Distribution of Clay Mining and Quarries in South Africa

Senzani FED*, Mulaba-Bafubiandi AF and Viljoen F

University of Johannesburg, P. O. Box 526, Wits 2050, South Africa

**Corresponding Email Address: freeman_senzani@hotmail.com*

Abstract

A map plot of clay and associated earth materials mine and quarry locations shows that the activity is conducted in all provinces of South Africa. State records indicate that of the 249 clay mines and quarries registered in the country, 193 supply the materials to their own factories. However, attapulgite is produced by eight companies, two mainly for own consumption while the other companies supply customers in Germany, the United Kingdom, the United States, France, Italy and Austria in addition to South Africa. Montmorillonite is produced separately by one company, while bentonite is produced by three companies, flintclay by nine. Only two producers of diatomaceous earth have been reported while those for kaolin are eleven. Only eight produce plastic clay. Local beneficiation and application of the specialised clays in manufacturing need to be investigated.

Keywords: *anauxite, attapulgite, bentonite, chlorite, clay, cookite, dickite, fireclay, flintclay, GIS, illite, kaolinite, kieselguhur, mine, montmorillonite, muscovite, nacrite, palygorskite, pyrophyllite, quarry, sepiolite, serpentinite, shale, South Africa and, talc*

1. Introduction

Clay has many definitions. It may be defined as a diverse group of fine grain minerals. It is also a rock term, and refers to the material produced when such fine grain minerals form a coherent mass. It is a natural, earthy substance composed largely of crystalline minerals known as the "clay" minerals (Le Fond, 1989). Most mineralogists will emphasise that it is inorganic, with a maximum grain size of 2µm. Yet another definition highlights its rheological properties when wet, pointing out that it is generally plastic at certain appropriate levels of moisture content, but hardening when dried or fired, that is, in comparison with the moistened material (Horn et al, 1998).

In terms of the crystal structure, clay minerals may be considered to be composed of two types of layers. The first type comprises of SiO_4 tetrahedra (pyramids with triangular bases) composed of 4 oxygen ions, with the three basal ones being shared with those of adjacent tetrahedra. The fourth is placed on top of the basal three, while the silicon atom sits in the centre of the oxygen tetrahedron. The second layer type consists of octahedra of oxygen/or hydroxyl ions with the centres being occupied by the metal ions of aluminium, iron, or magnesium. The apical oxygen ions of both the tetrahedra and octahedra are shared, creating a two-layer system of alternating tetrahedra and octahedra (Heckroodt, 1992; Horn et al, 1998).

In the 1:1 arrangement, tetrahedra and octahedra layers alternate, as is the case with the serpentinite-kaolinite-dickite series of clay minerals. A representative of this is kaolinite with the mineral formula $Al_2Si_2O_5(OH)_4$.

The 2:1 arrangement, as seen in the pyrophyllite group, which includes montmorillonites and smectites, has an octahedral layer being sandwiched by two tetrahedral layers. There is an overall negative charge which is balanced by combinations of K^+, Ca^{2+}, Na^+, OH^- and organic materials. Smectites are represented by the mineral formula $(^1/_2Ca, Na)_{0\text{-}7}(Al, Mg, Fe)_4,(SiAl)_8O_{20}(OH)_4.nH_2O$ (Heckroodt, 1992; Horn et al, 1998).

The inverted 2:1 arrangement of the palygorskite (attapulgite)-sepiolite range have a similar arrangement to the pyrophyllite group with the exception that it has an acicular habit, itself being due to the apical oxygen atoms pointing in opposite directions at fixed intervals. The pipeways formed by the structure become channels which in turn result in high sorptive properties. The generalised formula for the group is $(Mg,Al)_2(Si_4O_{10})(OH).4H_2O$ (Heckroodt, 1992; Horn et al, 1998).

Clays have found many applications since the beginning of civilization. They are used among many others, in the manufacture of bricks, tiles, paving and pipes, cement, ceramics, refractories, paper, medicine, pharmaceuticals, extenders, drilling mud, animal feed, glassware, catalysts and molecular sieves.

Using GIS software, this study has plotted all sites where clay and allied material mining or quarrying has been recorded by the relevant government agency, namely the Department of Mineral Resources, formerly the Department of Mines and Energy, of South Africa. It is intended to show where the different fine earth products can be obtained. While specific clays have been identified as occurring in specific clay fields, there are mine and quarry sites falling outside the nominal areas. It is hoped the plots will assist in exploration when new production is required. They will also help identify potential sources at present.

2. Clay Sites

There are approximately 156 producers of clay, mostly for production of bricks but also tiles, paving and pipes, in South Africa. The largest of the clay brick producers in South Africa is Corobrik, with its headquarters in the Kwazulu-Natal Province. It has fifteen of its own factories around the country, as well as allied partner producers. In 2007, it produced 270M bricks, 18M roof tiles and 5400 tons of clay pipes.

Bricks produced include face-brick standard (FBS), face-brick extra (FBX), face-bric aesthetic (FBA), non-facing plastered (NFP) and non-facing extra (NFX).

Typical constituents of a brick clay are silica (50 % to 60 % as quartz and as part of other silicates), lime (2 % to 5 %), alumina (20 % to 30 %), oxide of iron (5 % to 7 %) and magnesia < 1 %.

3. Brickmaking Shale Sites

There are approximately 20 producers of shale, used as a substitute for clay in production mostly of bricks but also tiles, paving and pipes in South Africa.

The largest of the clay brick producers in South Africa is Corobrik, with its headquarters in Kwazulu-Natal. It has fifteen of its own factories around the country, as well as unspecified alliance partner producers. In 2007, it produced 270M bricks, 18M roof tiles and 5400t of clay pipes.

Bricks produced include face-brick standard (FBS), face-brick extra (FBX), face-bric aesthetic (FBA), non-facing plastered (NFP) and non-facing extra (NFX).

Typical constituents of a brick clay, of which the shale is a component, are silica (50 % to 60 % as quartz and as part of other silicates), lime (2 % to 5 %), alumina (20 % to 30 %), oxide of iron (5 % to 7 %) and magnesia < 1 %.

4. Shale Sites

In addition to brickmaking, shale is added to limestone ($CaCO_3$), silica (SiO_2) sand and iron-oxide (Fe_2O_3) to produce a mixture with a lime saturation factor (LSF) calculated as $CaO/(2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3)$ between 0.92 and 0.98, a silica ration (SR) or $SiO_2/(Al_2O_3 + Fe_2O_3)$ in the range between 2 and 3, and a alumina ratio (AR) $(Al_2O_3/(Fe_2O_3)$ lying between 1 and 4. The mixture is calcined produce clinker, the main component Portland Cement.

In South Africa cement is produced at operations located on sites of limestone deposits, shown on the map to occur in all provinces of the country, although only small and widely separated bodies are present in Free State and Mpumalanga.

Shale is, in place of or in addition to silica and feldspar, also added to clay in the manufacture of traditional ceramics such as tiles, bricks, pipes, china tableware, industrial abrasives and refractory linings. A case in point is Ceramic Industries (Pty) Ltd, the largest producer of wall and floor tiles in the country. The company also produces sanitaryware.

5. Kaolin Sites

This is a group of clay minerals, kaolinite being the main one, but also including nacrite, dickite, and anauxite. They have a two-layer crystal structure in which silicon-oxygen and aluminum-hydroxyl sheets alternate. The approximate chemical composition is $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Where lithified, the clays form a soft, non-plastic white rock, also composed principally of kaolin. The rock is also known as bolus alba or white clay.

Kaolinite has a low shrink-swell capacity and a low cation exchange capacity (1-15 meq/100g). It is a soft, earthy, usually a white-pink-orange-red mineral produced by the chemical weathering of aluminium silicate minerals like feldspar. Kaolin has a wide range of uses which includes paper manufacture, production of ceramicware, medicine, additives in food and toothpaste, diffusing materials in incandescent light bulbs, TiO_2 extender in paint, in rubber, in adhesives, smoking pipes, carrriers of insecticide and herbicide sprays in farming, additive in Portland Cement, medicine, facial masks, hunger suppression, etc.

There are eleven production sites of the material in South Africa. Their location coincides with areas underlain by granite, and where deep weathering occurred.

6. Fired Clay

Fire clay, one of the seat earths, is a term applied to a range of refractory clays used in the manufacture of ceramics, especially fire brick. High grade fireclays can withstand temperatures of 1775 °C (3227 °F, PCE 35), but to be referred to as a "fire clay" the material must withstand a minimum temperature of 1515 °C (2759 °F, PCE 19). Fire clays range from flint clays (non-plastic) to plastic fire clays. Fire clays consist of natural argillaceous materials, mostly potassium group clays, along with fine-grained micas and quartz, and may also contain organic matter and sulphur compounds. Alumina contents are high, between 24 % and 34 % while silica is between 50 % and 60 %.

Fireclay is suitable for lining furnaces, as fire brick, and manufacture of utensils used in the metalworking industries, such as crucibles, saggars, retorts, and glassware. Because of its stability during firing in the kiln, it can be used to make complex items of pottery such as pipes and sanitaryware.

Fireclays often underlie coal beds and are therefore associated with lower Karoo Supergroup in South Africa, which also displays the thirteen quarries in the country.

7. Montmorillonite Sites

Montmorillonite is a very soft phyllosilicate group of minerals that typically form in microscopic crystals, forming clay. It is named after Montmorillon in France. Montmorillonite, a member of the smectite family, is a 2:1 clay, meaning that it has 2 tetrahedral sheets sandwiching a central octahedral sheet. The particles are plate-shaped with an average diameter of approximately one micrometre. Members of this group include saponite. Montmorillonite is the main constituent of the volcanic ash weathering product, bentonite.

The water content of montmorillonite is variable and it increases greatly in volume when it absorbs water. Chemically it is hydrated sodium-calcium-aluminium-magnesium-silicate-hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$. Potassium, iron, and other cations are common substitutes, the exact ratio of cations varying with the source. It often occurs intermixed with chlorite, muscovite, illite, cookeite, and kaolinite.

Montmorillonite is used in the oil drilling industry as a component of drilling mud, as a soil additive, in construction of earthen dams and levees and as a protective liner for landfills to prevent the leakage of fluids, as a component of foundry sand and as a desiccant, as an annular seal or plug for water wells, as an anti-caking agent in animal feed, in paper making and as a retention and drainage aid component, in cosmetics, in some cat litter products, as a soil conditioner for playing fields and bonsai soil. It is also widely used in medicine and pharmacology. It is used in medicine as an adsorptive of heavy metals, toxins, and hazardous chemicals.

In South Africa, the clay is quarried only on the farm Maandagshoek 254KT by Attaclay Products (Pty) Ltd.

8. Bentonite Sites

The term “bentonite” was first used for clay found in about 1890 in upper cretaceous tuff beds near Fort Benton, Wyoming, USA. The main constituent, which is the determinant factor in the clay's properties, is the clay mineral montmorillonite. This in turn, derives its name from a deposit at Montmorillon, in Southern France.

Bentonite is clay generated frequently from the alteration of volcanic ash, consisting predominantly of smectite minerals, usually montmorillonite. Other smectite group minerals include hectorite, saponite, beidelite and nontronite. Smectites are clay minerals, whose crystallites are three-layer clay minerals. They consist of two tetrahedral layers and one octahedral layer. In montmorillonite, tetrahedral layers consisting of $[SiO_4]$ - tetrahedrons enclose the $[M(O_5,OH)]$-octahedron layer (M = and mainly Al, Mg, but Fe is also often found). The silicate layers have a slight negative charge that is compensated by exchangeable ions in the intercrystallite region. The charge is so weak that the cations (in natural form, predominantly Ca^{2+}, Mg^{2+} or Na^{+} ions) can be adsorbed in this region with their hydrate shell. The extent of hydration produces intercrystalline swelling. Depending on the nature of their genesis, bentonites contain a variety of accessory minerals in addition to montmorillonite. These minerals may include quartz, feldspar, calcite and gypsum. The presence of these minerals can impact the industrial value of a deposit, reducing or increasing its value depending on the application. Bentonite presents strong colloidal properties and its volume increases several times when coming into contact with water, creating a gelatinous and viscous fluid. The special properties of bentonite (hydration, swelling, water absorption, viscosity, thixotropy) make it a valuable material for a wide range of uses and applications in foundries, cat litter, pelletising, in civil engineering, water purification, as geosynthetic clay liners, drilling, oil purification, fluid clarification, animal feed supplements and pelletising, ion exchanger in soil conditioning, porous agent for pesticides/herbicides.

Only Cape Bentonite, owned by Ecca Holdings (Pty) Ltd, and G and W Base and Industrial Minerals produce bentonite at two main sites, near Heidelberg in the Western Cape Province for the former, and near Koppies in the Free State Province in the case of the latter.

9. Flint Clay Sites

This is a smooth, flint-like refractory clay or mudstone composed dominantly of kaolin. Flint clay breaks with a pronounced conchoidal fracture and resists slaking in water. Flint clay can be either detrital or authigenic in origin. Detrital flint clays consist of kaolinite-rich sediments eroded and transported from uplands deeply weathered under tropical climates and redeposited within the coastal plains, in which coal-bearing strata accumulated. Authigenic flint clays consist of sediments altered in place after deposition as beds within acid, organic sediments, i.e. peat, accumulating within swamps and mires. Flint clays associated with coal typically occur as thin, laterally continuous

layers (bands), called "tonsteins", found within coal beds. At least, in case of tonsteins found within coal, the formation of flint clays resulted from the alternation of glass comprising volcanic ash by acid waters after it accumulated as thin beds within peat swamps or mires.

In South Africa, it is produced at nine sites. These fall in the Free State and Gauteng provinces, where the fire clay it is associated with the lower Karoo carbonaceous beds and possibly weathered granite, respectively.

10. Plastic Clay Sites

Fireclay (see elsewhere on this poster) which forms a moldable mass when mixed with water is referred to as plastic clay. In turn, fireclay, one of the seat earths, is a term applied to a range of refractory (heat resistant) clays used in the manufacture of ceramics, especially fire brick. High grade fireclays can withstand temperatures of 1775 °C (3227 °F, PCE 35), but to be referred to as a "fire clay" the material must withstand a minimum temperature of 1515 °C (2759 °F, PCE 19). Fire clays range from flint clays (non-plastic) to plastic fire clays. Fire clays consist of natural argillaceous materials, mostly K group clays, along with fine-grained micas and quartz, and may also contain organic matter and sulphur compounds. Alumina contents are high, between 24 % and 34 % while silica is between 50 % and 60 %.

In terms of properties, fireclay it is resistant to high temperatures, having fusion points higher than 1,600°C, therefore it is suitable for lining furnaces, as fire brick, and manufacture of utensils used in the metalworking industries, such as crucibles, saggars, retorts, and glassware. Because of its stability during firing in the kiln, it can be used to make complex items of pottery such as pipes and sanitaryware.

Fireclays often underlie coal beds and are therefore associated with lower Karoo Supergroup in South Africa, which also displays the thirteen quarries in the country. Production of plastic clay is reported at eight locations in South Africa.

11. Attapulgite (Palygorskite) Sites

Attapulgite clays are a composite of smectite and palygorskite. Smectites are expanding lattice clays of which bentonite is a commonly known generic name. The palygorskite component is an acicular bristle-like crystalline form which does not swell or expand. Attapulgite forms gel structures in fresh and salt water by establishing a lattice structure of particles connected through hydrogen bonds. Attapulgite, unlike bentonite, will form gel structures in salt water and is used in special salt water drilling mud for drilling formations contaminated with salt. Palygorskite particles can be considered as charged particles with zones of + and - charges. It is the bonding of these alternating charges that allow them to form gel suspensions in salt and fresh water.

The material is used in suspensions, reinforcements, binding, paints, sealants, adhesives, tape-joint compounds, catalysts, suspension fertilisers, wild-fire suppressants, foundry coatings, animal feed suspensions, molecular sieve binders, in medicine to bind toxic and acidic substances in the alimentary canal, and as an anti-diarrheaal agent.

Attapulgite is produced in South Africa at four sites by Arleco Mining (Pty) Ltd, G & W Base and Industrial Mineral, Matutu Clay Mining, and Attaclay (Pty) Ltd.

12. Silica Sites

This occurs in nature as the mineral quartz, and exists in five forms, namely sand, sandstones (including quartzites), massive quartz derived from veins or pegmatites, quartz crystals from cavities and as silcrete.

Silica is the main source of silicon, which is used in chemical, metallurgical and electronic industries. Naturally occurring silica is converted to chemical-grade silicon, which is then converted to a halide or halosilane. These intermediate products are then converted to high-grade silicon, which is suitable for the electronic industry. For these processes, the natural source needs to contain at least 99.5% silica, and not more than 0.04 to 0.08% Fe_2O_3.

Silica is also used in the manufacture of glass and glass fibre, for the manufacture of silicon-carbide, for mouldings in the foundry industry, for the manufacture of sodium-silicate and other chemicals, for sandblasting, for the manufacture of abrasive papers, and as a filtering medium. It is also a primary raw material for many whiteware ceramics such as earthenware, stoneware, porcelain, as well as industrial Portland cement. Silica is a common additive in the production of foods, where it is used primarily as a flow agent in powdered foods, or to absorb water in hygroscopic applications. It is the primary component of diatomaceous earth which has many uses ranging from filtration to insect control. It is also the primary component of rice husk ash which is used, for example, in filtration and cement manufacturing.

The sand should have a uniform grain-size, a silica content of 99 % or more and low iron, alumina, lime and magnesia contents. Clays are usually added in order for the sand to have the plasticity and strength necessary for foundry work.

Silica is produced by four companies at the sites shown on the above map. These are G & W Base and Industrial Minerals (Pty) Ltd, Idwala Industrial Holdings (Pty) Ltd, Fine Industrial Minerals CC and Consol Ltd. The Western Cape deposits appear to have been derived from Table Mountain sandstones, themselves sourced from granitic basement. Almost pure sand is produced by further aeolian transport, coupled with a lagoonal and fluviatile activity. In Gauteng, foundry sands occur in the Moot Valley of Pretoria.

13. Kieselguhr Sites

Kieselguhr, diatomite or diatomaceous earth are names normally used for a remarkably light-weight, soft, white or pale-coloured, finely granular, highly porous and friable sediment mainly of the opaline hollow shells of diatoms. One cubic centimetre of diatomite could contain up to 30 million shells. In general, commercial diatomite contains more than 80 % silica.

The variation in shape and internal structure of diatoms impart to diatomite two of its most important properties: an extremely large surface area, and loose packing that results in very high porosity. Porosity may by 75% or even higher. The powder form can absorb up to two times its own weight before becoming saturated, while the surface area of 210g is 4000m^2. Kieselguhr is also a thermal and sound insulator. Kieselguhr is used as a filter agent, a thermal insulator, carrier for catalysts and insecticides, anticaking agent, pozzolanic admixture to cement, a mild abrasive and as a source of reactive silica.

In South Africa, there are only two producers namely G & W Base and Industrial Minerals (Pty) Ltd, and De Hoek Kieselguhr Belange BPK.

14. Talc Sites

Talc is a hydrated magnesium silicate with a chemical composition of $Mg_3Si_4O_{10}(OH)_2$ and pyrophyllite the aluminium equivalent $Al_2Si_4O_{10}(OH)_2$. Though chemically distinct, the two have many similar chemical and physical properties, and, hence, industrial applications. For this reason, they are often grouped together in resource studies. Talc varies in colour, is commonly white, and grinds to a white powder. This, along with along with its softness (1 on the Moh's Scale), pearly lustre and greasy feel make for easy identification.

The properties which make talc important in industry are its softness, smoothness, lubricative capacity, chemical inertness, high oil absorption, low thermal conductivity, high fusion point, low thermal expansion, and, above all else, its whiteness. Pyrophyllite shares the above properties, but differs by being a little harder and more refractory. Uses of talc include as a major component of ceramics, various porcelains, floor and wall tiles, electrical insulators and refractories, extenders in paints, carriers for insecticides, fillers or additives, in plastics and in rubber, and as a pitch control agent in the manufacture of paper. It may also be used in as a component of cosmetic and pharmaceutical products. Talc in the form of soapstone is used for ornamental purposes. Current economic deposits of talc have been reported only at Witpoort Mine, Northwest Province.

15. Conclusions

Clays have found many applications since the beginning of civilization. They are used among many others, in the manufacture of bricks, tiles, paving and pipes, cement, ceramics, refractories, paper, medicine, pharmaceuticals, extenders, drilling mud, animal feed, glassware, catalysts and molecular sieves.

This study has plotted all sites in South Africa where clay and allied material mining or quarrying has been recorded by the relevant government agency, namely the Department of Mineral Resources, formerly the Department of Mines and Energy, of South Africa. It has shown where the different fine earth products can be obtained. While specific clays have been identified as occurring in specific clay fields, there are mine and quarry sites falling outside the nominal areas. The plots will assist in exploration when new production is required. They will also help identify potential suppliers at present.

A map plot of clay and associated earth materials mine and quarry locations shows that the activity is conducted in all provinces of South Africa. State records indicate that of the 249 clay mines and quarries registered in the country, 193 supply the materials to their own factories. However, attapulgite is produced by eight companies, two mainly for own consumption while the other companies supply customers in Germany, the United Kingdom, the United States, France, Italy and Austria in addition to South Africa. Montmorillonite is produced separately by one company, while bentonite is produced by three companies, flintclay by nine. Only two producers of diatomaceous earth have been reported while those for kaolin are eleven. Only eight produce plastic clay. Local beneficiation and application of the specialised clays in manufacturing need to be investigated.

References

Department of Minerals and Energy (DME) (2010) Operating mines and quarries and mineral processing plants in the Republic of South Africa. Directory D1/2010

Heckroodt, R. O. (1992) Kaolin resources of the republic of South Africa: Handbook, Geological Survey of South Africa, 13,102pp.

Horn, G. F. J. and Strydom, J. H.) Clay in Wilson, M. G. C. and Anhaeusser, C. R. (1998). The mineral resources of South Africa 6th Edition. Council for Geoscience Handbook 16. p. 106-135.

Le, Fond, S. J. (editor) (1989) Industrial minerals and rocks (non-metallics other than fuels), 5th Edition: Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineering, p 585-651.

Martini, J. E. J. (1979) A copper-bearing bed in the Pretoria Group in the North-eastern Transvaal: Special Publication of the Geological Society of South Africa, 6, p65-72.

Oosterhuis, W. R. Silicon and Silica in Wilson, M. G. C. and Anhaeusser, C. R. (1998). The mineral resources of South Africa 6th Edition. Council for Geoscience Handbook 16. p. 587-592.

Strydom, J. H. (1998) Kieselguhr in Wilson, M. G. C. and Anhaeusser, C. R. (1998). The mineral resources of South Africa 6th Edition. Council for Geoscience Handbook 16. p. 417-423.