Cerâmica
Print version ISSN 0366-6913*On-line version* ISSN 1678-4553

Cerâmica vol.44 no.287-288 São Paulo May/June/July/Aug. 1998

http://dx.doi.org/10.1590/S0366-69131998000400002

The constitution, evaluation and ceramic properties of ball clays*

(Constituição avaliação e propriedades cerâmicas de "ball clays")

Ian Richard Wilson
Overseas Geological Services
ECC International Europe
John Keavy House, ST. Austell
Cornwall, PL25 4DJ, England

Abstract

Ball clay is a fine-grained highly plastic, mainly kaolinitic, sedimentary clay, the higher grades of which fire to a white or near white colour. The paper will review the origin of the term "Ball Clay" and the location and origins of several deposits with particular emphasis on the mineralogical, physical and rheological properties which make the clays so important in ceramics bodies. Particular attention will be paid to the well known bay clay deposits of Devon and Dorset in southwest England, which are mined by ECC International Europe and Watts Blake Bearne & Company PLC, and brief descriptions from elsewhere in the world of ball clays from the United States, Germany, Czech Republic, Thailand, Indonesia, Argentina and China. The evaluation of deposits will be covered along with a description of the main types of ball clay for ceramics with details of the mining, processing and blending techniques which are necessary to ensure long term consistency of products. A brief description in given of the ceramic properties of some Brazilian ball clays. The location of some ball clay deposits is shown in Fig. 1.

Resumo

"Ball clay"é uma argila sedimentar, essencialmente caulinítica, muito plástica e com uma granolometria muito fina; os tipos de melhor qualidade queimam com cor branca ou próxima à branca. Este artigo apresenta uma revisão do termo "Ball Clay" e a localização e origens de vários depósitos, com ênfase particular nas propriedades reológicas, mineralógicas e físicas que fazem essas argilas tão importantes para certos tipos de massas cerâmicas. Uma atenção especial é dedicada aos bens conhecidos depósitos de "ball clays" de Devon e Dorset no sudoeste da Inglaterra, os quais são minerados pela ECC International Europe e pela Watts Blake Bearne & Company PLC. Descrições sumárias são apresentadas de outros depósitos de "ball clays"nos Estados Unidos, Alemanha, República Tcheca, Tailândia, Indonésia, Argentina e China. A avaliação dos depósitos será feita conjuntamente com uma descrição dos principais tipos de "ball clays" para Cerâmica, com detalhes sobre a mineração, processamento e técnicas de mistura que são necessários para garantir uma constância de propriedades dos produtos ao longo do tempo. É feita uma breve descrição das propriedades cerâmicas de algumas “ball clays” brasileiras. A localização de alguns dos depósitos de “ball clays”é mostrada na Fig. 1.

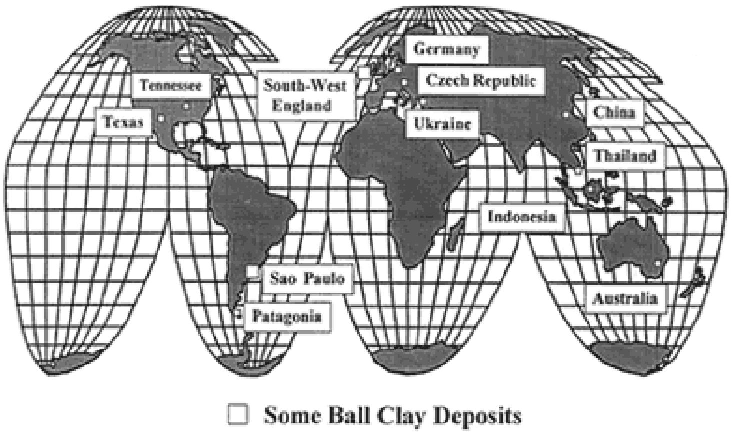

Figure 1: The location of some Ball Clay Deposits in the World.

WHAT IS BALL CLAY?

Ball clay is a fine-grained highly plastic, mainly kaolinitic, sedimentary clay, the higher grades of which fire to a white or near white colour in an oxidising atmosphere. They consist of varying proportions of kaolinite, mica and quartz, with small amounts of organic matter and other minerals, and are commercially values because they increase the workability and strength of various ceramic bodies and have white or near white firing characteristics.

The name "Ball clay" is believed to be derived from the original method of extraction, in which the clay was cut on the floors of open pits with approximately 25 cm cubes or "balls" weighing about 15-17 kgs. This original production method was carried out up to 50 years ago in England and is still the main method of mining in the island of Kalimantan (Indonesia) as illustrated in Fig. 2. Alternatively the name was derived from the digging implement formerly used called a tubal. Even to this day a power driven spade is used underground in Dorset to mine the very highest quality ball clay.

Figure 2: Ball Clay being mined with a tubal in Kalimantan Island, Indonesia.

Figure 2A: Ball Clay from the Kalimantan mine being stacked up ready for transportation.

A detailed description of the origins, properties and uses of English ball clays in ceramics was presented at the Brazilian Ceramic Congress in Recife in 1982 [1].

The term "Ball clay" has, therefore, no mineralogical significance, nor does it describe the age, properties or utilisation of the clay.

LOCATION OF BALL CLAY DEPOSITS

The location of some of the word's ball clay deposits is shown in Fig. 1. It is beyond the scope of this paper to include all known deposits of ball clay but an attempt will be made to describe some of the important areas for ball clay production. Particular attention will be paid to the English ball clays to demonstrate the procedures necessary from evaluation through to utilisation.

BALL CLAYS FROM SOUTHWEST ENGLAND

General

England is home to world-class deposits of ball clay and the consistency and high quality has allowed the United Kingdom to become a leading world exporter of ball clays. The importance of the industry was recognised in 1949 when the Ball Clay Standing Conference was constituted by the Minister of Town and County Planning. Because of the national importance and scarcity of ball clay, deposits from needless sterilisation by other forms of development. Three areas - the Bovey and Petrockstow Basins in north and south Devon respectively and the Wareham Basin in Dorset - were identified as being of strategic importance for production. United Kingdom sales of ball clay, by area, are shown in Table I for the years 1990-1993:

Table 1: UK Sales of ball clay for 1990-1993 (in tonnes) (source: British Ball Clay Producers'Federation).

Location	*1990*	*1991*	*1992*	*1993*
North Devon	125,966	-	116,819	126,876
South Devon	534,714	-	496,242	483,490
Dorset	144,852	-	131,317	135,465
Total	805,532	728,575	744,831	745,831

Since 1993 the production of ball clay from the United Kingdom has increased as the data in Table II demonstrates:

Table II: United Kingdom production of Ball Clay, 1991-95 (source: British Geological Survey, 1995).

Year	*1991*	*1992*	*1993*	*1994*	*1995*
Ball Clay *('000 tonnes)*	729	744	746	825	870

LOCATION OF ENGLISH BALL CLAYS

The location of the Devon and Dorset ball clay deposits in shown in Fig. 3. The commercial ball clay deposits are confined to three Tertiary basins in south-west England: the Bovey Basin of south Devon, the Petrockstow Basin in north Devon and the area around Wareham in south-east Dorset. Similar Tertiary clays occur in Northern Ireland but they are silty and have too high an iron content to be of commercial value as high quality ball clays.

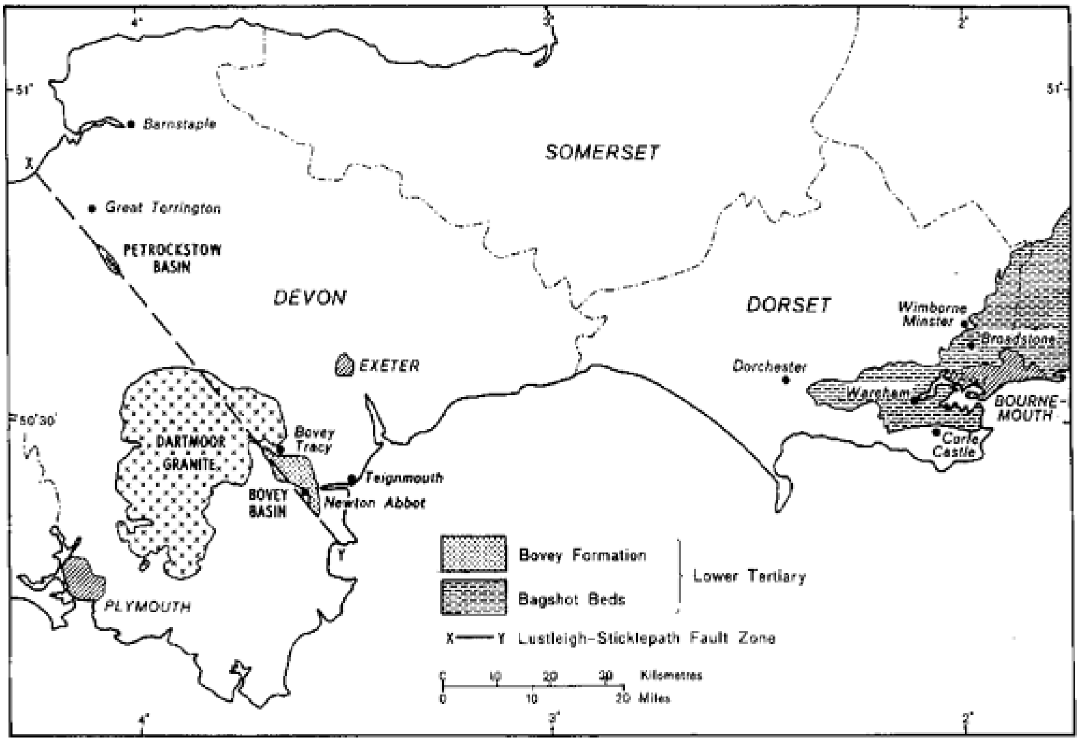

Figure 3: Location of ball clay deposits in southwest England.

Derivation and Deposition of the Ball Clays

The climate in the lower Tertiary period was sub-tropical and the very warm and wet conditions resulted in a deep weathering mantle on the Carboniferous and Devonian slates and the granite uplands. The feldspar minerals within the granite were changed to a moderately ordered kaolinite. The unweathered slates have a clay mineralogy dominated by illite and chlorite. The weathering process converted all the chlorite and some illite to a disordered kaolinite. Bristow [2] has demonstrated that the weathered Carboniferous slates preserved beneath the ball clays in North Devon show a complete gradation from fresh slate to a ball clay mineralogy.

Further movement and erosion along the Sticklepath-Lustleigh fault system in the mid-Tertiary period resulted in a large northwest-southeast trending valley. Sediments derived from the erosion of the thick weathering mantle were channelled into this valley by rivers. The coarser sands and gravels formed alluvial sheets or fans on the valley floor and the clay, silt and vegetation debris accumulated in the swamp-like lakes. A series of tectonic basins developed along the fault line giving rise to the south Devon Bovey Basin and the north Devon Petrockstow Basin. These tectonic basin were areas of crustal weakness which enabled the slow accumulation of ball clays, unconsolidated sands and lignites. Subsidence of the valley floor in the basin areas was probably linked to periods of earthquake activity and movement on the fault system. A Bovey Basin gravity survey recorded a maximum depth in excess of 1300 metres [3] : at Petrockstow a British Geological Survey borehole confirmed a maximum depth of approximately 750 metres [4]. These sediments have been dated by examining pollen samples and they range from upper Eocene to Middle Oligocene, 35 to 28 million years old [5].

The South Devon Bovey Basin

The Bovey Basin extends for approximately 11 km northwest-southeast and 6 km in an east-west direction (Fig. 4). A complex sedimentary history with sediments derived from different sources has been identified [6, 7]. The ball clay mineralogy comprises varying proportions of disordered or ordered kaolinite, illite and quartz. The ball clays containing a high content of ordered kaolinite were largely derived from weathered granite - these types of ball clay are often found in the upper levels of the sequence and may represent the products of unroofing and erosion of the Dartmoor granite. Those sediments containing disordered kaolinite and illite are probably derived from weathered slates.

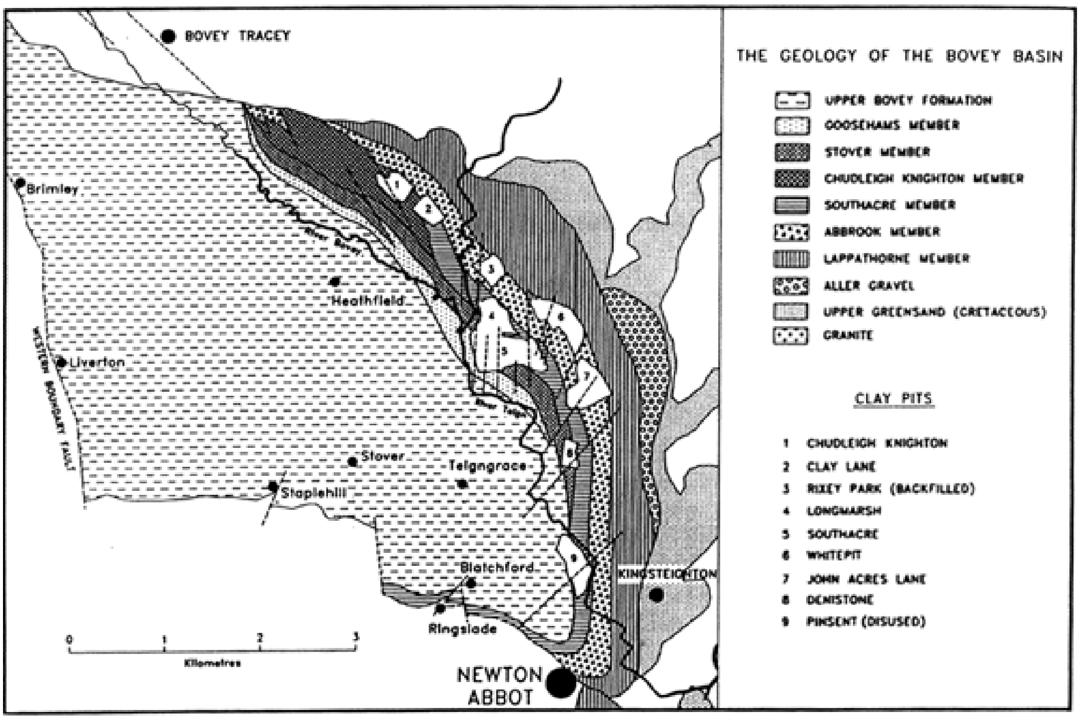

Figure 4: Stratigraphy of Bovey Basin, south Devon.

The geological sequence (Bovey Formation) has been sub-divided based on the clay, sand and lignite content and the clay mineralogy (Fig. 3). The sequence is a follows (Table III).

Table III: The Bovey Formation.

Geological Formation	*Type of Sediment*
Chudleigh Knighton Member	Occurs in the NE part of the basin and contains clays with a high content of ordered kaolinite. Some similarities with the Group 1 clays of the Southacre Member. Sandier towards the north.
Goosehams Member	Currently forms the top of the worked sequence in the eastern part of the basin. They clays are variably carbonaceous and in part resemble those found in the Southacre Member, but there can be a higher free quartz content and occasional sand horizons.
Stover Member	Contains abundant quartz-tourmaline sands and gravels in the southern and central parts of the basin. To the north the Stover Member becomes increasingly dominated by clays and lignites. The ball clay contain the Parkes seam which largely consists of ordered kaolinite derived totally from weathered granite.
Southacre Member	Contains a high proportion of lignites and lignitic clays - more carbonaceous. These fawn to brown Group 1 ball clays have a higher content of ordered kaolinite and little free quartz. They are traditionally known as Whiteware Clays.
Abbrook Member	Forms the base of the economic clay sequence the grey ball clays have a variable free quartz content, contain a higher proportion of illite than elsewhere in the sequence and are largely noncarbonaceous. The Abbrook Member contains Groups 2, 3 and 4 ball clays and the lower part yields the traditional Stoneware Type Clays.

A geological section across the eastern part of the Bovey Basin is shown in Fig. 5.

A typical view of a sequence from a ball clay pit in the Bovey Basin is shown in Fig. 6 exhibiting the wide range of working seams interbedded with lignites.

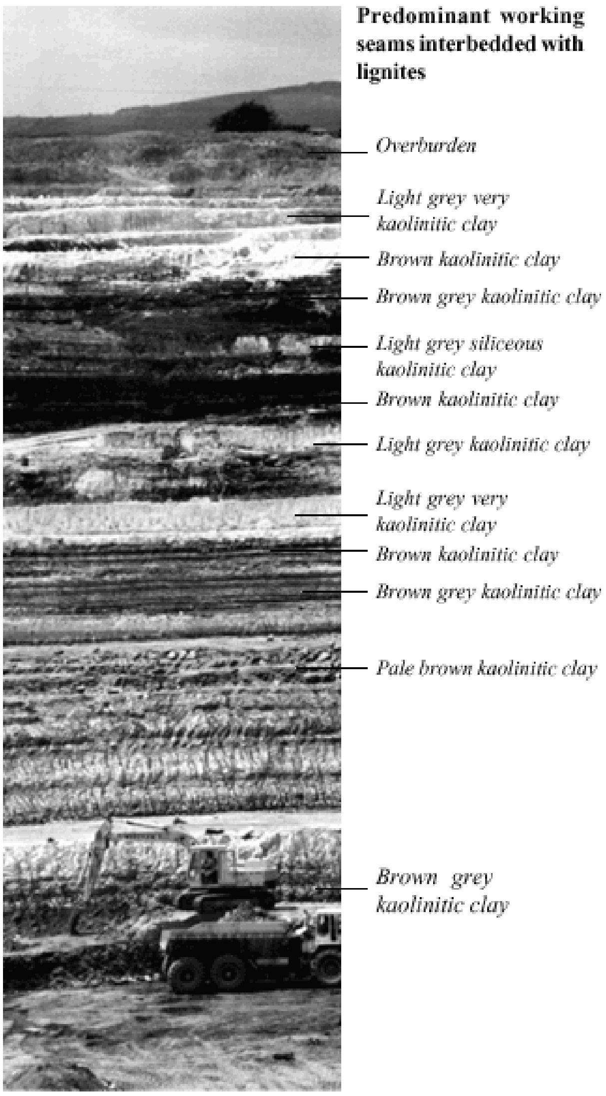

Figure 6: A typical south Devon Ball Clay pit face.

The North Devon Petrockstow Basin

The Petrockstow Basin is narrower and more elongate that the Bovey Basin being 6 km northwest-southeast by 1.5 km east-west.The basin is divided into a deep, axial trough and shallower, marginal shelves in the northeast and southern areas, which have been developed for clay extraction. The clay area is bounded by two north-westerly trending faults of the Sticklepath-Lustleigh fault zone (Fig. 7). Faulting divides the basin into a deep central trough with marginal shelf areas. In the centre of the trough, a hole drilled on the site of a small negative gravity anomaly proved a total thickness of 661 m of Tertiary sediments, overlying Upper Carboniferous strata. The sediments filling the axial trough consist largely of silts, sands and gravels, with only subordinate brown clays and lignites. On the marginal shelf areas coarse sediments are absent and ball clays with variable silt content and some lignite are dominat, but towards the central trough the quality of the clay rapidly deteriorates. The Petrockstow Basin is thought to be the relic of a river system which flowed northwards along the line of the Sticklepath fault zone, the coarse sediments being deposited along the central trough, with deposition of the ball clays taking place under the gentler conditions of a flood-plain environment.

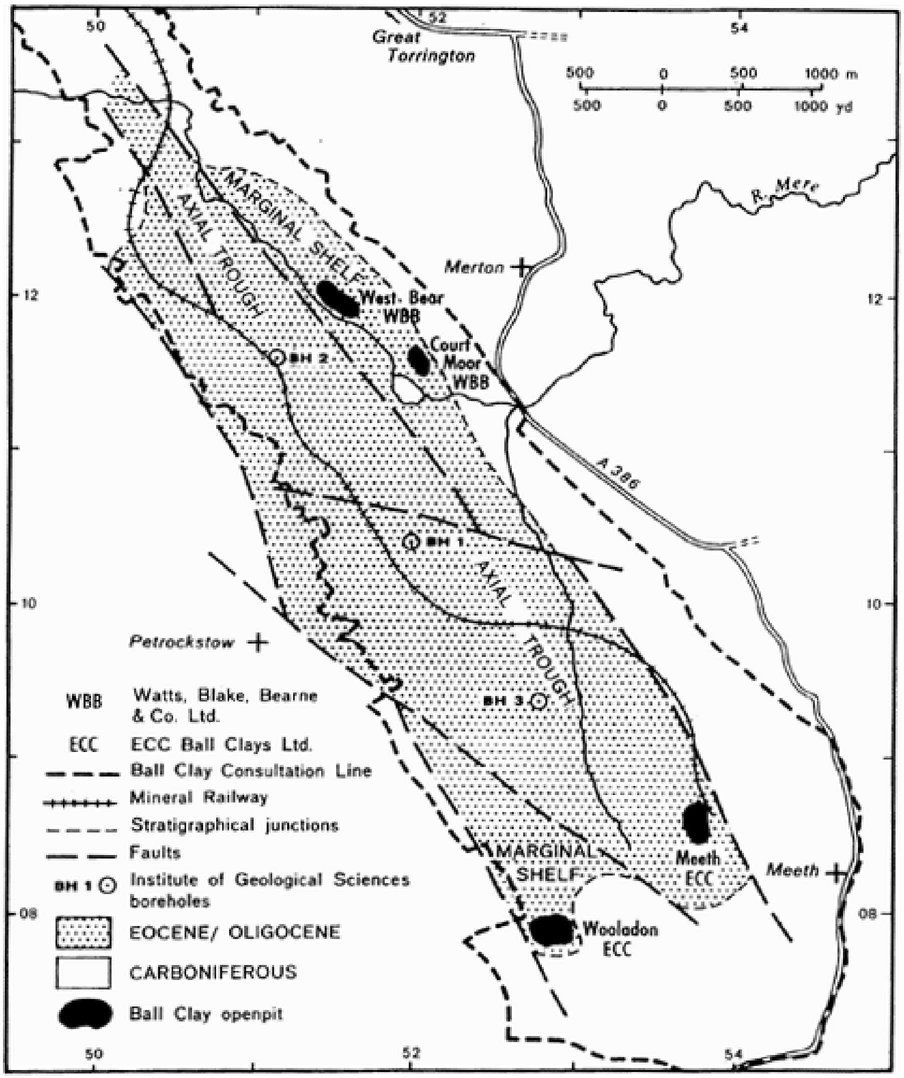

Figure 7: Geological map of the Petrockstow Basin, north Devon.

Wareham Basin

The Dorset ball clays in the Wareham Basin (Fig. 8) are formed from the erosion of Juarassic and Createaceous rocks under sub-tropical conditions. The clays were transported down meandering rivers to a large flood-plain. Here the clay-laden suspension mixed with acid swamp water causing sedimentation of the clay particles (by flocculation?). Dorset ball clays occur within the various clay sequences of the Poole Formation within the Brackelsham Group (Fig. 9) formerly known as the Bagshot beds and are of lower-mid Eocene in age. The sediments comprise interbedded sands, silts and clays deposited in a large flood-plain.

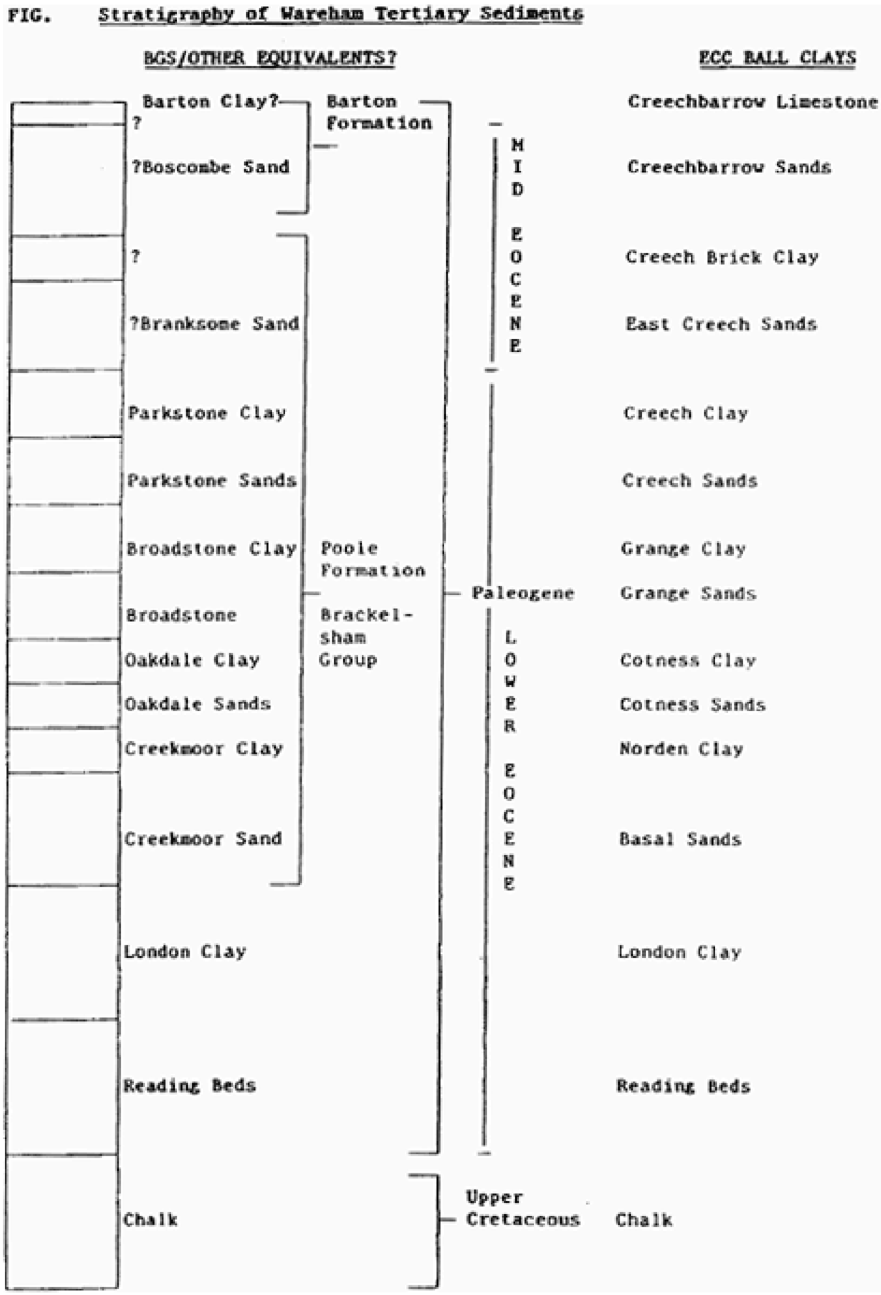

Figure 9: Stratigraphy of the Wareham Basin Tertiary Sediments, Dorset.

Dorset clays are fine grained, very plastic and exceptionally low in carbon content.

Geological Evaluation of Deposits

Both ***ECC International Europe*** - ***ECC Ball Clays*** (will be referred to as **ECC**) **and *WBB Devon Clay Ltd*** (*the operations in Devon of* ***Watts Blake Bearne & Co PLC*** - will be referred to as **WBB**) have carried out detailed exploration and, on a regular basis, carry out drilling for deposit evaluation and mine control purposes.

Despite the vast array of sophisticated geological, geochemical and geophysical exploration tools available today few have any real application to assist in the exploration for ball clay:

Exploration Methods

a. Geochemistry has little application as most ball clays are relatively inert and do not leachable or mobile trace elements which show up in stream or soil samples.

b. Geophysics can be defined into two types, first remote sensing from satellites or aircraft and second group systems. Remote sensing may well prove useful and essential in parts of the globe where the terrain is difficult or there are no maps. Also spectral analysing certain wavelengths of light, some are capable of identifying clay minerals where exposed at surface or where they affect vegetation. They also allow structural analysis to be carried out which may prove invaluable in defining fault zones and basins. Most importantly maps can be made from satellite imagery and air photographs.

Ground based geophysics may help identify whether a clay sequence or seam is present, or indicate its subsurface features/geometry (Seismic profiling. Gravity surveys can help define basins like Bovey and Petrockstow).

Whilst borehole geophysics and gamma logs have their uses it does not tell the user the clay quality or quantity.

c. Borehole Geophysics can assist in the exploration for stratified clay deposits and has advanced considerably with many slim hole systems now available. The main method used is the natural gamma logger. A probe is lowered down the hole which contains a scintillation counter which is extremely sensitive and picks up radioactive particles which is extremely sensitive and picks up radioactive particles which is extremely sensitive and picks up radioactive particles which occur naturally. In most sediments the isotope of Potash (K40) is present - the greater the clay content the greater the K40. Sands and lignites obviously give very low levels. Therefore a continuous recording of each borehole can be made (Fig. 10), which is more important for its signature than its actual radioactive count. It is in essence a geological finger-print with comparison of logs through the same sequence exhibiting similar patterns which can be utilised for correlation purposes in defining the stratigraphy and, sometimes, the structure.

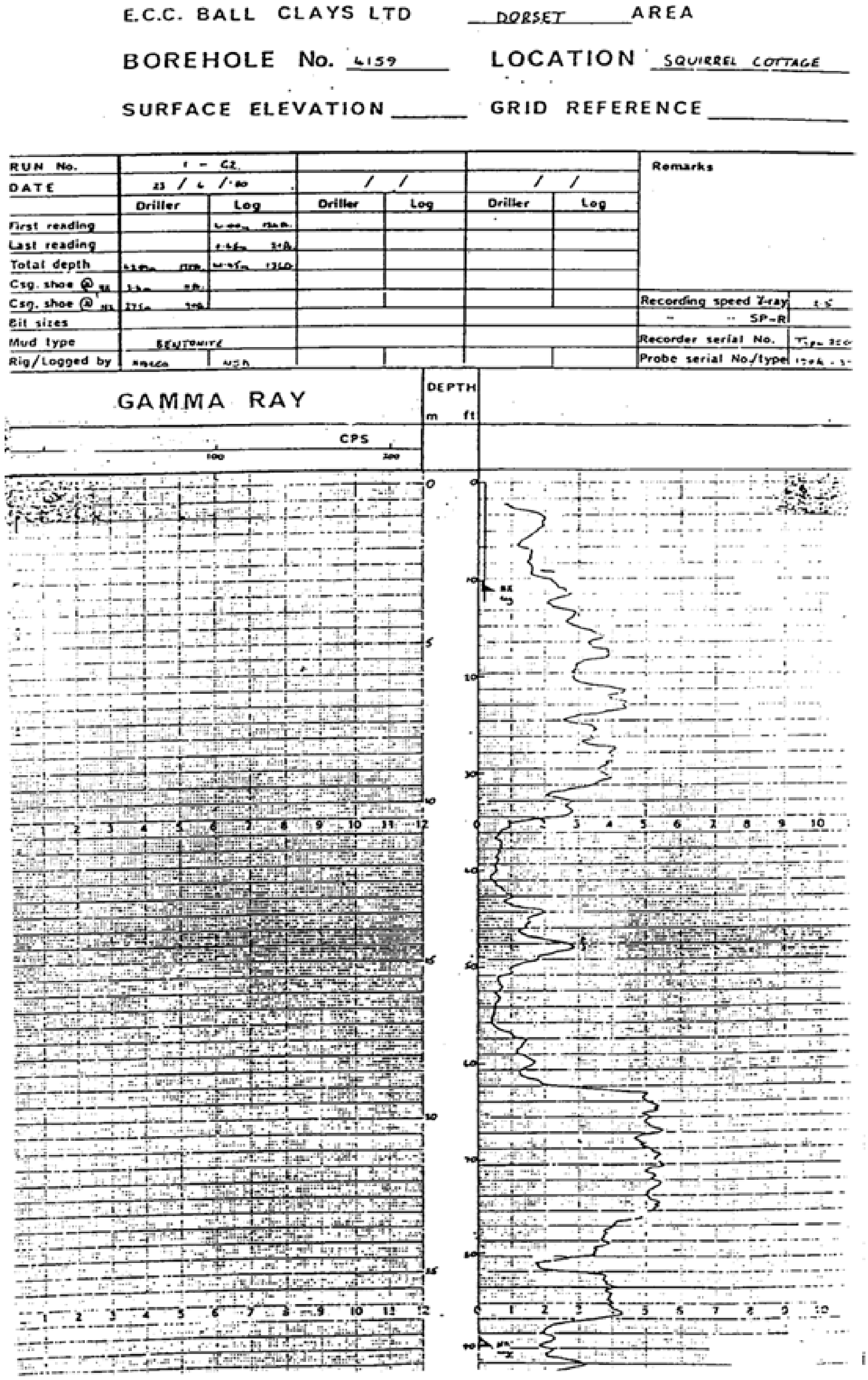

Figure 10: Gamma Ray Borehole log from a Dorset Borehole.

d. Drilling is the only satisfactory way to explore and develop ball clay deposits by obtaining representative samples regularly spaced in the seam and across the deposit. This can be achieved by core drilling (typical drill rig shown in Fig. 11), percussive shell and auger, flight auger, or by pitting and face samples. These are the only positive methods. Because ceramic test require large amounts of sample, and often clays are difficult to core drill, large diameter samples are desirable. In the U.K. "N" size (55 mm) or "H" size (75 mm) core are taken and have proved effective for evaluating clay deposits. ***ECC*** utilise the ***"Datamine"*** system for evaluating reserves and detailed plots are prepared (Fig. 12) from borehole information (a typical borehole print-out is shown in Fig. 13).

Figure 11: A Geological Exploration rig drilling for Ball Clay in Devon.

Figure 12: Computerised logging of pit geometry utilising borehole information.

Planning and Environmental Matters

The need for planning permission to work a mineral is a major hurdle to overcome in developing a mineral resource. The planning process is complex, frequently taking several years to prepare an application which it is hoped will prove successful. The planning process required description of the deposit, the need for the mineral, how it will be worked, the methods of working and removal of mineral, and importantly how the site will be restored at the end of the day. Recently, certain mineral developments have been required to produce an environmental assessment of their proposal which basically requires an existing audit of the environment at the site and surrounding area - these include assessments of geology, ecology, archaeology and landscape value of a site. Also details must be given of environmental protection and restoration. Having prepared all the relevant information a planning application is lodged with the mineral planning authority. At this stage the application is publicised, the public invited to comment and statutory or nominated consultees are given the application to comment on (bodies such as Nature Conservancy, English Heritage and Ministry of Agriculture). The planning authority collate and examine the responses and recommend to the elected representatives whether the scheme should be approved or not. If it is approved then a permission is issued with conditions which have to be met by the mineral developer. The whole process can take months as the information is exchanged, sought and clarified.

Summary of Explorations Stages

A brief summary of exploration activity would be as follows;

1. Geological Investigation based on market demand for internal and export markets.

2. Target areas selected, exploration permit acquired.

3. Drilling programme drawn up.

4. Limited objective drilling programme;

    4.1 To determine geology.

    4.2 Occurrence of ball clay seams (one hole per 20 hectares).

5. Intensive drilling programme - every 50 m our down to 20 m spacing if necessary.

    5.1 Determine detail for mine planning.

    5.2 Sufficient sample for laboratory assessment.

    5.3 Establish ceramic grade and continuity of quality (one hole per hectare - minimum).

6. Report, analyses, reserves. Bulk sampling and detailed laboratory investigation with trial samples to customers. Body work evaluation.

7. Planning permission: Public enquiry.

8. Working of pit.

9. Above all - a good return on investment.

Mineralogical Composition of Ball Clays

Ball clays, unlike china clays, generally cannot be economically refined after they have been excavated, and therefore the customer has to accept them as they are, with all the mineralogical components still present in the sediments. All the components are in a finely divided form, and occur as an intimate mixture which defies attempts at separation without the use of expensive and lengthy processes. The principal components of ball clays are disordered kaolinite, micaceous matter and quartz. The kaolinite components of ball clays of Devon is of the `b-axis disordered' type. A TEM of a typical ball clay (Fig. 14A) showing the disordered kaolinite is compared with a crystalline kaolinite derived from a Cornish granite (Fig. 14B). Various workers have suggested methods by which the degree of crystallinity of the kaolinite may be quantified. A degree of crystallinity of zero represents completely disordered kaolinite, whilst a degree of crystallinity of approximately 2 represents nearly perfectly formed kaolinite. For the south Devon clays, a range of values from approximately 0.1 to 0.9 has been obtained, whilst the range of values from the north Devon deposit is much narrower, ranging from less than 0.1 to 0.25 - 0.30. In addition of the structural disorder, isomorphous substitution is known to occur within the kaolinite lattice. The most common substitution which occurs is that of iron and magnesium replacing aluminium in the octahedral layer of the kaolinite which results in a charge inbalance which will affect certain other properties of the clay, for example its cation exchange capacity. Ball clays from both the Devon deposits contain substantial amounts of micaceous materials. A great many ideas have been put forward as to the exact nature of the micaceous matter, it having been variously described as illite, micromica, hydromica and hydro-muscovite. Its silica-alumina ratio and alkali content point to its being a hydro-muscovite. Its silica-alumina ratio and alkali content point to its being a hydro-muscovite, and this is borne out X-ray diffraction patterns being similar to muscovite.

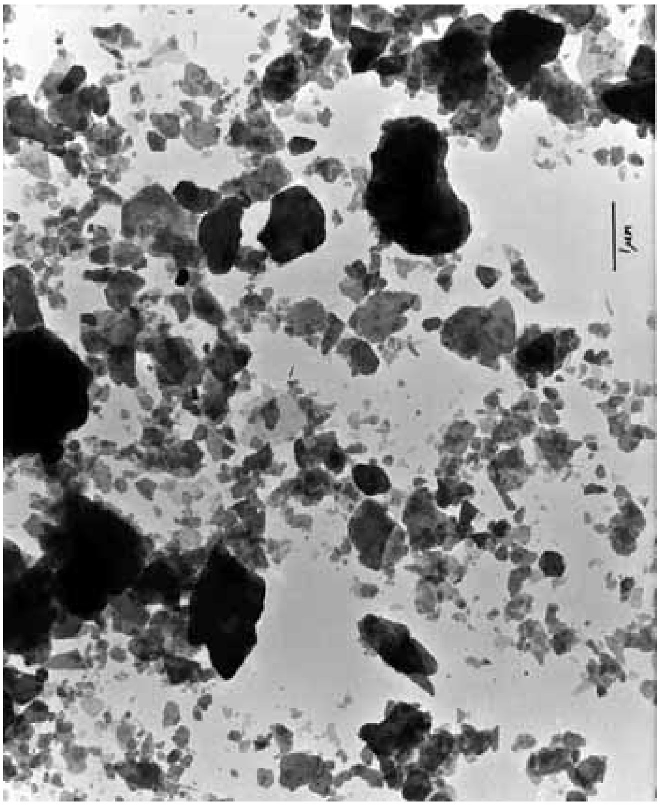

Figure 14A: TEM of a typical Devon Ball clay showing dis-ordered kaolin type.

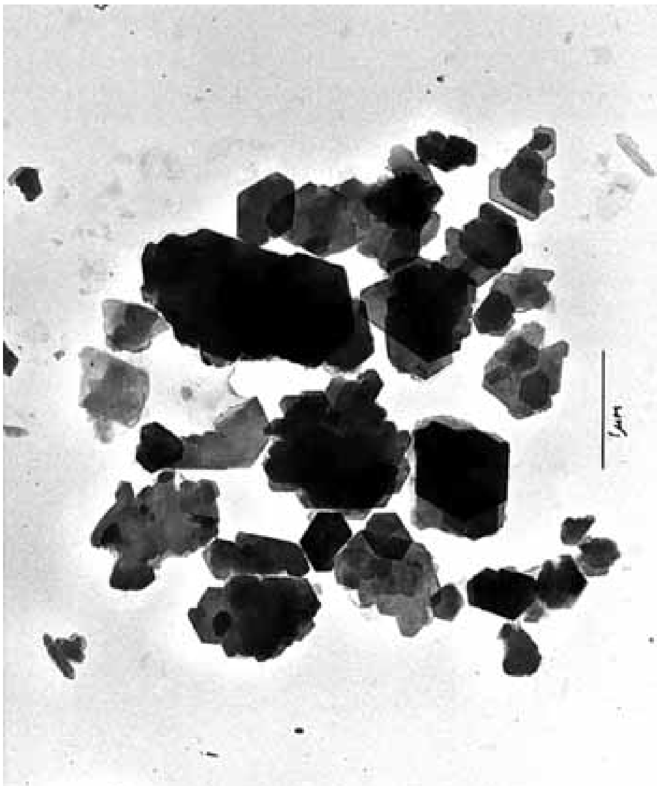

Figure 14B: TEM of a typical Cornish China clay showing crystallinity of kaolin.

The quartz found in the ball clays is not the same coarse angular material found in china clay matrix but a much finer water-worn material, as to be expected from the fact that it has been subjected to several different sequences of transportation. A significant characteristic of the fine quartz-sand in ball clays is the absence of tourmaline present in association with china clay quartz-sand.

Ball clays, being whole sediments, in a number of cases contain traces of other mineral substances classed as minor impurities or accessory minerals. The main ones are lignite, anatase, goethite, siderite, hematite, limonite and pyrite. The most significant of these, particularly in south Devon is lignite, which is a soft brownish coal-like substance formed by the compression of decayed peat beds sandwiched in between successive seams of clay. The type of sequences shown in Fig. 6 were common during Tertiary times and are known as V-P-L phases (vegetation-peat-lignite). During the Tertiary era there were a considerable number of these V-P-L phases, giving rise in places to numerous seams of lignite. In some parts of the Westerwald of West Germany as many as seven V-P-L phases can be identified as one cuts down through the clay bearing strata, The United Kingdom deposits are not so lignitic as those in the Westerwald, but are not completely free of its. In the Bovey Basin beds of lignite separate the Eocene sands from dark grey clays, above which a further seam of lignite underlies early Oligocene sandy clays, and all told there are four separate seams of lignite or lignitic material. Very little lignite occurs in the clay beds of the Petrockstow basin, but in the West Marland Beds there is one seam of black lignitic clay. The Wareham Beds (Dorset) do not contain much lignite, but there is evidence of one V-P-L phase during the period of deposition, which manifests itself as seam of lignite about one metre thick.

The composition of the lignite is: resins and tannins; fats and waxes; lignin and humic acids; cellulose and some residual mineral matter. An analysis of a typical lignite is given as Carbon, 46.8%; Hydrogen, 3.5%; Nitrogen, 0.5%; Sulphur, 3.2%; Oxygen, 18.3% and ash, 27.8%.

The carbonaceous material has a profound effect upon the green strength of clays. The modulus of rupture of a ball clay increases with increasing carbonaceous content matter. There are dangers though if the carbonaceous matter is too high and these will be mentioned later in the section on Fired Properties. Carbonaceous matter can also contribute to the problem of specking of ware, largely due to the relatively high amounts of ferruginous matter associated with the rather coarsely particulate (approximately 50 microns) lignite.

Montmorillonite present in ball clays increases the green strength, the plasticity and the dry contraction. In the firing of clays, the presence of montmorillonite increases the firing contraction and, because it contains iron, also has deleterious effect on the fired colour of the product. Probably the major effect of montmorillonite, however, is in ceramic casting slips where it materially affects the deflocculation behaviour of the clay resulting in a high deflocculant demand, low slip stability and high slip viscosity.

In summary the mineralogical composition of ball clays is tremendously variable from one area to another and within the same deposit. Whilst summarising such varied compositions is often meaningless the mineralogical composition of English ball clays is shown in Table IV.

Table IV : Mineralogical Compositions of Ball Clays, Including Siliceous Ball Clays [8].

Mineral (wt.%)	*Petrockstow Basin*	*Bovey Basin*	*Dorset*
Kaolinite	33-68	20-90	20-83
Quartz	15-48	0-60	5-60
Mica	0-22	0-40	0-30
Organic Matter	0-3	0-16	0-8

Detailed work carried out on the mineralogy of the -1/2 micron fraction shows some interesting relationships. The north Devon clays contain montmorillonite and the Dorset clays a significant amount of mixed layer mica-montmorillonite, the south Devon clays tend to be composed essentially of an illitic mica. Relating this to strength clays, it would seem that the montmorillonite of north Devon is more efficient weight for weight in bringing about a high strength clay than the mixed layer material of Dorset, and both the north Devon and Dorset materials are more effective than the illite mica of south Devon. It would appear that the cause of high strength clays lies in the mica-type minerals rather than the kaolinite. Thus a small amount of montmorillonite thoroughly dispersed may endow the whole clay with high strength and high plasticity while the same number of expanding layers in an illitic mica are less effective.

For general descriptive purposes a ball clay can therefore be regarded as an idealised ternary system consisting of kaolinite, mica and quartz. Thus, ternary composition diagrams can be prepared which show the general range of composition of Devon ball clays. Two such composition diagrams are shown in Fig. 15.

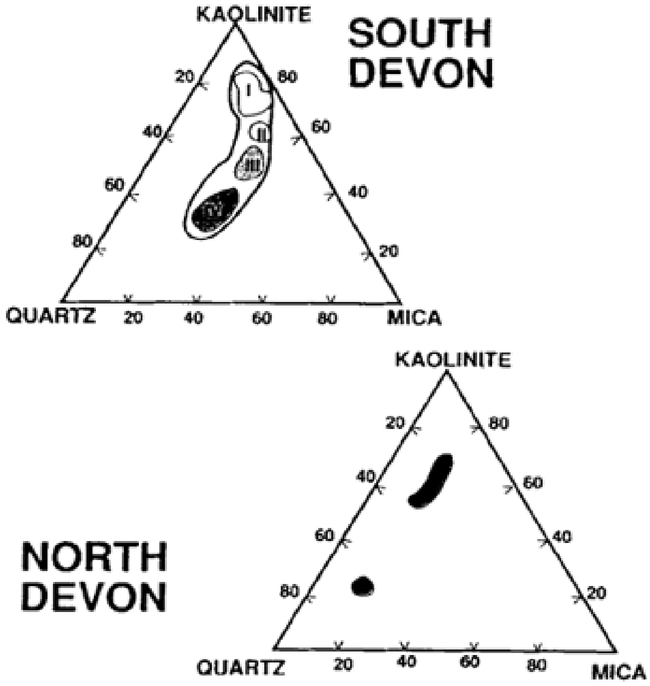

Figure 15: Mineral Compositions of the south and north Devon Ball Clays.

Physical and Rheological Properties

Compared with primary china clays, the United Kingdom ball clays contain a remarkably high proportion of extremely fine particles. The north Devon clays are the coarsest, with 20-30% finer than 0.2 microns and 45-60% finer than 1 micron.

The south Devon clays have between 25-40% of particles below 0.2 microns and between 65-90% finer than 1 micron. With such fine particle sizes, all the British ball clays exhibit high modulus of rupture, the south Devon and north Devon clays having modulus of rupture between 4.0 - 10.0 MNm^{-2} dried at 110 ^{o}C while Dorset clays have modulus of rupture between 4.5 - 7.5 MNm^{-2} (nowadays the MOR values are often given as MNm^{-2} or MPa (1 MPa = 1 MNm^2) whilst previously the results were given as kgf/cm^2 or lb/in^2 (lb/in^2 = MPa x 145 and kgf/cm^2 = MPa x 10.2).The south Devon black clays contain most disordered kaolinite, least hydro-muscovite and fairly high quantities of lignitic matter. They are inclined to lack plasticity, but they have good white fired colour. The south Devon blue clays are fat and very plastic with a high content of colloidal material. The south Devon semi-lean clays are higher in quartz and lower in carbonaceous matter content than the blue and black clays, while the high silica stoneware types of clay have a higher content of coarse particles and lower unfired modulus of rupture. The north Devon clays are all of the lean stoneware type but can be divided into two types. Some of the mica content of these clays consists of mixed-layer illite montmorillonite or leverrierite, and not type has a significant montmorillonite content, having very high strength and plasticity for a lean clay, while the other type is lower in its montmorillonite content and is lower in strength and plasticity. The Dorset clays do not differ so much from one another as do the Devon clays. They all have high modulus of rupture as shown above, and they have high plasticity, the exception being a very siliceous stoneware type clay which has a modulus of rupture of only 15 kgf/cm^2 at 80% relative humidity.

As might be expected from their mineralogical composition there is a considerable variation in the rheological behaviour of ball clays. The carbonaceous matter content and soluble salts content both affect the rheology. The black and blue south Devon clays exhibit fairly high fluidity and low deflocculant demand, due, so it seems to their humic acid content, this appearing to act as a buffer. Although the blue clays produce casting slips which are easily deflocculated, they tend to need high speed dispersion. The leaner south Devon clays tend to be very thixotropic, this property being made use of when blended clays are produced for slip casting. The north Devon clays, with their traces of mixed-layer-illite-montmorillonite tend to be less easy to deflocculate. The Dorset clays produce rather low fluidity slip with high thixotropy. It is these slip characteristics which commend them for use in sanitaryware recipes.

Fired Properties

The fired properties of ball clays vary in accordance with their chemical and mineralogical composition. To be able to estimate the probable fired properties of a given ball clay, it is not enough merely to know its chemical composition. It is also necessary to know how the various elements present are distributed as minerals - in other words, where the SiO_2, Al_2O_3, Fe_2O_3 and alkalis are known, the amount of each of these in combination as kaolinite, hydromuscovite and quartz must be established. Generally speaking, a ball clay with a high iron and titanium content will fire to a darker colour than one with a lower content of the two, but where some of the iron occurs as a substitution for aluminium in the lattice it has less effect on the fired colour than when free iron is present as limonite or siderite. The appearance of the raw clay before firing is no guide to its fired colour, as some of the blackest and darkest brown of the ball clays both from the English deposits and from the Westerwald fire white. Given proper firing conditions, the carbonaceous matter which is the cause of this dark colour in the raw clay should be all oxidised to carbon dioxide and eliminated from the body. The south Devon clay which of all clays from the Bovey Basin contains the highest amount of carbonaceous matter is also that which has the highest fired brightness. Where the carbonaceous matter occurs in particulate form and there are an excessive number of large particles of this material present in a body, care is needed during the firing operation to avoid the problems of what is known as "black coring". Large lignite particles may also give rise to the phenomenon of specking, but this is more often caused by the presence in the body of nodules or crystals of anatase, pyrites, marcasite or siderite. The south Devon black and dark brown clays also have the highest fires contraction and are of medium to good strength. The dark blue clays generally speaking do not fire so bright but show lower fired contraction. The semi-lean and lean clays again have lower fired brightness and also lower fired contraction. The north Devon clays fire to a brightness similar to that of the leaner south Devon clays. They have the lowest fired contractions of all the Devon clays. Dorset clays fire mostly from ivory to buff although one or two with higher iron contents fire to a russet shade. Strangely, one clay with a fairly high iron and titanium content has the best fired colour of all the Dorset clays. This is because the iron is bound up in the kaolinite lattice and not present in the free state. It has, however, the highest fired contraction, but is of good strength. Apart from this clay, almost all the other Dorset clays fire to a similar fired contraction of between 9 - 11% at 1180 ^oC. The only exception to this is the very lean stoneware clay which has a good fired colour but the lowest strength of all Dorset clays. It has, however, also the lowest fired contraction, even lower than the very lean north Devon clays. The presence of the finely divided micaceous material in both north Devon and Dorset clays appears to contribute greatly to their vitrification.

Classification of Ball Clays

WBB have proposed a classification of ball clays - for the south Devon area the clays have been divided into four groups;

South Devon (Bovey Basin) Ball clays.

Group 1. Clays in this group are noted for their excellent fired colour. They are dominantly kaolinitic with low mica and quartz contents and frequently contain appreciable quantities of carbonaceous matter. This carbonaceous matter can act as a protective colloid in the production of clay/water slips, and ensure a high fluidity and low alkali demand at optimum deflocculation. historically, clays from this group were termed "black" ball clays.

Group 2. The clays from this group, the so called "dark blue" clays, are again dominantly kaolinitic, but contain rather more micaceous mineral and quartz than the clays of Group 1. These clays also contain a certain amount of carbonaceous matter which is generally helpful in producing easily deflocculated casting slips. The clays of this group are amongst the strongest clays found in the South Devon deposit.

Group 3. The clays of this group, the so-called "light blue" clays, contain rather less kaolinite and higher proportions of mica and quartz than clays of the preceding two groups. Generally speaking, the carbon content of these clays is low (less than 0.5%). Clays in this group tend to be extremely thixotropic and use is made of this property in the production of blended clays intended for slip casting.

Group 4. The clays of this group are the most siliceous of the Devon clays. They are generally similar to the clays of Group 3, but with higher quartz contents and lower carbonaceous contents.

Fig. 16 shows the general form of the dilatometric curves of clays of each of these groups - the original basis of this classification. To a certain extent these groupings are arbitrary and, inevitably, some overlap occurs with some seams falling between adjacent groups.

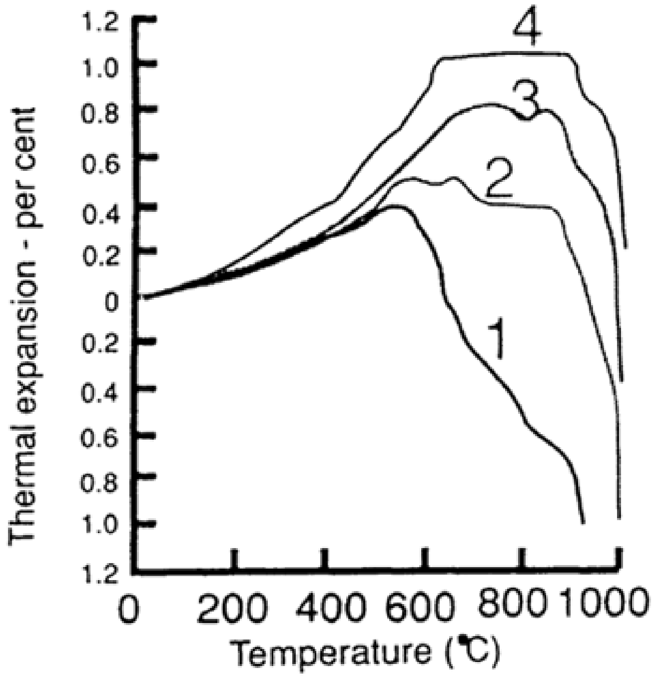

Figure 16: Characteristic thermal expansions of south Devon Ball Clays.

North Devon Ball Clays (Petrockstow Basin)

The north Devon clays are more difficult to classify, but basically there are two types:

Type 1. Contain appreciable quantities of montmorillonite resulting in high deflocculant demand values and relatively high slip viscosities.

Type 2. Contain relatively little montmorillonite, and consequently have lower deflocculant demand values and relatively high slip viscosities.

This relatively simple classification can, however, be confused somewhat by the presence of extremely siliceous types of clay found in association with both the above groups. Table V summarises the chemical analyses of clays typical of th above mentioned groups of south and north Devon ball clays.

Table V: Chemical and Mineralogical analyses of Typical Devon Ball Clays.

	CLASSIFICATION	SiO_2	TiO_2	Al_2O_3	Fe_2O	CaO	MgO	K_2O	Na_2O	Loss on Igniton	Kaolinite	Mica*	Quartz*	Carbonaceous Master*
SOUTH DEVON	GROUP I	48	0.9	34	1.0	0.2	0.3	1.6	0.2	13.8	70	16	8	3.2
	GROUP II	50	1.0	33	1.1	0.2	0.3	2.2	0.3	11.9	62	22	11	2.3
	GROUP III	55	1.3	31	1.0	0.2	0.3	2.5	0.3	8.4	54	25	18	<0.5
	GROUP IV	67	1.4	22	0.9	0.1	0.3	2.2	0.3	5.8	34	22	41	<0.3
NORTH DEVON	TYPE 1	59.5	1.4	27	1.0	0.2	0.5	2.4	0.4	76	44	25	28	0.4
	TYPE 2	58	1.3	28	1.0	0.2	0.4	2.5	0.4	8.2	45	26	25	0.7
	SILICEOUS	75	1.4	16	0.8	0.1	0.3	1.6	0.3	4.5	24	17	56	0.4

Physical Properties of Ball Clays

The principal physical characteristics of ball clays from the various production area in Devon are summarised in Table VI, and, generally the widest spectrum of properties is obtained from the south Devon clays, this being consistent with their origins and previously described mineralogy. Fig. 17 illustrates typical ball clay deflocculation curves of Type A and Type B referred to in Table VI. Figs. 18 and 19 illustrate fired colour and vitrification characteristic of the four main groups of south Devon clays.

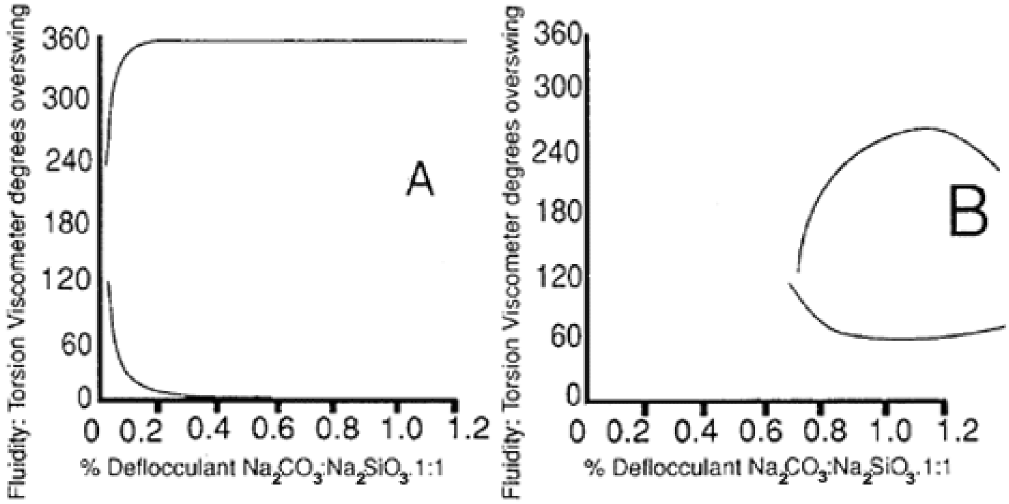

Figure 17: Deflocculation characteristics of English Ball clays from Devon.

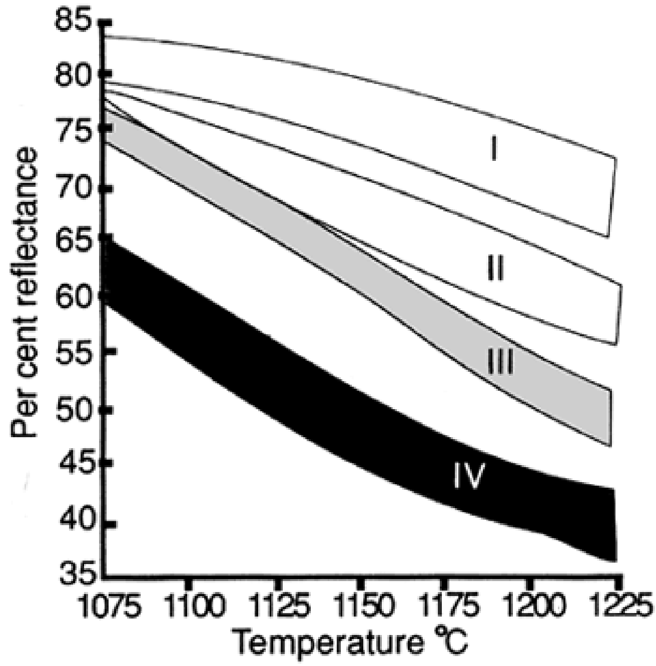

Figure 18: Fired colour/temperature relationship of south Devon Ball Clays.

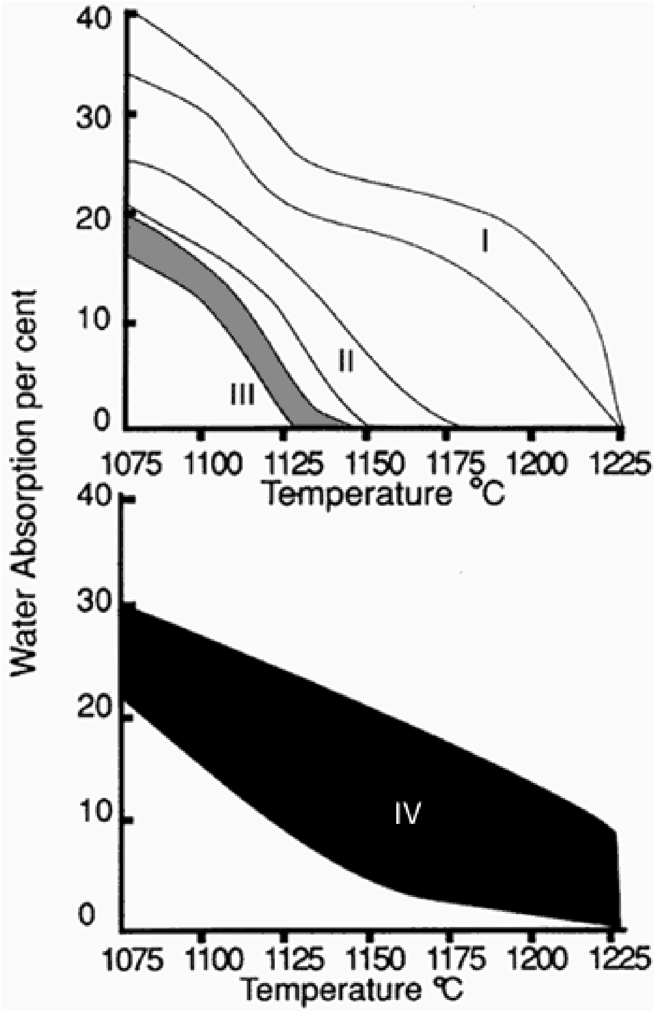

Figure 19: Vitrification characteristics of south Devon Ball Clays.

It is rare that any single clay can be found which completely satisfies all the manufacturing requirements of any one product. For this reason blended clays are produced which consist of many components from several individual seams, each selected in order to provide its own specific contribution to the physical properties of the final blend. Thus, it is possible to buy blends of south Devon Group 1, Group 2 and Group 3 clays, as well as blended clays containing components from the north Devon production areas.

Obviously different sets of criteria are important to the production of any specific blend. For example, a blended clay produced principally for use in the sanitaryware industry would have as its principal requirement an easily deflocculated, easily controlled, fast casting, stable, predictable slip, with high green strength, yet without excessive drying contraction which can result in cracking and distortion. Such a blend may be produced by the judicious mixing of the carbonaceous Group 1 south Devon clays with, for example, plastic Group 2 clays and some of the north Devon material to assist in vitrification. Undoubtedly, the most suitable clays for the production of this type of ware are blends of the north Devon clays. These have the additional advantage of remaining workable over a wide range of moisture content and are also eminently suitable for extrusion or large pieces which are to be subsequently finished by turning.

The ball clay producer, ever mindful of the changing circumstances throughout the industry due to the rapid advancement of technology, continues to improve the flexibility and control of each blend he produces, and additionally continues his researches for new blends to remain abreast of the steady improvements and modifications in production methods.

Production Processes

For ***ECC*** the production process is essentially the same in all three areas - North and South Devon and Dorset. Initially the raw component clays are selected and mined in the pit according to the recipe in question. A general view of a ball clay pit is shown in Fig. 20 with an underground mine entrance in Fig. 21. An intimate knowledge of the different clays in the deposit allows the pit operatives to select the different seams of clay with great accuracy with digging machines (Fig. 22). Nearly all the production is in open pit working, but ***ECC*** also operates four underground mining is high but it is believed that the quality benefits imparted by these hard-won materials are extremely worthwhile.

Figure 20: A general view of a Ball Clay pit from Devon.

Figure 21: An underground Ball Clay Mine entrance.

Figure 22: Accurate selection of Ball Clay seam in a typical pit.

The individual component clays are then transported to a central processing plant where they are stored in individual bays awaiting blending. Some blends contain clays from more than one production location. Each component clay undergoes a process of shredding (Fig. 23) before being mixed with others according to the blend recipe. Some very complex blends are made up from a number of sub-blends which are then mixed to ensure homogeneity (Fig. 24). The final blend is then stored separately ready for despatch. Most of the ball clays are sold in this shredded form, but facilities also exist for a range of further processing options, in particular drying, granulating, milling and classifying. For instance, shredded clays can be dried to a moisture level of 8%, and the, if required, broken down to a granular form. The most common form of further processing however is milling (Fig. 25). ***ECC*** operates six mills in which the clay is first dried and then disintegrated into powder. If required the powder clay may then be further refined by a process of microseparation. Most of the powder clay is then bagged, palletised and shrink-wrapped. Several stages of further beneficiation of ball clays are carried out at ***ECC's*** Caly Center in Stoke-on-Trent (Fig. 26). These involve the refining of the materials to a condition where they are ready-to-use by the customer without further processing. They clay is mixed with water to form a slurry which further processing. They clay is mixed with water to form a slurry which is passed through vibratory sieves and across electro-magnets. The clay slurry can then either be delivered to customers in ready-to-use form or spray dried to form a granulate. Spray dried granulate ***(Hypure)*** is extremely easy to turn into slurry or to blend with other materials in an extensive mixing process. A summary of the ball clay production process is shown in Fig. 27.

Figure 23: Primary shredding of the Ball Clay.

Figure 24: Blending of the various components in a mixer.

Figure 25: A typical milling facility to process Ball Clay.

Figure 26: The Clay Centre at Stoke-on-Trent.

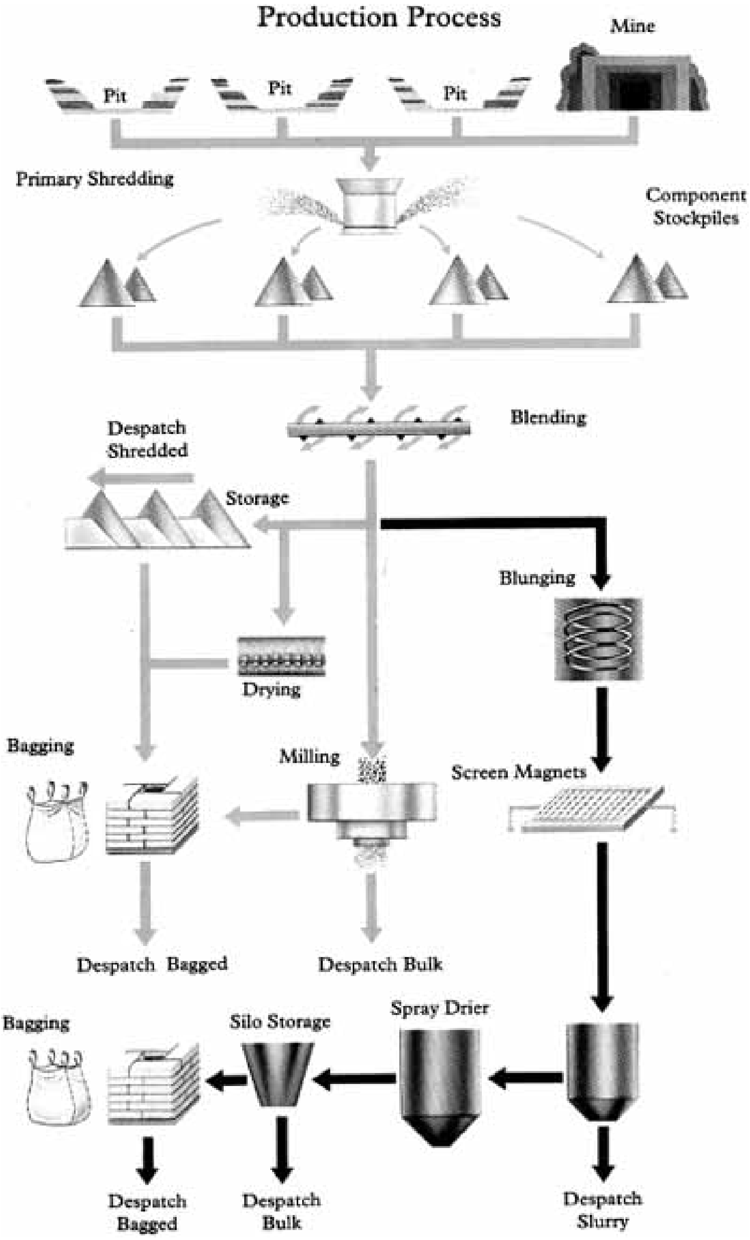

Figure 27: Summary of the Ball Clay Production Process.

Quality control is an important aspect of the production process and beings at the exploration stage continuing throughout the whole process by sampling clay at the pit face, before, during and after blending, and finally, prior to despatch. All testing takes place on a routine basis in the production control laboratories situated in each of the three production areas. Clays are tested for various characteristics such as chemical composition, modulus of rupture, rheological and fired properties. A standard system of testing is used and details of these tests were presented previously [8].

BALL CLAY PRODUCTS

A summary of some of the **ECC** ball clay products from Devon and Dorset is presented in Table VII and VIII respectively. There are a large number of products but the main types may be summarised as follows (Table IX):

Table IX: Main Types of Ball Clays

Type of Ball Clay	Main properties	Utilisation
HYCAST	Good fluid properties	Sanitaryware
HYWHITE	High fired brightness	Tableware
HYMOD	High strength	Tiles, electrical porcelain
HYPLAS	Strong and plastic-siliceous	Tiles, electrical porcelain

WBB Devon Clays Ltd produce a wide range of refined, composite and standard ball clay blends along with a range of clays based on the Groups 1 to 4. A summary of their product range from Devon is shown in Table X.

BALL CLAY UTILISATION

Tableware

The **ECC International Europe** tableware ball clay range consists of seven key products - ***Hyswite Astral, Hywite Superb, Hywite Magnum, Hymod Blue, Hymod Prima, Hyplas 64 and Hypure Sigma.*** The key characteristics of the seven products are fired colour, strength and plasticity and fluidity. The range is suitable for all types of tableware and most production processes including plastic making, slip casting, pressure casting, dust pressing and ram pressing. Table XI summarises the data for the seven products with details of typical recipes for Earthenware, Fine stoneware, Hotelware and Porcelain.

Table XI: The ECC International Europe tableware ball clay range.

The range *The ECC International Europe tableware ball clay range consists of seven key products*

		Hywite Astral	Hywite Superb	Hywite Magnum	Hymod Blue	Hyplas	Hyplas 64	Hypure Sigma
Typical data: *The principal properties relevant to tableware production are:*								
Fe_2O_3	mass %	1.2	1.1	1.2	1.4	1.4	1.0	1.1
TiO_2	mass %	0.9	0.9	0.9	1.0	1.2	1.6	0.9
K_2O	mass %	1.9	1.8	2.0	3.2	3.1	2.1	2.1
< 2 micron	mass %	85	84	87	89	88	75	86
< 1 micron	mass %	75	75	79	79	79	65	78
Casting concentration	mass % mass % Solids	61.5	65	62.5	60.5	61.5	64.5	62
MOR dried at 110 °C	MNm^{-2}	10.0	5.5	7.5	8.0	8.0	8.5	10.7
Absorption 1120 °C	%	8.5	11.0	9.5	4.0	4.0	7.0	10.9
Absorption 1180 °C	%	6.0	6.5	5.5	2.5	2.5	4.0	4.9
Brightness 1120 °C	%	74	78	76	64	62	62	78
Brightness 1180 °C	%	67	72	70	57	54	54	70
Contraction 1120 °C	%	10.5	11.8	12.0	11.5	11.5	7.8	11.2
Contraction 1180 °C	%	12.0	14.0	14.0	12.2	12.5	9.0	12.5
Key features *The key chacacteristica of the seven products are:*								
Fired colour		•	•	•	•	•	•	•
Strenght/ plasticity		•	•	•	•	•	•	•
Fluidity		•	•	•	•	•	•	•
Applications *The ECCI Europe tableware ball clay range is suitable for all types of tableware and most production processes*								
Plastic making		•	•	•	•	•	•	
Slip casting			•	•			•	•
Pressure casting			•	•			•	•
Dust pressing		•	•	•	•	•	•	•
Ram pressing		•	•	•	•	•	•	

RECIPE	
Earthenware 1	
Superb/Magnum	mass % 25
China clay	mass % 28
Calcined flint/Quartz	mass % 35
Flux	mass % 12
Tradicional English earthenware body	

RECIPE	
Earthenware 2	
Blue/64	mass % 15
China clay	mass % 35
Calcined flint/Quartz	mass % 36
Flux	mass % 14
Extra white English earthenware body	

RECIPE	
Fine atoneware	
64	mass % 40
China clay	mass % 10
Pegmatite	mass % 50
Vitrified low colour body	

RECIPE	
Alumina Hotelware	
Prima	mass % 6
Magnum	mass % 11
China clay	mass % 24
Alumina	mass % 16
Quartz	mass % 27
Nepheline syentie	mass % 16
Strong hotel porcelain	

RECIPE	
Alumina Hotelware	
Super magnum 64	mass % 10
China clay	mass % 30
Pegmatite	mass % 25
Alumina	mass % 35
Very strong white porcelain	

RECIPE	
Hard Porcelain	
Astral/Sigma	mass % 0-5
China clay	mass % 50-55
Pegmatite	mass % 45
European type reduction fired body	

Sanitaryware

The **ECC International Europe** sanitaryware ball clay range consists of four key products - ***Hycast Classic, Hycast Rapide and Hycast Mega.*** Table XII shows the typical data for the clays with key characteristics and applications shown. Some typical recipes for various end uses are also shown.

Table XII: The ECC International Europe sanitaryware ball clay range.

The range *The ECC International Europe tableware ball clay range consists of seven key products*

		HYCAST CLASSIC	HYCAST VC	HYCAST RAPIDE	HYCAST MEGA
Typical data: *The principal properties relevant to sanitaryware production are:*					
SiO_2	mass %	56	53	55	55
K_2O	mass %	2.2	2.0	1.6	1.8
LOI	mass %	10.7	12.2	12.0	11.7
Carbon	mass %	1.5	2.2	2.0	1.9
> 125 micron	mass %	0.8	1.5	2.0	1.7
< 1 micron	mass %	66	69	60	62
< 0.5 micron	mass %	55	56	45	48
Casting concentration	mass % solids	66.5	66.5	70.0	69.0
Deflocculant demand	% for 0.7 Pa.s	0.4	0.8	0.5	0.5
MOR dried at 110 °C	MNm^{-2}	7.5	5.5	3.5	4.5

Key features *The key chacacteristics of the four products are:*

	PLASTIC STRONG	GENERAL PURPOSE	FAST CASTING	DESIGNED FOR PRESSURE CASTING
Applications *The ECCI Europe sanitaryware ball clay range is suitable for most types of sanitaryware and most production processes*				
Bench casting	•	•		
Battery casting	•	•		
Low/medium pressure casting	•	•	•	
High pressure casting		•	•	
Vitreous	•	•	•	•
Fine fireclay	•	•		

RECIPE		
CLASSIC	mass %	25.0
China clay	mass %	28.5
Non-plastics	mass %	46.5
Body properties		
Slip density	g/l	1820
Viscosity	Pa.s.	0.6
V 60	Pa.s.	6
Time for 8 mm cast thickness	min	60
Dry strength	MPa	3.5

RECIPE		
RAPIDE	mass %	25.0
China clay	mass %	28.5
Non-plastics	mass %	46.5
Body properties		
Slip density	g/l	1825
Viscosity	Pa.s.	0.6
V 60	Pa.s.	6
Time for 8 mm cast thickness	min	30
Dry strength	MPa	2.3

RECIPE		
VC	mass %	25.0
China clay	mass %	28.5
Non-plastics	mass %	46.5
Body properties		
Slip density	g/l	1820
Viscosity	Pa.s.	0.6
V 60	Pa.s.	6
Time for 8 mm cast thickness	min	45
Dry strength	MPa	3.1

RECIPE		
MEGA	mass %	25.0
China clay	mass %	28.5
Non-plastics	mass %	46.5
Body properties		
Slip density	g/l	1820
Viscosity	Pa.s.	0.6
V 60	Pa.s.	6
Time for 8 mm cast thickness	min	38
Dry strength	MPa	2.6

Summary of Producers

The largest producer of ball clay in the UK is **WBB Devon Clays** which operates seven open pits and two mines in the Bovey Basin and two open pits in the Petrockstow Basin. The company produces about 500,000 tpa from these two deposits. Around 200,000 tonnes of production is used in sanitaryware applications, including some 135,000 tpa of ***Sanblend***. Blended specifically for the sanitaryware industry, the series includes ***Sanblend 75***, the world's first refined ball clay. Over 80% of **WBB Devon Clays'** products are exported and world-wide demand continue to grow. To meet this increasing demand the company is planning to integrate its south Devon operations to form a single pit, thus allowing the efficient extraction of higher levels of ball clay. This expansion will be achieved by close cooperation with local planning authorities and environmental bodies [9].

ECC International Europe Ball Clays produces approximately 330,000 tpa from its three deposits. Almost 95% of the production is sold to the ceramics industry. New products are fast being developed to meet the increasing demand for high quality and consistency.

BALL CLAYS FROM THE WESTERWALD, GERMANY

General Geology

Clays are mined throughout Germany but by far the most important regions for the production of plastic clays is the Westerwald region. The Westerwald region is situated between Frankfurt and Bonn (Fig. 28) and the main area of the basin is divided into a number of topographic and generic basins which are controlled bye earlier fault patterns. The nature and geology of the clays the Westerwald region differs from those found in the UF, in that the structural geology is simpler and clay more variable in their content (as demonstrated by the mineralogy in Fig. 29). Clay bearing sequences were laid down in subsidence hollows in the Tertiary period, some 25 - 45 my ago. The deposits comprise fine grained clays, largely disordered kaolinite, together with sand, silt and other detritus derived from the Devonian strata. The clays were laid down in phases, the first being a period of sandy outwash fan deposition, with occasional lacustrine interludes. The more complex second phase followed which occurred over a much wider area leading to deposition of clays ranging from coarse sediments to fine grained plastic clays. Volcanic activity commenced towards the end of the second phase, and the subsequent weathering of the mainly basaltic lavas dramatically increased the iron content of the clays. The clays deposited during the volcanic episode are characterised by high iron contents, the highest of which impart a clear red colour to the fired body. During the final phase of sedimentation grey clays of lower iron content are predominant. However the presence of small amounts of montmorillonite in these final phase clays still indicates some volcanic influence.

Figure 28: Location of the Westerwald Ball Clay area, Germany.

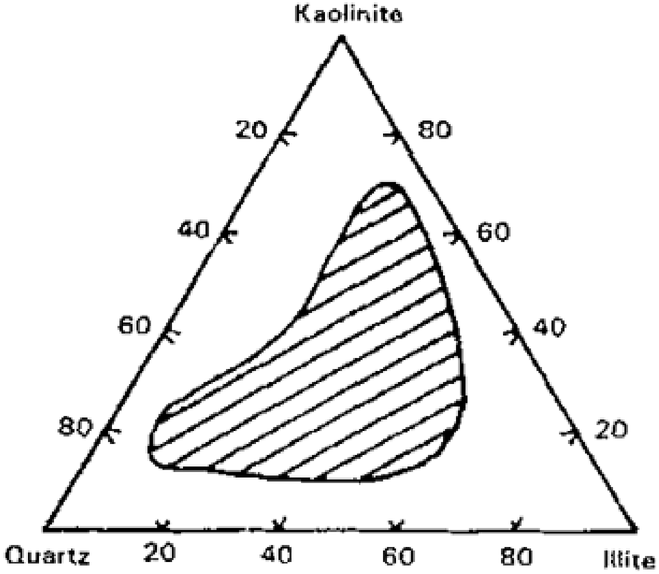

Figure 29: Ternary composition of the Westerwald Ball Clays.

A Major Producer - WBB's Fuchs-Ton

The Italian floor tile market accounts for over 30% of Fuchs'Westeerwald ball clay sales, and whilst the weakness of the Italian Lira since September 1992 has boosted the already substantial export sales of Italian ceramic tile customers, it has also generated strong pressures on the pricing of imported Westerwald ball clay. This pressure has been exacerbated by increasing imports of competitively priced Ukrainian and French ball clays. Mainly as a result of these pressures, Fuchs lost some important customers at the end of 1993. Whilst sales tonnages in Italy recovered during the year, Fuchs were unable to increase prices in Italy in line with production costs in Germany.

In the German domestic market for Westerwald ball clays, demand from Fuchs'high quality facing-brick customers was strong, but demand weakened from their ceramic drainage pipe customers. Demand from the domestic floor tile sector also weakened due, principally, to increased imports, especially from Italy. Although exports to Belgium and the Netherlands continue to grow, Fuchs' ball clay sales tonnages in 1994 fell by 1% to about 1.07 million tonnes.

In 1994, Fuchs-Ton's substantial ceramic body preparation busines in the Westerwald had to contend with the loss of a number of local ornamentalware customers, who went out of business due to the recession in Germany and increasing imports of low priced products from countries such as Portugal. Nevertheless, some of the surviving companies have performed very strongly, enabling ceramic body sales tonnage to be maintained at about 105,000 tonnes.

The total turnover of the on-going Westerwald ball clay and ceramic body businesses in 1994 was unchanged from the pervious year at DM63 million whilst margins fell about 1.5%.

WBB acuire MPR

In 1994 Fuchs-Ton completed the acquisition on the 1st October of Martin & Pagenstecher Rohstoffbetriebe ("MPR). MPR is the third largest producer of ball clays in the Westerwald whose sales tonnage in 1994 was almost 550,000 tonnes. It has reserves and operations largely complementary to those of the existing Fuchs-Ton business. The sales of MPR in the year ended 30th September, 1994 were approximately £7.5 million, and the pre-tax profit, before exceptional items, was approximatly £0.7 million. **WWB** HAS Significantly added to its reserves of Westerwald ball clay by this acquisition which strengthens its leading market position already enjoyed by Fuchs-Ton - the company now have a wide range of ball clays available and the business is already benefiting from the application of the group's technology.

Seilitz-Lothain, Fuchs-Ton's kaolin and ball clay operation near Meissen (formerly East Germany) which was acquired in 1990, had a very successful year in 1994, with sales tonnages up more than 40% to almost 80,000 tonnes resulting in a substantial increase in profitability.

Products

Fuchs-Ton produce plastic clays from the westerwald, Vordereifel and Pfaz regions of Germany. A large number of grades of ball clay are prepared on the basis of their fired colour - white-light grey, light grey-light cream, yellow and light red-dark red. These colours are largely dependent on the iron values with titania levels being much the same in all types of clay. A summary of the Plastic Clays is shown in Table XIII along with kaolinitic clays from elsewhere in Germany and plastic clays from the small operation of ***Pornon & Cie*** in the Allier region of France (40,000 tpa).

Fuchs-Ton also produce in Germany a plastic body, crumble body, dry powdered body, spray-dried body and a casting slip by bulk container.

U.S.A. BALL CLAYS

Ball clays of the U.S.A. are found in Kenthcky and Tennessee (Eocene Age) and in Texas (Lower Eocene Wilcox Group). The total production is around 1 million tonnes and the main companies involved are ***Kentucky-Tennessee Clay Company*** and ***United Clays Inc (a subsidiary of Watts Blake & Bearne PLC).***

The prime market in the USA for ball clay is the whiteware industry, with dinnerware and pottery, wall and floor tiles and sanitaryware market sectors dominating. Significant quantities are also used to produce refractories, tableware, electrical porcelain and glazes, and in total these applications account for more than 70% of domestically produced material. There has also been an increase in the amount of ball clay consumed in the fiberglass industry and also in insulating fireboard as the amount of asbestos used decreases. This is owing to ball clay's intrinsic properties as a fire retardant and filler [13].

Kentucky-Tennessee operates from active mines in Kentucky, Tennessee and Mississippi and has four processing plants at Mayfield, Kentucky; Gleason, Tennessee; Whitlock Tennessee; and Sledge, Mississippi. Approximately over 500,000 tpa is produced with over 50 different blends to suit specific customers'requirements.

United Clays Inc (WBB) produce 400,000 tpa of ball clay and soapstone from their operations in the USA. The ball clay is mined in Indiana, Mississippi, Tennessee and Texas. The growing Mexican ceramics markets became increasingly important for ***United Clays*** during 1994. They are only producer of Texas ball clays which are particularly well located to serve both the Texas and Mexican ceramic tile markets. In the early part of 1994 a new grade of Texas ball clay for ceramic wall tile manufacture was successfully introduced and, achieved substantial sales during the year, helping total Texas ball clay and soapstone sales tonnages to increase by 16%. The Mexican sanitaryware and dinnerware industries are important markets for Tennessee ball clays. During the early part 1994, pilot plant production of refined ball clay noodles for this market was successfully tested by a leading Mexican sanitaryware customer, as a result of which the pilot plant was scaled ut to satisfy sales, currently running at the rate of 25,000 tpa. ***United clays*** are the only US producers of refined ball clay noodles, and the introduction of this product has further enhanced their technical reputation.

The greater part of US ball clay sales to the domestic sanitaryware industry is supplied in the form of refined slurry, of which ***United Clays*** is a leading producer. Slurry sales form the Gleason plant in Tennessee continued to grow in 1994.

The range of ball clays produced in the USA by ***United Clays*** is shown in Table XIV.

CZECH REPUBLIC BALL CLAYS

The areas for ball clay production in the Czech Republic are shown in Fig. 30. There are three main types of ball clays ("tone" clays) exploited in the Czech Republic as follows;

a. White burning clays (white firing).

b. Ball Clays.

c. Refractory Clays.

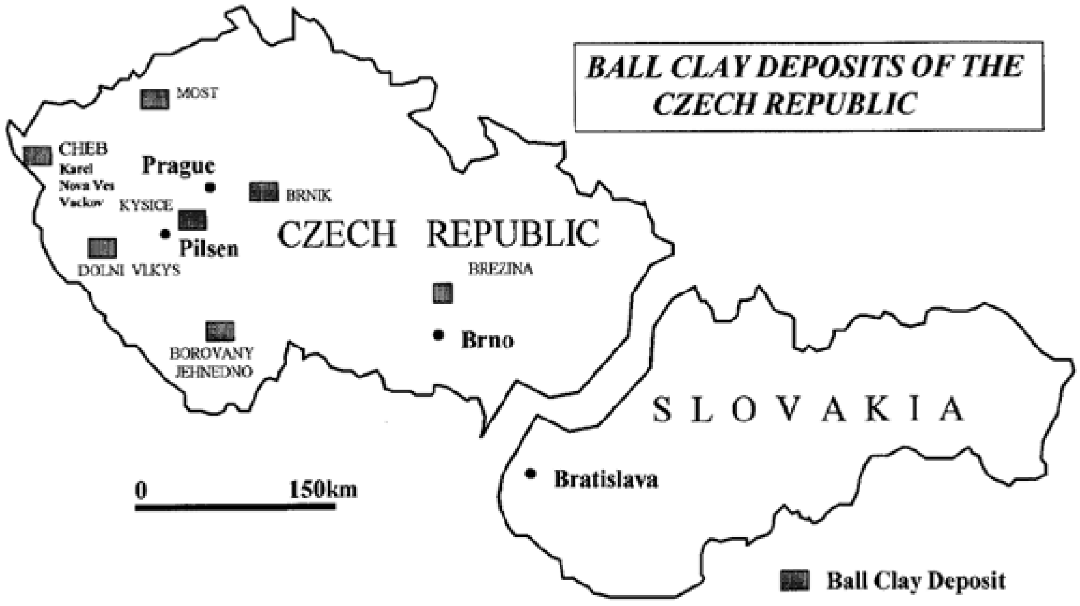

Figure 30: Location of the Czech Republic Ball Clays.

There are mine area for ball clay production and these areas are described in Table XV with the name of the mine, ball clay classification and production name. There are five companies operating in the mine areas but the situation regarding ownership is changing since privatisation of large parts of the Czech economy.

Table XV: Ball clay producing regions with details of Mines, Clay types and Product Names, Czech Republic.

Region	*Mine*	*Company*	*White Burning Type/Product*	*Ball Clay Type/Product*	Refractory *Type/Product*
Cheb	Nova Ves	KSNP	Nero F	-	CH
"	"	"	IB(IBV, IBN)	-	HC
"	Karel	"	Wi	-	KB
"	Vackov	"	-	AGU, AGB	-
Pilsen	Kysice	ZKZ	KyF	KyS	-
"	Dolni Vlkys	ZKZ	-	DV	-
Prague	Brnik	MSLZ	IBB	-	W Extra
Most	Jsnisuv Ujezd	SKZ-Most	-	BH	-
"	Strkovice	"	-	K	-
S.Bohemia	Borovany	Calofrig	-	MIC	-
"	Jehnedno	Calofrig	-	JHD1	-
W.Moravia	Brezina	MSLZ-Velke	-	-	BI/Bp

Production and Quality of Czech Ball Clay

In the Czech Republic the best quality white firing ball clay is often used on wall tiles - even though with glazing this is not important on the wall the Czech's by tradition, will always look at the unglazed side to see if it is white firing!

The production of clays in the Czech Republic is as follows for 1990 (Table XVI):

Table XVI: Production of Ball Clays in the Czech Republic for 1990.

Type of Clay	*Annual Extraction (tonnes)*
Refractory Clays	400,000
Refractory Clays for grog	986,000
White (fired) wall-tile clays	45,000
Other Clays for ceramics	183,000
Total	1,614,000

For **white-burning clays** the best quality ball clay is found in the Cheb basin. The ball clay is mined in the Nova Ves, Karel and Vackov areas (Fig. 30). These deposits have been exploited since the nineteenth century and some clays is exported to Germany. The lower part of the basin is formed by lignite covered by green clays. In the deposit of Nova Ves the white burning clay series commence above the green clays with a very bituminous clay knows as ***Nero F*** and continues to the ***IB*** clays. These clays are characterised by fine particle size, very good plasticity, white firing, good MOR and relatively low iron and titania. Production of white burning clays from the Cheb region is said to be 160,000 tpa. The clay***Wi*** from the Karel mine is deposited on the green clays and shows similarities to the ***IB*** clay but with higher iron and titania. The ***KyF*** ball clay from the Kysice deposit (Pilsen area) is said to be white-firing but is not of the same quality as ***Nero F.*** The **white-burning** clays are the ones that we would compare to ball-clays from other regions. The so called **ball-clays** and **refractory clays** is mainly used in heavy clayware and as source of sintering clays [14].

BALL CLAYS OF THAILAND

Location and Geology

Claymin (a subsidiary of WBB) was established in 1986 and is a joint venture to develop the ball clay deposits of Northern Thailand. Total sale of all products in 1994 exceeded 100,000 tonnes. The thriving domestic ceramics industries are the major market for these clays, and exports continue to grow steadily. The deposits are situated in the Lampang area of Northern Thailand (Fig. 31) at Mae Than, Wang Nua and Jae Korn. Geologically the oldest of the three deposit is at Mae Than, about 40 km south of Lampag. The Mae Than deposit is of Lower Triassic age and the workable clays found consist of reddish-brown conglomerates, sandstones, tuffaceous sandstones and calcareous shales. The main clay sequence, underlain by a subbituminous coal seam, probably represents lacustrine and backswamp enviromental phases. It is 24 metres thick and includes 22 seams of five different selections.

Figure 31: Ball Clay Deposits of Northern Thailand.

The deposit at Jea Korn, 65 km north of Lampang, lies unconformably upon the Triassic rocks of the area, and is of Tertiary age. The Tertiary rocks include freshwater sandstones, shales, carbonaceous shales, limestones and lignites. The clays sequence occurs in the shales of Pliocene and Miocene age and includes clays of mainly white, yellow and red colour.

Their third clay deposit is situated in the Wang Nua area, 100 km north of Lampang, and these clays are the most recent in origin and contain much organic material. They were probably laid down in a backswamp environment associated with the rise in sea level around 6-8000 years ago. There is very little overburden covering these clays enabling the extraction process to be easily carried out.

Properties of the Clays

Mae Than Area

Mae Than area contains five different types of clay and in each the principal clay mineral is disordered kaolinite, associated with illitic mica and quartz. In addition, certain of the seams contain an interstratified clay mineral, and colloidal carbonaceous matter.

Two Types of carbonaceous clays may be identified, which represent the most plastic and strongest, which is almost certainly a reflection of the influence of the colloidal carbonaceous matter which is present. Clays of this type (e.g. ***Mae Vit W***) are particularly suited to the production of tableware (both vitreous and porous) where a clean fired result is desired. The second type of carbonaceous clay, containing rather less carbonaceous material, is again a strong and plastic clay which deflocculates easily and presents a good, clean, fired colour. The properties of this type of clay make it ideally suited to incorporation in blends for the production of vitreous china sanitaryware (e.g. ***Mae San***). The carbonaceous clays from Mae Than represent the most fine grained of materials available from this area.

The remaining three types of clay are all non-carbonaceous, and contain more free silica in the form of quartz than the carbonaceous clays. They are less plastic and more coarsely grained, and careful blending of these three types can produce a clay ideally suited to the production of white-firing porous wall tiles (e.g. ***Mae Tile***).

Jae Korn Area

Three types of clay may be identified from the Jae Korn deposit on the basis of their raw and fired colours; a red firing clay, a buff firing clays and a white firing clay. All three types are extremely fine grain, very strong and highly plastic. For some of these clays, green strengths in excess of 150 kg/cm^2 have been recorded. The clay consists of a disordered kaolinite together with illitic mica and quartz, with varying amounts of chlorite. Occasional goethite has also been noted. It is the presence of chlorite, and to a lesser extent goethite, in the red and buff burning varieties, which give rise to the fired colour exhibited by these materials. The presence of organic matter in either colloidal or massive form is not significant. Because of their strength and plasticity, the red and buff burning varieties are ideally suited to the production of extruded vitrified products, particularly split tiles and bricks (e.g. ***Jae Vit R***). The white burning variety, which can be deflocculated readily, has useful application as a plasticising agent in many white firing ceramic compositions, including sanitaryware and tableware bodies.

Details of the quality of the Mae Than and Jae Korn products are shown in Table XVII.

Wang Nua Area

The clay in this area consists of a disordered kaolinite, associated with small quantities of illitic mica and some quartz. Very small quantities of interstratified mineral have also been detected, and all examples of the clays contain large quantities of colloidal carbonaceous material. A consequence of the fine grain size and the high level of colloidal carbonaceous matter is a very high green strength, in excess of 150 kg/cm^2. The clays deflocculate readily, have generally low residues and fire to a clean cream colour at 1200 °C. Their chemical and physical properties make these clays suitable for inclusion in blends intended for the production of vitreous sanitaryware and also white firing porous and vitreous tableware.

Chinese Ball Clays

WBB Pacific Clays have a joint venture in Guangdong Province, China, in which the Division has invested through ***Clayorient*** in Hong Kong, has not been as successful as planned owing to the slow acceptance in the region of the particular refined clays produced by Xiangshan. Another problem has been the sterilisation of ball clay reserves as a result of the extremely rapid development of construction in the area where the plant is located. However, because of the enormous potential of the Chinese market, other opportunities exist which are being actively pursued.

The quality of ***Ball Clay No.1*** is shown in Table XVII.

BALL CLAYS OF INDONESIA - KALIMANTAN

There are a number of ball clay prospects in Indonesia and the one considered here is the operations of ***PT Clayindo***. The ball clay concessions of the company are situated approximately 100 km north of Pontianak (on the equator) on the island of Kalimantan (formerly Borneo). Geologically the sequence is 4-5 m of overburden with an observed sequence of up to 10 metres of light creamy brown ball clay interbedded with sandy horizons. The method of mining is the traditional way with a "tubal" (see Fig. 1 earlier) following removal of overburden by an excavator. Production is up to 5,000 tonnes per month. There appears to be potential in the region for good quality ball clay and the current mined material is white firing but with low strength. Blending with other grades of ball clay may be necessary to meet the specification of higher quality ceramic potting applications. A typical result from the deposit near Pangkalam Batu shows a MOR of 23 (at kg/cm^2 at 110 °C), a fired brightness of 74, absorption of 17.5 and contraction of 3.7 at 1120 °C, and iron and titania levels at 1.1 and 1.2 wt.% respectively and the SiO_2 level of 58% is reflected in the mineralogy of 73% kaolinite, 8% mica and 19 wt.% quartz.

BALL CLAYS OF ARGENTINA

The San Julian area of Patagonia (Fig. 32) contains sedimentary clays of Quaternary age which are exploited as ceramic kaolins and utilised as a ball clay substitute. There are some 70 prospects in the area of which several are being mined. Some years ago the following mines were producing with the product name and utilisation shown (Table XVIII):

Figure 32: Location of the San Julian Ball Clays, Argentina.

Table XVIII: Mines, products and utilisation of San Julian ceramic kaolins.

Mine	*Product*	*Utilisation*
Tehuelche	Frente A	Sanitaryware
	Super	Porcelain, ceramics, tableware
	Mora	Electrical porcelain
El Chulengo	Frente Z	Sanitaryware
Refractaria	T. 42	Refractories
La Capa	Frente U	Tableware

The Tehuelche mine shows three distinct layers of clay which are mined selectively for different end-uses as indicated in Table XVIII. There is little difference between the quality of the layers apart from the presence of carbonaceous (lignite) material present. The El Chulengo mine exhibits a grey to white matrix, the colour depending on the carbonaceous content, and consists of kaolinite and fine-grained silica. The clays here are not so fine grained as ball clays elsewhere in the world but they have been effectively used as a ball clay substitute.

A typical analysis of a ceramic kaolin from the Tehuelche and El Chulengo mines is shown in Table XIX.

Table XIX: Quality of "Ball clay" from San Julian, Argentina.

% + 10 microns	22
% - 2 microns	49
Modulus 80% R.H. Kgf/cm^2	25.6
Casting Concentration (% solids)	62.0
P84 for minimum viscosity	0.93
Fired Trials to 1180°C	
Brightness	80.1
Absorption	15.8
Contraction	3.6
Chemistry (wt.%)	
SiO_2	67
Al_2O_3	22
Fe_2O_3	0.95
TiO_2	0.42
CaO	0.30
MgO	0.26
K_2O	0.59
Na_2O	0.04
L.O.I.	8.4
Mineralogy (wt.%)	
Kaolinite	77
Quartz	23

BALL CLAYS OF BRAZIL

General

There are a number of small producers of so called "ball clay" in Brazil especially in the region around São Paulo - São Simão, Suzano and Ribeirão Pires, amongst others (Fig. 33). All the clays, with a few exceptions, can be classified as ceramic kaolins rather than the true ball clays and it is often necessary to blend one or two of the different clays to arrive at a suitable ceramic body. There is a need still in Brazil for more investment in the exploration and exploitation of ball clays to meet the future requirements of the important ceramic industry. A brief description of some of the deposits is now given.

Figure 33: Location of Ball Clays in the São Paulo Region, Brazil.

São Simão Ball Clay

The São Simão ball clays are mined in a number of concessions and are sedimentary in origin. They are usually light grey silty to sandy clays with little carbonaceous matter. One sample, a browner variant, contain much peat-like fibrous material which suggest a young (perhaps Quaternary?) age for the deposits. Orange and yellow staining is common in the near surface samples; the iron contaminant is finely divided and has a deleterious effect on fired colour.

Most of the free quartz, which can be as high as 24%, is sufficiently coarse to be removed by screening at 300#. The -120# quartz may be advantageous in modifying rheological properties for sanitaryware. For tableware further screening of the siltier clays at a finer mesh would probably be beneficial in reducing abrasion and improving plasticity.

Testing of a number of samples from the São Simão area shows a wide range of fired brightness values. The principal clay mineral present is kaolinite, probably a very well-ordered variety. Electron micrographs show hexagonal platelets with well defined crystal faces throughout the particle size range (Fig. 34 - this should be compared to the TEM of an English ball clay in Fig. 13 which is a disordered kaolinite). Free quartz varies from 3 to 24%, kaolinite accounting for more than 90% of the remaining minerals. Mica content is low with the kaolinite/mica ration being close to 20:1. Traces of montmorillonite were detected by XRD but are too small to have any effect on physical properties. Similarly not more than 1% gibbsite is present; minor peaks are clearly evident on the DTA curves but here also the quantities are not significant.

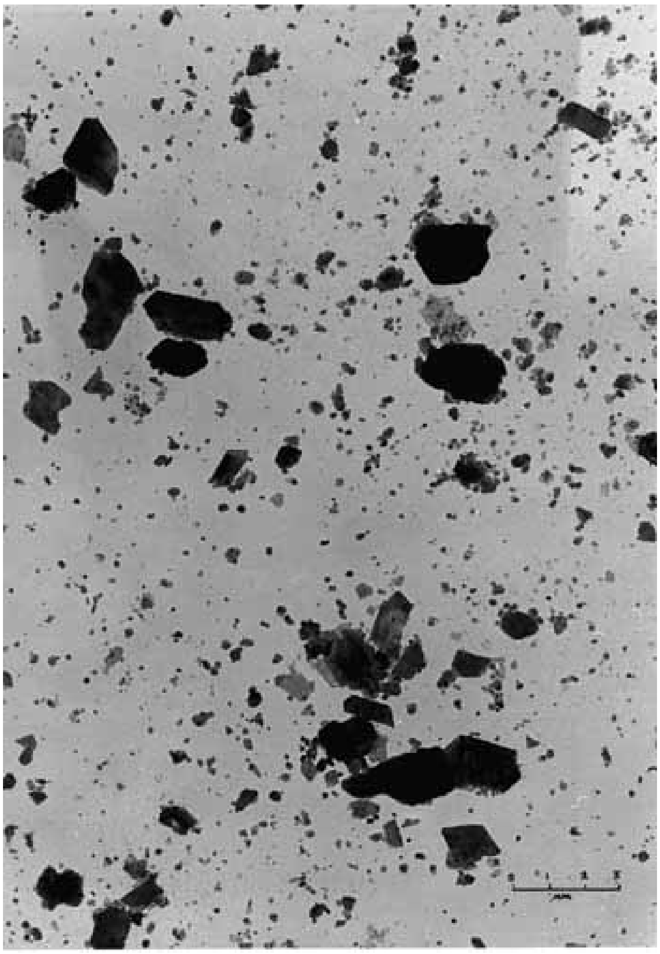

Figure 34: SEM of the São Simão Ball Clay, Brazil.

Particle size distributions were carried out on nine samples and the results are shown in Fig. 35. Apart from the finer sample, G, the particle size distributions are similar in shape and range are typical of sedimentary kaolins. The sub-micron fractions are considerably less than British ball clays. There is a very broad relationship with moduls of rupture (Fig. 36). Halloysite was not detected by XRD or in the electron micrographs. Good casting concentrations and casting rates with low deflocculant demand and thixotropy were found.

BRAZILIAN CLAYS Sao Simao PSD -300# Fraction (Calculated)

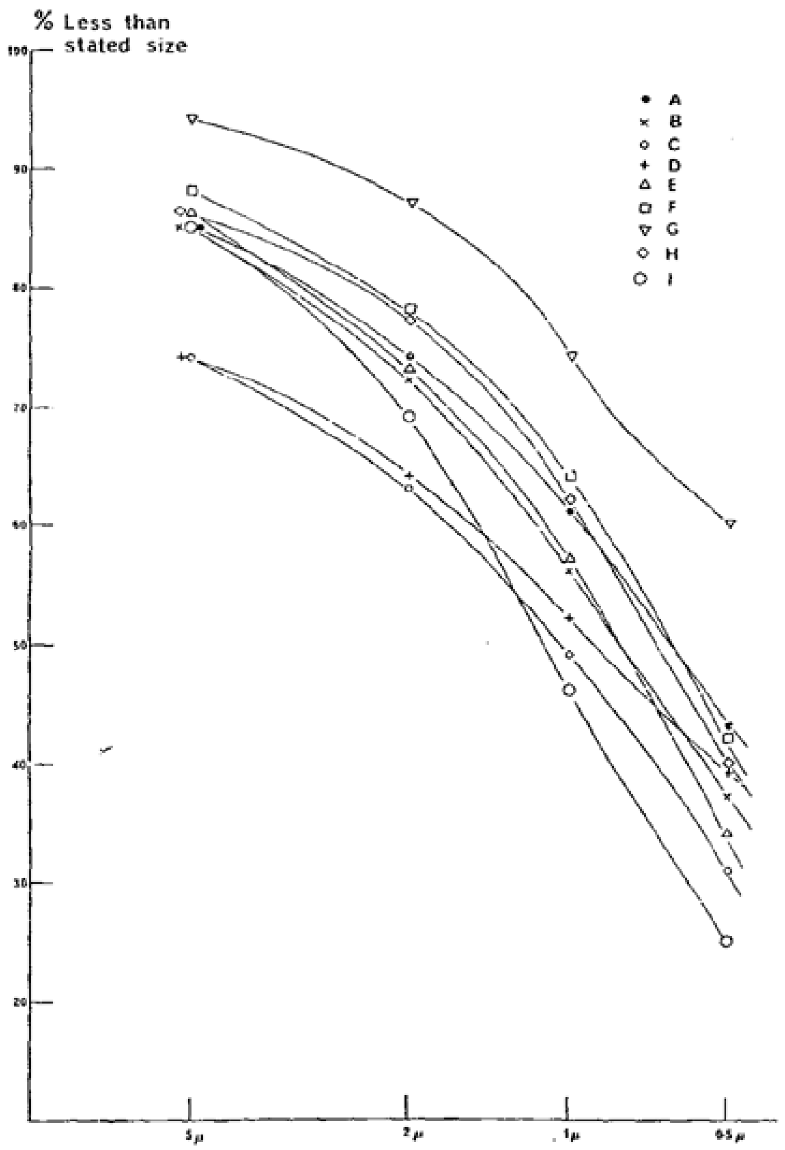

Figure 35: BRAZILIAN CLAYS São Simão PSD -300# Fraction (Calculated).

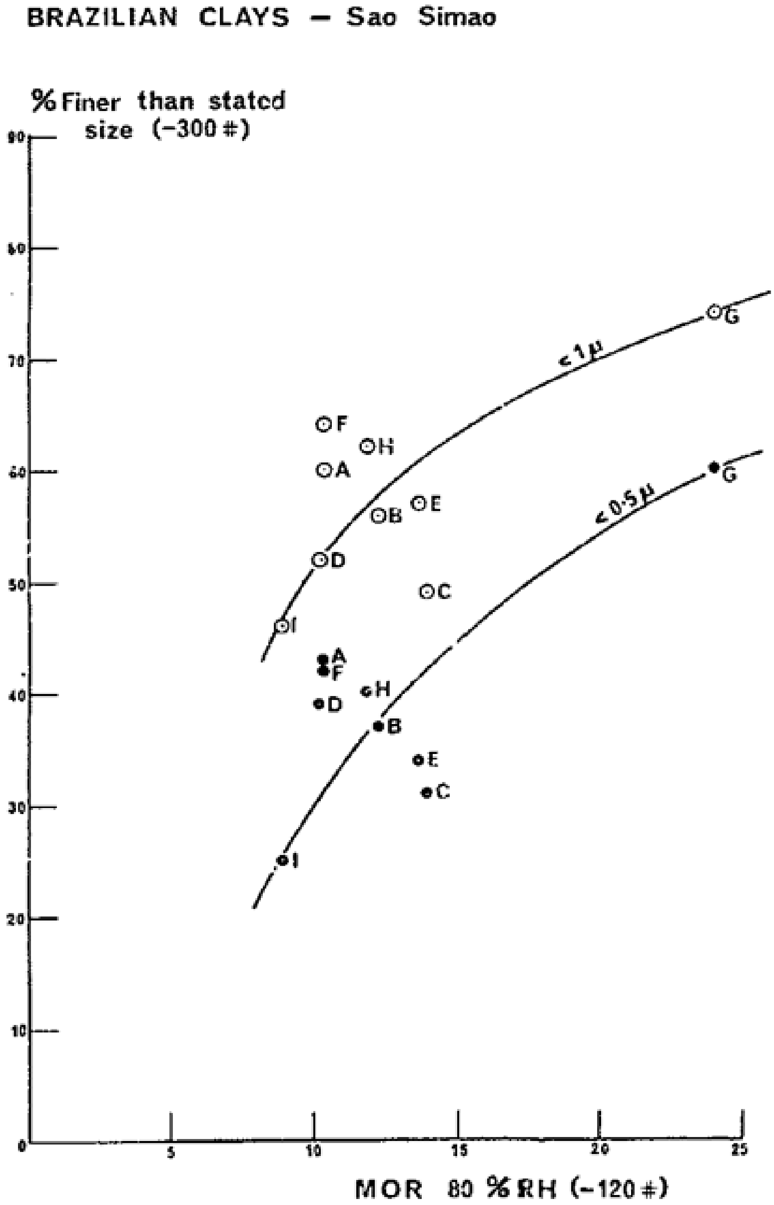

Figure 36: BRAZILIAN CLAYS - São Simão.

Of the samples examined only G has physical properties approaching a ball clay. Its strength is similar to ***Hywhite Superb*** (a blend of carbonaceous clays from south Devon) but its casting concentration is inferior. Nevertheless, a blend of G with any of the unstained São Simao clays could form the total clay component of a good casting body.

The future development and importance of the São Simão deposits would be considerably enhanced if more of the G type clay could be found. Its strength together with good fired colour are invaluable and it could be used to greater advantage than fine clays from other areas. for other uses, such as tiles and tableware, the São Simão clays would serve as kaolins but need to be supplemented by stronger, more plastic clays from elsewhere.

The results of the São Simão clay (sample G) are shown in Table XX.

Table XX: Test results of a São Simão Ball Clay.

Chemistry (wt.%)	
SiO_2	46
Al_2O_3	35
Fe_2O_3	1.0
TiO_2	1.0
CaO	0.27
K_2O	0.48
Na_2O	0.07
L.O.I.	15.5
Particle Size Distribution (%)	
>53 microns	1
<5 microns	94
<2microns	86
<1micron	73
<0.5 micron	59
Casting Properties	
Casting Rate, mm^2/min	0.18
Casting Concentration (%)	60.5
Amount P84 at 10 poise	0.4
Fired Properties at 1180 °C	
Absorption	21
Contraction	8.1
Brightness	87
Mineralogy (wt.%)	
Kaolinite	94
Mica	2
Quartz	3
Montmorillonite	1
Modulus of Rupture	
kgf/cm^2 at 110 °C	51.2

Santo Amaro Clays, Ribeirão Pires

The Santo Amaro clays are light, brown-grey, sandy to gritty, and slightly carbonaceous. From samples examined the quartz content varies widely, ut to maximum 29%. Apart from those samples containing much free quartz, plasticity and modulus are similar to the south Devon range of ball clays. The particle size distribution curves (Fig. 37) for the Santo Amaro clays are alike; each clay contains a high proportion of sub-micron material. Their high moisture absorption is also consistent with large surface area. On the contrary, casting properties are better than expected for this particle size range. Casting concentrations are high though deflocculant demand is high. Deflocculation curves are quite normal and slip control should not be difficult. Gibbsite present has no adverse effect on rheology.

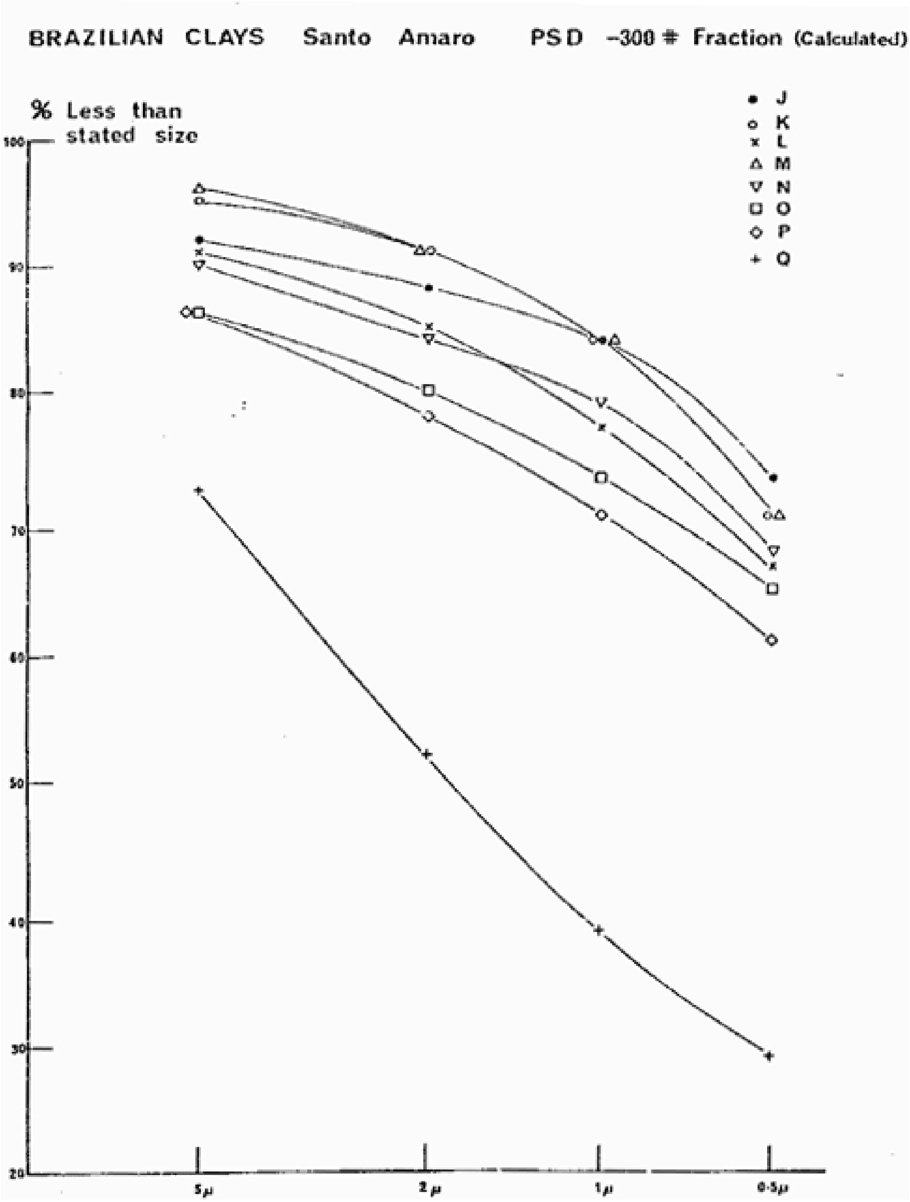

Figure 37:BRAZILIAN CLAYS Santo Amaro PSD -300# Fraction

With high alumina and low alkalis, the clays are open burning and even more so when gibbsite and carbonaceous matter are present. Mineralogically the clays are dominantly kaolinite - probably of a fine, disordered type.

The Santo Amaro clays are useful in providing strength and plasticity, an to supplement the weaker sedimentary kaolins. Their main disadvantage is their variable quartz content which has to be largely removed to prevent abrasion and cracking and to improve workability and surface finish.

Suzano and Nigrii Clays

The clays from this area are light grey to brown, sandy to very sandy clays with very little iron staining. The free quartz varies from 7 - 45% in the Suzano samples examined and 12 - 41% from the Nigrii deposits. Abnormally high alumina is due to appreciable amount of gibbsite, particularly in the Suzano clays (as high as 41% Al_2O_3 with 13% gibbsite in one sample). The excess alumina and low alkalis make these clays open burning. Improved vitrification of the -300# material is due to removal of quartz and coarse gibbsite particles. The coarse gibbsite can be visually separated from the free quartz; it is a dull white microcystalline material. Fe_2O_3 values fall within fairly narrow limits, 1.0 - 1.4% in the raw unscreened samples. TiO_2 is more variable, 1.1 - 2.8%, and is mainly responsible for variation in fired colour.

Kaolinite is of fine particle size, mainly disordered. Halloysite is detected by electron microscope in some of the samples. Particle distribution curves (Fig. 38) are similar in shape to those for Santo Amaro clays but the >5 micron fractions are greater. The range of modulus of rupture is also similar but plasticity is impaired by high free quartz content. Casting properties are generally good. Thixotropy is low and there is no evidence that it is influenced by gibbsite in the samples examined.

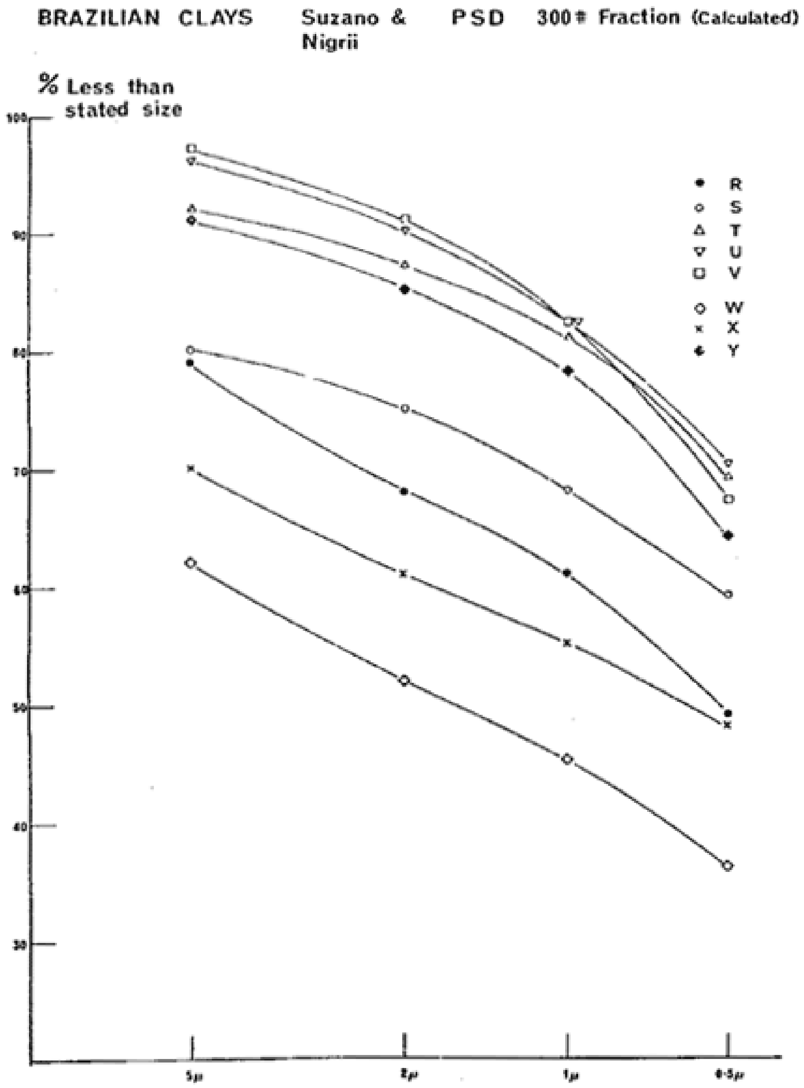

Figure 38: BRAZILIAN CLAYS Suzano & Nigrii PSD -300# Fraction (Calculated).

Summary of São Paulo Region Ball Clays

The São Simão clays are sedimentary kaolins with variable quartz content. Strengths are typically low with poor plasticity but rheological properties are good. Although iron and titania levels are of the order of 203%, high fired colour and absorption reflect the low level of alkalis. They are used in sanitaryware, tableware and tiles. The finer clays from Santo Amaro, Suzano and Nigrii are more like ball clays in strength and plasticity, but have the disadvantage of containing considerable amounts of free quartz. They are also fairly open burning with low alkalis: fired colours at 1180 °C are good but are likely to fall with additional fluxes in a body. Gibbsite is a common constituent in these clays but appears to have little effect on their good rheological behaviour.

Mineração Tabatinga Ltda

A visit was made to operations of Min. Tabatinga following the Curitiba Congress in 1993. The area is within the Parana depression and consists of a series of sedimentary sequences which are green, grey and whitish in colour. The project started some 15 years ago and following a detailed drilling and evaluation programme a resource of some 500 million tonnes, enough for 400 years, has been identified. Production in 1993 was put at 12,000 tonnes per month, mainly destined for the São Paulo market due to being adjacent to the main BR101 highway. Strip mining was taking place at the rate of 1 hectare/year.

Clay is mined from several areas - Mina1, Mina 2, Susi, Preta and AD44. Various grades are sold for tableware, sanitaryware, refractories, tiles and many other uses.

The physical and chemical characteristics from several of the mines is shown in Table XXI.

ACKNOWLEDGMENTS

The writer would like to thank the Brazilian Ceramic Association for their kind invitation and support to attend the 1993 Congress in Curitiba during May 1993 and to present this paper on Ball Clays. Thanks are also due to the Directors of Mineração Tabatinga for organising such an excellent field trip to their ball clay operations. I would particularly like to thank Quentin Palmer, Chief Geologist of ECC Ball Clays, Wareham, Dorset for providing some of the information on ball clay exploration. Also to Nigel Glasson, the Technical Director of ECC Ball Clays, for many discussions on ball clays over the past few years. Thanks to my colleagues in ECC International Europe, especially Chris Hogg, Ian Attwood, Richard Hirst and Caryl Gould for information on ceramic raw materials, and also to Simon Warren of ECC Am-Pac based in Atlanta, USA. I would also like to thank Dr. Simon Mitchell of Watts Blake & Bearne Ltd for kindly sending me information on their range of products and operations in many parts of the world. I would particularly like to thank all the mine owners in many parts of the world for permission to visit their operations. In Brazil I would like to thank the late Frederico Angeleri of Celite S.A. who introduced me to the ball clay deposits of the S. Paulo regions. Thanks also to Ivo Pellegrino of Santo Amaro S.A. for being so helpful in supplying information on his mines and products. May I also thank once again Professor Persio de Souza Santos for all his help in preparing this paper and for all his kindness over the last 20 years in introducing me to so many mine owners and ceramic companies. Finally thanks also to my colleagues in ECC do Brasil, particularly Jan Bidwell (Managing Director) and Pedro Bottesi (Geologist and responsible for Mining and Exploration).

REFERENCES

[1] I. R. Wilson, "Ball Clays" inglesas; origens, propriedades e usos em cerâmica, Cerâmica, 29, **165** (1983) 217-238. [Links]

[2] C. M. Bristow, The derivation of the Tertiary sediments in the Petrockstow Basin, North Devon, Proceedings of the Ussher Society, **2** (1968) 29-35. [Links]

[3] M. J. R. Fasham, A gravity survey of the Bovey Basin, Geological Magazine, **108** (1971) 119-130. [Links]

[4] E. C. Freshney, et al., Geology of the country around Chumleigh, Memoirs of the Geological Societh of Great Britain, London, (1979). [Links]

[5] M. E. J. Chandler, The Oligocene flora of the Bovey Tracey lake basin, Devonshire, Bulletin of the British Museum (Natural History), **3** (1957) 71-123. [Links]

[6] A. Vicent, Sedimentary environments of the Bovey Basin, Unpublished M. Phil. Thesis, University of Surrey, England, (1974). [Links]

[7] R.A. Edwards, Tertiary sediments and structure of the Bovey Basin, South Devon, Proceedings of the Geologists Association, **87** (1976) 1-26. [Links]

[8] D.A. Holdridge, Composition variation in ball clays, Transactions of the British Ceramic Society, **11** (1959) 645-659. [Links]

[9] WBB Devon Clays Ltd. WBB publication on "The production and properties of Devon Ball Clays", Booklet. [Links]

[10] I.R. Wilson, Constituição, avaliação e propriedades cerâmicas de caulins de alta qualidade, Cerâmica, 41, **270** (1995) 81-100. [Links]

[11] Industrial Minerals, March 1996, UK Minerals, Section on Ball Clay, 39-41.

[12] Watts Blake & Bearne & Co PLC, Report & Accounts for 1994. [Links]

[13] A. Russel, Ball & Plastic Clays - value added products for ceramic demands, Industrial Mineral, October (1988) 27-47. [Links]

[14] Czech "Tone" (Ball-Clays) Clays, Czechoslovak Ceramics Booklet.

(*) A tradução adequada de"ball clays"é argilas plásticas para Cerâmica Branca; não é usada na Indústria Cerâmica Brasileira, nem a tradução ao pé-da-letra "argila bola". Já é pratica normal o uso do termo original "ball clay".

CCTM-IPEN
C.P. 11049
05422-970 S. Paulo, SP, Brasil
Tel. (55 11) 3133-9203

e-Mail

ceramica@ipen.br