper Marl'	Redware garden and utility pots, and brick specials.
Hepworth Group (Hepworth Iron Co., Ltd)		Comprehensive range of vitrified clay pipes and fittings.
1. Hazlehead, Stockbridge, S. Yorks.	Lower Coal Measures	
2. Woodville, Swadlingcote and Ellistown.	Middle Coal Measures fireclay	
3. Jacksdale, Nottinghamshire.	Fireclay from S. Derbyshire	
4. Operations of Northern Ceramic Pipe Co. Ltd in Lancashire: Burnley and Horwich factories.	Lower Coal Measures mudstones	Field drains. Field drains.
5. Escrick, near Yorks.	Vale of York drift	
6. Glanboig, Scotland.	Middle Coal Measures virgin blaes	
Hinton, Perry & Davenhill Ltd Dreadnought Works, Pensnett, Brierley Hill (Ketley Brick Co. Ltd)	Coal Measures shales	Engineering bricks and pavers.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Ibstock Building Products Ltd		Comprehensive range of facing and engineering bricks, handmade bricks and pavers.
1. Ibstock Brick Aldridge Ltd, Aldridge, W. Midlands.	Etruria Marl	
2. Ibstock Brick Cattybrook Ltd, Almondsbury, Bristol.	Middle Coal Measures shales & fireclays	
3. Ibstock Brick Himley Ltd, Kingswinford, Brierley Hill, Staffs.	Etruria Marl	
4. Ibstock Brick Leicester Ltd, Ibstock, Leicester. (2 works).	'Keuper Marl'	
5. Ibstock Brick Nostell Ltd, Nostell, Wakefield, Yorks.	Middle Coal Measures shales	
6. Ibstock Brick Roughdales Ltd,		
a) Chester Lane Factory, St. Helens, Merseyside.	Upper Coal Measures shales and fireclays	
b) Elton Head Works, Sutton, St. Helens, Merseyside.	Upper Coal Measures shales and fireclays	
7. Ibstock Brick Hudsons Ltd,		
a) West Hoathly Works, W. Sussex.	Basal Wadhurst Clay	
b) Laybrook Works, Pulborough, W. Sussex.	Weald Clay	
J. & A. Jackson Ltd		Facing and common bricks.
1. Adswood Works, nr Stockport, Cheshire	Boulder clay	
2. Denton Works.	Carboniferous Shale from Glossop (Mouselow)	
3. Poynton Works.		
Jacksons (Warwickshire) Brickworks Ltd Coventry Road, Bickenhill, Solihull, W. Midlands.	'Keuper Marl'	Facing and common bricks.
J. Jameson & Son Ltd Corbridge-on-Tyne, Northumberland.	Fireclay	Salt glazed pipes & fittings.
H. & R. Johnson-Richards Tiles Ltd Highgate Tile Works, Tunstall, Stoke-on-Trent.		Unglazed earthenware floor tiles (among other products).

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Kenneths Building Services Ltd (Scottish Brick Corporation), Annandale Brickworks, Kilmarnock. Pitcon Brickworks, Dalry, Ayrshire. Commondyke Brickworks, Auchinleck. Broadie Brickworks, Dalry, Ayrshire.	Coal Measures shales	Common bricks.
Keymer Brick & Tile Co. Ltd (Maidenhead Brick & Tile Co. Ltd, subsidiary), Keymer Brick Works, Burgess Hill, nr Haywards Heath, W. Sussex.	Weald Clay	Handmade clay roofing tiles.
Kirkheaton Brickworks Ltd (subsidiary of S. Wilkinson & Sons), Lane Side, Kirkheaton, Huddersfield, Yorks.	Lower Coal Measures shales	Engineering bricks.
W. T. Knowles & Sons Ltd Ash Grove Sanitary Pipe Works, Elland, W. Yorks.	Lower Coal Measures mudstones and fireclay	Vitrified clay pipes.
W. T. Lamb & Sons Ltd Pitsam Works, nr Midhurst, W. Sussex. South Godstone Works, Surrey.	Gault Clay Weald Clay	Facing bricks and briquettes.
Leadbetters Ltd Grotton Brickworks, Grotton, nr Oldham, Lancs.	Coal Measures	Clay products.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
London Brick Co. Ltd		
1. Dogsthorpe Star Brickworks, Dogsthorpe, nr Peterborough.	Lower Oxford Clay	Fletton, Common and facing bricks, and at some works, Fletton field drain pipes.
2. Northam Brickworks, Eye Green, Peterborough.	Lower Oxford Clay	
3. Beebys Brickworks, Yaxley, Peterborough.	Lower Oxford Clay	
4. Kings Dyke Brickworks, Whittlesey, Peterborough.	Lower Oxford Clay	
5. Saxon New Brickworks, Whittlesey, Peterborough.	Lower Oxford Clay	
6. Orton Brickworks, Yaxley, nr Peterborough.	Lower Oxford Clay	
7. London Brick No. 1 Brickworks, Fletton, Peterborough.	Lower Oxford Clay	
9. Hicks No. 1 Brickworks, Fletton, Peterborough.	Lower Oxford Clay	
10. Hicks No. 2 Brickworks, Fletton, Peterborough.	Lower Oxford Clay	
11. Calvert Brickworks, Steeple Clayton, Bucks.	Lower Oxford Clay	
12. Bletchley Brickworks, Newton Longville, Bletchley, Bucks.	Lower Oxford Clay	
13. Jubilee Brickworks, Skew Bridge, nr Bletchley, Bucks.	Lower Oxford Clay	
14. Ridgmont Brickworks, Ridgmont, Beds.	Lower Oxford Clay	
15. Coronation Brickworks, Stewartby, Beds.	Lower Oxford Clay	
16. Clockhouse Brickworks, Capel, Surrey.	Weald Clay	Simulated handmade bricks.
17. Warboys Brickworks.	Upper Oxford Clay	
18. Arlesey Works, Beds.	Gault Clay	
Lumley Brickworks Ltd Woodstone Village, Houghton-le-Spring, Co. Durham.	Coal Measures shale and fireclay	Engineering and facing bricks.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Maltby Metallic Brick Co. Ltd (Nottingham Brick Co. Ltd subsidiary), Maltby Brickworks, Maltby, S. Yorks.	Upper Coal Measure shales	Facing, common and engineering bricks.
H. G. Matthews Dundridge Manor, St. Leonards, nr Tring, Herts.	Clay-with-flints	Facing bricks.
Michelmersh Brick Co. Ltd Michelmersh, Romsey, Hants.	Reading Beds	Facing bricks and briquettes.
Milton Hall (Southend) Brick Co. Ltd		Facing bricks and briquettes.
1. Cherry Orchard Lane, Rochford, Essex.	Loam brickearth; terrace of the River Crouch	
2. Starr Lane, Wakering, Essex.	Loam brickearth; terrace of the River Crouch	
Thos. Mosedale & Sons Ltd Flixton Brickworks, Flixton, Lancs.	Late glacial laminated clays	Facing and common bricks.
Naylor Bros. (Clayware) Ltd Denby Dale, Huddersfield, Cawthorne, nr Barnsley.	Lower Coal Measures shales and fireclay	Comprehensive range of vitrified clay pipes and fittings.
New Brick & Tile Co. (Newhey) Ltd Huddersfield Road, Newhey, Rochdale, Greater Manchester.	Coal Measures	Facing and engineering bricks.
Normanton Brick Co. Ltd 1. Newland Lane Brickworks, Normanton, W. Yorks. 2. Wakefield Road Brickworks, Normanton, W. Yorks.	Middle Coal Measures	Facing and engineering bricks.
Northcott Works Ltd Blockley, Moreton-in-Marsh, Glos.	Lower Lias	Common and facing bricks, handmade bricks and briquettes.
Nottingham Brick Co. Ltd Lime Lane, Arnold, Nottingham.	'Keuper Marl'	Facing bricks

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Ockley Brick Co. Ltd 1. Smoke Jacks Brickworks, Walliswood, Ockley, Dorking, Surrey.	Weald Clay	Repressed facing bricks.
2. Ewhurst Brickworks, Horsham Lane, Ewhurst, Surrey.	Weald Clay	Machine and handmade facing bricks.
Daniel Platt & Sons Ltd Brownhills Tileries, Tunstall, Stoke-on-Trent, Staffs.	Etruria Marl	Quarry tiles and acid-resisting tiles.
Pluckley Brick & Tile Co. Ltd Pluckley, nr Ashford, Kent. (Redlands Bricks Ltd., subsidiary)	Weald Clay	Facing bricks and pavers.
Ravenhead Brick Co. Ltd (Steetley Brick), Chequer Lane Factory, UpHolland, and Stormy Corner Plant, Greater Manchester.	Lower Coal Measures shales and some fireclay	Facing and engineering bricks and pavers, clayware field drain pipes.
Redbank Manufacturing Ltd Measham, Leics.	Etruria & 'Keuper' marls, and fireclays	Roof ridges, land drains, air bricks.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Redland Bricks Ltd		Comprehensive range of facing bricks, London Stocks and handmade bricks; Calculon common bricks, pavers and fireplace briquettes.
1. Warnham (Pressed & Wealdon) Langhurstwood Road, Horsham, Sussex.	Weald Clay	
2. Southwater, Horsham, Sussex.	Weald Clay	
3. Chailey, South Chailey, Lewes, Sussex.	Weald Clay	
4. Hamsey, South Chailey, Lewes, Sussex.	Weald Clay	
5. Nutbourne, Roundals Lane, Hambledon, Godalming, Surrey.	Weald Clay	
6. Lingfield, Pikes Lane, Crowhurst, Kingfield, Surrey.	Weald Clay	
7. North Holmwood, Spook Hill, North Holmwood, Dorking, Surrey.	Weald Clay	
8. Beare Green, Newdigate Road, Beare Green, Dorking, Surrey.	Weald Clay	
9. Ashford Works, Turkey Road, Bexhill-on-Sea, Sussex.	Tunbridge Wells Sand	
10. Tonbridge, Quarry Hill, Baltic Road, Tonbridge, Kent.	Lower Tunbridge Wells Sand & Wadhurst clay	
11. Crowborough, Farningham Road, Crowborough, Sussex.	Ashdown Beds	
12. Conyer, Sittingbourne, Kent.	Brickearth	(care and maintenance).
13. Funton, Sheerness Road, Lower Halstow, Sittingbourne, Kent.	Brickearth	(care and maintenance).
14. Otterham, Otterham Quay Lane, Gillingham, Kent.	Brickearth	(care and maintenance).
15. South Holmwood, Beare Green, Dorking, Surrey.	Weald Clay	(care and maintenance).
Rudgwick Brickworks Co. Ltd Lynwick Street, Rudgwick, Horsham, Sussex.	Weald Clay	Facing bricks, briquettes and pavers.
Sandtoft Tileries Ltd Doncaster, S. Yorks.		Clay & concrete roofing tiles.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Scottish Brick Corporation		
1. Airdrie Brickworks, Peersburn Road, Airdrie, Lanarks.	Mixed bing blaes, virgin blaes	Common bricks.
2. Cadder Brickworks, Balmuildy Road, Glasgow.	Mixed colliery blaes & virgin blaes	Common bricks.
3. Centurion Brick Factory, Balmuildy Road, Glasgow.	Virgin dug blaes	Facing and engineering bricks.
4. Dalry Brickworks, Carsehead, Dalry, Ayrshire.	Bing blaes from Limestone Coal Group	Common bricks.
5. Gartshore Brickworks, Twechar, nr Kilsyth, Glasgow.	Mixed bing blaes & virgin blaes	Common bricks.
6. Holytown Brickworks, New Stevenson, Motherwell, Lanarks.	Mixed bing blaes & virgin blaes	Common bricks.
7. Meta Brickworks, Fishcross, by Alloa, Clackmannanshire.	Mixed bing blaes & Virgin blaes	Common bricks.
8. Niddrie Brickworks, Portobello, Edinburgh.	Mixed bing blaes, virgin blaes & colliery washery slurry.	Common bricks.
9. Northfield Brickworks, Shotts, Lanarkshire.	Mixed bing blaes & virgin blaes	Common bricks.
10 Roslin Brickworks, Roslin, Midlothian.	Mixed bing blaes, virgin blaes & colliery washery slurry	Common bricks.
11. Skares Brickworks, nr Cummock, Ayrshire.	Bing blaes from Limestone Coal Group	Common bricks.
12. Summerston Brickworks, Balmore Road, Glasgow.	Mixed colliery blaes & virgin blaes	Common bricks.
13. Whitehill Brickworks, Rosewell, Midlothian.	Mixed bing blaes, virgin blaes & colliery washery slurry	Common bricks.
14. Newton brickworks, Uddingston, Glasgow.	Barren Red Marls	Common bricks.
15. Blackhill Brickworks, Balmore Road, Glasgow.		(care and maintenance basis.)
Selbourne Brick & Tile Co. Ltd Honey Lane Works, Selbourne, nr. Alton, Hants.	Gault	Facing bricks & pavers.
Sevenoaks Brick Works Ltd Greatness, Sevenoaks, Kent. (clay brick works)	Gault	Facing bricks

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Severn Valley Brick Co. Ltd Severn Road Avonmouth.	Estuarine alluvium	Facing bricks.
Sheffield Brick Sales Ltd Rutland Road, Neepsend, Sheffield 3.	Lower Coal Measures shales.	Common, facing and engineering bricks.
W. H. & J. Slater Ltd Denby, nr Derby.	Coal Measures fireclay	Clay pipes and conduits.
Stoneware Ltd Dosthill, nr Tamworth, Staffs.	Etruria Marl	Clay pipes, conduits, tiles.
Stourbridge Brick Co. Ltd Shut End Works, Pensnett, Brierley Hill, Staffs.	Etruria Marl	Facing and Engineering bricks and pavers.
Swallows' Tiles (Cranleigh) Ltd Brookhurst Hill, Cranleigh, Surrey.	Weald Clay	Tiles.
Swanage Brick & Tile Co. Ltd Godlingston Tileries, Swanage, Dorset.	Weald Clay or Wealdon beds	Facing bricks, handmade bricks, briquettes and pavers.
The Swarland Brick Co. Ltd Thrunton Works, Whittingham, Alnwick, Northumberland.	Boulder clay	Facing bricks.
W. Thomas (Wellington Bricks) Ltd (Steetley Brick), Poole Works, Wellington, Somerset.	'Keuper Marl' + some fireclay	Facing bricks.
Tilling Construction Services Ltd Tilcon Wilnecote Brick, Hedging Lane, Wilnecote, Tamworth, Staffs.	Etruria Marl	Facing and engineering bricks.
Tyrone Brick Co. Ltd Dungannon, Co. Tyrone, N. Ireland	Carboniferous shales	Facing bricks and pipes.
United Fireclay Products Ltd (Steetley Brick) 1. Etna Works, Armadale, West Lothian. 2. Brownhill Works, Cleland, Lanarks.	Coal Measures bing blaes	Common bricks
H. F. Warner Ltd Star Works, Knowl Hill, Reading, Berks.	Reading Beds	Roofing tiles.

a)

COMPANY & WORKS	DEPOSIT WORKED	PRODUCTS
Websters Hemming & Sons Ltd Midland Brickworks, Coventry.	Etruria Marl	
The Wellawood Brick Co. Ltd Wellawood, Dunfermline, Fife.	Lower Limestone Group bing blaes	Common bricks.
Wemyss Brick Co. Ltd Wemyss Brickworks, Denbeathy, Methil, Fife.	Virgin Coal Measure blaes + boulder clay	Facing and common bricks.
Westbrick Ltd 1. Pinhoe Brickworks, Exeter, Devon.	Culm	Facing bricks, handmade bricks and pavers.
2. Rougemont Works, Monks Road, Exeter, Devon	Culm	
3. Steer Point Works, Brixton, nr Plymouth.	Devonian	
Westgate Brick Co. Ltd Dewsbury Road, Wakefield, W. Yorks.	Middle Coal Measures shales	Common and engineering bricks.
Wheatly & Co. Ltd Springfield Tileries, Trent Vale, Stoke-on-Trent.	Etruria Marl	Floor tiles: quarries and acid resisting.
S. Wilkinson & Sons Ltd 1. Atlas Works, South Lane, Elland, Yorks.	Lower Coal Measures shales	Facing and engineering bricks.
2. Calder Works, Elland, Yorks.	Lower Coal Measures shales	
H. Williamson & Co. Ltd Broomfleet, Brough, N. Humberside.	'Keuper Marl'	Facing bricks, roofing tiles, and field drains.
Williamson Cliff Ltd Stamford, Lincs.	Upper Estuarine Series	Hand and machine made facing bricks and pavers.
The Withnell Brick & Terra Cotta Co. (1912) Ltd Abbey Village, nr Chorley, Lancs.	Coal Measures	
G. Woolliscroft & Son Ltd Stoke-on-Trent, Staffs.	Etruria Marl	Floor tiles and acid resisting tiles.
Yorkshire Brick Co. Ltd 1. Stairfoot Works, nr Barnsley, W. Yorks. 2. South Elmsall, nr Pontefract, W. Yorks.	Middle Coal Measures shales	Facing, common and engineering bricks.

b)

Beacon Hill Brick Co. Ltd, Corfe Mullen, Wimborne, Dorset.

Brick Division, Blue Circle Enterprises, Portland House, Stag Place, London.

Ensor (Sandbach) Ltd, Forge Fields, Wheelock, Sandbach, Cheshire.

Esk Manufacturing Co. Ltd, Dalston Road, Carlisle, Cumbria.

Kentish White Brick Co. Ltd, Greatness Farm Road, Sevenoaks, Kent.

Kirkforthar Brick Co. Ltd, Kirkforthar, Markinch, Fife.

Mansfield Standard Sand Co. Ltd, Sandhurst Avenue, Mansfield, Notts.

Midhurst Whites Ltd, The Common, Midhurst, west Sussex.

Ryarsh Brick Co. (Celcon Group), Ryarsh, West Malling, Kent. (incorporating Sevenoaks Brick Works Ltd., Greatness, Sevenoaks, Kent).

Stavely Lime Products, Buxton, Derbyshire.

GLOSSARY

Absorption	The process by which a liquid or gas is drawn into and tends to fill permeable pores in a porous solid body. As applied to ceramic products, the weight of water which can be absorbed by the ware, expressed as a percentage of the weight of the dry ware.
Adsorption	Taking up by physical or chemical forces of the molecules of gases, of dissolved substances or of liquids by the surfaces of solids or liquids with which they are in contact.
Air brick	A brick pierced to provide for ventilation.
Alluvium	A general term covering all detrital materials transported by flowing water and deposited in comparatively recent geological time as sorted or semi-sorted sediments in riverbeds, estuaries, flood plains, lakes, shores and mountain slope fans.
Alumina	The only stable anhydrous oxide of aluminium; Al_2O_3. When the compositions of silicate minerals are stated in terms of the component oxides, alumina is found to be important in such groups as the felspars, micas and clays.
Band	A thin stratum. Now used chiefly as part of the compound words Blackband, Clayband, Musselband etc. in Carboniferous terminology.
Bastard	Impure, e.g. bastard fireclay, bastard limestone.
Bing	A heap, e.g. a coal bing, A dirt bing. (Scottish).
Black coring	A condition usually resulting from the premature vitrification of the exterior of a ceramic body which prevents the oxidation of carbonaceous material, sulphur compounds etc., the interior remaining in a reduced state.
Blaes	Carbonaceous mudstones and shales of a blue-grey colour associated with coal seams and oil shales; brittle, but produce a crumbling mass on weathering which, when wetted, is plastic.
Bloating	The expanding or swelling of a ceramic shape during firing. Results in a defective ware and is generally caused by overfiring of black coring. The expansion of certain nonmetallic materials by heating until the exterior of the particle or pellet becomes sufficiently pyroplastic or melted to entrap gases generated in the interior by the decomposition of gas-producing compounds.
Bonding	The regular arrangement of bricks in a pattern for strength or decoration.

Boulder clay	Glacial drift that has not been subjected to the sorting action of water and therefore contains mixed particles ranging from boulders to clay sizes. The most widespread and distinctive of the glacial deposits left behind upon melting of an ice sheet; also called till.
Brick clay	An impure, mainly argillaceous sediment. In industry applied to any clay, loam or earth suitable for the manufacture of bricks or structural clay ware.
Brickearth	Strictly the term applies only to silty clays or loams of the Pleistocene period found in parts of the Thames and Kennet Valleys, Middlesex, East Anglia, the north of Kent, West Sussex and southern Hampshire. In practice often used to denote any material of an earthy nature suitable for making bricks.
Brick Slips	Thin pieces of brick specially moulded and fired or cut to match the headers and stretchers of ordinary brickwork. Used for example to cover concrete beams or stanchions in order to give the illusion of a continuous brick wall.
Brick-tiles (Mathematical tiles, mechanical tiles)	Tiles with one face moulded like the face or end of a brick. They were nailed to battens on a timber frame or bedded into plaster rendering over cobble stones or pebbles, and were then pointed to resemble bricks.
Calm	White or light coloured blaes. (Scottish).
Calmy	Of an argillaceous nature. (Scottish).
Cavity wall	A wall built of two adjacent vertical leaves of bricks or blocks, separated by an air space but linked by ties of galvanized wire or wrought iron.
Ceramic	Any of a class of inorganic, nonmetallic products which are subjected to a high temperature during manufacture or use.
Ceramic Industries	Industries which manufacture products from nonmetallic materials by heat treatment. These products include brick, tile, terra-cotta, sewer pipe, drain tile, lightweight aggregate, china, pottery, porcelain, (cement, plaster), glass, enamel, refractories, insulants, ceramic coatings etc.
Clamp	A stack of unburnt bricks fashioned into a temporary kiln and made ready for firing.
Clay-with-flints	A deposit of mixed chalk flints and clay in England that lies directly on the Chalk in many areas and is often seen in potholes or in pipes. It is normally ascribed to the effect of solution-weathering on the Chalk, but in many instances there may be an additional admixture of Tertiary material. Often erroneously applied to almost all clay-flint drift deposits that rest on the Chalk.
Compressive strength	The load per unit of area under which a block fails by shear or splitting.
Concrete bricks	Bricks moulded from cement, sand and aggregate. Unlike clay bricks they are not burnt in a kiln. They are used as common bricks in districts which lack clay or cheap fuel, but are rough to handle and easily chipped.
Crushing strength	The resistance which a body offers to vertical pressure placed upon it.The maximum load per unit area, applied at a specified rate, that a material will withstand before it fails.

Diagenesis	Any change occurring within sediments, subsequent to deposition and before complete lithification, that alters the mineral content and physical properties of the sediments.
Drying shrinkage	The reduction in size of a mass of shaped clay consequent upon drying in order to drive off pore and adsorbed water.
Efflorescence	White to grey soluble salt deposits which have a crystalline appearance that develop on the surface of ceramic ware after a period of exposure to the weather.
Engineering bricks	Dense bricks with high crushing strength and low porosity. They have been employed mostly for structures such as railway viaducts, bridges or large buildngs.
Extrudability	The ease of extruding a clay mixture through a die.
Facing bricks	Bricks selected for use on the exposed surface of a wall because of their superior appearance to common bricks.
Fakes	Laminated sandy shale (Scottish).
Fireclay	A clay that is high in alumina or silica; diffusion is not less than cone 19 (1515°C). Fireclays may be sedimentary or residual, plastic or nonplastic, are dominantly composed of kaolinite and are low in iron and alkalis. Classification is often imprecise and may be related to composition, refractoriness, use, associated with other materials etc., such as plastic fireclays, nonplastic fireclays, high alumina fireclay, siliceous fireclay, Coal Measures fireclay. Fireclay is plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of sufficient purity and refractoriness for use in commercial refractory products; (see "underclay").
Firing range	The range of firing temperature within which a ceramic composition develops properties which render it commercially useful.
Firing shrinkage	The decrease in size that usually occurs when ceramic ware is fired; it is usually expressed as a linear percentage contraction from the dry to the fired state. Firing shrinkage always occurs with shaped products containing plastic clay and often amounts to 5 or 6 per cent.
Flashing	Manipulation of the valence state of iron oxide to produce certain desired colours on clayware in the kiln; accomplished by reducing the air supply to the deficiency side of perfect combustion by either decreasing the air supply to the fuel or introducing excess fuel.
Flettons	Common and facing bricks made from the Lower Oxford Clay using the semi-dry process.
Fluvioglacial	Of, pertaining to, produced by, or resulting from combined glacial and river action. Fluvioglacial drift is transported by waters emanating from a glacier.
Flux	A substance or mixture which lowers the normal vitrifying temperature of a ceramic body or composition.
Fluxing	The development of the liquid phase in a ceramic body under heat treatment by the melting of low fusion components.

Frog	An indentation in the surface of a brick which reduces its weight, enables better mortar adhesion and in many cases helps to ease inherent stresses set up in the brick during firing. When it is laid "frog-up" the indentation must be filled with mortar by the bricklayer.
Glacial lake clay	Of, relating to, or coming from lakes deriving much or all of their water from the melting of a glacier.
Glazed bricks	Bricks with a shiny surface resulting from the application of a salt glaze during firing. Usually only one end and one face are glazed. Used in situations where easy cleaning or light-reflecting properties are important.
Green strength	The ability of a clay, after it has been rendered plastic by the addition of water and has been shaped, to retain that shape till it is dried.
Ion exchange	1) Refers to exchange reactions taking place at the solid-liquid interface between anions and cations held in unbalanced charges at or near the surface of the solid material and with ions present in the surrounding mobile phase. 2) Reversible exchange of ions contained in a crystal for different ions in solution without destruction of crystal structure or disturbance of electrical neutrality.
Interglacial	An age or time of comparatively warm or day climate between times of glaciation.
Lightweight expanded clay aggregate	A bloated clay aggregate made by the sudden heating of suitable clays either in a rotary kiln or less commonly on a sinter hearth. It is used as an aggregate and for making lightweight blocks and concrete.
Lime blowing	The falling away of small pieces from the face of a clay building brick as a result of the expansion (following hydration and carbonation by the atmosphere) of nodules of lime present in the fired brick.
Load-bearing	Designed to support loads in addition to their own weight.
Marl	A calcareous clay or argillaceous limestone, or intimate mixture of clay and carbonate particles.
Marl Slate	Calcareous shale; a variety of marl splitting into thin plates.
Metric bricks	Bricks made to metric dimensions, e.g. 215 x 107.5 x 65 mm.
Mullite	An aluminium silicate, $3Al_2O_3 . 2 SiO_2$, formed by heating other aluminium silicates to high temperature; the only stable member of the group. Used in refractories and in glass.
Paving bricks (Pavoir bricks)	Bricks of special composition and dimensions to serve as paving; designed for hard wear, low porosity and resistance to frost.
Permeability	The permeability of a porous solid is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter.
Periglacial	Refers to areas, conditions, processes and deposits adjacent to the margin of a glacier.

Plasticity	The ability of a clay-water mass at its maximum consistency to be shaped and to hold its shape after the forming forces are removed.
Plastic limit	The water content corresponding to an arbitrary limit between the plastic and the semi-solid states of consistency of a soil.
Quarry tile	A vitreous unglazed tile, usually 6 square inches or more in surface area and ½ to ¾ inch in thickness made by the extrusion and firing of natural clays and shales.
Raised beach	A shelf or terrace of shingle, gravel, sand and silt elevated above the present level of the lake or sea in which it was formed, and indicating a change in the relative level of land and water surface.
Refractoriness	The capacity of a material to resist high temperature. The pyrometric cone equivalent is a comparative value used to determine the refractoriness of a material.
Rendered brickwork	Brickwork covered externally by some variation of plaster. The finish may be stucco, roughcast, or pebble-dash.
Residual clay	A clay deposit produced by the decay of rock in situ; often by the removal of soluble material from the original substance.
Souring	Some clays and shales derive considerable benefit from being exposed to the action of atmospheric weathering. Although there is little evidence to prove that such souring is an advantage in subsequent stages of manufacture, it is often convenient to leave clay in stockpiles when extraction is seasonal.
Specials	Purpose-made bricks of non-standard shape, e.g Bullnose bricks.
Staffordshire Blue bricks	Dense hard bricks of slate-grey to deep purple colour made from Staffordshire shales. Intended for engineering or industrial purposes and damp-proof courses.
Stock-brick	Originally applied to any brick hand-made with the aid of a brick stock, a wooden board on which a frame was placed to contain the clay.
Structural clay products	Building material units which, when assembled in a structure, may be load-bearing or non-load-bearing.
Terracotta	Burnt clay of uniform and fine-textured quality. Can be glazed or unglazed, and may be moulded to provide architectural details.
Till	see Boulder clay (above).
Underclay	A bed of clay, in some cases highly siliceous, in many others highly aluminous, occurring immediately below a coal seam, and representing the soil in which the trees of the Carboniferous swamp forests were rooted. Many underclays are used as fireclays.
Vitrification	The progressive partial fusion of a clay, or of a body, as a result of a firing process. As vitrification proceeds the proportion of glossy bond increases and the apparent porosity of the fired product becomes progressively lower.

Vitrification range	Also known as the maturing range of a vitreous body; it is the temperature interval between the beginning of vitrification of a ceramic body and the temperature at which the body begins to become deformed.
Vitrified	That characteristic of a clay product resulting when the temperature in the kiln is sufficient to fuse all the grains and close all the pores of the clay, making the mass non-porous.

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