Ceramic parameters in the financial evaluation of brick clay deposits, with reference to two South African examples.

by

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DECLARATION

I declare that the thesis that I hereby submit for the Masters Degree in Earth Science Practice and Management at the University of Pretoria has not previously been submitted by me for degree purposes at any other university.

SIGNATURE OF STUDENT: __________________ DATE: ___________

Preface

It is with a deep sense of gratitude that I would like to thank:

1) The Lord Jesus Christ for allowing me to study a very minute part of His wonderful creation.

2) My children for their patience, understanding and encouragement.

3) Prof. Hennie Theart for his leadership, dedication, commitment and for sharing some of his knowledge.

4) John Anthony and Chris Dickinson for making time to edit this document.

Abstract

Brick clay deposits, in the area north of Cape Town, were formed as a result of three independent geological processes. The intrusion of the syn- to post tectonic granitoids into micaceous (indicated by the absence of halloysite; Orris, 1998), feldspathic Malmesbury sandstone beds, approximately 500 Ma ago, created a hydrothermal vein structure, which enriched the shale with feldspar/kaolinite and quartz, restricted to the vein network. This was followed by extensive *in-situ* weathering of these hydrothermally altered rocks resulting in residual kaolin deposits, the effects of which were more pronounced along the more permeable shear zones. The final process, formation of ball clay deposits, initiated by the erosion of the primary kaolinite deposits, which have been transported in water, together with organic material, to shallow depressions where clays were deposited.

Brick clay is exclusively used for the manufacturing of clay brick products and must derive its value from the sales revenue generated from these products. Evidence from the two exploration programs described, suggests that the clay deposits explored has no value as individual deposits as the clay from both deposits lack specific ceramic properties to successfully manufacture clay bricks. It is however clear that if the clay from the two deposits is mixed in specific proportions; body mixes with ceramic properties suitable for light coloured clay face brick manufacturing is possible. The value of the beneficiated product, clay bricks, may then be used to determine the value of both clay deposits.

Discounted Cash Flow Models (DCFM) and Net Present Values (NPV) were used to determine the fundamental value of the clay deposits explored, as it determines the time value of money (Kernot, 1999). These models clearly showed the dependency of the value of clay brick deposits on variables such as raw material quality, capital expenditure and clay brick yields.

Geological, chemical and ceramic knowledge of individual brick clay deposits and the management of the raw materials extracted from these deposits is key to the profitable

manufacturing of clay bricks. Risks, at the quarrying level, related to these aspects need to be managed to ensure the profitable and efficient functioning of the entire brick production process.

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CHAPTER 1 - INTRODUCTION

Brick clay or common clay, as referred to internationally, is rarely traded, as proximity to a brick plant is essential. Because of this these deposits have no value other than being used as raw materials for clay brick production. Value is therefore added to the deposit only when it can be demonstrated that bricks, meeting various value criteria, can be produced and sold commercially.

The South African clay brick industry is totally dependant on the state of the economy, in particular the strength of the local currency, related interest rates and business confidence levels. Building and construction closely mirror the business confidence index with a lag of a few months (BER, Fourth Quarter 2004). This may directly be linked to economic growth of private enterprise and the ability of government to create new infrastructure as the South African clay brick market currently consists of the following segments:

- Government construction and low cost housing
- Commercial
- Residential, which includes renovations and additions

Since 2002, a steady growth of above 15% in the use of clay brick has been realised in the building and construction industry, especially in the residential sector, representing an increase of some 200 million bricks year on year (Martin, 2004). As a result, clay brick manufacturers have experienced renewed pressures regarding supply, as demand, based on the popularity of clay brick products, expansive cluster development and relatively low interest rates, outstrips brick production. Most brick manufacturing plants are running at full capacity, to satisfy current demand. The statistics (Duval, 2004) shown in Table 1 below confirm this trend and show a consistent increase in the production of brick clays since 2000 with a related increase in the production costs, leveling out during 2002/2003.

The South African Clay Brick Association estimates that 75% of all bricks sold are genuine clay bricks, when compared with other substitute wall products such as concrete blocks, pre-cast concrete bricks, aluminium and glass.

Annual studies conducted by the United States Geological Survey (USGS) showed that 55% of common clay was used for the production of bricks, 19% for cement, 16% for light aggregate and the remaining 10% for other uses. The strong housing and commercial building market has helped maintain sales of common clay and shale for brick and lightweight aggregate manufacture for the past several years steadily increasing to the high for 2004 as shown in Table 1 below. Privately owned housing leaped 3.7% as home buyers scurried to take advantage of low mortgage interest rates. (U.S. Department of Commerce, 2004).

Table 1 - USA and RSA brick clay production statistics.

	2000	**2001**	**2002**	**2003**	**2004**
USA production (metric tons)	13035000	12760000	12650000	12705000	16335000
USA value ($/ton)	6	6	6	6	5
RSA production (metric tons)	313359	5807922	6577616	7580497	Not available
RSA value (R/ton)	7.05	8.28	9.36	9.23	Not available

The method deployed to evaluate an industrial-mineral commodity is largely dependent on the applications for which it is intended (Horn, 1994). The properties that are normally investigated are those that characterise the ore in terms of its mineralogical nature, its geochemical character and its physical properties. The demand for the various clay minerals and their beneficiated products can be related to the special chemical and physical properties that clay imparts to its products. These properties are to a large extent, a reflection of the crystal structure of the minerals as well as the chemical composition of the clay. For this reason different types of clays are utilized in a large range of products ranging from building bricks and ceramic products.

It is therefore also true that in order to know if a clay deposit is suitable for clay brick manufacturing a sound knowledge of how the raw material will react during the different phases of the manufacturing process is required. Geoscientists who explore brick clay deposits should understand these critical relationships between the geological, chemical and ceramic properties or constraints of these deposits, and the quality of the clay bricks manufactured from it. This knowledge combined with a basic understanding of brick manufacturing processes would allow them to be able to explore, valuate and exploit such deposits to benefit brick manufactures by supplying affordable, quality raw materials to the manufacturing process.

Currently fifteen clay brick manufacturing facilities operate in the Western Cape and produce up to 475 million bricks annually, requiring up to 1055556 Spm^3 (Spm^3 - Stockpile cubic meter, measure of volume in constructed clay stockpiles) of natural clays suitable for clay brick manufacturing.

Most of these brick factories are situated within an area between Stellenbosch, Paarl, Malmesbury, Atlantis and Durbanville. They are usually found in close proximity to clay deposits thus eliminating the additional costs of transportation and denying competitors access to individual clay deposits thereby ensuring unique product ranges and product consistency.

Two clay deposits were evaluated to determine their suitability as raw materials for clay brick manufacturing, the location of which is shown in Figure 1 below. These deposits were identified during a regional geological investigation for brick clay deposits that led to an in-depth geological and ceramic exploration program, completed during the latter part of 2004.

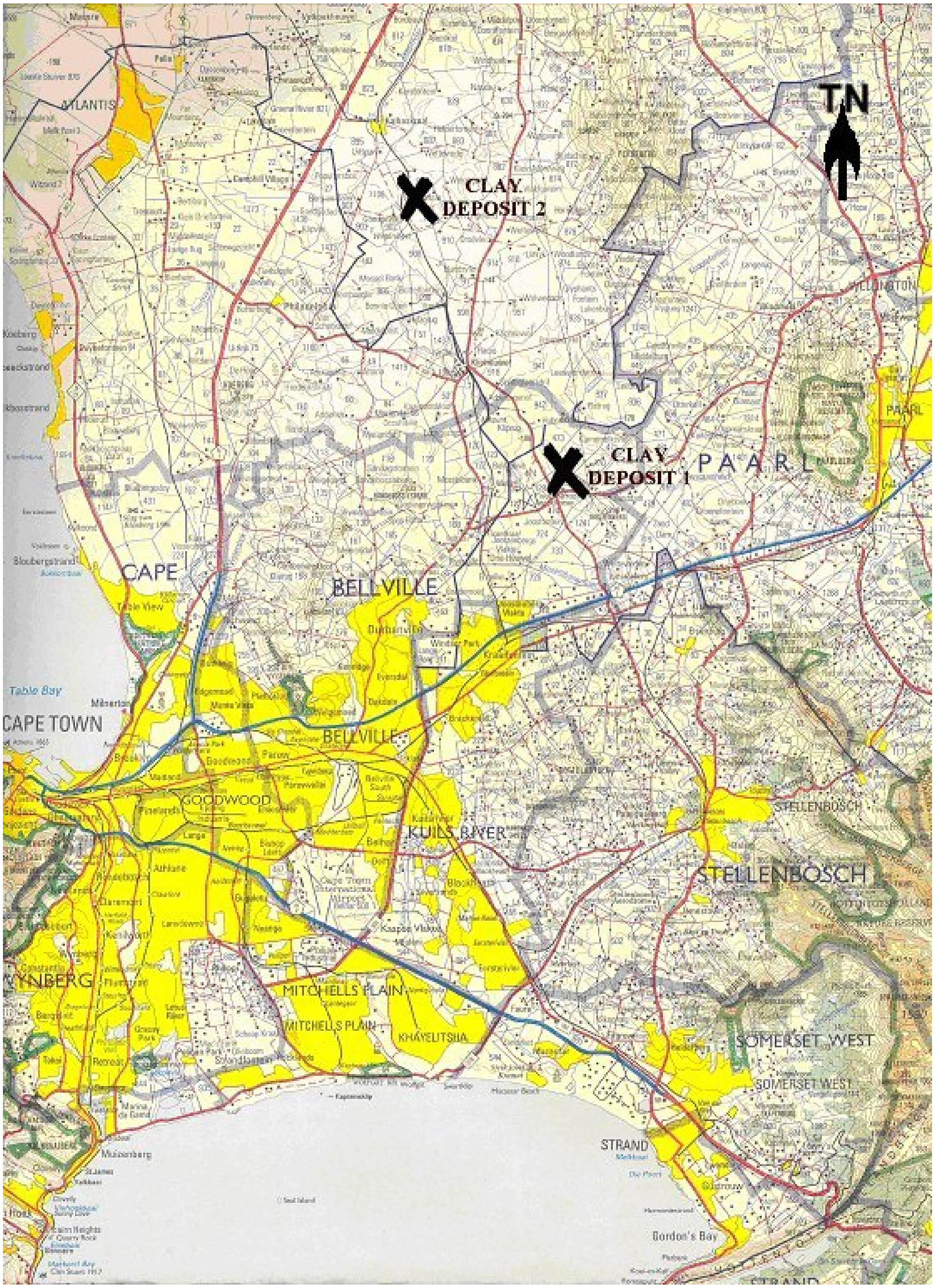


Figure 1 - Map of the area surrounding Cape Town showing location of clay deposits investigated in relation to major urban areas shown in yellow. (Map adapted from 3318 Cape Town, 1:250000 topographical sheet, sixth edition, 1994. Printed by the Government Printer, Private Bag X85, Pretoria)

The under mentioned factors were excluded from this geological and ceramic exploration program and subsequent financial evaluation:

a) The influence that different sampling and analyzing techniques may have on reported laboratory values. Methods used will however be referred to.
b) The influence that the use of other raw materials in product mixes may have on the quality, consistency and durability of the fired product.
c) The influence that the condition, layout and management skills of a processing facility has on the quality of the fired product.

In addition, all borehole logs and raw analytical results with regard to chemical and mineralogical analyses could not be presented in this document as permission to do so were not granted by the owner of the data.

CHAPTER 2 – THE CLAY BRICK

2.1. Introduction

The current definition of a ceramic product would be an article made wholly or partly of clay, with or without the addition of other materials, and shaped in a plastic condition, then dried and fired to give it the required strength and durability (Brownell, 1976).

It is common practice to group the different ceramic industries into categories according to their similarities in service application of the final product, in manufacturing method, or in raw material use. These categories are:

a) Refractories: Ceramic products resistant to heat
b) Special or technical ceramics: highly specialized products developed for use in environmental, agricultural, mining, food, textile, paint, foundry, chemical, pharmaceutical, rubber, plastics, heavy-engineering and steel industries.
c) Pottery or whiteware: Table ware, wall tiles, sanitary ware, etc.
d) Heavy clay wares or structural ceramics: Includes roofing tiles, sewer pipes, conduit and associated junctions, as well as the various types of building bricks and blocks.

A clay brick or burnt clay masonry unit is defined by SABS 227, (2002), as a masonry unit made basically from clay or shale (with or without an admixture of other materials), molded or extruded into rectangular form, hardened by firing, with or without frogs, perforations or cavities.

Although the definition in respect of the class of clay brick differ from country to country standards clearly differentiate between face bricks and non-facing or common bricks. The biggest difference being the requirements for durability and degrees of uniformity for size, shape and colour for face bricks.

2.2. Manufacturing Process.

Bricks were originally made from sun-dried mud. For some 5000 years or more they have been mainly of fire-burnt clay, the firing process giving them increased strength and durability and also increasing the range of colors. And they said to one another, “Come, let us make bricks, and burn them thoroughly.” (Genesis 11:3).

According to Brownell (1976), Clews (1969) and, Singer and Singer (1963), manufacturing methods for clay bricks have developed from simple hand molding and relatively crude firing to automated production. The clay brick manufacturing process is referred to as a ceramic process, which could best be described as a solid-state pyro-metallurgical process. This term, “ceramic”, is derived from the ancient Greek word keramos (meaning burning or firing).

A basic understanding of the manufacturing process is essential in that it defines the different properties the raw material should have in order to manufacture marketable products.

Four main production phases, Figure 2 below; have been observed from the Western Cape clay brick manufacturers:

- Obtaining and preparing the material
- Shaping
- Drying
- Firing

Clay preparation.

After the raw materials have been extracted and stockpiled; it is prepared by crushing, grinding and mixing in a variety of ways, dependant upon the type of raw material, the end product and drying and firing method employed. Water content is controlled and the material going on to the shaping process may have moisture contents varying from between 17% to 30%, dependant on the different raw materials used, and the crudeness of the water addition process.

Shaping the bricks.

Of the five different shaping systems that are in use only extrusion, that does not involve material being forced into mould by pressure, are employed by the larger clay brick manufacturers in the Western Cape.

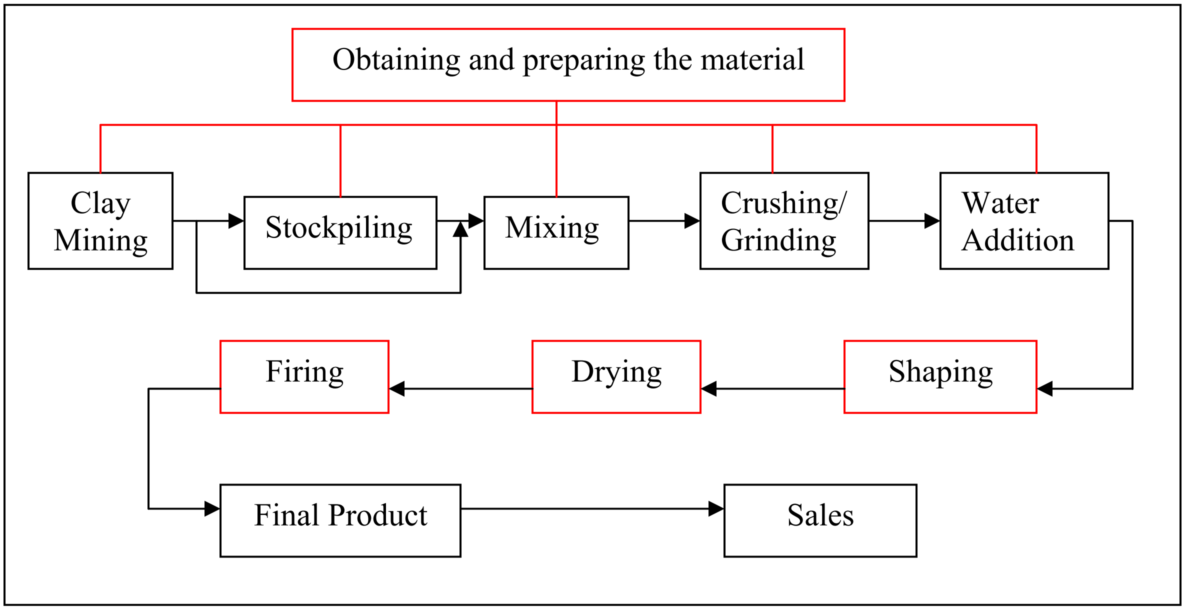


Figure 2 - Simplified schematic representation of the clay brick manufacturing process.

The shaping method used depends upon the type of raw material and in particular upon water content and type of brick required. These methods are:

- Hand molded
- Soft mud process
- Semi-dry process
- Stiff-plastic
- Extrusion process

The extrusion process is the most modern process. Most clay, except those that have high inherent water content, is shaped by this method. After preparation the clay is extruded through dies, with or without the forming of perforations, which may be formed through the extruded column. The extruded column of clay ensures correct length and width of the finished bricks. The extruded material is then cut with wires to obtain brick thickness. The wire-cut process also provides flexibility in producing varying sizes and shapes of brick and is an economical method for mass production.

Drying.

Drying is necessary in all cases where the brick, after forming, is soft and unable to withstand the weight of other bricks when being stacked in a kiln. This occurs with all handmade and soft mud types and also with wire-cut bricks where the moisture content of the extruded column is relatively high. In the drying stage the bricks are often arranged on pallets so that a flow of heated air can pass over them. This process is carried out in a series of chambers (intermittent dryers) or tunnels (continuous dryers) in which the temperature and humidity of the air is regulated to control the shrinkage which takes place during drying. Most dryers draw the hot air required to dry the product from the cooling zones of the kilns.

Most of the plaster brick manufacturers in the area do not use intermittent or continuous dryers. They dry their bricks in the sun (hackdrying), a process that can take from 3 to 6 weeks, depending on weather conditions. During wet weather conditions these manufacturers are forced to cover their green (unfired) bricks to prevent re-wetting.

Firing.

Firing produces a number of complicated chemical and physical changes in clay and the degree of control obtained is important. Ultimate firing temperature and type of atmosphere determine the ceramic properties and colour development of the final product. Three of the four firing methods are in use in the area:

1. Clamp

   The oldest method largely used for stocks and handmade bricks. Green bricks are closely stacked on a layer of fuel while the bricks themselves also contain combustible material. The clamp is set on fire and usually allowed to burn itself out. Control is dependant on the amount of fuel added, with the result that bricks may vary considerably in quality. Generally used for common (plaster) brick production but bricks are usually sorted into grades before sale.

   The thermal efficiency of a clamp is very low as it is difficult to utilize the heat from the fired bricks.

2. Intermittent kilns (Not used in the area)

   Intermittent kilns were the only other method of firing until 1858, when the Hoffman Continuous Kiln was introduced. These kilns are now principally used for the manufacture of special types of bricks.

   Although heat from the firing and pre-heat chambers are used to dry green bricks, heat losses occur by heating the large outside surface area of these kilns; the result of their circular design.

3. Continuous kilns

   These kilns consists of a number of chambers connected in such a way that the fire can be led from one to another, so that the stationary bricks are heated, fired and cooled. They are referred to as Transverse Arch, TVA, Kilns if the fire travel is across the chambers. This system combines economy and a good degree of control. Bricks produced from these kilns are usually facing bricks but some Western Cape manufacturers produce plaster bricks from them.

A flue system, that allows clean hot air from the cooling chambers to pass directly to drying and pre-heat zones of the kiln and the low heat capacity of the structure results in high thermal efficiencies. Heat loss is however still experienced with the constant heating and cooling of the chambers as the fire moves from chamber to chamber.

4. Tunnel kilns

   These are a more recent innovation and their use is steadily increasing. In tunnel kilns the fire remains stationary while bricks, set on cars, pass along a tunnel through pre-heating, firing and cooling zones. The ability to vary temperatures and track speeds provides optimum conditions for quality control and thus the exclusive production of facing bricks.

   These kilns, if properly maintained, are thermally very efficient as the drier and kiln zones are maintained at a given temperature.

Within broad limits, the properties of a particular type of clay brick can be foreseen but, increasingly, more precise information is needed to ensure consistency of individual product types year on year.

2.3. Standards.

The ability of clay brick to compete against competitors like cement, sand, stone, paint, wood and gypsum is best ascribed to the fact that brickwork is affordable, aesthetically satisfying and is a functionally efficient form of construction, which will withstand the test of time and rigors of our climate, when designed with understanding. (Handisyde and Haseltine, 1974).

Building and Construction Industry standards for clay brick products are in use as guidelines in many clay brick producing countries around the world. Table 2 below, compares the standards for the Republic of South Africa (SABS 227, 2002), the United States of America (ASTM C 652, 1992) and Britain (BS 3921, 1985).

Table 2 - Comparison of standards for burnt clay masonry units (clay bricks) for the Republic of South Africa (SABS 227, 2002), the United States of America (ASTM C 652, 1992) and Britain (BS 3921, 1985).

Requirements	SABS 227 2002	ASTM C 652 1992	BS 3921 1985
Class	3.1	3.1	5/7/8
Shape/Size	4.1.1	7.1	3.1
Size of voids	2.12	10	3.2
Appearance	4.1.2	8	0.3
Texture	4.1.3	9.2	0.3
Colour	4.1.3	9.1	F.2
Dimension deviations	4.2	7.1	4
Warpage	4.3	7.2	4
Compressive strength	4.4	5.3	7
Efflorescence	4.5	6	6
Durability	2.6	5.1	5
Soundness	4.6	N. A.	N. A.
Frost resistance		5.1	5.1
Water absorption	4.7	5.3	8
Water-soluble salts	4.7	6.1	5.2
Moisture expansion	4.7	N. A.	N. A.
Freezing and Thawing	N. A.	5.2	5.1
Suction Rate	N. A.	5.4	H

N.A. – Not applicable.

The standards differ mainly due to the impact that varying climatic conditions, in different regions, has on the durability of the clay brick. It therefore clearly differentiates between facing and common bricks as well as the degree in consistency for different classes of facing bricks by specifying different tolerances mainly for size, shape and colour. Methods of testing for compliance to the specifications with tolerances are also standardized and shown in these documents.

The standards protect the end-users by ensuring product consistency and uniformity. Many of the various functions that brickwork has the ability to fulfill, are a direct results of the quality standards. These functions are:

a) Appearance

   The appearance of brickwork derives from color, texture, size and shapes of the bricks, combined with color, width, shape and texture of the joints, including the effect of bond pattern. Part of the attraction of brickwork is the way in which it retains a pleasing appearance even after long-term weathering, but some changes does occur. Long-term appearance depends upon choice of materials, design details, workmanship and exposure conditions.

b) Durability

   Brickwork is very durable and generally requires little maintenance, but this is no guarantee against misuse. Disfigurement or damage can occur either from transport, incorrect construction or from using a type of brick or mortar unsuitable for its position. The durability of clay brick depends on:

   i. **Frost** Exposure conditions leading to continual saturation
   ii. **Salts** Disfigurement, and occasional; damage, may be caused by soluble salts crystallizing on or beneath the surface of brickwork. This usually appears in the form of white crystals on the brick surface, known as efflorescence.
   iii. **Detailing and adjacent materials** Concentrations of water run-off affect the long-term appearance of many facing materials. Often the effect upon brickwork is relatively slight: It will depend upon texture, absorption and color of the bricks.

iv. **Movement** Because of the multiplicity of joints, brickwork often takes up some movement without visible or damaging crack formation, but on all but small buildings the need for deliberately formed movement joints should be considered.

c) Strength

The widespread use of cavity walling as a means of water (rain) exclusion now often makes strength the important factor in determining thickness of brickwork in external walls. It has therefore become increasingly important for brickwork to be regarded as a form of construction to be calculated, just as is accepted for steel and concrete.

d) Environmental functions of brickwork.

These functions are:

i. Water exclusion
ii. Fire resistance
iii. Sound insulation
iv. Sound absorption
v. Thermal properties

e) Design flexibility

The small size of bricks together with the ease in making minor adjustments in joint size has always provided the advantage that brickwork could usually be made to fit the building requirements.

2.4 Body composition.

Clay brick manufacturers often combine a number of raw materials with unique chemical and physical properties, in specific ratio's, from one or more different natural deposits, see Table 3 below, to form a mixture that will produce a clay brick with specific, predetermined, quality parameters. This concept was practiced in China, to produce ceramic wares, as early as the Sung Dynasty, AD 960 – 1279 (Sellschop, 1994).

Table 3 - A typical example of an annual production program for a clay brick production facility.

	PRODUCTION	PRODUCT 1		PRODUCT 2		PRODUCT 3		PRODUCT 4		PRODUCT 5		TOTALS % WASTE	9.75
Production Split (%)			47.00		13.00		0.00		8.00		32.00		100.00
Production volumes (million)			19.789		5.474		0.00		3.368		13.474		42.105
RAW MATERIAL	SOURCE	%	Spm^3	%	Spm^3	%	Spm^3	%	Spm^3	%	Spm^3	%	Spm^3
Clay 1	Deposit 1	75.00	32652	55.00	6624			50.00	3705	67.00	18055	67.98	61036
Clay 2	Deposit 1			10.00	1204			25.00	1853			3.87	3057
Clay 1	Deposit 2	25.00	10884									13.78	10884
Clay 1	Deposit 3			20.00	2408			25.00	1853	33.00	8893	12.08	13154
												0.00	0
SAND				15.00	1807							2.29	1807
TOTALS		100.00	43536	100.00	12043			100.00	6805	100.00	26948	100.00	89938

Spm^3 of Clay used to extruded a thousand units	2.20	2.20	1.95	2.20	2.00

CHAPTER 3 – CLAY DEPOSITS OF THE AREA NORTH OF CAPE TOWN

3.1. Regional Geology.

Sediments belonging to the Malmesbury Group normally underlie the brick clay deposits of the Western Cape. According to Siegfried (1993), Malmesbury sedimentation started with enlargement of the Adamastor Ocean due to continuous rifting and separation of the Kalahari and Rio De La Plata Cratons between 900 – 700 Ma. Dalziel et al. (1994) suggest formation of the basin between 780 – 750 Ma. With the formation of Gondwanaland between 700 – 600 Ma, the Kalahari and Rio De La Plata Cratons moved closer and initiated closure of the Adamastor Ocean accompanied by folding and thrusting leading to the deformation of the sediments. Rozendaal et al. (1999) propose that reversal of spreading in the Adamastor Ocean occurred between 600 – 570 Ma.

The Malmesbury Group is subdivided into three tectonostratigraphic terranes, Figure 3 below, separated by major dislocation zones (Theron et al., 1992). The Boland Terrane occurs east of Wellington-Piketberg discontinuity and consists of the Piketberg and Porterville formations. The Swartland Terrane is the central terrane of the Malmesbury Group and is composed of the Berg River, Klipplaat, Moorreesburg and Franschhoek Formations. The Colenso Fault separates this terrane from the most southerly Tygerberg Terrane that is composed of only one formation, the Tygerberg Formation. This formation consists of alternating greyish to greenish fine- to medium grained greywacke, phyllitic shale, siltstone and quartzite with scarce calcareous and volcanic units (SACS, 1980). The strata are characterized by near upright, tight folds with a northwesterly orientation and an axial-plane cleavage, which is slightly inclined to the northeast, sub parallel with bedding (Cole and Viljoen, 1995).

The Malmesbury Group was intruded by plutons of the Cape Granite Suite between 630 and 500 million years ago (Theron et al., 1992), that was dominated by the final deformations and suturing of the two cratons when syn- to post-tectonic magmatism of the Cape Supersuite occurred (Siegfried, 1993). Recent dating, however, suggests 550 – 510 Ma (Cole, 2003). These granites are mostly coarse-grained, porphyritic and biotitic and have been kaolinised in places.

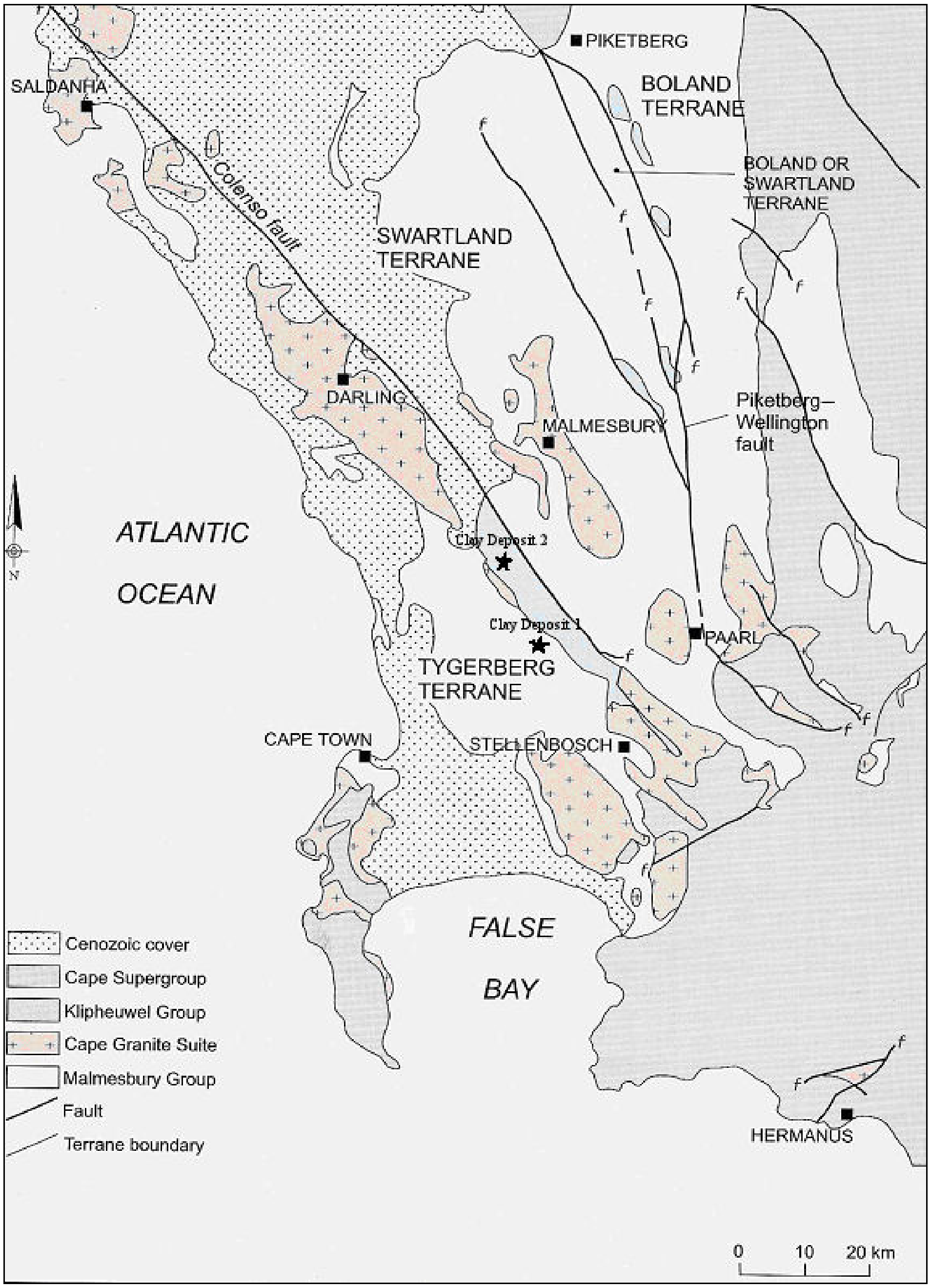


Figure 3 – Simplified geological map of the cover rocks in the Western Cape Province. Modified after Cole (2003) and Kisters et al. (2002).

Outcrops of the Cambrian, 510 – 475 Ma (Cole, 2003), Klipheuwel Group, Magrug and Populierbos Formations, occur to the south west of both clay deposits (Figure 3). The Populierbos Formation, consisting of a red shale-mudstone zone, overly the Magrug Formation, conglomerate-grit-sandstone zone (Theron et al., 1992). The depositional environments are described (Theron et al., 1992) as speculative alluvial fan for the Magrug Formation, culminating in lacustrine sedimentation (Populierbos Formation).

The rocks of the Cape Supergroup, that covers large areas towards the south and south east of the study areas, do not influence the outcome of this research.

Cenozoic rocks of significance to clay brick manufacturing possibly include minor deposits of clay, sand, lignite and ball clay of the Miocene Elandsfontyn Formation (Theron et al., 1992). These deposits are preserved in the depressions and paleochannels excavated into Malmesbury Group bedrock in the Atlantis, Kraaifontein and Koelenhof areas (Cole and Viljoen, 1995). Research by Mulholland (1993) indicates that these deposits are mainly covered by Pleistocene eolian, quartzose sand of the Springfontein Formation.

Cole and Viljoen (1995) reports that the remaining geological deposits comprise yellow, red or brown clayey colluvium and eluvium overlying the Malmesbury Group, reddish to light brown, sandy to gritty, clayey colluvium above the Cape Granite Suite and scattered outcrops of Cenozoic silcrete and ferricrete, which tend to form duricrusts on ancient planation surfaces (Partridge and Maud, 1987; Theron et al., 1992). Alluvial deposits, which are predominantly sandy to clayey, border the major streams and rivers in the area.

3.2. Deposit Models.

Literature (Grim, 1953; Moorhouse, 1959; Deer, Howie and Zussman, 1992 and Orris, 1998) describes the formation of different clay minerals as the result of either weathering or hydrothermal alteration dependant on physical-chemical conditions and the nature of parent materials. e.g. feldspars, micas, volcanic glasses or ferromagnesian minerals.

The clay deposits in the Western Cape can be classified as either residual or sedimentary in origin. Theron et al. (1992), mentions the occurrence of three different types of clay deposits in the area surrounding Cape Town. The occurrence of large potential reserves of brick clay associated with weathered Precambrian Malmesbury rocks, ball clay deposits that are evidently of Cenozoic age and kaolin derived from the Cape Granite Suite.

Research done by Heckroodt (1979) on brick clay in the Western Cape revealed the presence of widespread, “limitless resources”, of weathered shales and phyllites of the Malmesbury Group and “limited” resources of recent sediments, plastic clay, suitable for brick manufacturing.

Studies by Heckroodt (1979,1992) on kaolin deposits derived from the Cape Granite Suite, suitable for use in the ceramic and whiteware industries, revealed that these kaolin deposits have formed, to a large degree, as a result of *in situ* decomposition of the granites. The very deep surface weathering of the coarse porphyritic Cape Granites are ascribed to:

a) Strain and resulting weaknesses in the big feldspar crystals, which resulted from the micropoikilitic intergrowth of feldspar and quartz.
b) Prominent faults and joints, which allowed good ground water circulation, thereby promoting chemical disintegration of the primary minerals.
c) A hot, humid tropical climate, which allowed the extensive leaching required for the formation of kaolin deposits during the early to middle Miocene Period.

Cole and Viljoen (1995) reports that the weathered profile of many Malmesbury clay deposits, which are capped with silcrete/ferricrete, is not horizontally-layered but consists of alternating, steeply-dipping, yellow, brown, grey and white clay horizons which grade down into shale, siltstone and minor sandstone of the Malmesbury Group. As no evidence, that the clay was transported after weathering exists, these deposits developed as a result of the *in situ* weathering and are described by Orris (1998) as residual kaolin.

Partridge and Maud (1987), ascribed the formation of the Malmesbury clay as the result of a long period of residual weathering leading to deeply-weathered profiles. During the weathering process (Orris, 1998), meteoric water containing carbonic, organic, or other acids, percolates downward through the rocks converting feldspar to kaolinite (from a feldspathic rock with a high mica content) or halloysite (from a feldspathic rock with a low mica content).

Cole and Viljoen (1995) suggest that the distribution of the clays within the Malmesbury Group might be controlled by the proximity of granite intrusions of the Cape Granite Suite. They argue that some clay developed preferentially in metasomatically/hydrothermally-altered metasediments in areas where the Malmesbury shales were retained as a thin cover above granite intrusions and are possibly the result of more intense weathering along metasomatically-altered shear zones, or kaolinisation of feldspathic sandstone beds.

Table 4 below summarizes the most important characteristics of residual kaolin deposits as described by Orris (1998).

Spruce Pine in North Carolina (USA), Kikino Mine in Japan, Alberhill District in California (USA) and Cornwall in the United Kingdom are examples of residual kaolin deposits.

The younger (Cenozoic) ball clay deposits described by Heckroodt (1979) overlies the steeply dipping Malmesbury shales and displays horizontal bedding. Orris (1998) describes these deposits as sedimentary kaolin, subtype ball clay. The term ball clay is

Table 4 - Common characteristics of residual kaolin deposits as described by Orris (1998).

Age range	Regolith forming – Cretaceous to Tertiary
Host rocks	Felsic rocks ranging from Precambrian to Tertiary
Alteration	Katamorphic – kaolinite, halloysite from feldspar
Ore mineralogy	Kaolinite, halloysite
Gangue mineralogy	Quartz, ilmenite and muscovite and other heavy minerals
Typical ore dimensions	Deposits are irregularly shaped
Effect on weathering	Once formed these deposits must be protected from subsequent weathering and erosion
Maximum limit of overburden	20 m
Physical/chemical properties affecting end use	Halloysite contains more water than kaolinite and requires additional treatment for removal. Brightness, colour, opacity and particle size affect end use.
Compositional/mechanical Processing restrictions	Recovery of kaolin from saprolite requires beneficiation

applied to these clays as they consist mainly of kaolinite having a very fine particle size and containing organic material, which imparts good plastic properties. Small amounts of illite and montmorillonite may be present. It is believed that these clays are secondary products of kaolinised granite, which have been transported by water, together with organic material, to shallow depressions where they were deposited (Van der Merwe and Botha, 1992). See Table 5 below for a summary of the most common characteristics of sedimentary ball clay deposits as described by Orris (1998).

Paris in Tennessee (USA), Skalna area in Czechoslovakia, Westerwald area in Germany and Bovey Basin in Devon (United Kingdom) are typical examples of Cenozoic ball clay deposits.

Table 5 - Common characteristics of sedimentary ball clay deposits as described by Orris (1998).

Age range	Tertiary
Host rocks	Lignitic shale, silty clay, sand, lignite
Alteration	None
Ore mineralogy	Ball clay is largely composed of poorly crystalline kaolinite (about 70%) and small amount of illite and (or) montmorillonite, chlorite.
Gangue mineralogy	Quartz, carbonaceous material, chlorite, feldspar, rutile, zircon
Typical ore dimensions	Lengths range from 100 to 800 m, width from 50 to 300 m, thickness commonly range from 1 to 5 m
Effect of diagenesis/burial	Deeper, longer burial lithifies plastic ball clay into non-plastic fireclay.
Maximum limit of overburden	20 m
Physical/chemical properties affecting end use	Plasticity, brightness, colour and refractoriness affect end use. Have high plasticity, high dry-green strength, excellent adhesion and toughness
Compositional/mechanical Processing restrictions	Iron and carbonate minerals may make the material unusable

Surficial weathering of acidic and basic igneous rocks often results in massive kaolin deposits. Controlling parameters include subtropical or tropical climate, good drainage, and a high rate of leaching of soluble elements such as K, Na, Mg, Ca and Fe, which enrich the residue in Al and Si (Theron et al., 1992). These deposits are known as lateritic kaolin deposits and are currently forming in tropical areas. The decomposition of feldspar to form kaolin is also substantially accelerated by the presence of carbon dioxide or humic acids.

3.3. Mineralogy and Chemistry.

Research by Brownell (1976), Vogt and Vogt (2004), Keeling (1963), Worrall (1969), Horn (1994) and many others on monomineralogical clay specimens and natural clay deposits has resulted in a better understanding of the specific properties of the individual clay minerals and their behaviour in mineral mixes. They all agree that the mineral constitution, chemical composition, grain size distribution and colloid behaviour of clay raw materials (primary properties) determine the physical properties of the material such as shaping, drying, firing and ceramic body behaviour. A sound knowledge of clay minerals, their primary and physical properties, and the geology, mineralogy and chemical signature of known clay deposits is required to be able to determine sampling techniques and quality parameters to test for, when exploring brick clay deposits.

Clay is a widely used term and can refer to, Dictionary of Geological terms (1976):

a) Any of a diverse group of fine-grained minerals
b) Could be used as a rock term
c) Could refer to a range of particle sizes, < 4µm.

The Nomenclature Committee of the Association Internationale Pour l'Etude des Argiles (AIPEA) defined clay during 1996 as any naturally occurring material, composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when dried or fired.

Although clay minerals consists largely of phyllosilicate minerals it may contain other materials that impart plasticity and affect the hardening when dried or fired. This means that minerals and materials other than phyllosilicates can be included in the definition of a clay mineral (AIPEA).

The term phyllosilicates refer to a group of silicate minerals with similar structures characterized by silicon-oxygen tetrahedral linked in a planar arrangement (Figure 4).

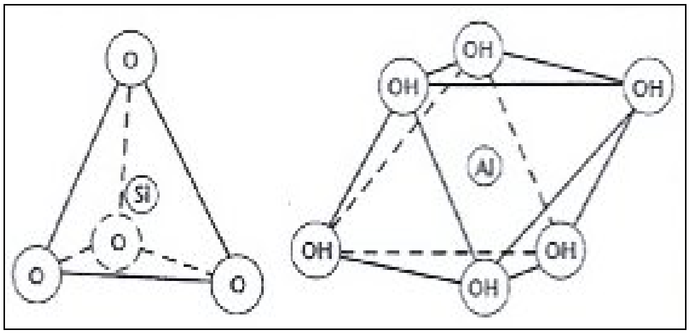


Figure 4 - Tetrahedral and octahedral layers as basic elements of the clay minerals. (After Vogt and Vogt, 2003).

Clay minerals consist of layers, as illustrated in Figure 5 and Figure 6 below, identified by a specific arrangement of sheets. The most basic arrangement is kaolin, consisting out of two sheets. One sheet comprises two planes of oxygen atoms arranged in tetrahedral coordination around Si^{4+} (or Al^{3+} and Fe^{3+}) cations by sharing the basal oxygen between adjacent tetrahedra. The other sheet consists of OH^- groups ordered in octahedral coordination around centrally Al^{3+}, Mg^{2+}, Fe^{2+} and Fe^{3+} cations.

Each clay mineral group (Table 6 below), can be identified by a very characteristic arrangement of these sheets in layers, the layers displaying very distinct basal spacing for a specific clay mineral.

Where the composition and crystal structure differs significantly from the textbook ideal, the clay is described as disordered and poorly crystallized. The variety of conditions under which brick clay deposits were formed signifies that most are disordered and complex and consists of a mixture of clay and accessory minerals whose properties cannot be described by the properties of any one mineral.

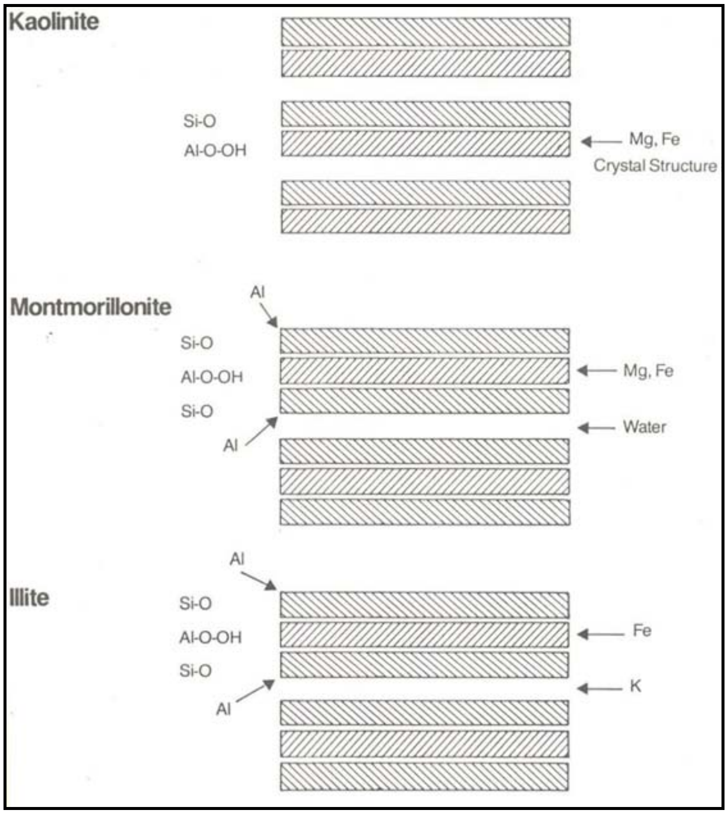


Figure 5 - Structure of the most common clay minerals associated with kaolin deposits in the areas investigated.

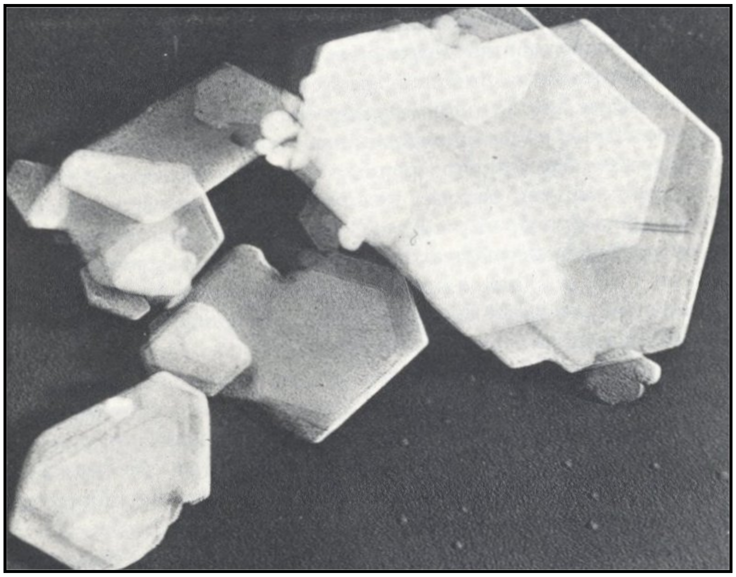


Figure 6 - Electron microscopic photograph of kaolinite crystals. (After Brownell, 1976). x 38 600

Tabel 6 - Classification of the phyllosilicates and related clay minerals. The layer type refers to the tetrahedral:octahedral sheet ratio. (modified after Bühmann in Saggerson 1986).

LAYER TYPE	GROUP	SUBGROUP	MINERAL SPECIES (most important)
1:1	Kaolinite-serpentine	Kaolinite Serpentine	Kaolinite, dickite, hallosite, chrysotile, baumite, greenalite, ect
2:1	Pyrophyllite-talc	Pyrophyllite Talc	Pyrophyllite, ferri-pyrophyllite Talc, willemseite, kerolite, pimelite
	Smectite	Dioctahedral smectite Trioctahedral smectite	Montmorillonite, nontronite Saponite, hectorite
	Vermiculite	Dioctahedral vermiculite Trioctahedral vermiculite	Dioctahedral vermiculite Trioctahedral vermiculite
	Mica	Dioctahedral mica Trioctahedral mica	Muscovite, paragonite, glauconite, illite. Phlogopite, biotite, siderophyllite, lepidolite
	Brittle Mica	Dioctahedral brittle mica Trioctahedral brittle mica	Margarite Clintonite, anandite
	Chlorite	Dioctahedral chlorite Di-trioctahedral chlorite Trioctahedral chlorite	Donbassite Cookeite Clinochlore, nimite
2:1 (Inverted ribbons)	Palygorskite-sepiolite	Palygorskite Sepiolite	Palygorskite Sepiolite

Heckroodt (1979) reported that the weathered Malmesbury shale consists largely of kaolinite, hydrous mica and quartz with varying concentrations of iron oxides and hydroxides, the kaolin:hydrous-mica ratio varying from 1:1 to 1:<1. These findings concur with the model for residual kaolin (Table 4). Hydrous micas are secondary minerals consisting of grains of variable size ranging from visible crystallites to particles of the same dimensions as the clay minerals (Grimshaw, 1971).

Van der Merwe and Botha (1992) reported that the ball clay of the area consists mainly of kaolin with small amounts of mica and quartz and that the clay has a high organic content. These findings concur with the sedimentary ball clay model (Table

5), but do not mention any presence of montmorillonite and chlorite as described by Orris (1998).

Kaolin and hydrous-mica (Illite) are the primary and most important clay minerals found in brick clay deposits in the Western Cape with minor amounts of montmorillonite (Figure 5):

a) Kaolinite, $Al_2Si_2O_5(OH)_4$, form part of the chemically most pure and comparatively largest clay mineral group with a theoretical Al_2O_3 content at a high of 39,5 % (Vogt and Vogt, 2003). Replacement of some of the aluminium by magnesium and iron can occur resulting in disordered kaolinite with a smaller crystal structure and greater plasticity (Singer and Singer, 1963; Grimshaw, 1971; Clews, 1969).

b) Montmorillonite, $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_{2.}nH_2O$, has a three-layered structure where the octahedral sheet containing aluminium is sandwiched between two silicon-oxygen coordinated tetrahedral sheets. Some of the silicon is replaced by aluminium and some of the aluminium by magnesium and iron, leaving the layers negatively charged so that other metal ions with positive charges are attached to the surface of the clay particles and to the spaces between the layers. Water molecules can also be absorbed into the structure resulting in a clay with a high inherent moisture content and a high drying contraction (Singer and Singer, 1963; Grimshaw, 1971; Clews, 1969).

c) Illite, $K_{1.5-1.0}Al_4[Si_{6.5-7.0}Al_{1.5-1.0})O_{20}](OH)_4$ (Deer, Howie and Zussman, 1992), has a similar structure to montmorillonite with some of the silicon replaced by aluminium resulting in a mineral with a negative charge which is neutralized by the attraction of K^+ ions. These K^+ ions fill the gaps between the stacked layers and bond them together thus preventing water molecules to gain access to the structure Singer and Singer, 1963; Grimshaw, 1971; Clews, 1969).

3.4. Accessory Minerals.

The bulk of natural brick clay deposits, between 70 – 80 %, as indicated by semi-quantitative mineralogical analysis and full chemical results, consists of other minerals whose content and variability in content have a significant effect on the manufacturing process and overall quality of the final product. These minerals can be classified into the following categories:

a) Minerals resistant to weathering

   i. Rutile and Anatase (TiO_2).

      These minerals are present in most clay deposits (Deer, Howie and Zussman, 1992) and have no significant affect in concentrations of a percent or less; at higher concentrations it will act as a colour enhancer because it enhances the staining power of iron oxide (Brownell 1976, Sellschop 1994).

   ii. Mica.

      Mica is like feldspar alumina silicates containing basic metal ions and is found in a range of igneous rocks. Its structure is very stable, preventing mica to decompose easily accounting for its presence in many clay deposits (Deer, Howie and Zussman, 1992). Minerals containing basic metal ions like Na^+ and K^+ are described as fluxes and lower the vitrification temperature of the clays. Potassium is a very powerful flux and determines to a large extent what the water absorption of the final product will be after firing at a specific top temperature. The water absorption of the final product fired at a specific temperature is a measure of the refractoriness of the clay (Brownell, 1976).

   iii. Iron Oxides.

      Are the principle colouring agents in clay. It must however be highlighted that it is only the “free” iron compounds which contributes to colour development (Brownell, 1976). The particle size of the iron compound and the kiln atmosphere (reducing or oxidizing) has a direct influence on the colour of the final product, even (disseminated) or speckled. In a disordered or complex clay mineral part of the iron will be absorbed into the crystal structure, and will have no effect on colour development.

iv. Quartz (SiO_2).

Quartz is frequently the major mineral found in sedimentary clay rocks (Deer, Howie and Zussman, 1983). During processing of the clay, before firing, it is a non-plastic filler. Its properties are opposite to those of clay minerals (Brownell, 1976). It reduces the strength, plasticity and drying contraction of clays. Moderate quantities of quartz are beneficial in clays, which would otherwise be too plastic and have a large drying shrinkage. (Singer and Singer, 1963; Grimshaw, 1971; Clews, 1969).

On firing some of the Silica forms a molten glass in combination with basic metal oxides such as Sodium (Na), Potassium (K), Iron (Fe), Calcium (Ca), and Magnesium (Mg). This vitrification process is accompanied by shrinkage as solid material melts and flows, filling the vacant pore spaces.

Quartz exists in two forms; α - quartz is stable at temperatures up to $573^{o}C$ and β - quartz above this temperature. This change is rapid and reversible with a sudden expansion on heating and a sudden contraction on cooling due to slight re-alignment of the atoms of silicon and oxygen. The product has to be strong enough to withstand the stresses developed by the quartz inversion at $573^{o}C$ on the heating cycle and the cristobalite inversion between $260^{o}C$ and $220^{o}C$ on the cooling cycle.

Excessive quartz concentrations in a body mix would negatively influence product yield resulting in crazing and or cracking of the product during firing caused by the processes explained above.

b) Organic materials.

The only organic material associated with brick clay deposits in the area surrounding Cape Town is peat and disseminated plant material associated with ball clay deposits (Theron et al., 1992). The presence of some organic material in natural brick clay deposits, such as coal and lignite, are beneficial to the extent that they reduce energy costs by limiting the amount of fuel required for vitrification.

The absence of suitable coal deposits in the Western Cape forces the local brick manufacturers to import duff coal, at great expense from the inland provinces, to use as a body fuel by mixing it into the clay mixtures.

c) Chemical precipitates.

With the formation of clay minerals from chemical reactions, salts such as carbonates, chlorides and sulphates also form directly or indirectly from these reactions. These salts are either soluble or insoluble:

i. Soluble salts.

Salts that are very soluble in water and dissolves during the brick-forming phase. It is brought to the exposed surfaces of a brick during the drying process where it is deposited. During firing, the salts melt, decompose or reacts with silicates to form a mineral phase on the exposed surfaces of clay products (Brownell, 1976). This process is known as scumming.

Examples of soluble salts are salts of potassium and sodium. They are vigorous fluxes and will be removed by solution in the glassy melts during firing. Magnesium sulphate ($MgSO_4$) is also soluble in water and causes efflorescence if not destroyed during the firing process.

ii. Insoluble salts.

They occur as either small particles (disseminated) or larger lumps of solid material in the brick clay. The coarser lumps of salt like carbonate of calcium and magnesium decomposes on heating, respectively at 900°C and 700°C, giving off carbon dioxide as a gas leaving behind reactive oxides CaO and MgO. The rapid decomposition of the salts causes explosive gas release blowing out pieces of the product (lime popping) immediately surrounding the salts lump (Brownell, 1976).

The oxides of iron (FeO), calcium (CaO) and magnesium (MgO) are active fluxes once they start melting and produce fluid silica melts over a short temperature range resulting in narrow vitrification ranges, demanding close temperature control to prevent over firing that will cause bloating of the product (Brownell, 1976).

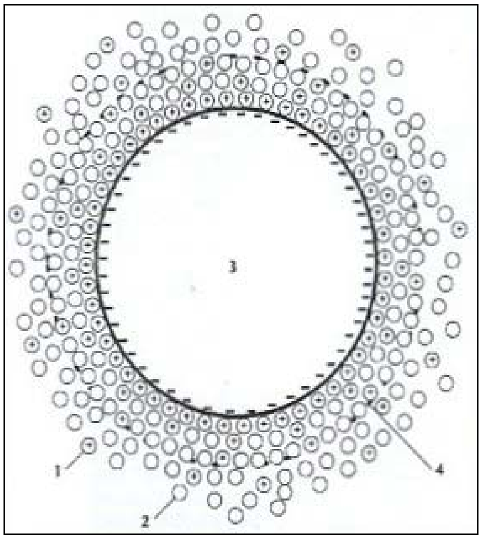
d) Minerals formed after deposition.

Unpopular minerals formed after deposition is mostly sulphides of iron with ferrous sulphate (FeS_2) as the most common. They are formed during the chemical reduction of ferric compounds by carbonaceous material. During firing sulphur is released and combines with the surrounding water vapour to create forms of sulphuric acid vapours, which attacks the metalwork around the kiln. It also converts lime ($CaCO_3$) in the body mix to gypsum ($CaSO_4.2H_2O$), which causes bloating (Brownell, 1976).

3.5 Physical Properties.

Clay mineral crystals lie within the colloidal range and therefore have colloidal properties that do not obey the normal sedimentation laws (Singer and Singer, 1963; Grimshaw, 1971; Clews, 1969). The clay mineral particles of less than 100nm in size are responsible for the colloidal properties of the raw material. These minute particles have a negative charge and attract water molecules that totally enclose the individual particles (Figure 7), causing a volume increase (swelling) of the clay body (Vogt and Vogt, 2003).

The negative charge of clay particles also attracts other cations from solution. Vogt and Vogt, 2003, has shown that bonding with Ca^{2+} forms a frame structure known as a “house of cards”. This structure is created by the extra positive charge bonding two kaolin platelets together, Figure 8. Water is stored in the gaps of the frame structure.



1. Hydratized cation.
2. Water molecule.
3. Clay mineral particle with negative surface charge.
4. Limiting range of the hydratized cations firmly adhering to the surface

Figure 7 - Clay cell with a double layer of firmly adhesive and mobile water molecules. (After Vogt and Vogt, 2003).

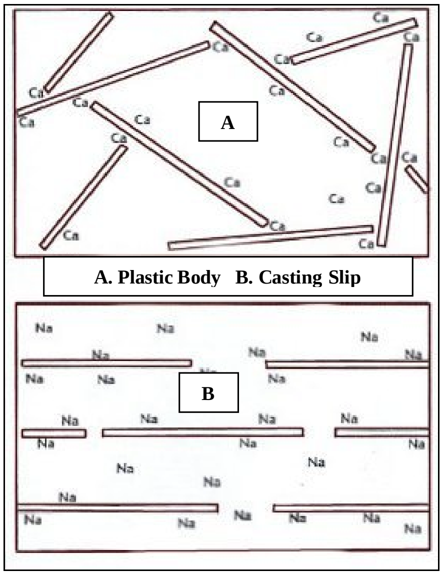


Figure 8 - "House of cards" structure of the clay mineral particles in plastic clays (After Vogt and Vogt, 2003)

Plasticity is achieved with the application of an external force when the bonding forces holding the frame structure upright is broken down and the ceramic body begins to flow as long as the external force is applied. With the removal of the external force the particles again combine and the clay article keeps the shape it had when the force was applied.

The colloidal properties of clay minerals are therefore responsible for the plasticity, ductility, drying sensitivity, dry bending strength and shrinkage of ceramic bodies. The more important properties to test for when exploring brick clay deposits that are functions of the colloidal properties as discussed are; drying sensitivity, extrusion behaviour, modulus of rupture (MOR), extrusion moisture, drying shrinkage and loss on ignition (LOI). These properties are lost after heating the material to between 250 ^{o}C and 300^{o}C.

Heating of the ceramic clay body above 250-300 ^{o}C, leads to the destruction of all minerals present, at different temperatures, excluding non-converted quartz and feldspar, with the formation of amorphous silicates and various new minerals (mullite, anorthite, gehlenite, diopside, calcium aluminates and silicates, spinel) dependent on the initial constitution of the ceramic body. For this reason most natural raw materials attain strengths, which are comparable with contact metamorphic rocks. Figure 9 below summarizes the basic reactions occurring during the firing of clay bodies.

Important ceramic properties to test for, when exploring brick clay deposits are; fired shrinkage, fired water absorption, compressive strength and fired colour. It is advantageous to test for these properties at different temperatures to be able to formulate the vitrification range of the ceramic body. The mentioned properties will be discussed in Chapter 4, section 4.2.3 and 4.3.3.

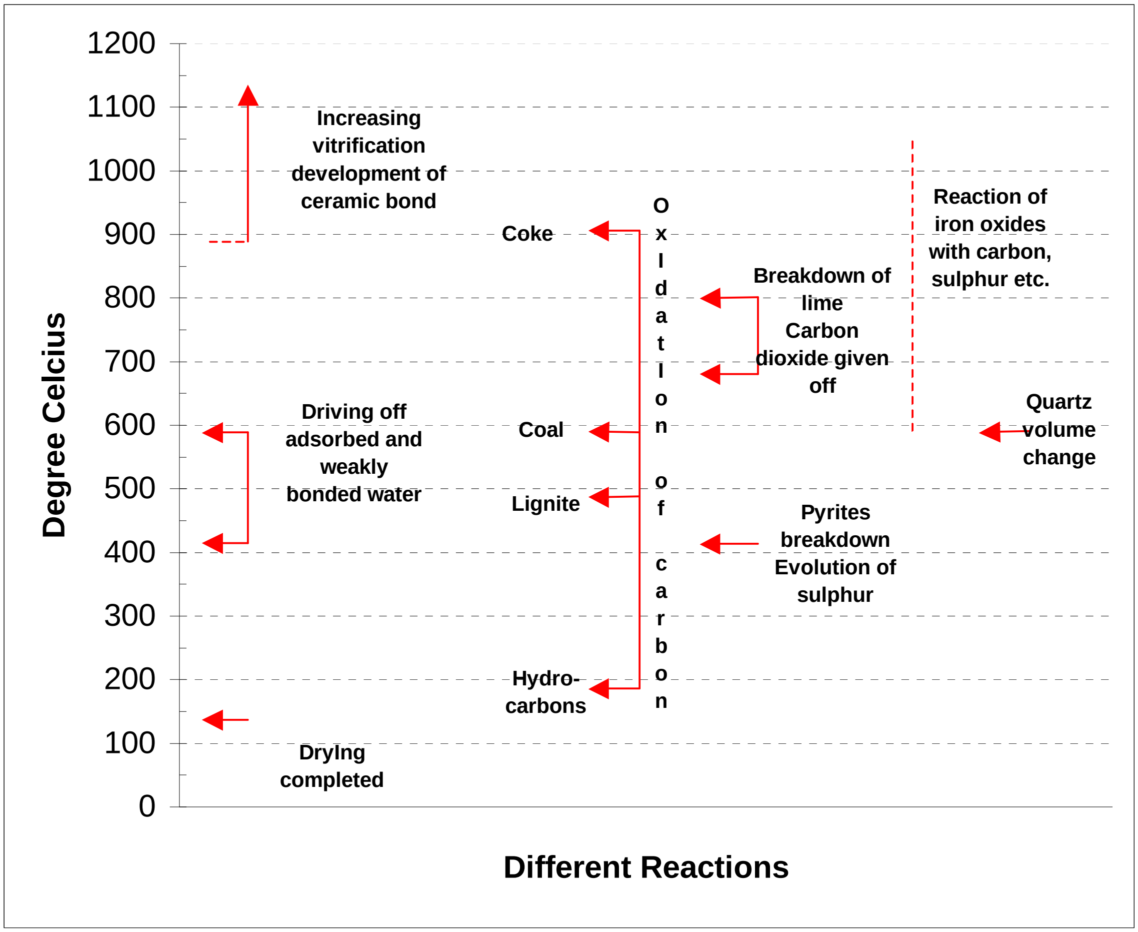


Figure 9 - Summary of basic reactions taking place during the firing of clay brick bodies.

CHAPTER 4 – EXPLORATION

The end result of any exploration programme for brick clay deposits, given the complexity of the brick manufacturing process, requires the identification and accurate modeling of geological, chemical and ceramic quality criteria. This will ensure consistent and continuous compliance with the relevant quality standards demanded by the targeted market.

The identified variability of the quality parameters and related confidence levels would allow the setting of standards for the reporting of resources and reserves as prescribed by the South African Code for Reporting of Mineral Resources and Mineral Reserves (SAMREC Code). Compliance with the SAMREC Code would automatically imply compliance with the JSE rules as the code was written to regulate ore reserve and resource statements of new and existing listed companies.

4.1 Exploration Program.

The selection of the two inferred clay resources described in this section follow from an ongoing programme to identify and secure suitable clay deposits, in the area, in order to ensure sufficient proven clay reserves for future clay brick production.

After careful consideration of all available options, it was decided to evaluate two inferred resources, by following proven evaluation methodologies that would results in clear go / no go decisions as the evaluation progresses. The phases decided on were:

a) Securing the mineral rights.
b) Initial exploration phase.
   The goal of this phase was to identify, by drilling a limited number of boreholes on a 200m x 200m grid, the mineralogical nature, geochemical variation, ceramic properties and geological nature of the clay deposits.
c) Bulk sampling.

This phase would follow on the initial exploration phase if deemed successful and would consist of taking bulk samples for production trials. The size and quality parameters of the bulk samples would be determined during the initial exploration phase.

d) Follow-up exploration.

This phase would only be initiated after the successful completion of the production trials. The goal would be to increase the geological and ceramic confidence by delineating the deposit for grade and volume estimations and deposit valuation.

The depth of the boreholes were limited to 20.25 meters with the exception of a few boreholes drilled to a final depth of 24,75 meters. The borehole collar positions were to be placed by experienced surveyors.

To ensure that all samples taken were representative of their physical location and unbiased it was decided to use core drilling for sample collection. An NX drilling bit, with a core diameter of approximately 75 mm, was selected. The boreholes were drilled on an even grid to allow for the construction of meaningful semi-variograms for quality parameter estimation of the deposits (Clarke and Harper, 2000).

For instance, frequency distributions may be meaningless if drill hole data points are located on a 10-meter grid in the high-grade area and on a 100-meter grid in the lower grade areas. It is also important that the data, to be processed, has a constant support size. It has therefore been decided that all samples submitted for testing would consist of 100% of the core recovered for a specific sample length, which are normally 1,5 meter or 3.0 meter intervals, based on the presence of detectable geological contacts.

All samples were submitted to reputable laboratories for chemical, ceramic and mineralogical analysis. Testing methods included XRD for Semi Quantitive Mineralogical Analysis, AA for Chemical Analysis, Gravimetric analysis to determine the free quartz content and physical testing as prescribed by SABS 227 (2002).

A standardized data capture procedure was enforced during the borehole logging. Data was recorded of each identifiable lithological unit in terms of eight descriptive criteria. The criteria, and codes used are summarised in Table 7. This practice was adopted to ensure continuity for any future work.

Table 7 - Geological code descriptions for mapping/logging clay deposits.

Domain	Description	Code	Description	Code	Description	Code
Rock Type	Phyllite	PHY	Ouklip	OUK	Sand	SND
	Shale	SHL	Topsoil	TSL	Marl	MRL
	Siltstone	SLT	Subsoil	SSL	Alluvial Clay	ACL
	Dolerite	DOL	Greywacke	GKE	Dolomite	DOM
	Quartzite	QTS	Plastic Clay	PCL	Chert	CRT
	Quartz	QTZ	Ball Clay	BCL	Dwyka Tillite	DTL
	Sandstone	SST	Flint Clay	FCL		
Lithology	Shaley	LSHL	Clayey	LCLY		
	Silty	LSLT	Sandy	LSST		
Geochemistry	Carbonaceous	CCBN	Micaceous	CMIC	Quartz Veins	CVQZ
	Ferruginous	CFER	Kaolinitic	CKAL	Smectitic	CSME
	Siliceous	CSIL	Sericitic	CSER	Organic	CORG
Grain Size	Very Fine	GVF	Medium	GCO	Gravel	GGR
	Fine	GFI	Coarse	GME	Boulders	GBO
Texture	Massive	FMA	Fissile	FFI	Plastic	FPL
	Blocky	FBO	Friable	FFR	Slickenside	PSL
Hardness	Very Hard	HVH	Medium	HME		
	Hard	HHA	Soft	HSO		
Weathering	Extreme	WEX	Partially	WPA		
	Moderate	WMO	Fresh	WFR		
Colour	Grey	GRY	Red	RED	Beige	BGE
	White	WHT	Orange	ORG	Green	GRN
	Black	BLA	Purple	PRP	Brown	BRN
	Cream	CRM	Yellow	YEL		

All sample data and geological information gathered were electronically captured in Surmin geological databases for interpretation through the creation of three-dimensional electronic block models.

The exploration results of both clay deposits will not be discussed as obtained per phase but rather as end results for each project. The two deposits will not be identified for confidentiality reasons, but will be referred to as Deposit One and Deposit Two.

4.2 Deposit One.

4.2.1 Geology and Mineralogy.

Information gathered from both surface mapping and the drilling of the exploration area (Figure 10) shows that the area is capped with silcrete and ferricrete with occasional outcrops of the red, yellow and white to cream Malmesbury weathered shales (clay), where the silcrete and ferricrete had been removed for road construction purposes in the past. The average thickness of the cover intersected was 0.99 m, with a recorded maximum thickness of 1.7 m (Figure 11).

Field observations and the results of semi quantitive mineralogical analysis (SQMA), Table 8 and Table 9 below, indicated that the clay intersected could be subdivided into four clearly identifiable units, which will be discussed in the subsequent sections.

4.2.1(a). Red clay.

Red, soft, extremely weathered, fine-medium grained, plastic clay (Figure 12). When present, it is most commonly found directly below the overburden. Often mistakenly identified as recent alluvial clay due to the fact that no horizontal or steeply dipping cleavage and/or bedding could be distinguished.

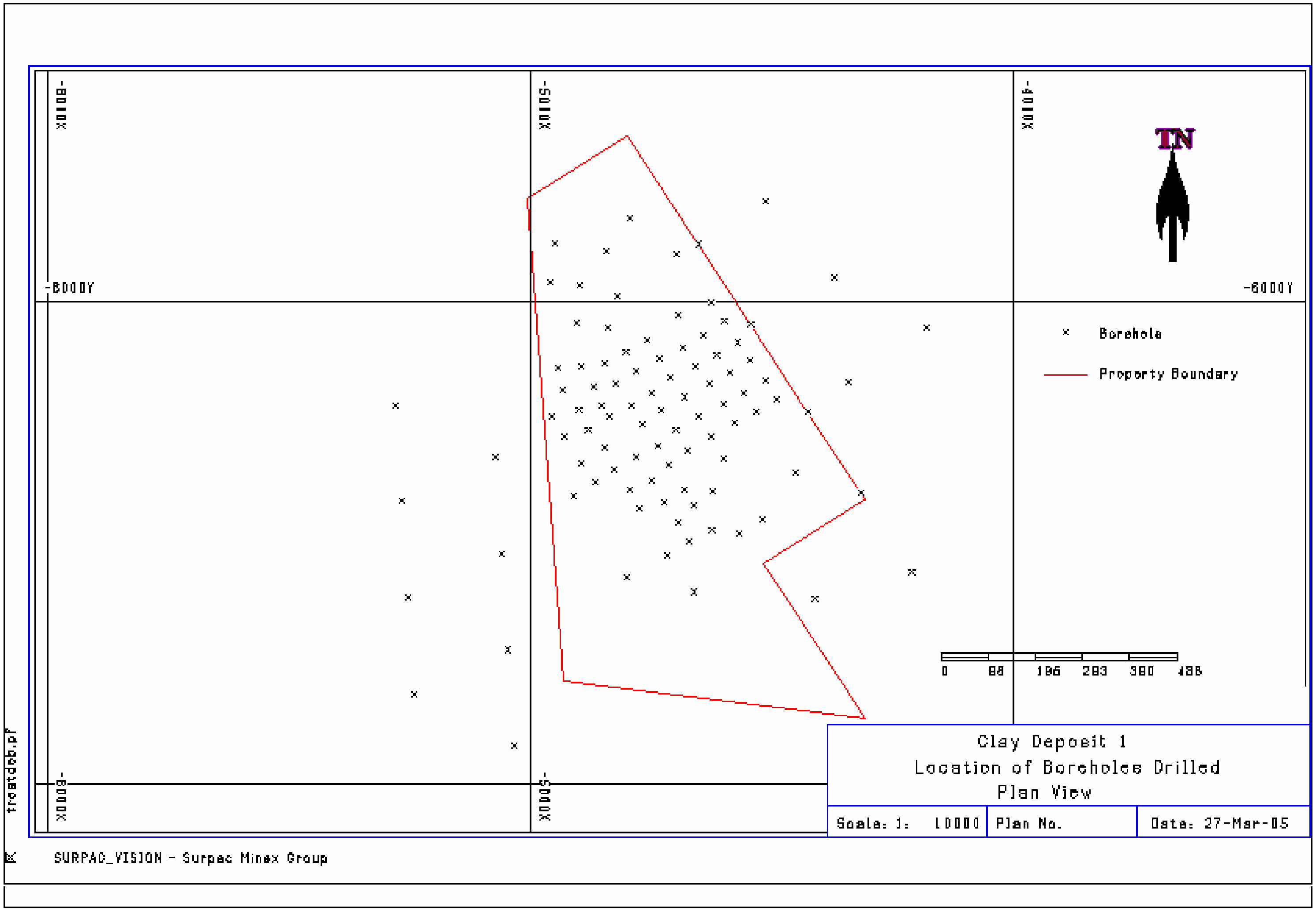
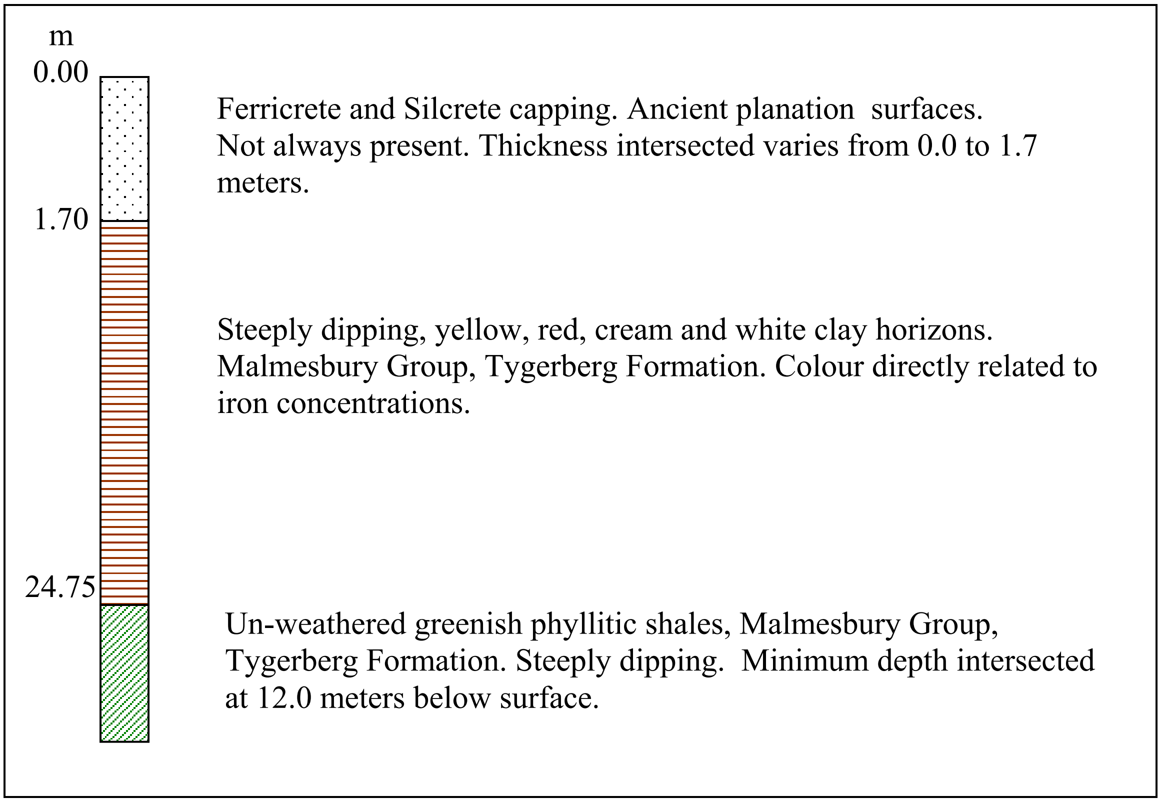


Figure 10 - Map showing positions of boreholes drilled at Deposit One.



Ferricrete and Silcrete capping. Ancient planation surfaces. Not always present. Thickness intersected varies from 0.0 to 1.7 meters.

Steeply dipping, yellow, red, cream and white clay horizons. Malmesbury Group, Tygerberg Formation. Colour directly related to iron concentrations.

Un-weathered greenish phyllitic shales, Malmesbury Group, Tygerberg Formation. Steeply dipping. Minimum depth intersected at 12.0 meters below surface.

Figure 11 - Simplified geological succession of Deposit One showing maximum depths below surface.

Table 8 - Total Sample, semi quantitive mineralogical analysis results of the clay/rock from Deposit One. (Fs = Feldspar, Hm = Hematite, St = Smectite, Kt = Kaolinite, Qz = Quartz, Go = Goethite, Mi = Mica)

Rock Description	% Fs	% Hm	% St	% Kt	% Qz	% Go	% Mi
Fresh Rock	4	0	0	12	74	0	10
Partially weathered Rock	4	0	3	18	69	0	6
White clay	0	0	0	25	59	0	16
Yellow clay	4	0	0	30	53	5	8
Red clay	0	5	0	21	69	0	5
Vein Material	0	0	0	67	33	0	0
White clay with vein material	0	0	0	22	70	0	8

Table 9 - Clay Fraction Sample, semi quantitive mineralogical analysis results of the clay/rock from Deposit One. (St = Smectite, Kt = Kaolinite, Qz = Quartz, Go = Goethite, Mi = Mica)

Rock Description	% St	% Kt	% Qz	% Go	% Mi
Fresh Rock	13	62	6	1	18
White clay	0	67	6	0	27
Yellow clay	0	14	52	31	3
Red Clay	3	95	0	0	2
Vein Material	0	88	7	2	3

This clay consists of varying amounts of kaolinite, quartz, mica, and hematite responsible for the red colour.

Semi quantitive mineralogical analysis results of the clay fraction confirmed that kaolinite is the major mineral present with minor amounts of smectite and mica.

Figure 12 - Photo of red and yellow plastic clay from Deposit One.

4.2.1(b). Yellow clay.

Yellow, silty to clayey, extremely weathered ferruginous clay (Figure 12). Plasticity is clearly detectable and seems to vary with varying iron content of this unit. The different shades of yellow relate directly to the iron concentrations in the clay; dark yellow would indicate a higher iron concentration. The fissility and dip is not always detectable and diminishes with increased plasticity. This horizon is normally located directly adjacent to and above, the white to cream coloured shale.

This clay differs mineralogically from the red clay in that it contains traces of unaltered Feldspar, similar to the fresh and slightly altered rock. The clay derives its yellow colour from the presence of goethite.

Semi quantitive mineralogical analysis results of clay fraction samples showed the presence of kaolinite, goethite and quartz as the major minerals present in this fraction with minor amounts of mica.

4.2.1(c). White clay.

White to cream coloured, silty, extremely weathered, kaolinitic shale with fissility clearly distinguishable (Figure 13), dipping steeply (70^o – 80^o) in a northwesterly direction. The grain size of the shale varies from fine to very fine, totally dependent on the amount of free quartz present. Kaolinite, quartz and mica are the most abundant minerals with high concentrations of kaolinite and mica in the clay fraction.

The presence of vein quartz, and white clay veins (Figure 14) of thicknesses up to 12 mm had been detected in a few boreholes, indicating hydrothermal activity. Semi quantitive mineralogical analysis results showed that the vein

Figure 13 - Photo of white silty clay from Deposit One.

Figure 14 - Photo of hydrothermal veins intersecting Deposit One.

material consists primarily of kaolinite and quartz with no mica detected in the total sample. Semi quantitive mineralogical analysis results of the clay fraction showed that kaolinite is the major mineral present (up to 88%) with quartz, goethite and mica occurring as accessory minerals.

4.2.1(d). Fresh Malmesbury Shale.

Partially weathered to fresh (un-weathered), steeply dipping, hard, light green phyllitic Malmesbury shale (Figure 15) that indicates the floor of the deposit. The photo clearly shows the angle of the bedding planes and the presence of thin hydrothermal veins cutting through the bedding. The contact is normally gradational in that the state of weathering changes within a few meters from extremely weathered shale to hard, fresh rock. The floor is uneven and is controlled by the depth of weathering which varies from 0.2 meters to 24.75 meters in the area drilled (Figure16).

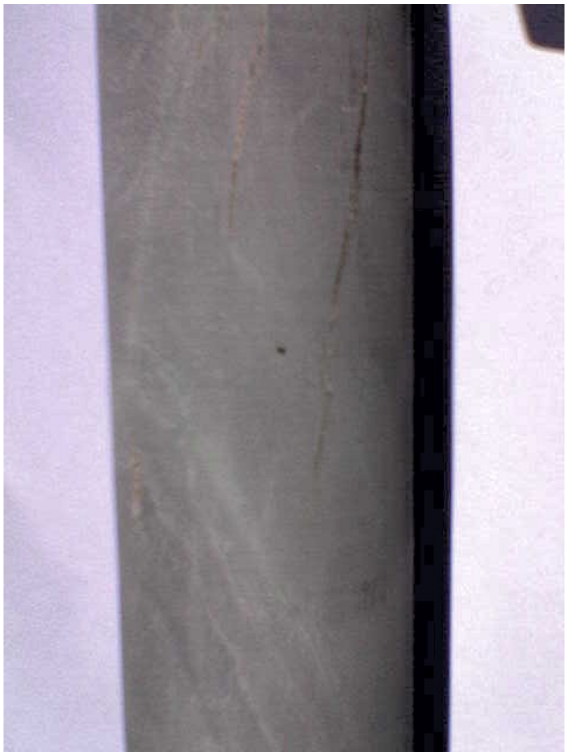


Figure 15 - Photo of partially to un-weathered phyllitic Malmesbury shale.

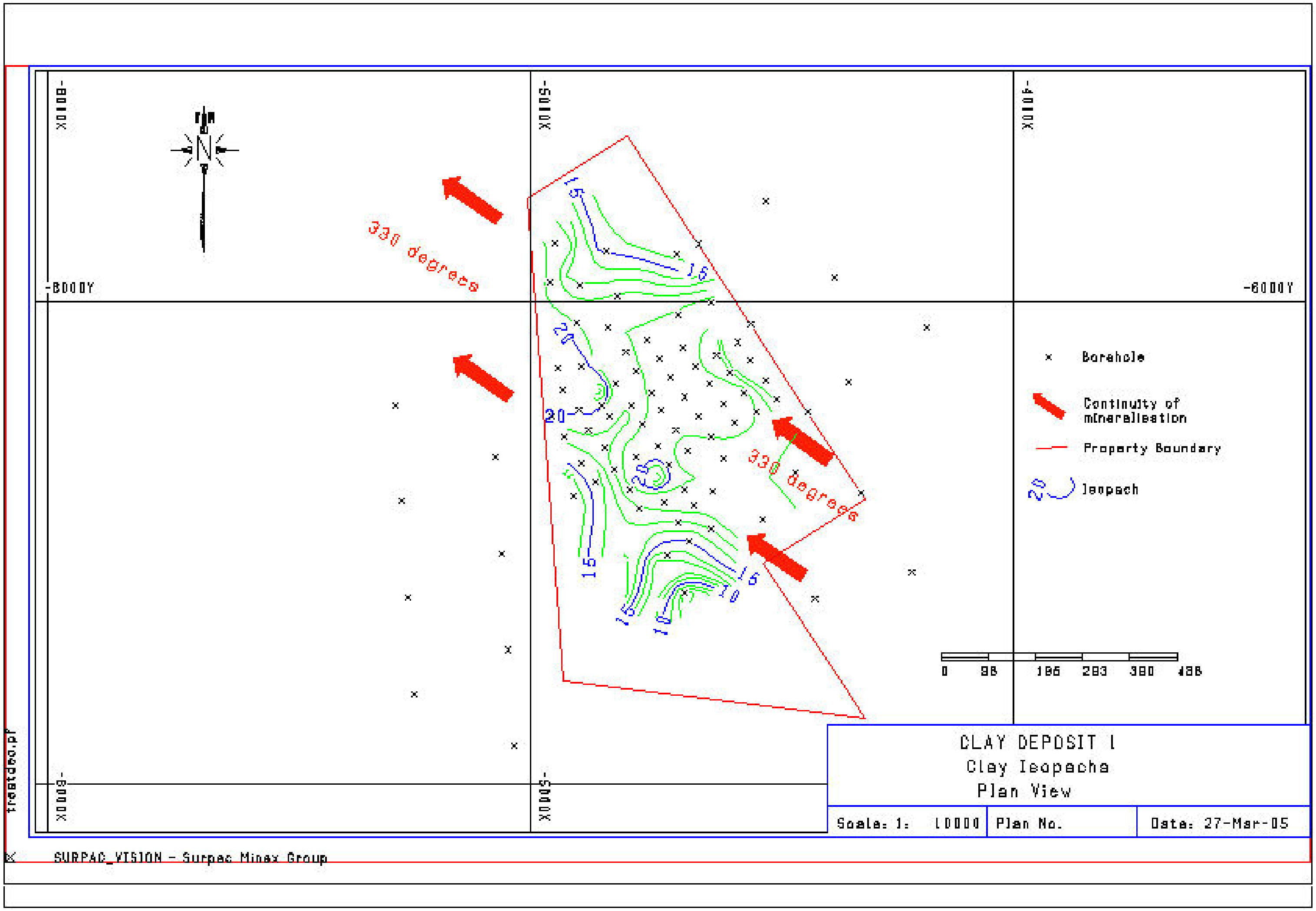


Figure 16 - Plan showing clay isopachs, Deposit One.

Semi quantitive mineralogical analysis results indicated that the mineralogical composition of the fresh shale is very similar to that of the weathered material consisting of quartz, mica and some kaolinite. Semi quantitive mineralogical analysis results of the clay fraction showed that kaolinite is the major mineral present, with minor concentrations of smectite, mica and quartz.

The kaolinite concentrations in the shale are lower than in the weathered material and probably mostly confined to the hydrothermal veins. Further research is however required to substantiate this assumption.

4.2.2 Chemical Results.

Table 10 below summarizes the chemical results of the 111 clay samples taken for analysis from the initial core-drilling phase and Table 11 the corresponding Spearman's rank correlation coefficient calculated from these samples. The major elements were determined by x-ray fluorescence (XRF) whereas the abundance of quartz was determined by gravimetric analysis.

Table 10 - Summary of chemical results from samples taken during the initial core-drilling phase, Deposit One (results in %, n = 111).

	SiO_2	Al_2O_3	MgO	CaO	Na_2O	K_2O	Fe_2O_3	TiO_2	LOI	Quartz
Min	53.00	15.1	0.01	0.01	0.00	0.10	0.90	0.00	4.80	18.70
Max	75.20	30.00	1.40	4.00	0.30	5.33	5.60	2.95	11.50	57.40
Avg	65.36	20.91	0.65	0.12	0.12	3.10	1.87	0.99	6.38	40.72
STD	4.97	3.07	0.36	0.39	0.08	1.02	0.80	0.40	1.26	8.46

Since uncertainty exists that all the variables, Table 11 below, follow similar distributions it has been decided to use a "distribution free" or "non-parametric" approached in calculating the correlation coefficients shown (Clarke and Harper, 2000). This was accomplished by applying a rank transform by ranking the data in order of value and by replacing the smallest sample value by 1, the second smallest by 2 and the last sample, with the highest value, by 111. This approach ensured that all data followed uniform distributions.

Table 11 - Correlation data of chemical results from samples taken during the initial core-drilling phase, Deposit One (n=111).

	SiO_2	Al_2O_3	MgO	CaO	Na_2O	K_2O	Fe_2O_3	TiO_2	L.O.I
Al_2O_3	-0.94								
MgO	-0.36	-0.17							
CaO	0.15	0.65	0.18						
Na_2O	-0.14	0.55	-0.13	0.68					
K_2O	-0.40	0.33	0.65	-0.08	-0.23				
Fe_2O_3	-0.40	0.32	0.47	0.25	-0.11	0.65			
TiO_2	-0.05	0.01	-0.20	-0.08	0.42	-0.10	-0.28		
L.O.I	-0.67	0.76	0.14	0.30	0.12	-0.09	0.06	-0.02	
Quartz	0.98	-0.98	-0.36	-0.35	-0.02	-0.35	-0.34	0.05	-0.71

The results clearly show huge variability for most of the major element oxides. The high concentrations of quartz present in the clay clearly indicates that quartz should be used as one of the quality parameters to model as excessive quartz concentrations in a body mix would negatively influence product yield resulting in crazing and or cracking of the product during firing as explained under paragraph 3.4. This is supported by the near perfect correlation between SiO_2:quartz and the excellent inverse relations between SiO2:Al2O3 and quartz:Al_2O_3 clearly indicating a decrease in clay minerals with increasing quartz content.

The L.O.I:Al_2O_3 and L.O.I:quartz correlations also provides direct evidence that the abundance of quartz will influence the plasticity, shrinking and ceramic properties of the clay and confirms that quartz should be used as one of the quality parameters to model.

The high average concentrations and variability recorded for K_2O and Fe_2O_3 would have a major impact on the colour development and vitrification ranges of the raw materials. The dispersion patterns of these oxide elements will be critical when these raw materials are used for brick production and have to be used as additional quality parameters to chemically model this deposit.

The selection of quartz, K_2O and Fe_2O_3 as diagnostic quality parameters is supported by the results of the semi quantitive mineralogical analysis that indicated quartz and kaolinite (K_2O is released when potassium feldspar alters to kaolinite) as the major minerals present with minor quantities of iron oxides, mica and feldspar.

Additional analysis for water-soluble salt concentrations of the 111 samples recorded the statistics as summarized in Table 12 and Table 13 below. Samples were prepared for, clay:water 1:10, water extraction followed by inductive couples plasma optical emission spectrum (ICP OES) analysis for cation concentrations and ion chromatography analysis for anion concentrations.

Table 12 – Water soluble salt analysis, Deposit One (results in ppm, n = 111).

	K	Na	Ca	Mg	SO_4	Cl
Min	0.48	58.80	0.50	0.40	23	56.18
Max	11.55	1277.50	36.50	195.00	326.7	2853.20
Avg	5.16	312.54	13.55	41.21	96.59	652.34
STD	2.80	244.93	9.33	51.83	72.50	625.11

Cl correlates well with Na, Ca, Mg and to a lesser extent with SO_4 while Cl and Na recorded the highest concentrations. NaCl has thus been selected as the quality parameters to model the dispersion of soluble salts in the deposit. This was done by mathematically calculating the NaCl concentration from the Na and Cl results by using the ratios of the atomic mass of the two elements as shown below.

Na 1.000 = Cl 1.5421 and Cl 1.000 = Na 0.6485

Table 13 - Correlation data of soluble salt results from samples taken during the initial core-drilling phase, Deposit One (n = 111).

	K	Na	Ca	Mg	SO_4
Na	0.39				
Ca	0.39	0.79			
Mg	0.39	0.89	0.90		
SO_4	0.40	0.62	0.63	0.72	
Cl	0.45	0.94	0.84	0.93	0.60

The statistics of the four quality parameters selected, for all samples taken at the deposit, are shown in Table 14 below. These results were used to determine the dispersion patterns of each indicator by filling the block models with estimated values through applying ordinary kriging, a proven geostatistical technique (Clarke and Harper, 2000).

Table 14 - Summarizes the statistical characteristics of Deposit One dataset.

Compound	**Fe_2O_3** %	**K_2O** %	**NaCl** ppm	**Quartz** %
Statistical Distribution	3 Parameter Log Normal	Normal	3 Parameter Log Normal	Log Normal
Number of Samples	661	661	664	661
Minimum	0.70	0.20	31.00	17.20
Maximum	7.50	5.63	5325.00	78.10
Mean	1.89	3.30	887.92	40.42
Variance	0.98	1.13	742128.25	91.86
Standard Deviation	0.99	1.06	861.47	9.56
Coefficient of variation	0.52	0.32	0.97	0.24
Skewness	2.84	-0.16	1.87	0.528
Kurtosis	13.96	2.25	6.88	2.77
Median	1.70	3.40	587.00	38.60
Trimean	1.70	3.34	655.32	39.43
Biweight	1.68	3.33	644.71	39.57
MAD	0.384	0.77	380.96	6.67
Alpha	-0.38	-0.20	11.67	-17.03

A very useful guide to determine the variability of the data and their subsequent suitability for use in geostatistics is the use of the coefficient of variation. As a general rule, those distributions with a coefficient of variation less than one should produce a reasonable variogram model; if the coefficient of variation is greater than one it implies that the data are quite variable and it is difficult to produce a good variogram model; if the coefficient of variation is greater than two there is virtually no chance of producing a good variogram model (Clarke and Harper, 2000). Table 14 clearly indicate that the coefficient of variation for all four-quality parameters is less than one with NaCl the most variable.

ALPHA value: The ALPHA value is the third parameter used in a 3-parameter lognormal transformation, to normalise the logarithms, and is sometimes called the location constant. It is calculated from the cumulative frequency distribution for untransformed data and only has meaning for reports on raw data. A 3-parameter lognormal transformation may be performed by specifying the alpha value for the raw data as the constant in a Natural Log (with constant) transformation.

Fe_2O_3, Table 14, is not normally distributed; the data is positively skewed with the mean value greater than the median. This becomes clear when comparing the Fe_2O_3 raw data histogram and cumulative frequency curve, Figure 17, and Fe_2O_3 raw data probability plot, Figure 18, with the Fe_2O_3 lognormal probability plot, Figure 19, and the Fe_2O_3 three-parameter lognormal probability plot, Figure 20. The plot of the cumulative frequency on log-probability paper produced, with a α value of 0.38, a "straight" line as shown in Figure 20 below, indicating that the data has a three-parameter lognormal distribution.

Kriging requires the calculation of semi-variograms for the raw data and applying mathematical models to the semivariograms on a best-fit basis. Surpac Vision software has been used for the semivariogram constructions.

It is also very important to understand the geometrical anisotropy of the ore body for each variable to determine if the continuity of the mineralisation is better in one direction than it is in other directions. The anisotropy can often be quantified by using directional semivariograms in terms of the bearing and range of the major axis of the anisotropy ellipsoid and the anisotropy ratios.

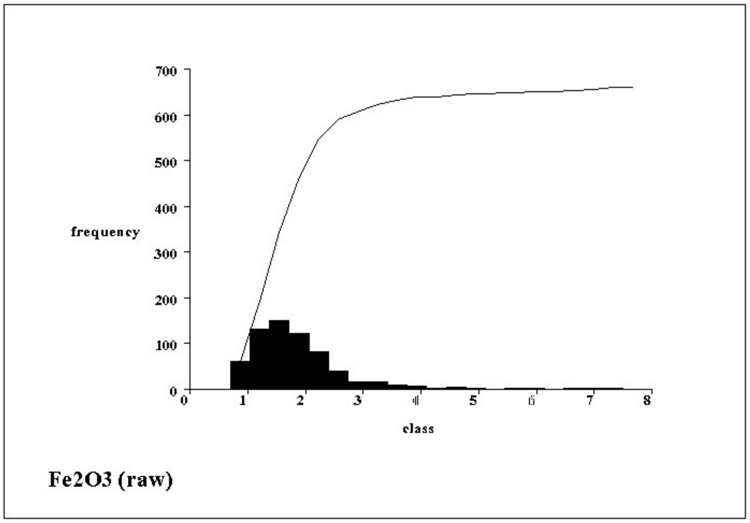


Figure 17 - Fe_2O_3 raw data histogram and cumulative frequency curve, Deposit One.

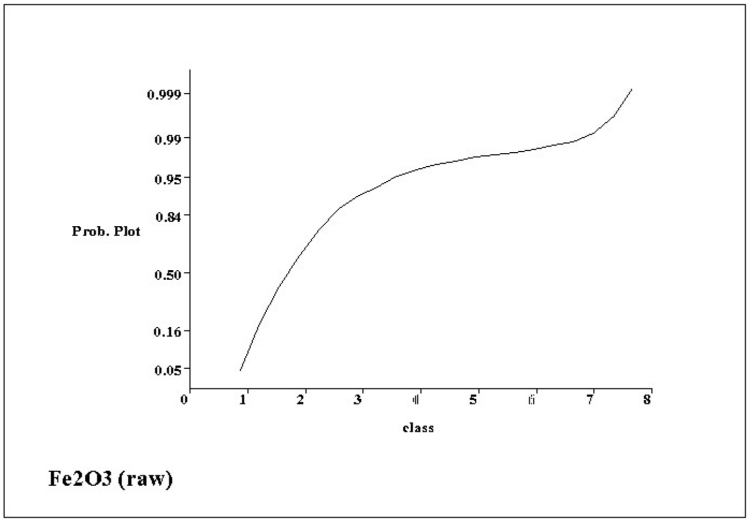


Figure 18 - Fe_2O_3 raw data probability plot, Deposit One.

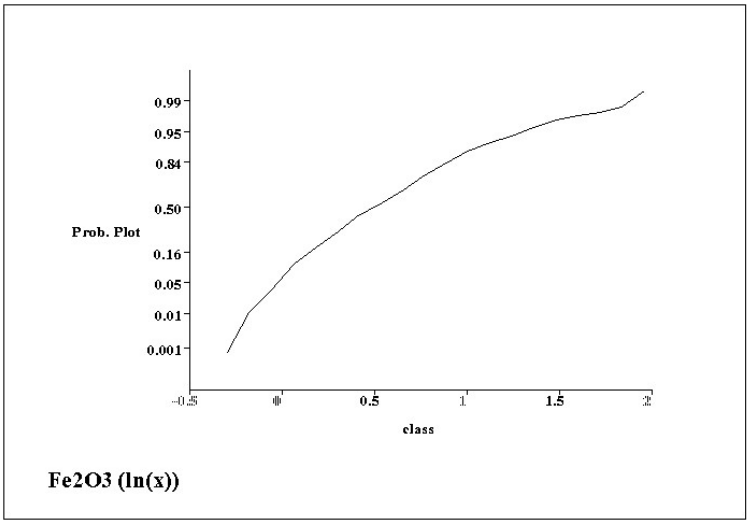


Figure 19 - Fe_2O_3 lognormal probability plot, Deposit One.

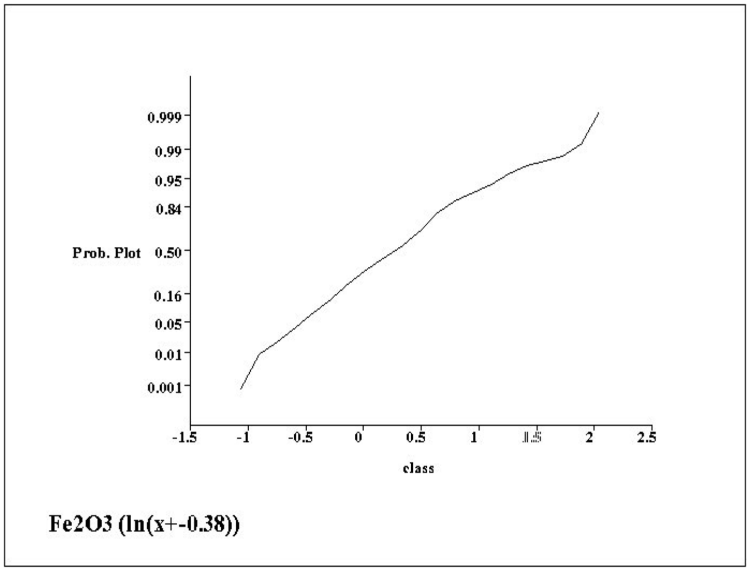


Figure 20 - Fe_2O_3 three-parameter lognormal probability plot, Deposit One.

The directions to be considered are usually chosen taking known geological controls on the mineralisation into account. Because of the north westerly trend of cleavage and/or bedding and the shape of the ore body as defined by the clay thickness contours (Figure 16) it was decided to test for anisotropy in the following four directions: 330^{o}, 285^{o}, 240^{o} and 195^{o}.

If the semivariograms in these four directions are to correctly model geometric anisotropy, the nugget and sill value for each semivariogram should be the same, and only the range of each semivariogram will be different. If the range in each direction is the same, then there is no anisotropy in the variables tested.

The determination of the final semivariogram and mathematical model, is a very repetitive and tedious task and might be influenced by the following:

1. Not enough samples.
2. Heterogeneous data. The area being studied might not be homogeneous and therefore does not have a constant variance.
3. Semivariogram parameters are wrong. Sometimes the semivariogram is quite sensitive to the choice of class size, lag distance, and window tolerance.
4. Sample data bad. Any errors made during sampling and assaying add a random component of variance to the semivariogram and increase the nugget effect. If the data are bad, the semivariogram may show a total nugget effect.
5. Data needs trimming. The estimator of the variance is very sensitive to outliers. A chaotic looking semivariogram can often be improved by limiting the maximum grade value used in the calculation.
6. Sample support size not constant. The data values must all have the same support length. The larger the composite size, the lower the sample variability, which will ultimately result in a higher tonnage and lower grade estimation.
7. Mixing of data sets. If a number of drill hole sizes, sampling methods or assaying methods were used, each data set should be statistically analysed separately to see if there are any significant differences.

The continuity of the Fe_2O_3 mineralisation in three directions; 330^o, 285^o and 105^o were found to be very similar with a range of influence of 244 m, a nugget effect of 0,382 and a sill of 1.08. The semivariogram calculated in the 240^o direction showed high gamma values for distance greater than 2 x lag. This semivariogram function becomes a random function independent of distance after about 96 m showing that the continuity of the mineralisation is better in the other directions. The down hole semivariogram showed a vertical range of influence of 11.48 m.

See Figure 21 below for the Fe_2O_3 omni-directional average semivariogram calculated in the 330° direction.

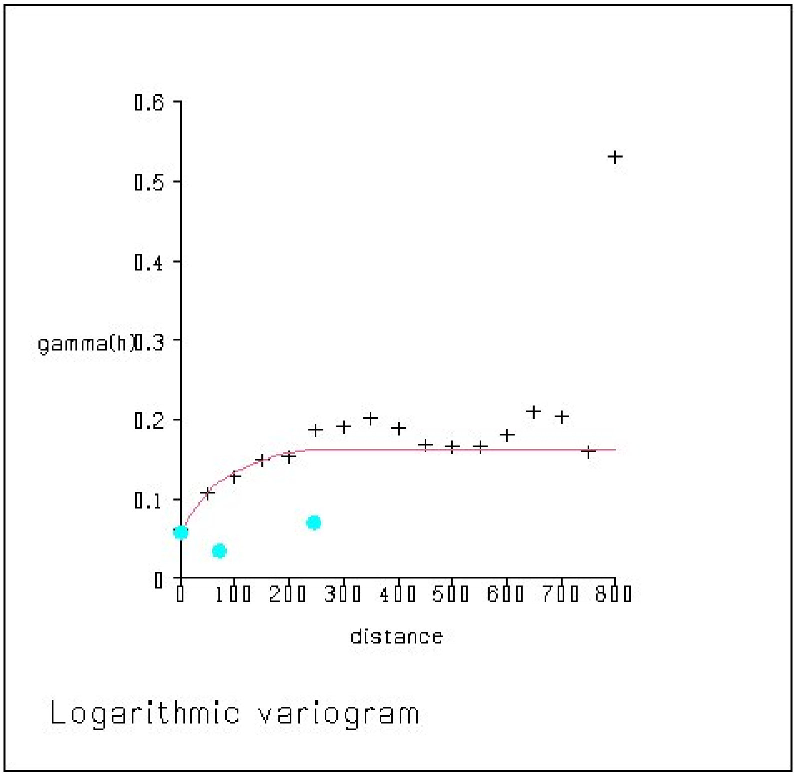


Figure 21 - Fe_2O_3 omni directional semi-variogram model, Deposit One.

This semivariogram was used to estimate Fe_2O_3 values of the deposit. The model is spherical and defined by:

$$\gamma(0) = 0$$

$$\gamma(h) = 0.382 + 0.227\mathrm{Sph}(a_1) + 0.471\mathrm{Sph}(a_2) \quad \text{when } 0 < h < 72.12,$$

$$\gamma(h) = 0.382 + 0.227 + 0.471\mathrm{Sph}(a_2) \quad \text{when } 72.12 < h < 244.10$$

$$\gamma(h) = 0.382 + 0.227 + 0.471 \quad \text{when } h > 244.10$$

with the following search ellipsoid:

a) Orientation

Bearing	330°
Plunge	0°
Dip	0°

b) Anisotropy ratios

Max search reach	244.10 m
Major/Semi-Major	2.54
Major/Minor	21.25

Having fitted the above curve, the semivariogram were validated by estimating a kriged grade for each data point and comparing it with the measured grade. There are several key points to look for in this output. The summary statistics of the kriging errors give the variance of the actual kriging errors along with the theoretical kriging variance. If the variogram model is a good model for the data set used, then the variance of the actual kriging errors and the theoretical kriging variance will be within 15% of each other. The mean of the actual kriging errors should be very close to zero and the percentage of the kriging errors within two standard deviations of the mean should be about 95%, indicating that the spread of kriging errors is not very large.

The output, Table 15, meets all of the abovementioned criteria implying that the variogram model used is appropriate for the data set.

Similar calculations were done to determine variogram models for K_2O, NaCl and Quartz.

Table 15 - Summary statistics of the kriging errors, Deposit One.

	Fe_2O_3	K_2O	NaCl	Quartz
Mean	-0.150	-0.0083	0.1995	0.0279
Variance	0.5358	0.4532	488726	50.37
Average Kriging Variance	0.6295	0.5270	593479	59.28
Percentage of the kriging errors within two standard deviations	96.51	98.17	96.99	95.88

A three-dimensional block model was created in Surpac (20 x 20 x 1.5m blocks) and constrained with the current delineated ore body. This was achieved by creating an upper and lower digital terrain model of the overburden-clay and the clay-fresh shale contacts determined from the geological interpretation of the drill holes.

The blocks created was filled with estimated Fe_2O_3, K_2O, NaCl and Quartz values by kriging the intersecting drill-holes data points closest to the block centroids. See Figures 22, 23, 24 and 25 for the dispersion of the estimated values at Deposit One.

By comparing the kriging results and the clay thickness contours shown in Figure 16, the following observations are obvious:

a) The possible existence of a Fe_2O_3 and K_2O depletion zone, caused by selective removal of these elements, which resulted in high quartz concentrations, associated with the white/cream clay.

b) The Fe_2O_3 and K_2O were most likely transported to immediately outside this zone resulting in altering the shales to varying degrees of the red and yellow plastic clays as shown in Figure 12 above.

c) Soluble salts do not follow the exact same dispersion and seem to concentrate more in the central and northern portion of the exploration area. This might be indicative of hydrothermal hotspots to be discussed further in Chapter 5.

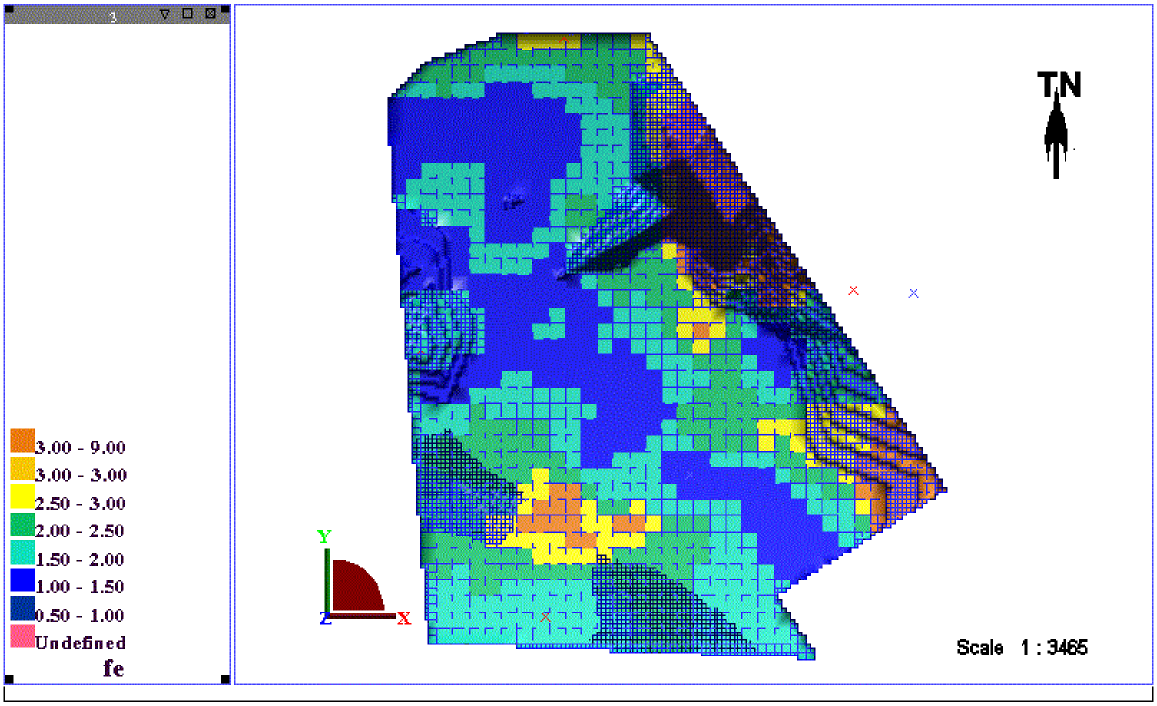


Figure 22 - Fe_2O_3 dispersion, Deposit One.

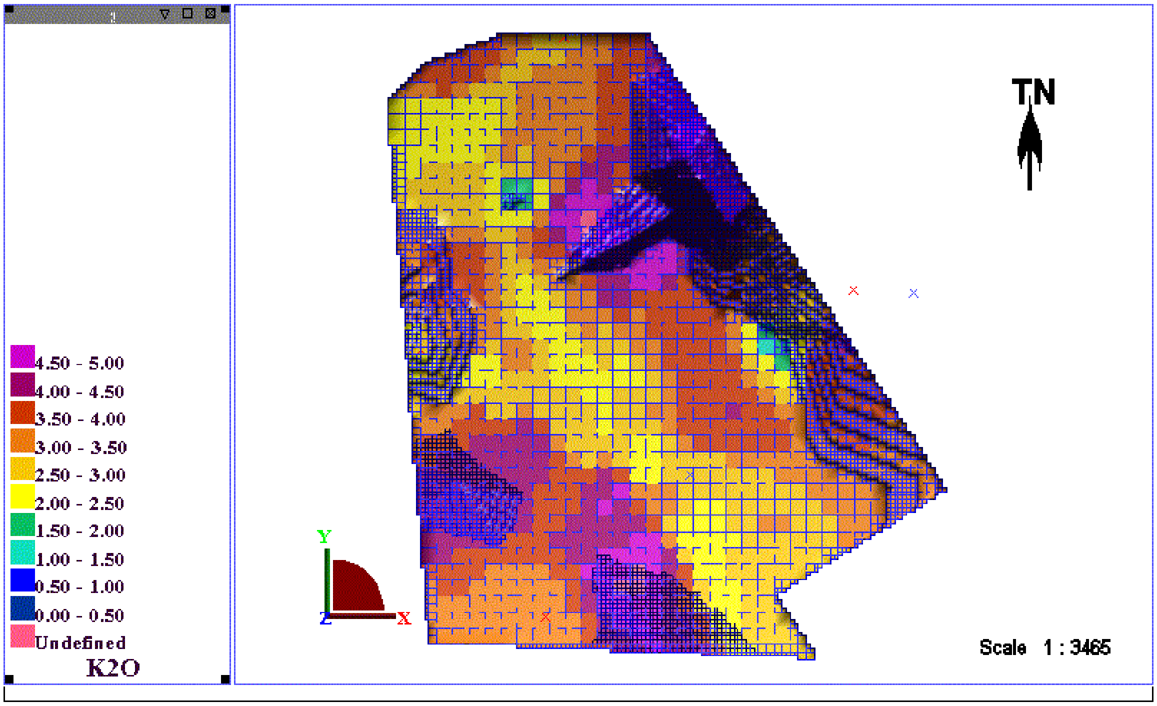


Figure 23 - K_2O dispersion, Deposit One.

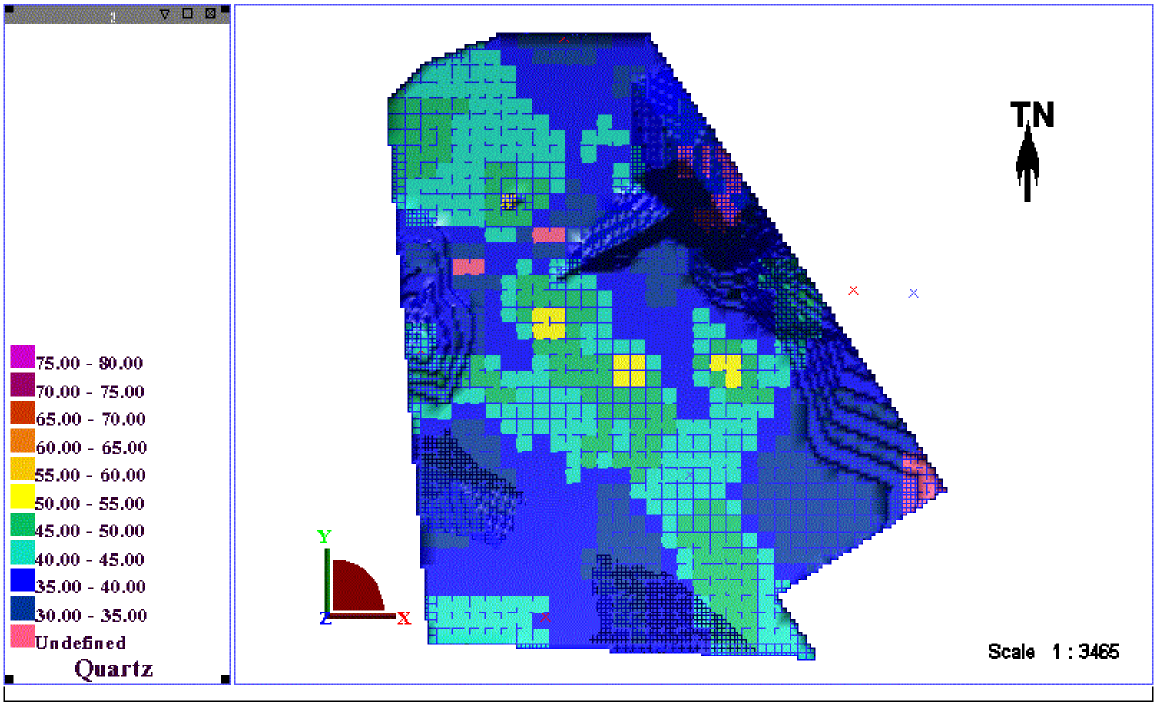


Figure 24 - Quartz dispersion, Deposit One.

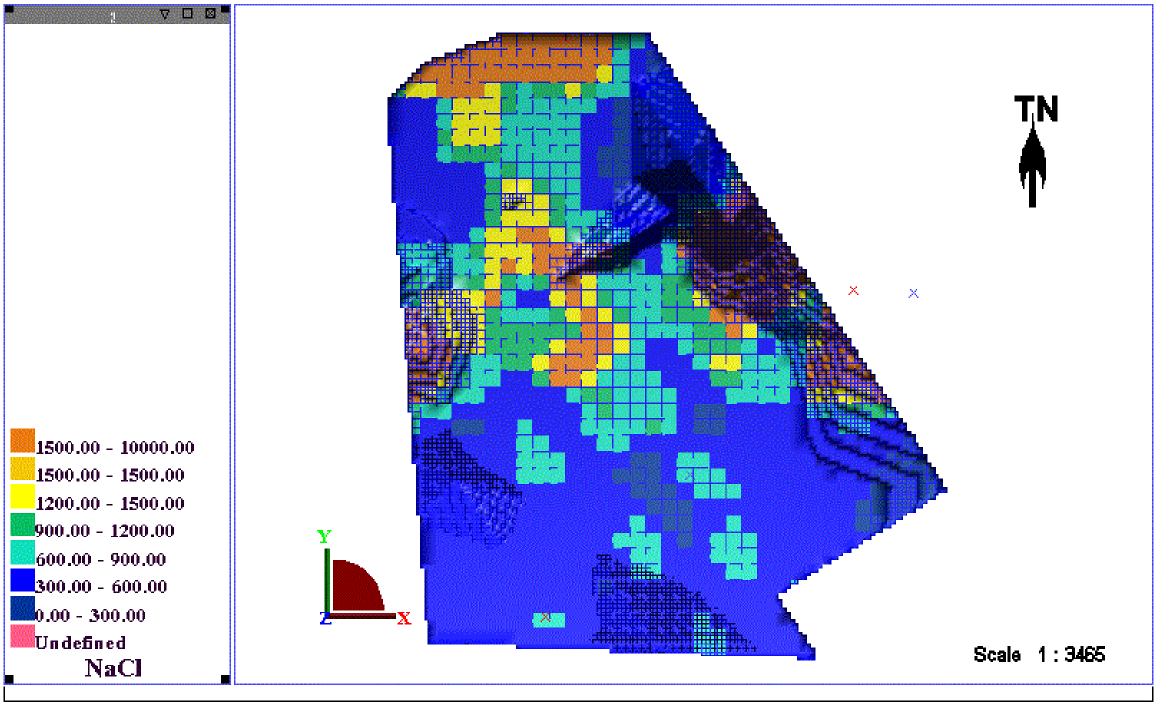


Figure 25 - NaCl dispersion, Deposit One.

4.2.3 Physical Results.

Bulk samples for the testing of the physical properties of the clay were based on Fe_2O_3 results to determine the colour development with increasing Fe_2O_3 concentrations. Burnt briquettes showed that subtle colour changes could be detected with Fe_2O_3 concentration increases of 0.2% from 1,65 % and above, becoming pink and eventually orange-red for the yellow and red coloured clays. It is therefore concluded that the white to cream coloured clay is a very important resource for the production of light coloured face bricks in the area.

Subsequent drilling and full physical testing were concentrated on this cream to white coloured clay to establish quality parameters for brick manufacturing. Bulk samples, based on Fe_2O_3 results, were prepared from the drilled core. These bulked samples were re-submitting for full chemical analysis and submitted for the testing of the ceramic properties essential to brick manufacturing as discussed under paragraph 3.5.

a) Extrusion behavior, extrusion moisture, and Modulus of Rupture (Green Strength).

All samples submitted extruded well. The average green strength (MOR – Modulus of Rupture) recorded was 0.4 Mpa ranging between 0.2 Mpa and 0.7 Mpa. This indicated that the clay could not be used for brick manufacturing on its own and would require the addition of a plastic clay to increase the green strength to above 1.2 Mpa.

The average extrusion moisture recorded was 28.4%. The extrusion moisture showed the following correlation; -0.87 with SiO_2, 0.84 with Al_2O_3, 0.86 with K_2O, 0.79 with Fe_2O_3 and -0.86 with quartz. These correlation clearly indicate that the volume of water required to extrude this raw material is directly dependent on the clay:quartz ratio and the fine grained and disordered nature of the clay particles that absorbs substantial quantities of water.

b) Drying shrinkage.

The average reported drying shrinkage (contraction) was 1.27% for the clay with an average Fe_2O_3 concentration of 1.48% and an average quartz concentration of 43.78%. Very little shrinkage occurs during drying which is beneficial in brick manufacturing. Surprisingly no correlation (-0.11) exists between the quarts content of the clay and the drying shrinkage as would normally be expected. This result is most probably a function of the spread and range of the relatively high quartz concentrations in the samples submitted for testing (38% - 52% quartz) and the fine grain size of the quartz.

Quartz reduces the strength, plasticity and drying contraction of clays. Moderate quantities of quartz are beneficial in brick making mixtures, which would otherwise be too plastic and have a large drying shrinkage.

c) Drying sensitivity.

All samples submitted ranged from slightly sensitive to insensitive to drying. Slight sensitivity occurs during the initial stage of the drying process with the removal of shrinkage water, from the clay body. This shrinkage occurs at a constant rate of drying is totally dependant on the rate of evaporation of water from the surface of the brick.

Once the free water evaporated a change in the drying mechanism occurs with the removal of chemically bound water. This stage also marks the end of liquid water migration to the surface, which is the end of soluble salt build-up on the exposed brick surfaces and the end of shrinkage.

The chemically bound water is released at temperatures between 500^{o}C to 750^{o}C as shown below:

$$6Al_2Si_2O_5(OH)_4 \longrightarrow 6Al_2Si_2O_7(OH)_4 - 12H_2O \text{ [at } 500^oC \text{ to } 750^oC]$$

The chemically bound water molecules, first removed, have relative low bonding energies to the clay but as evaporation proceeds the more tightly bounded water molecule require more energy to be removed (Brownell, 1976).

If the temperature gradient is to steep at this stage, the pressure buildup inside the brick, resulting from sudden vapour expansion due the release of chemically bound water combined with gasses released from carbon burnout and the quartz volume expansion, might exceed the tensile strength of the outer skin. This will cause cracking of the bricks resulting in poor saleable yields.

d) Fired shrinkage at various temperatures.

All test pieces were fired to 1050^{o}C, 1100^{o}C, 1150^{o}C and 1200^{o}C with the average fired shrinkages measured at these temperatures of 5.65%, 8.56%, 10.73% and 11.76% respectively.

Table 16 below is a summary of the Spearman's rank correlation coefficients calculated between the fired shrinkage at the indicated temperatures and some element oxides and quartz. The table clearly shows strong inverse correlations with SiO_2 and quartz indicating that fired shrinkage will decrease with increasing quartz concentrations due to a reduced concentration of clay minerals. It is further evident that K_2O, followed by Fe_2O_3 and MgO are the major fluxes present in the clay.

Figure 26 indicates the increase in the fired shrinkage with increasing K_2O concentrations. These results show that controlling the K_2O concentrations of the raw material before consumption can best control the fired shrinkage of the clay from Deposit One. Similar results were obtained for Fe_2O_3.

Table 16 - Spearman's rank correlations coefficients calculated between the fired shrinkage (%) at the indicated temperatures and some element oxides and quartz.

	Water Absorption (%)	Compressive Strength (Mpa)	SiO_2 (%)	Al_2O_3 (%)	K_2O (%)	MgO (%)	Fe_2O_3 (%)	Quartz (%)
1050°C	-0.95	0.75	-0.89	0.86	0.95	0.55	0.91	-0.84
1100°C	-0.98	0.46	-0.91	0.89	0.95	0.58	0.88	-0.87
1150°C	-0.91	0.14	-0.91	0.88	0.88	0.65	0.82	-0.88
1200°C	-0.95	0.24	-0.96	0.95	0.92	0.67	0.81	-0.94

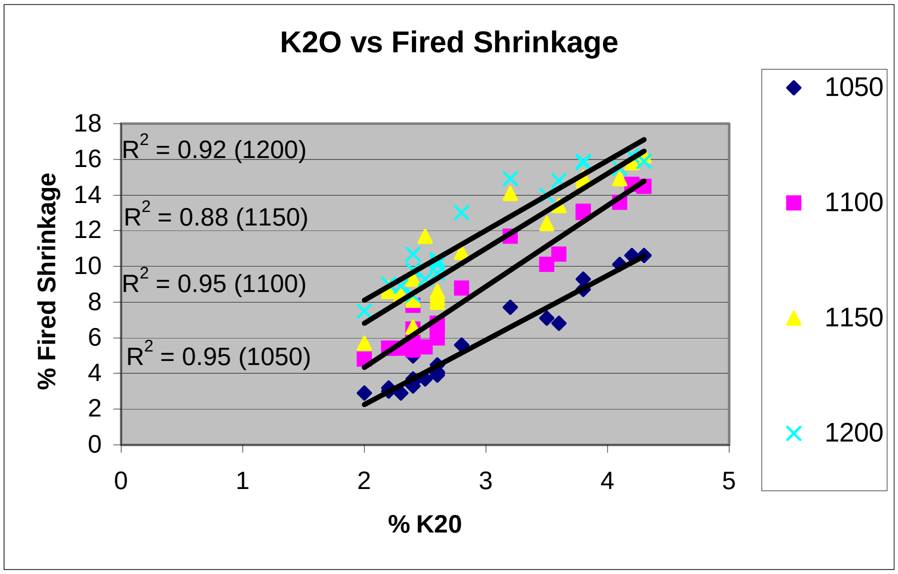


Figure 26 - Scatter diagram plots and regression lines between K_2O and Fired Shrinkage (%) at indicated temperature, Deposit One.

e) Water absorption at various temperatures.

The average fired water absorption measured at the four different temperatures were 14.68%, 9.41%, 5.62% and 3.54% respectively indicating that the ideal firing temperature for these clays are around 1118°C for a final product with a fired water absorption of between 7% and 9%. This target would only be achievable at K_2O concentrations of between 2.5% and 3.2% and Fe_2O_3 concentrations of between 1.5% and 1.75% as clearly indicated by Figures 27 and 28.

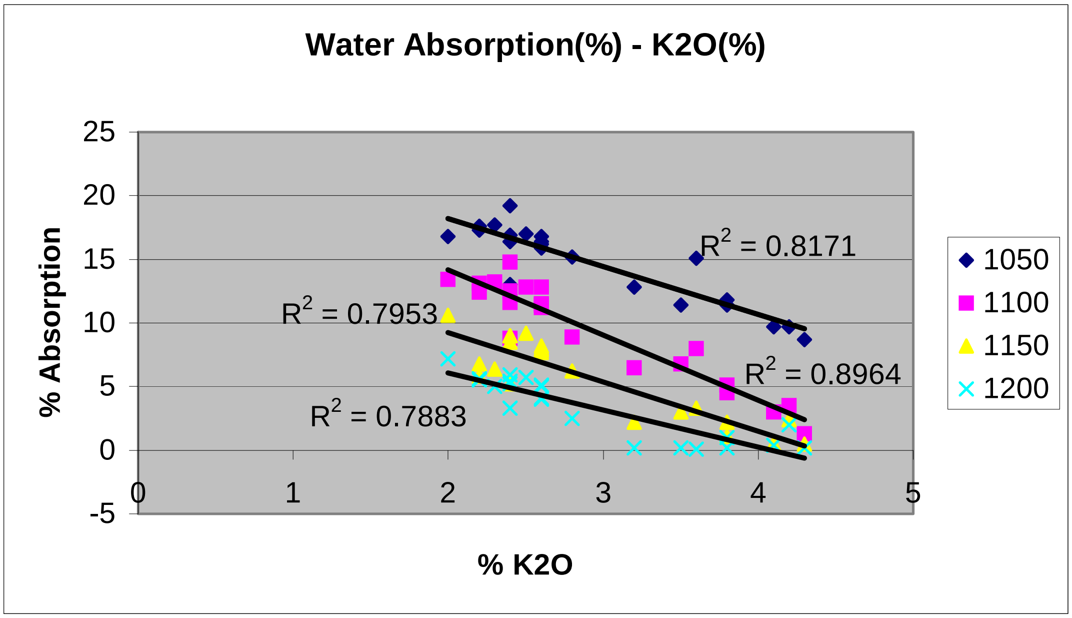


Figure 27 - Scatter plots and regression lines between water absorption and K_2O concentrations, Deposit One.

If the top firing temperature is increased, a further decrease in the water absorption for the same K_2O and Fe_2O_3 contents is expected, and vise versa. Control of these two element oxides in stockpiles to the set specification range will optimize fuel usage and cost over the life of the deposit.

Figure 29 defines an upper and lower quartz limit for the clays from Deposit One. Clay with quartz concentrations of between 40% and 50% would meet the intended targeted water absorption of 8% at 1125°C.

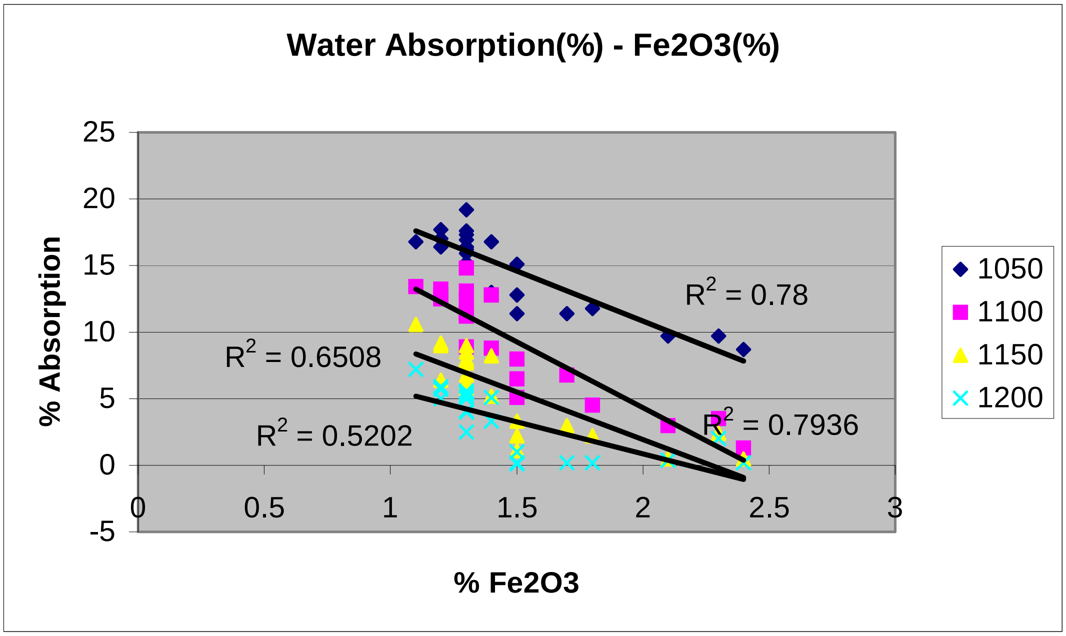


Figure 28 - Scatter plots and regression lines between water absorption and Fe_2O_3 concentrations, Deposit One.

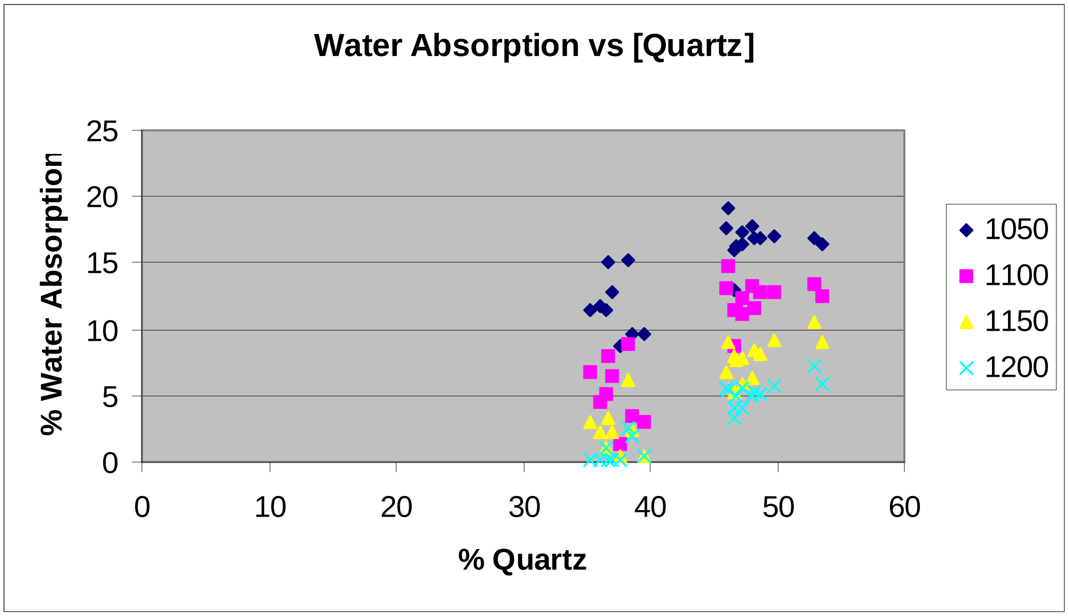


Figure 29 - Scatter plots between water absorption and Quartz concentrations, Deposit One.

If the quartz concentration drops below 40% the water absorption at this firing temperature would be too low and the firing temperature would have to be lowered to 1100°C. This will negatively influence the life of the clay deposit, as the average K_2O and Fe_2O_3 concentrations required to produce a product with an average water absorption of 8% at these quartz concentrations would be 3.2% for K_2O and 1.75% for Fe_2O_3 resulting in pink coloured bricks.

The test pieces fired also indicated that the effect of efflorescence is negligible between 1100°C and 1150°C for NaCl concentrations of 800 ppm and below.

4.2.4. Conclusions on suitability of Deposit One clay for brick manufacturing.

Table 17 is a summary of the results of the geochemical ore body modeling. A total measured resource of 3766538 bank cubic meters (*In-situ* cubic meters = Bm^3) was calculated based on the results of the chemical and physical parameters as discussed under paragraphs 4.2.2 and 4.2.3.

The chemical and physical characteristics of this deposit and the relationships that exist between them make it possible to predict the behaviour of this raw material during clay brick manufacturing and the quality of the clay brick manufactured from it, based on the four defined chemical quality parameters.

The expected behaviour of this raw material during clay brick manufacturing should be as follow:

a) Extrusion behaviour – Good.

b) Extrusion moisture – 28.4 %.

This relatively high volume of water required for extrusion will be expensive to remove during drying. A possible reduction in extrusion moisture might be attained by allowing the clay to sour (break down when exposed to atmospheric conditions) or mixing it with other clays that require less water for extrusion.

Table 17 - Block Model Report, Deposit One.

Fe_2O_3 %	NaCl ppm	Volume Bm^3	Fe_2O_3 %	Quartz %	K_2O %	NaCl Ppm
1.0-1.5	0-800	1034188	1.37	40.79	2.81	595.99
	800-1200	494663	1.36	42.48	2.92	965.72
	1200-5000	322275	1.34	43.84	2.70	1430.30
Sub Total		**1851125**	**1.36**	**41.77**	**2.82**	**840.03**
1.5-2.0	0-800	1372925	1.73	41.24	3.19	489.99
	800-1200	223600	1.61	40.22	3.28	1000.20
	1200-5000	318888	1.73	39.69	3.23	1562.94
Sub Total		**1915413**	**1.72**	**40.86**	**3.21**	**728.18**
2.0-2.5	0-800	993950	2.22	36.94	4.01	466.01
	800-1200	139688	2.17	39.64	4.09	967.83
	1200-5000	266738	2.22	37.37	3.63	1829.90
Sub Total		**1400375**	**2.21**	**37.29**	**3.94**	**775.85**
2.5-6.5	0-800	797988	3.13	33.49	4.01	356.39
	800-1200	147825	3.29	35.29	3.96	1016.90
	1200-5000	269663	3.71	35.22	3.71	2314.88
Sub Total		**1215475**	**3.28**	**34.09**	**3.93**	**871.22**
Total Resource		**5382388**	**2.02**	**39.05**	**3.40**	**798.32**
Total Measured Resource		**3766538**	**1.54**	**41.31**	**3.01**	**783.15**

c) Modulus of Rupture (MOR) – 0.4 MPa ± 0.2 Mpa

Probable cracking and squatting are anticipated when stacking green bricks on top of each other during manufacturing as a result of poor green strength. The addition of a plastic clay, with a high MOR (+ 3 Mpa), to bring the green strength of the body mix to at least 1.2 Mpa, is required.

d) Drying Shrinkage – 1.48 % ± 1.3%
e) Firing Temperature – $1125^{o}C \pm 25^{o}C$
f) Fired Shrinkage – 10% ± 1%

The fired shrinkage is unacceptably high and will cause excessive movement in the firing process resulting in pack instability with the possibility of packs collapsing. This is a direct result of the measured K_2O concentrations. The ideal fired shrinkage of 6% could only be achieved by lowering the K_2O concentration to an average of 2.7% by adding an inert or another raw material that will reduce fluxing and the related shrinkage during firing.

The anticipated properties of the clay bricks manufactured from this raw material comply with the face bricks specifications as described in Table 2 and should be as follow:

a) Water absorption – 5% to 8%
b) Compressive Strength – Above 50 Mpa
c) Fired Colour – Bricks with a light background colour (non red) dependent on firing conditions, additives and body fuel used.

It is recommended that no attempt be made to produce face bricks by using 100% of this material, as the anticipated problems discussed above will reduce product yield significantly, increasing production costs to unattainable levels. This material is however suitable for use as the main component in the production of a range of light coloured face brick products, if other suitable raw materials could be found that will neutralize the negative properties of the clay as discussed, without darkening the final product.

The exploration model developed provides good evidence that should further resources of this variety of clay need to be delineated related to this deposit, such deposits are likely to exist as lateral extensions of the structure identified in section

4.2.2. Clay in these areas could be expected to display similar characteristics as that of Deposit One as it should have evolved during similar conditions.

4.3 Deposit Two.

Refer to Figure 1 for the locality plan of the deposit and Figure 30 for the exploration areas and immediate infrastructure.

The exploration at this deposit, comprised a core-drilling programme, using NX diameter drilling bits and core barrels, drilled on a 50 x 50 meter grid over the exploration areas (A and B) and on a 100 x 100 m grid covering the old clay quarry. In total 69 boreholes were drilled. The planned 50 x 50 meter grid over area A could not be completed due to the erection of a power line during the execution of the exploration programme. The core from the boreholes was logged, sampled and submitted to accredited laboratories for the different chemical, ceramic and mineralogical analyses.

All data received was captured in a Surpac database from which a block model was created for interpretation and volume calculations.

4.3.1 Geology and Mineralogy.

Information gathered from both surface mapping and the drilling of the exploration area showed that the area is capped with Sand, Silcrete and Ferricrete with occasional outcrops of purplish to dark grey ball clay where the Silcrete and Ferricrete has been eroded away. The average thickness of the overburden recorded is 1.17 m with a maximum thickness of 5.48 m.

A generalized geological profile drawn from geological information gathered from the drilled holes indicated the following simplified geological stratigraphical column (Figure 31).

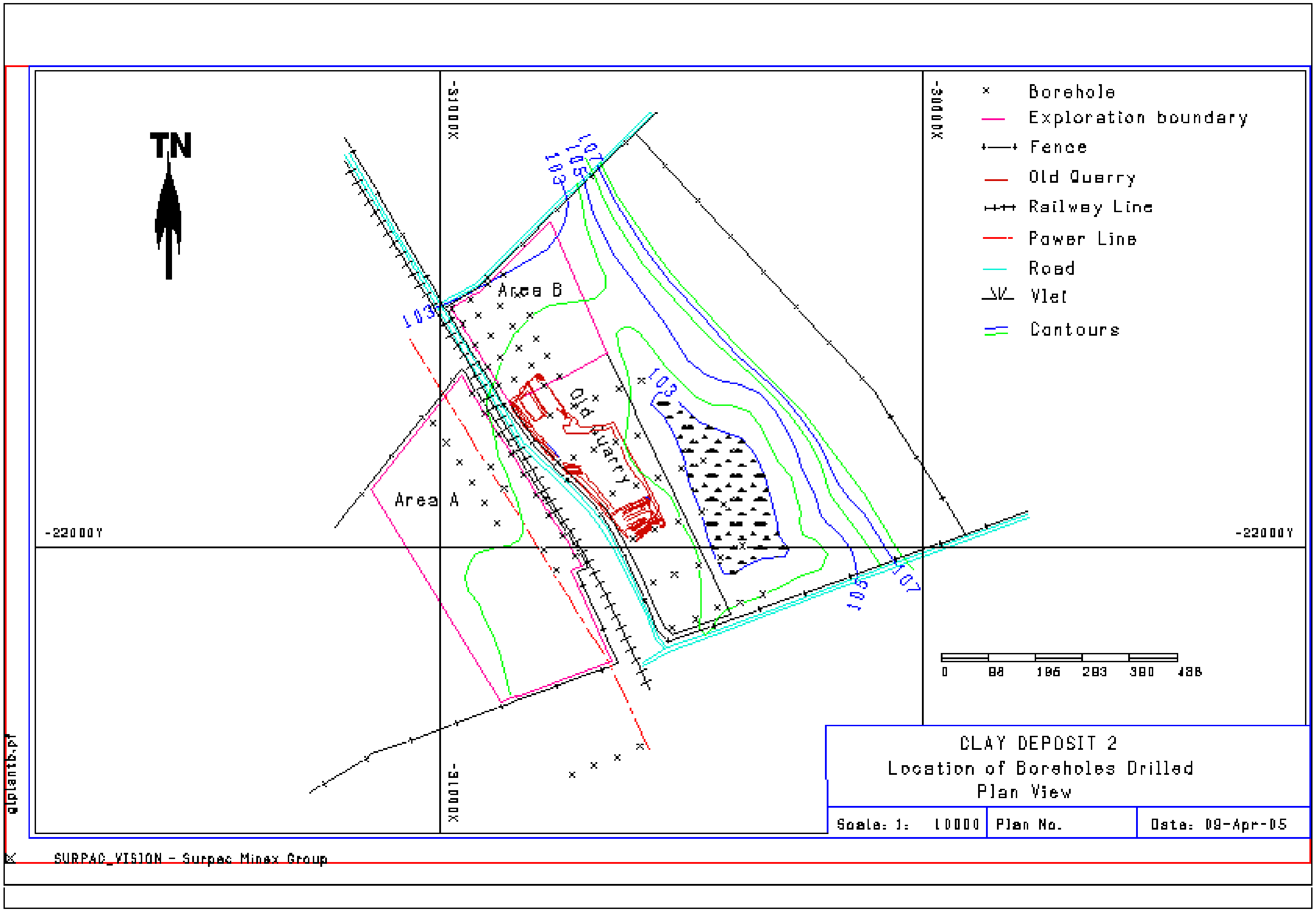


Figure 30 - Map showing positions of boreholes drilled at Deposit Two.

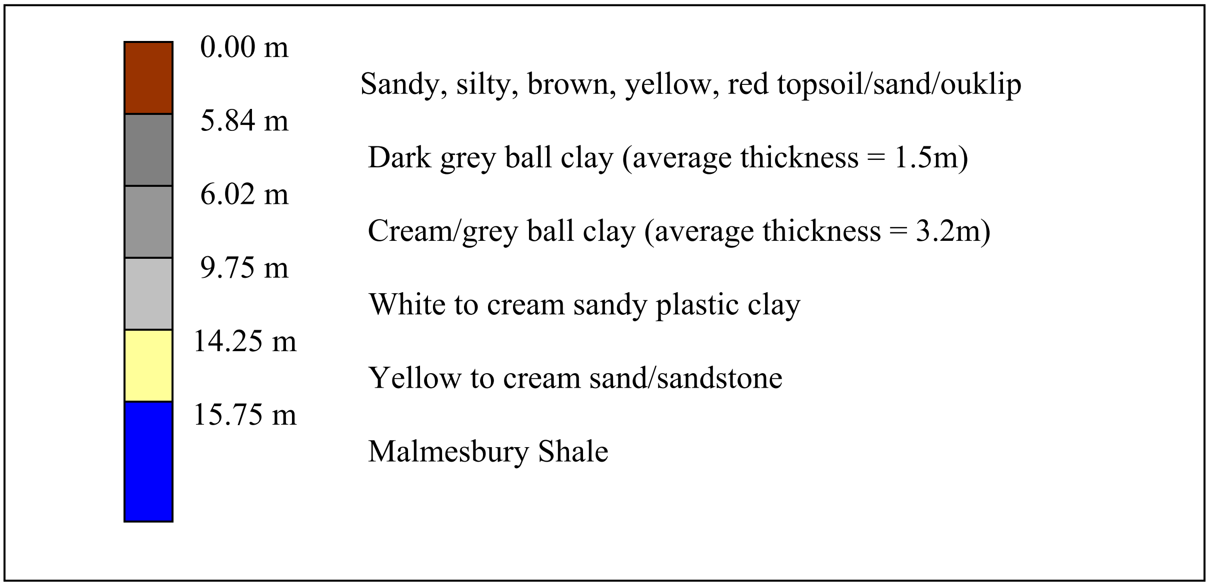


Figure 31 - Generalized geological profile of Deposit Two showing maximum depths below surface.

Differentiation of the clay units shown in Figure 31, were based on the following observations:

a) A very tough, dark grey and very plastic clay (ball clay) unit containing some finely disseminated organic material that is most probably responsible for the unique colour of the clay (Figure 32). The top of this unit is characterized by the presence of coarse to medium grained quartz grains (Figure 33), contained in a very fine-grained clay matrix. This sub-unit varies in thickness and was sampled separately from the very fine-grained plastic clay immediately below it.

b) The second geological unit identified was a silty medium grey very fine-grained plastic clay immediately below the ball clay unit. This material seemed to contain less organic material and displays reduced plasticity when compared to the unit immediately above it, Figure 32.

c) The third unit identified can be described as a white to cream, fine to medium grained sandy clay, less plastic than the units above it, containing very little organic material. This unit marks the end of the identified clay deposit and overlies yellow to cream sandstone.

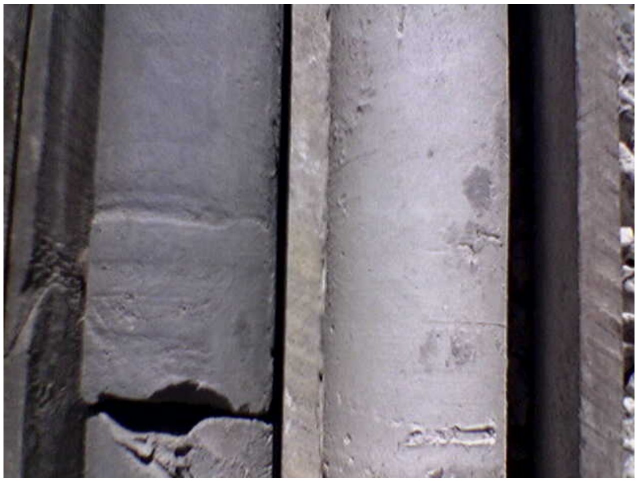


Figure 32 - Photo of the tough very dark grey and lighter medium grey ball units.

Figure 33. Photo of the top of the very dark grey ball clay unit showing the presence of coarse to medium grained quartz grains contained in a very fine-grained clay matrix.

d) The state of weathering of the sandstone varies from extremely weathered, friable (logged as sand), to partially weathered (sandstone). The sandstone overlies very silty fine-grained weathered Malmesbury shales similar to the clay described for Deposit One.

The result of semi quantitative mineralogical analyses of these clays is shown in Table 18. They primarily consist of quartz and kaolinite with minor quantities of rutile and alunite. The results clearly show that the quartz concentration increases with depth, which is typical of a sedimentary kaolinite deposit.

The presence of alunite ($KAl(SO_4)_2.12H_2O$) might indicate the Cape granites as the source rock for these deposits, as alunite is most commonly associated with acid igneous rocks where the rock has been extremely altered. Alunite probably formed as the result of the action of sulfuric acids upon potassium rich feldspars. These conditions of formation usually indicate relatively high pressures and temperatures (Ford, 1932; Hurlbut and Klein, 1985).

Table 18 - SQMA results of the rocks from Deposit Two, Total Sample. (Al = Alunite, An = Anatase, Mi/Ru = Microcline/Rutile, Kt = Kaolinite, Qz = Quartz).

Rock Description	% Al	% An	% Mi/Ru	% Kt	% Qz
Dark grey ball clay	6	1	1	42	49
Medium grey ball clay	6		1	31	62
Cream, sandy clay	3		1	20	77

4.3.2 Chemical Results.

Table 19 summarizes the chemical results of the 29 plastic clay samples taken for analysis from the initial core-drilling phase and Table 20 the corresponding Pearson correlation coefficients calculated from these samples.

Due to the relatively small number of samples taken, less than 30, normal distribution has been assumed for all reported variables.

Table 19 - Summary of chemical results from samples taken during the core-drilling phase, Deposit Two (n = 29).

%	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**LOI**
Min	**66.3**	**10.5**	**1.0**	**0.7**	**0.1**	**0.2**	**0.2**	**0.1**	**5.0**
Max	**78.5**	**17.4**	**1.8**	**2.2**	**1.1**	**1.0**	**0.6**	**0.6**	**9.2**
Avg	**69.3**	**16.4**	**1.49**	**1.69**	**0.58**	**0.62**	**0.47**	**0.41**	**8.19**
STD	**3.4**	**2.08**	**0.21**	**0.5**	**0.24**	**0.22**	**0.10**	**0.18**	**1.11**

The results obtained differs significantly from the results of Deposit One in that it is less variable and have a smaller range for all the major element oxides excluding CaO. The concentrations of SiO_2, CaO, Na_2O, TiO_2 and LOI are higher; Al_2O_3, K_2O and Fe_2O_3 are significantly lower, while MgO is unchanged. This indicates that although the clay from this deposit should be siltier and contains less clay mineral it should have better plasticity properties as indicated by the higher concentrations of CaO and higher loss on ignition.

Table 20 - Correlation matrix of chemical results from samples taken during the core-drilling phase, Deposit Two (n = 29).

	SiO_2	Al_2O_3	MgO	CaO	Na_2O	K_2O	Fe_2O_3	TiO_2	L.O.I
Al_2O_3	-0.91								
MgO	-0.75	0.51							
CaO	-0.67	0.46	0.42						
Na_2O	-0.42	0.26	0.36	0.04					
K_2O	-0.33	0.03	0.64	0.26	0.48				
Fe_2O_3	-0.63	0.53	0.53	0.47	0.34	0.25			
TiO_2	-0.11	0.17	0.42	0.47	0.44	0.90	-0.04		
L.O.I	-0.98	0.92	0.75	0.66	0.41	0.29	0.64	0.07	

The excellent inverse correlations between SiO_2:Al_2O_3, SiO_2:MgO and SiO_2:LOI and the high free quartz concentrations determined with semi quantitative mineralogical analyses, Table 18, indicate that quartz should be used as one of the quality parameters to model the deposit for reasons given in paragraph 3.4 and paragraph 3.5.

The higher average concentration for TiO_2 and the possible affect that this oxide might have on the colour development of the clay necessitated the continued analyses of Fe_2O_3 to test for relationships that might predict the fired colour from geochemical modelling if required. TiO_2 concentrations above 1% normally act as a colour enhancer because it enhances the staining power of iron oxide (Brownell 1976, Sellschop 1994).

Additional analysis for water-soluble salt concentrations would also be continued as high water-soluble salts concentrations negatively affect the aesthetics of the final product. The analysis of Na and Cl has thus been selected as the quality parameters to model the dispersion of water-soluble salts as it proved to be invaluable during the evaluation of Deposit One. This was done by mathematically calculating the NaCl concentration from the results by using the ratios of the atomic mass of the two elements as shown below.

Na 1.000 = Cl 1.5421 and Cl 1.000 = Na 0.6485

Continued analysis of K_2O has been suspended, as the concentrations are too low to have any significant effect as a fluxing agent to influence the water absorption of the final product after firing. It is believed that the organic material contained in the upper ball clay unit will have a greater influence on the refractory properties of the fired clay.

The statistics of the three quality parameters selected, for all samples taken at the deposit, are shown in Table 21. These results were used to determine the dispersion patterns of each indicator by filling the block models with estimated values by applying the same geostatistical methods used at Deposit One.

Table 21 - Summary of the statistical characteristics of Deposit Two dataset.

Variable	Fe_2O_3 %	NaCl ppm	Free Quartz %
Statistical Distribution	Log Normal	3 Parameter Log Normal	3 Parameter Log Normal
Number of samples	225	225	225
Minimum	0.200	80.000	23.600
Maximum	3.400	2454	90.500
Mean	0.620	1348.951	67.559
Variance	0.083	577090.464	149.950
Standard Deviation	0.289	759.664	12.245
Coefficient of variation	0.466	0.563	0.181
Skewness	4.510	0.495	-0.588
Kurtosis	39.690	2.856	3.448
Median	0.600	1360.000	67.700
Trimean	0.600	1312.000	68.250
Biweight	0.570	1316.100	68.319
MAD	0.129	546.600	8.180
Alpha	0.000	-79.2	4909.300
Sichel-t	1.94	NA	NA

Due to the limited size and consistency in the layering of the ore body it was decided to assume geometrical isotropy, similar continuity of the mineralisation in different directions.

A three-dimensional block model were created in Surpac (10 x 10 x 1meter blocks) with sub-blocking (5 x 5 x 0.5 meter blocks) and constrained with the current delineated ore body by creating an upper and lower digital terrain model of the overburden-clay and the clay-Malmesbury shale contacts obtained from the geological interpretation of the drill holes.

The blocks created were filled by estimating, ordinary kriging, Fe_2O_3, NaCl and free quartz values by using the intersecting drill holes data points closest to the block centroids. See Figures 34, 35 and 36 for the dispersion of the estimated Fe_2O_3, NaCl and free quartz values respectively.

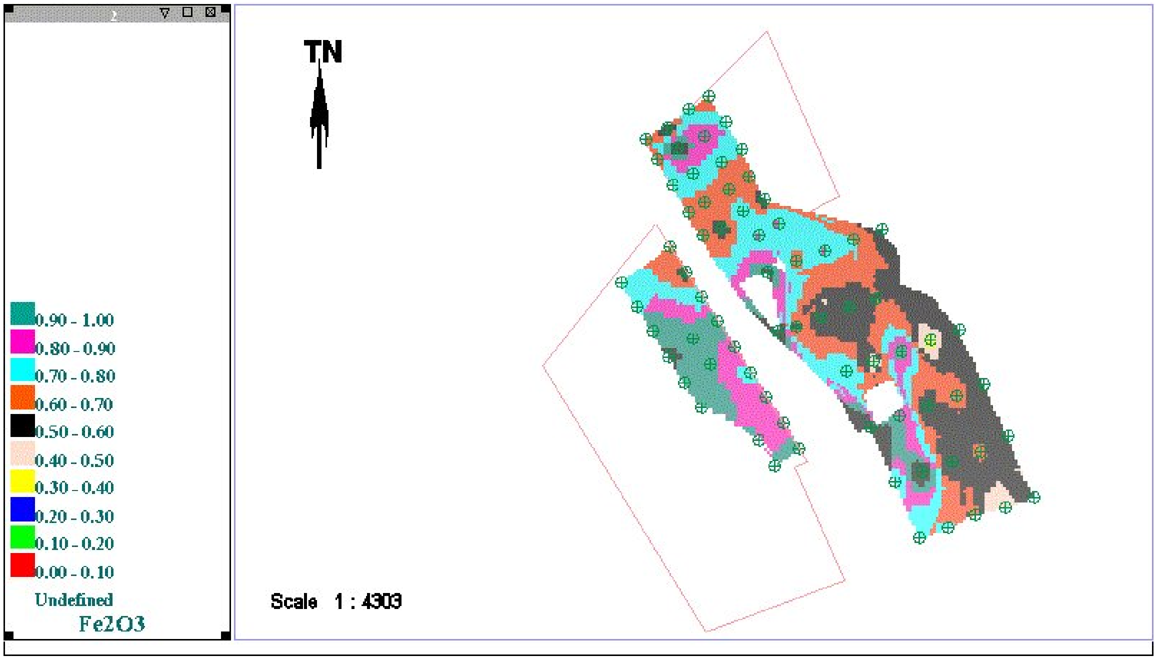


Figure 34 - Fe_2O_3 dispersion pattern, Deposit Two.

By comparing the kriging results and the current surface, Figure 30, the following observations are obvious:

a) The Fe_2O_3 concentrations are marginally lower in the old quarry area, indicating a higher total iron content in the dark ball clay unit, most likely the result of upward migration of iron during normal weathering.

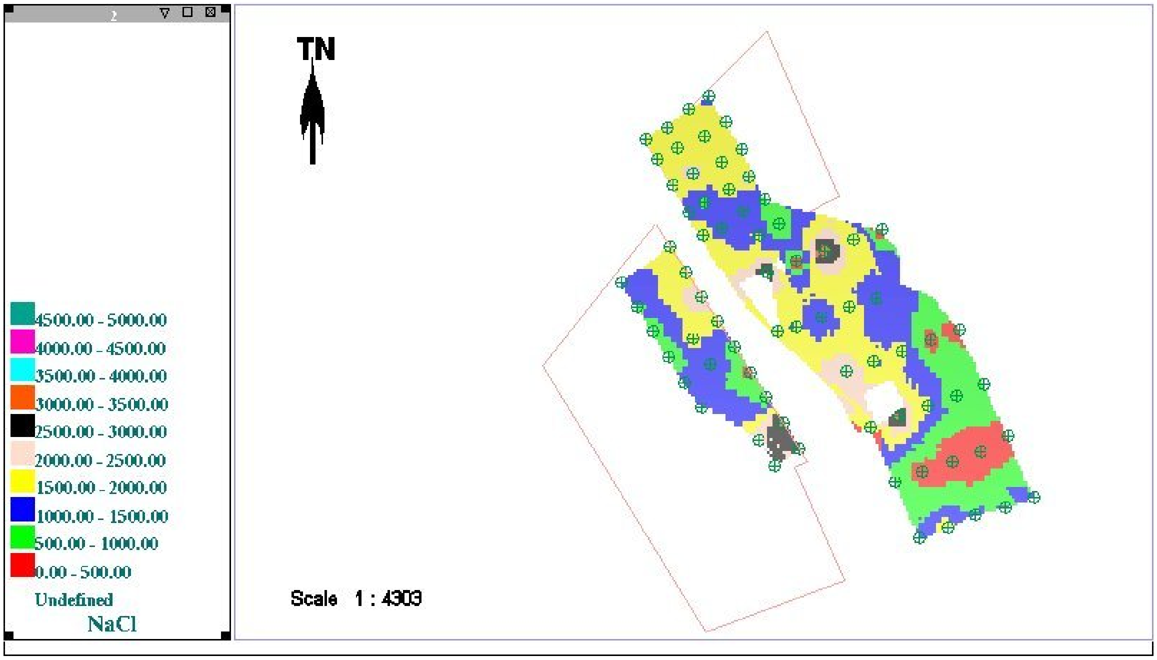


Figure 35 - NaCl dispersion pattern, Deposit Two.

Figure 36 - Free Quartz dispersion pattern, Deposit Two.

b) Water-soluble salts, namely NaCl concentrations, are more concentrated in the central and northern portion of the exploration area. This is a concern as it could result in scumming of the exposed surfaces of the clay bricks if excessive quantities of the ball clay are used in the manufacturing of clay bricks.

c) The quartz concentrations are significantly higher in the old quarry area, possibly indicating lower quartz content in the upper, dark ball clay unit. This tendency is most probably the result of normal sedimentation where the heavier minerals would settle first.

4.3.3 Physical Results.

The preparation of 27 bulk samples for physical testing, were based on the three different geological units identified, a mixture of equal proportions of clay from the first two units, and a mixture of equal proportions of the first and last unit. The coarse to medium grained silty material at the top of the dark ball clay unit, Figure 33, was excluded from all bulk samples.

The bulk samples were submitted for the testing of the physical quality parameters essential to brick manufacturing and chemical analysis for Fe_2O_3, K_2O, NaCl and Quartz. Tables 22 and 23 below summarize the average chemical and physical results received.

Table 22 - Average chemical results of bulk samples from Deposit Two (n = 27).

Bulk samples	Fe_2O_3 (%)	% K_2O (%)	NaCl (ppm)	Quartz (%)
Dark grey ball clay	1.1	0.3	991.9	59.9
Medium grey ball clay	0.6	0.4	214.3	45.00
1:1 Dark to medium grey ball clay	0.7	0.3	1280.6	52.96
1:1 Dark ball clay to Creamy sandy clay	0.6	0.3	1486.2	65.33
Creamy sandy clay	0.6	0.3	1343.5	79.70

Table 23 - Average physical results for Deposit Two clay fired at 1100°C.

Bulk samples	MOR MPa	Extrusion Moisture %	Drying Shrinkage %	Fired Shrinkage %	Water Absorption %	Compressive Strength %
Dark grey ball clay	4.2	16.90	3.73	1.50	8.80	70.50
Medium grey ball clay	2.5	19.30	2.56	0.7	12.20	66.60
1:1 Dark to medium grey ball clay	3.28	17.63	3.17	0.78	11.55	69.31
1:1 Dark ball clay to Creamy sandy clay	2.72	18.13	2.86	0.40	12.51	70.06
Creamy sandy clay	1.40	16.05	1.40	0.00	12.65	46.50

a) <u>Extrusion behavior, extrusion moisture, and green strength (MOR).</u>

All samples extruded well with average moisture contents of between 16.05% and 19.30%, significantly lower than 28,4% recorded at Deposit One.

The average green strengths ranges from a maximum of 4.2 MPa for the dark grey ball clay unit to a minimum of 1.40 MPa for the white to cream, sandy clay unit marking the floor of the deposit. The results indicate that the green strength of the clay increases with decreasing free quartz content (Table 37). The high green strength of 4.2 Mpa is significantly higher than the green strengths recorded for Deposit One and this clay would be ideal for use as a plastic clay in clay brick body mixes. The results clearly indicate that if the top dark grey plastic clay unit is mixed with an equal volume of middle medium grey plastic clay an average green strength of above 3 MPa is achievable which would double the available volume of useable plastic clay.

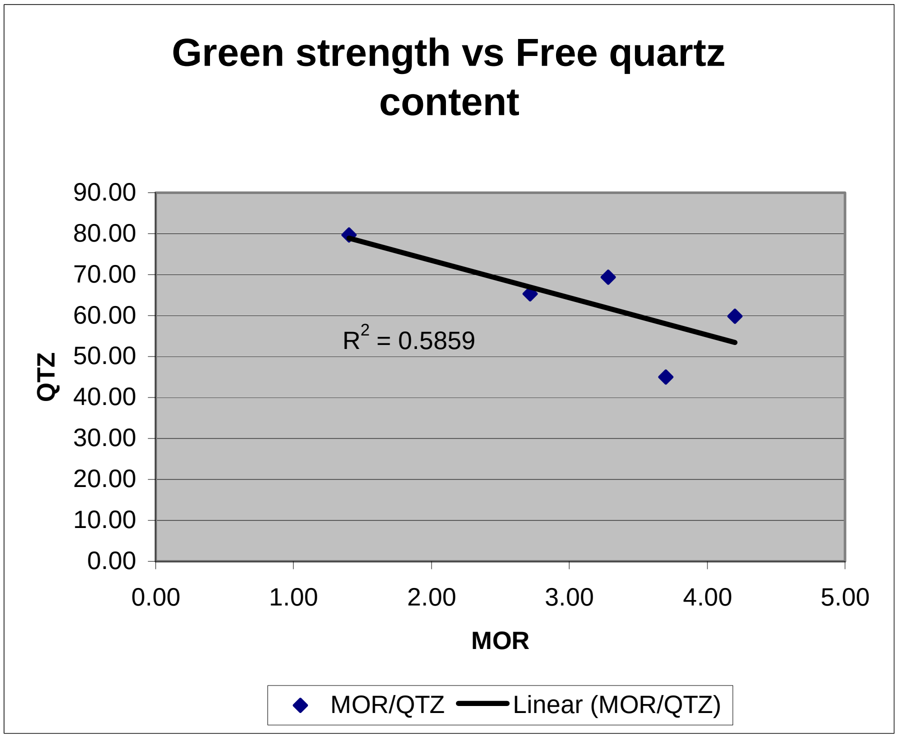


Figure 37 - Scatter plot and regression line between green strength and quartz content, Deposit Two.

b) Drying shrinkage.

The average reported drying shrinkage (contraction) varies from 3.73% to 1.40% for average quartz concentrations varying from 45.0% to 79.7%. Moderate shrinkage does occur during drying which is beneficial to brick manufacturing. The drying contraction is also controlled by the amount of quartz present in the clay as indicated by the correlation of -0.77 between the quartz content of the clay and the drying shrinkage as shown in Figure 38 below.

This correlation clearly shows that quartz reduces the drying contraction and to a lesser extent the green strength of this clay. Moderate quantities of quartz are beneficial in this clay, which would otherwise be to plastic and have a too large a drying shrinkage.

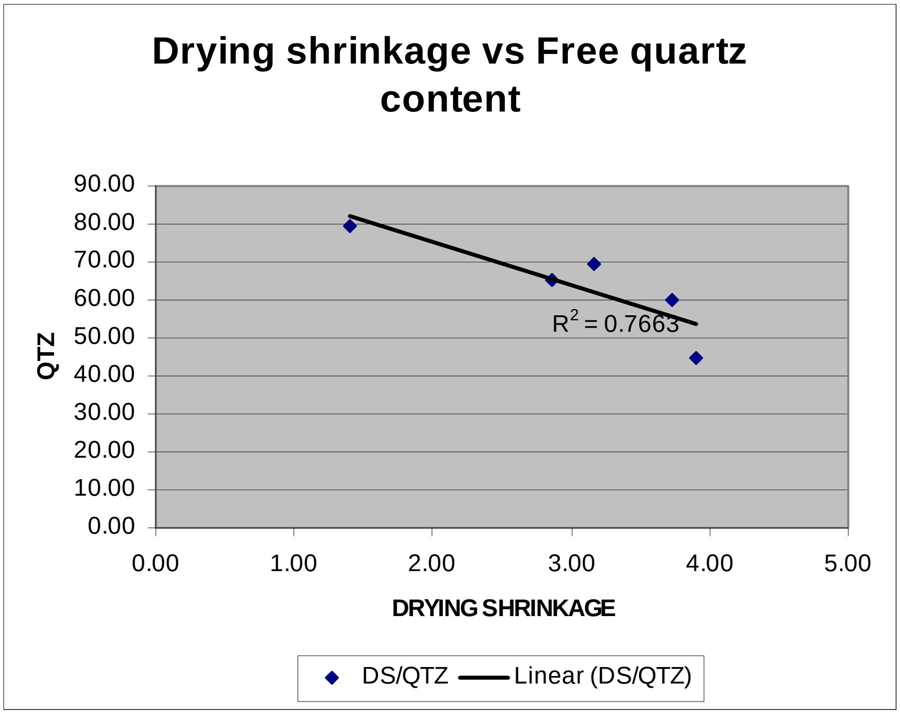


Figure 38 - Scatter plot and regression line between drying shrinkage and quartz content, Deposit Two.

c) Drying sensitivity.

All samples submitted were insensitive to drying.

d) Fired shrinkage and Water absorption.

All test pieces were fired to 1050°C, 1100°C, 1150°C and 1200°C. The results obtained are summarized in Table 24 below.

The fired shrinkage for all test pieces fired at the different temperatures shown above, varies only slightly with a maximum average fired shrinkage of 1.7% for the dark ball clay unit. No acceptable correlations were found to exists with any of the element oxides or quartz, indicating that the fired

Table 24 - Average fired shrinkage and drying shrinkage for clay units from Deposit Two (n = 27).

Bulk Samples	% Fired Shrinkage				% Water Absorption			
	1050 °C	1100 °C	1150 °C	1200 °C	1050 °C	1100 °C	1150 °C	1200 °C
Dark grey ball clay	1.2	1.5	1.7	1.7	9.8	8.8	7.4	7.3
Medium grey ball clay	0.3	0.7	1.3	1.5	12.8	12.2	10.2	9.7
1:1 Dark to medium grey ball clay	0.3	0.8	0.7	0.8	12.3	11.6	10.0	9.6
1:1 Dark ball clay to Creamy sandy clay	0.2	0.4	0.6	0.6	12.8	12.5	10.3	9.9
Creamy sandy clay	0	0	0.2	0.3	12.9	12.7	10.3	10.3

shrinkage is primarily controlled by the loss of organic particles during firing (plasticity), as confirmed by the excellent correlation that exists between fired shrinkage and MOR (figure 39 below). The low fired shrinkages recorded, and the fact that the fired shrinkages increases only marginally by 0.5% at temperature increases from 1050°C to 1200°C, indicate stability of the product during firing making this clay very beneficial to brick manufacturing.

The water absorptions of the fired test pieces varies from a low of 7.3% for the ball clay unit at 1200°C to 12.9% for the bottom clay unit at 1050°C, see table 24 above. A graphic display of the data, shown in Figure 40, clearly shows that the ball clay unit is the least refractory. It is also evident that the water absorption for all tested samples stabilizes at 1150°C, indicating that the vitrification process reached completion. Firing above this temperature would result in slightly reduced water absorption, dependent on the presence of high temperature fluxes, and also contribute very little to an improvement in the durability of the final product.

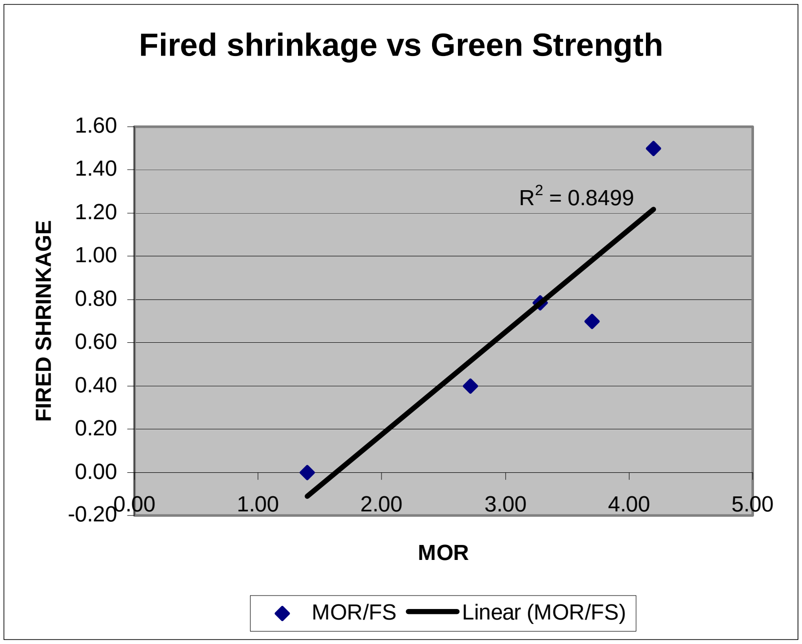
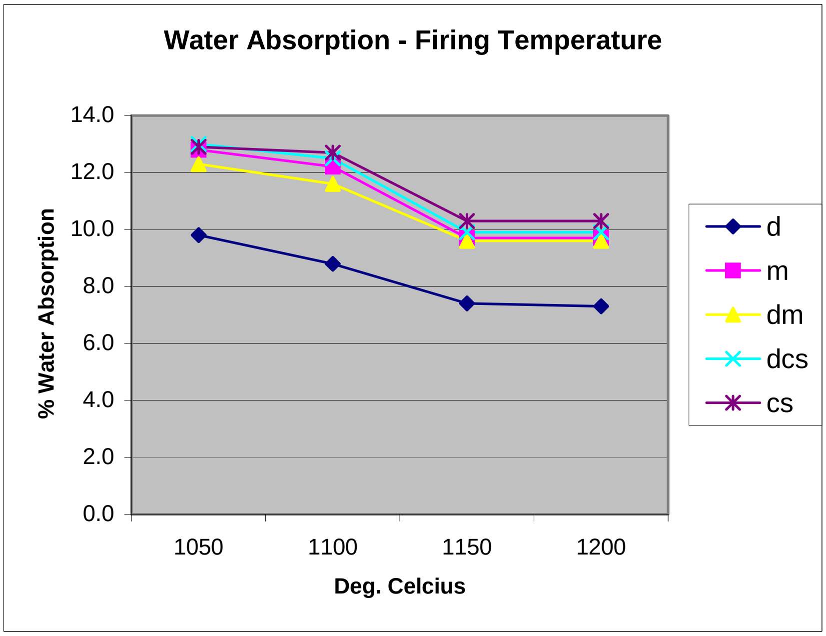


Figure 39. Scatter plot and regression line between fired shrinkage and MOR, Deposit Two.



d	- dark grey ball clay
m	- medium grey ball clay
dm	- 1:1 dark to medium grey ball clay
dcs	- 1:1 dark ball clay to creamy sandy clay
cs	- creamy sandy clay

Figure 40 - Average water absorption of the fired bulked samples, Deposit Two.

4.3.4. Conclusions on suitability of clay from Deposit Two, for brick manufacturing.

The fired colour of the clay from Deposit Two ranges from a light to dark cream, largely dependant on the firing conditions in the laboratory kiln as the iron concentration of the clay were found to vary only slightly.

Table 25 is a summary of the results from the geochemical ore body modeling of the deposit, showing a total measured resource of 794521 bank cubic meters (Bm^3). The resource estimations were restricted to the areas drilled and future exploration will most probably increase the clay resource. No attempt was made to estimate additional resources in the exploration areas not covered by core drilling because of the unknown and unpredictable extent of the ore body.

Table 25 - Block Model Report, Deposit Two.

Free Quartz	**Volume Bm^3**	**Free Quartz %**	**Fe_2O_3 %**	**NaCl ppm**
1.0-11.0	1438	1.000	10.000	1.000
11.0-21.0	0	0.000	0.000	0.000
21.0-31.0	1169	27.991	0.891	2923.814
31.0-41.0	6469	37.320	0.966	2322.796
41.0-51.0	18356	45.927	0.939	1936.580
51.0-61.0	214963	58.112	0.763	1700.044
61.0-71.0	366775	65.646	0.630	1286.549
71.0-81.0	184788	73.496	0.519	916.920
81.0-91.0	563	82.561	0.431	597.235
Total Resource	**794521**	**64.587**	**0.667**	**1335.505**

The high quartz content and the extreme plastic nature of this clay make it unsuitable for use on its own for clay brick production. The excessive quartz concentrations in the bulk of the clay from this deposit would negatively influence product yield resulting in cracking of the product during firing, caused by the quartz inversion at 573°C. The temperature gradient required to fire high silica clay bodies, normally 30°C per hour, would require extended firing cycles, resulting in unacceptable high production costs.

Additionally, the very plastic nature of this clay would require prolonged drying periods, resulting negatively in increased energy costs and additional work in progress stock.

However, the high green strengths of the ball clay from this deposit make this clay a very valuable source of plastic clay required for brick manufacturing. This is also evident when the green strength of Deposit Two clay is compared with that of Deposit One clay. Combinations of clay from both deposits would produce a range of light coloured face brick products meeting market expectations.

Results have shown that this would be possible by winning all the clay from the top, dark grey ball clay unit and mixing it with equal proportions of clay from the lighter grey ball clay unit immediately below it, resulting in a material with an average green strength of 3.2Mpa.

This reduces the total clay resource from this deposit to 242395 Bm^3 as shown Table 26.

Table 26 - Ball clay reserve life, Deposit Two.

Volume Bm^3	Free Quartz %	Fe_2O_3 %	NaCl ppm	Life of mine Years
60482	50.25	1.06	1822	4.55
93532	53.03	0.96	1779	7.03
126582	54.36	0.91	1758	9.52
159632	55.13	0.88	1746	12.00
192682	55.64	0.86	1738	14.49
225732	56.01	0.84	1733	16.97
242395	56.15	0.84	1731	18.23

The high water soluble salts concentrations present in these ball clay units, as indicated by the NaCl concentrations in Table 25, would not cause efflorescence if the use of this material is limited to not more than 25% in face brick material mixes.

The reserve life indicated was calculated on an annual estimated consumption of 13300 Bm^3. The erection of a power line across exploration area A, Figure 30, during the exploration period further reduces the useable clay. This has not been factored into the resource calculations, as it would be possible to move the power line if the need arises and it can be justified financially.

The estimations clearly indicate that the free quartz content has the greatest impact on useable reserves and ultimately on the life of mine. Both green strength and drying shrinkage increases with decreasing free quartz contents while fired shrinkage increases with an increase in green strength.

The predicted behaviour of the ball clay during clay brick manufacturing is as follows:

a) Extrusion behaviour – Good.
b) Extrusion moisture – 17.63 %.
c) Modulus of Rupture (MOR) – 3.2 MPa ± 0.2 Mpa
d) Drying Shrinkage – 3.17 % ± 0.5%
e) Ideal Firing Temperature – 1150^{o}C + 25^{o}C
f) Fired Shrinkage – 0.7% ± 0.1%

Scatter plots, to determine the relationships between free quartz, Fe_2O_3 and NaCl were constructed. See Figures 41 to 43. Excellent positive correlations were found between Fe_2O_3 and NaCl and inverse correlations between free quartz and both Fe_2O_3/NaCl.

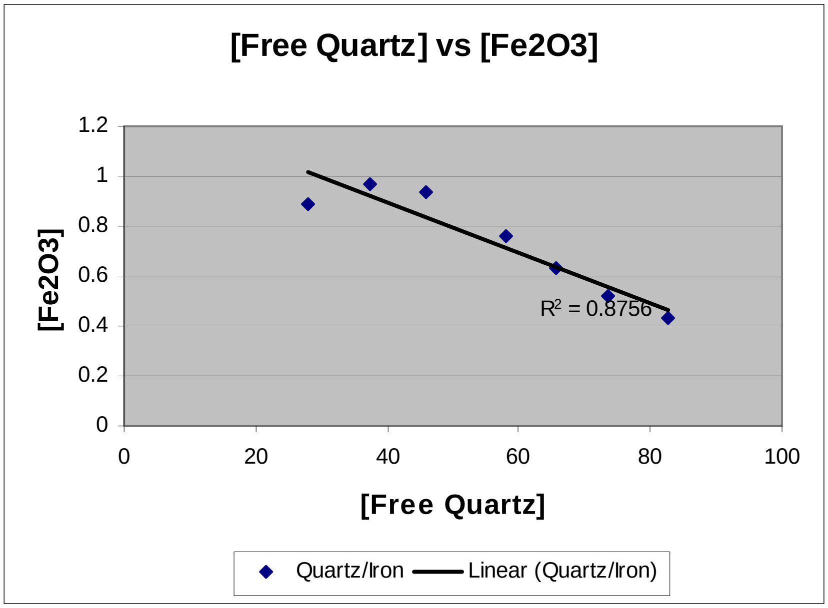


Figure 41 - Scatter plot and regression line between Free Quartz and Fe_2O_3, Deposit Two.

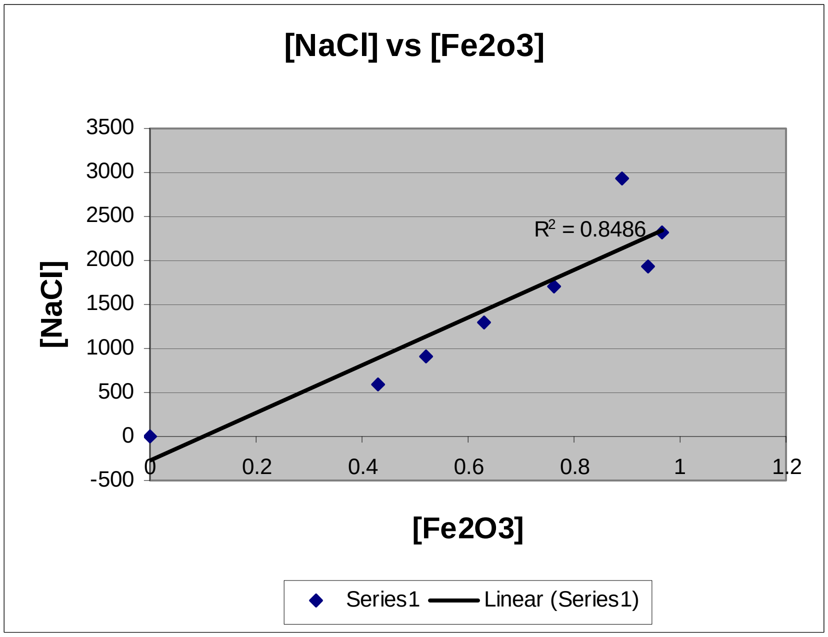


Figure 42 - Scatter plot and regression line between NaCl and Fe_2O_3, Deposit Two.

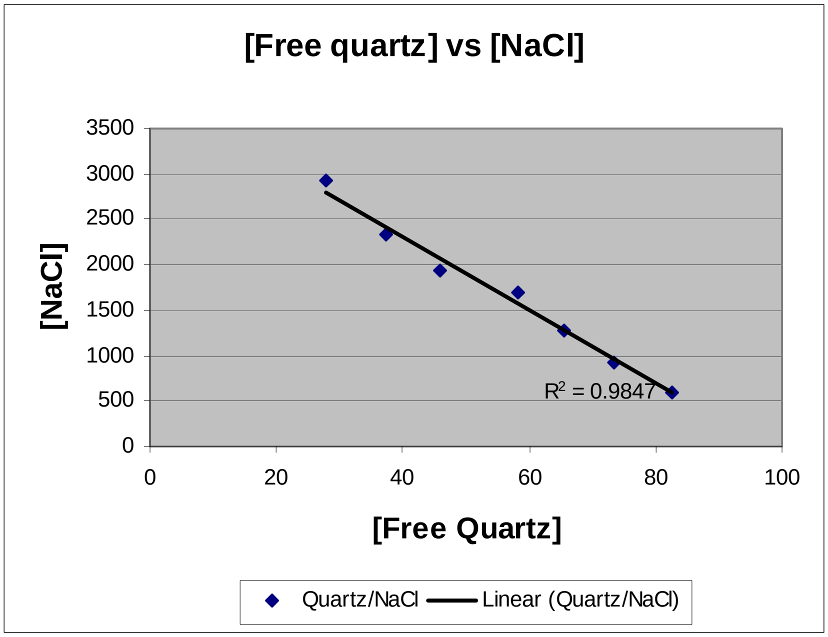


Figure 43 - Scatter plot and regression line between Free Quartz and NaCl, Deposit Two.

CHAPTER 5 – GENETIC MODELS FOR DEPOSITS ONE AND TWO.

Literature (Grim, 1953; Moorhouse, 1959; Deer, Howie and Zussman, 1992 and Orris, 1998) describes the formation of different clay minerals as the result of either weathering or hydrothermal alteration dependant on physical-chemical conditions and the nature of parent materials. e.g. feldspars, micas, volcanic glasses or ferromagnesian minerals.

From field observations and inference derived from the chemical results it may now be suggested that the clay deposits were formed as a result of three independent geological processes. The intrusion of the syn- to post tectonic granitoids into micaceous (indicated by the absence of halloysite; Orris, 1998), feldspathic Malmesbury sandstone beds, approximately 500 Ma ago, created a hydrothermal vein structure, which enriched the shale with feldspar/kaolinite and quartz, restricted to the vein network. Followed by extensive *in-situ* weathering of these hydrothermally altered rocks resulting in residual kaolin deposits, the effects of which were more pronounced along the more permeable shear zones illustrated in Figure 44.

The final process entails the formation of Deposit Two type clay deposits, initiated by the erosion and transportation of primary kaolinite deposits, which have been transported by water, together with organic material, to shallow depressions where they were deposited.

5.1. Concentration changes during alteration.

The application of Isocon diagrams (Grant, 1986) to analyze concentration changes during hydrothermal alteration requires the, very important, initial choice of the protolith for the altered rocks.

It was decided that, due to the high concentrations of kaolinite restricted to the hydrothermal veins as opposed to the lower kaolinite concentrations present in the clays, Table 27, to construct Isocon diagrams of the vein material and rocks/clay from Deposit One, using the S-type granites and fresh Malmesbury shale (the least-altered equivalent) as the respective protoliths. This was accomplished by using chemical results of representative rock/clay samples taken for analysis from the deposit and average major element compositions of S-type granites (Sa1) published by Scheepers (1995), Table 28.

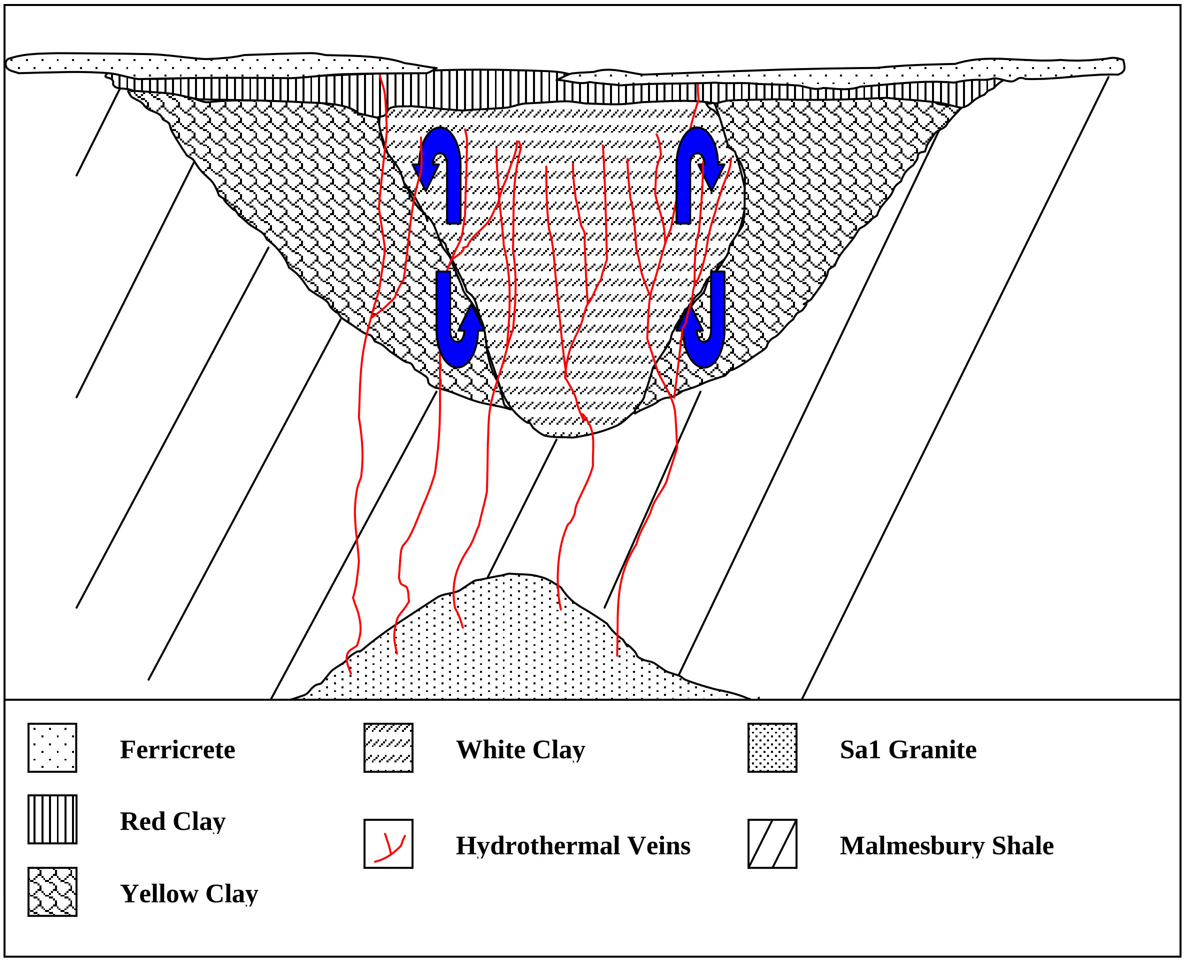


Figure 44. Graphical representation of the formation of clay from Deposit One, showing the zonal distribution of different alteration zones.

In plotting the data, ranges from 0 to 30 wt percent and 0 to 300 ppm has been selected. Components whose concentrations are not accommodated comfortably in these ranges have been scaled to fit to these ranges. The scaling factors are shown on the graphs as a number in front of the compound. Data for trace elements are plotted in 0.1 ppm.

Table 27 – Summary of Semi Quantitive Mineralogical Analysis results of the clay/rock from Deposit One. (Fs = Feldspar, St = Smectite, Kt = Kaolinite, Qz = Quartz, Mi = Mica)

Rock Description	Sample (100%)					Sample (clay fraction)			
	% Fs	% St	% Kt	% Qz	% Mi	% St	% Kt	% Qz	% Mi
Fresh Rock	4	0	12	74	10	13	62	6	18
White clay	0	0	25	59	16	0	67	6	27
Yellow clay	4	0	30	53	8	0	14	52	3
Red clay	0	0	21	69	5	3	95	0	2
Vein Material	0	0	67	33	0	0	88	7	3

Grant (1986) also states that the choice of the reference Isocon, used to determine the relative gains and losses of mobile components, is as important as determining the least altered equivalent. Because of the possibility of the hydrothermal alteration not being pervasive (restricted to the hydrothermal vein network) and that alumina, in the form of feldspar/kaolinite, have been added to the system, it was opted to use the TiO_2-V ratio for the Isocon. Research by Jenner (1996) reported that Ti-V is a very useful immobile element ratio for seawater and rock dominated environments.

The equation used by Grant (1986), to determine a measure of gain or loss in concentration change of a component relative to its concentration prior to alteration, assuming constant Al_2O_3, of $(\Delta C_i/C_i^O) = (C^O[Al_2O_3]/ C^A[Al_2O_3])(C_i^A/ C_i^O) - 1$ was modified to:

$$(\Delta C_i/C_i^O) = (C^O[TiO_2{:}V]/ C^A[TiO_2{:}V])(C_i^A/ C_i^O) - 1 \quad \text{for constant } TiO_2{:}V.$$

Where i = Subscript for component C = Concentration,

A = Superscript for altered sample

and O = Superscript for original sample

Table 28 - Summary of average major element compositions and Na, Cl and calculated NaCl concentrations of representative samples taken from Deposit One and average major element compositions of S-type granites (Sa1) published by R. Scheepers, 1995.

	Unit	Sa1 Granite	Malmesbury Shale	White Clay	Yellow Clay	Red Clay	Hydrothermal Vein Material
SiO_2	%	54.09	62.90	61.10	52.90	54.40	45.70
Al_2O_3	%	15.61	15.30	24.30	26.60	21.60	35.80
TiO_2	%	1.23	0.81	1.06	0.97	0.75	0.11
$Fe_{(Tot)}$	%	8.97	7.63	1.46	4.64	12.9	0.31
MgO	%	5.15	4.20	0.89	0.59	0.57	0.18
CaO	%	7.91	0.14	0.05	0.05	0.05	0.05
Na_2O	%	2.19	0.60	0.40	0.60	0.2	0.50
K_2O	%	1.77	3.66	1.96	2.63	1.15	0.05
P_2O_5	%	0.24	0.12	0.05	0.05	0.16	0.15
Na_{Sol}	ppm		54	112	147	117	2776
Cl_{Sol}	ppm		39	221	271	200	5561
Cr	ppm		50	84	75	62	102
Ni	ppm		41	11	9.6	6.9	87
V	ppm		101	172	116	93	53

Figure 45, 46 and 47 provides the Isocon diagrams where concentration changes of the fresh shale relative to the white clay, yellow clay and red clay are graphically displayed.

All three Isocon diagrams and Table 29 indicate that SiO_2, Cr and V are the other least mobile components after TiO_2. Losses, of the same order of magnitude, of MgO, CaO, K_2O and Ni are clearly visible, while gains are shown for water soluble Na and Cl and to a lesser extent for Al_2O_3 in all three clays. The weathered red clay shows a

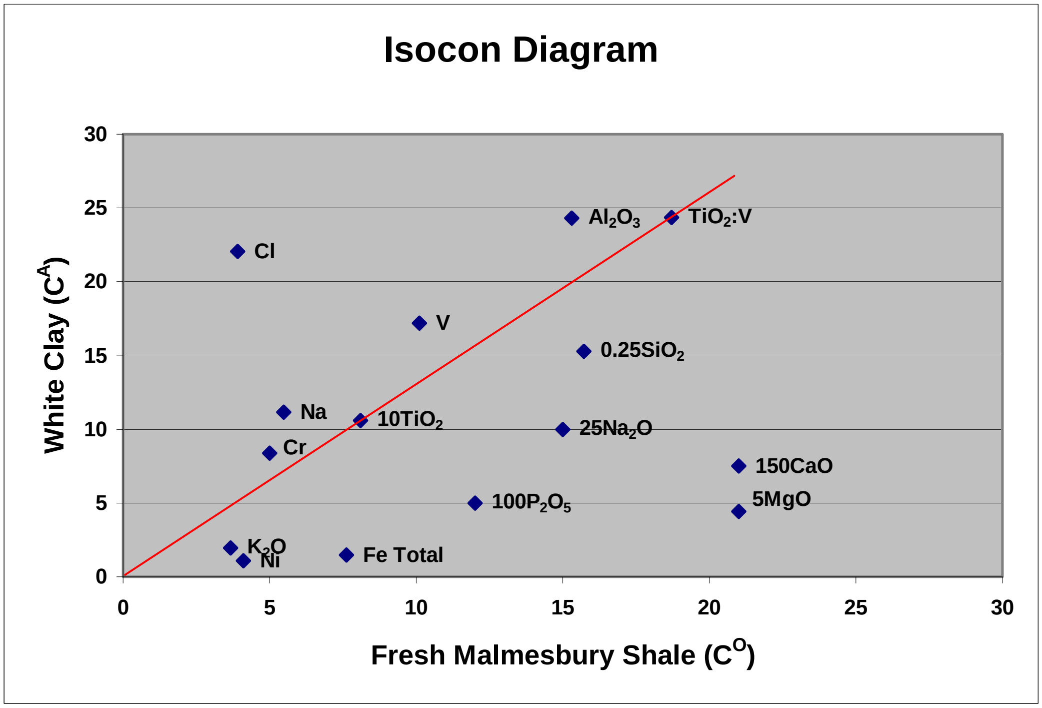


Figure 45 - Isocon diagram for analyses of fresh Malmesbury shale and white clay from Deposit One.

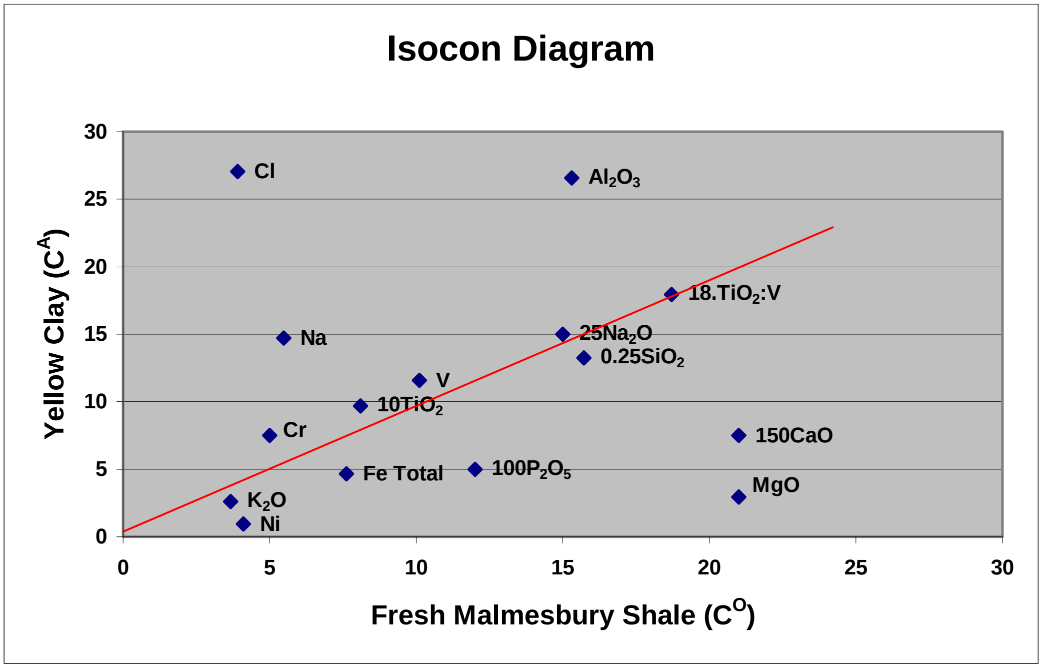


Figure 46 - Isocon diagram for analyses of fresh Malmesbury shale and yellow clay from Deposit One.

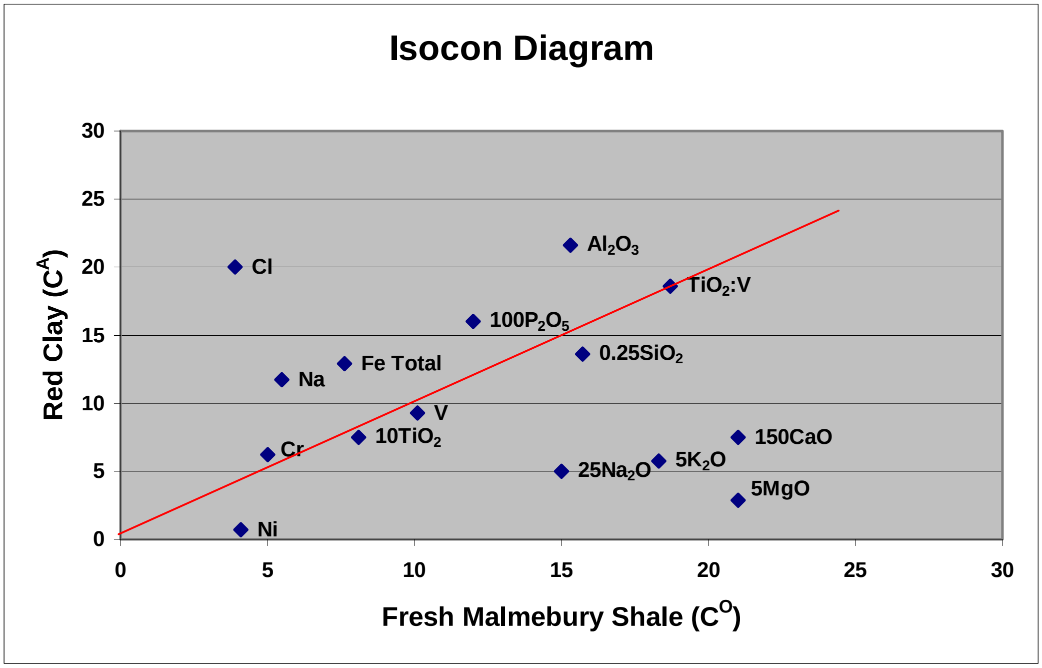


Figure 47 - Isocon diagram for analyses of fresh Malmesbury shale and red clay from Deposit One.

gain in total iron indicating the continuation of geochemical processes once kaolinite has been formed with the oxidation of goethite to hematite close to surface.

The extremely anomalous concentrations of Na, Cl and Al_2O_3 restricted to the hydrothermal vein material (Table 28) and the large concentration gains, calculated Δ values of up to 6.23 (Table 29), for water soluble Cl merited further investigation.

Magmatism in the Saldania belt, which started with a first phase of older (600-540 Ma) collision related syn- to post-tectonic granitoids with S-type features, intruded mainly the Tygerberg terrane (Scheepers, 1995), was the most likely source for hydrothermal fluids. An Isocon diagram, Figure 48, was constructed to evaluate concentration change between the Sa1-granite and the hydrothermal vein material. Because of the absence of V in the chemical values reported by Scheepers (1995) it was decided to use TiO_2 for the Isocon based on its apparent immobility as indicated by Figures 45, 46 and 47.

The equation used by Grant (1986), described earlier in this chapter, was modified to:

$$(\Delta C_i/C_i^O) = (C^O[TiO_2]/ C^A[TiO_2])(C_i^A/ C_i^O) - 1 \quad \text{for constant } TiO_2.$$

Table 29 - Concentration changes for the alteration of Deposit One rocks.

Protolith	Fresh Malmesbury Shale			Sa1 - Granite
	Constant TiO_2:V - $\Delta C_i/C_i^O$			Constant TiO_2 - $\Delta C_i/C_i^O$
	White Clay	Red Clay	Yellow Clay	Hydrothermal Vein
Δ SiO_2	-0.25	-0.13	-0.12	4.35
Δ Al_2O_3	0.22	0.42	0.81	16.23
Δ TiO_2	0.01	-0.07	0.25	Not available
Δ Fe_{Tot}	-0.85	0.70	-0.37	-0.70
Δ MgO	-0.84	-0.86	-0.85	-0.68
Δ CaO	-0.73	-0.64	-0.63	1.63
Δ Na_2O	-0.49	-0.66	0.04	5.14
Δ K_2O	-0.59	-0.68	-0.25	-0.90
Δ P_2O_5	-0.68	0.34	-0.57	8.20
Δ Na_{Sol}	0.56	1.15	1.80	Not available
Δ Cl_{Sol}	3.35	4.16	6.23	Not available
Δ Cr	0.29	0.25	0.56	Not available
Δ Ni	-0.79	-0.83	-0.76	Not available
Δ V	0.31	-0.07	0.20	Not available

The Isocon diagram presented in Figure 48 and Table 29, the calculated Δ values, indicate moderate concentration losses for K_2O, MgO and total iron with large gains for Al_2O_3, P_2O_5, SiO_2 and Na_2O. The flatness of the slope of the Isocon (Figure 48) also indicate extreme mass/volume changes when the vein material is compared to the original granite composition, indicating the possible introduction and subsequent precipitation of hydrothermal fluids into the Malmesbury Shales.

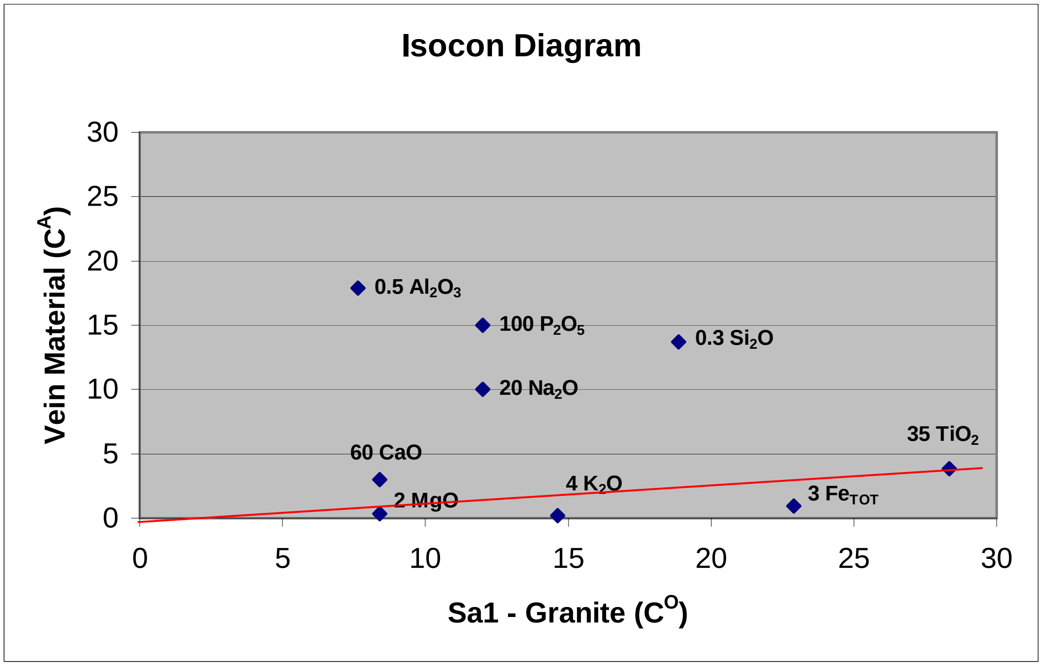


Figure 48 - Isocon diagram for analyses of Sa1-granite and hydrothermal vein material from Deposit One. (Sa1-granite composition from Scheepers, 1995).

5.2. Deposit One.

a) The hydrothermal phase:

Scheepers (1995) reported that mafic plutonic rocks were the first phase that intruded as subduction related magmas. They have a low K-content (<1.5% K_2O) and a low K_2O:Na_2O ratio (0.5). The end of this intrusion was marked by the introduction of granodioritic batholiths with a higher K-content (3.3% K_2O) and a higher K2O:Na2O ratio (1.2). These granites are commonly described as peraluminous, associated with a presence of K-feldspar megacrysts and have the highest MgO content of all plutonic events in the south-western Saldania belt.

Research, published by Grim (1953), on the synthesis of clay minerals shows that:

i. In the system $(CaMg)O-(K_2Na_2)O-Al_2O_3-SiO_2-H_2O$, at temperatures of 300°C and pressures of 8,82 Mpa for alkali solutions, montmorillonite forms at the expense of kaolinite. At moderately higher concentrations of

K_2O, and temperatures of 400°C and pressures of 30,4 Mpa, muscovite is formed.

ii. Data suggest that, in general, kaolinite is likely to be the phase formed at 300°C in an acid system containing any of the alkaline or alkaline earths. At 400°C muscovite will form in the presence of potash, and kaolinite will be converted to muscovite at this temperature in the presence of an excess of KCl.

iii. If the concentration of potassium and sodium ions was high, but no additional alumina was available, the feldspars remain unaltered.

It is thus possible that hydrothermal alteration of the Malmesbury shale most probably initiated during the intrusion of the mafic plutonic rocks resulting in the formation of montmorillonite and mica (muscovite). This is supported by the anomalous concentrations of mica in the fresh shale and white clay, and the restricted presence of anomalous concentrations smectite to the clay fraction of the fresh shale.

The absence of unaltered feldspar in the vein network indicate that with the differentiation of the magmas to granodioritic and the introduction of chlorine to the system that no additional alumina was available for the formation of kaolinite. The alteration of montmorillonite to kaolinite as the predominant phase, mostly confined to the vein network, indicates the end of hydrothermal alteration.

b) *In-situ* weathering phase:

In situ decomposition (residual weathering) of feldspar contained in the Malmesbury shale, restricted to the hydrothermally altered zone, to form kaolinite with the removal of K_2O, MgO, Na_2O and CaO that resulted in the formation of the white and yellow alteration zones. Followed by the concentration of Fe_2O_3, immediately below and on surface, for the formation of the red alteration zone and ferricrete, under oxidizing conditions.

It is suggested that, when comparing the dispersion patterns of Fe_2O_3, K_2O, quartz and NaCl, Figures 22 to 25, with the Isocon diagram results that the northwest striking zone of low iron clay is the results of:

a) Hydrothermal enrichment of the shale with montmorillonite, kaolinite, quartz and soluble salts.
b) Subsequent weathering of the feldspar and some mica to kaolinite with the removal of most of the other major elements.
c) This was followed by the transfer of iron to the surface during weathering as indicated by the iron concentration gain in the red clay and the formation of the ferricrete surface cover.

5.3. Deposit Two.

The ball clay deposits were clearly the last phase of the formation of clay deposits in the areas north of Cape Town. The mineralogical differences of the clays as opposed to the clays of Deposit One, the presence of organic material and alunite and the absence of mica, indicate that this deposit is most probably the result of the erosion and transportation of kaolinised granites that were exposed during the formation of the African surface.

The dispersion patterns of alunite, organic material and water-soluble salts, concentrated in the upper portion of the deposit, and quartz concentrated at the bottom of the deposit, indicates deposition in shallow (deposit thickness) lakes. This probably took place during normal sedimentation where the heavier minerals would settle first.

The Fe_2O_3 concentrations are marginally lower in the bottom part, and this is most likely the result of upward migration of iron during normal weathering. The grey colour of the clay indicates a reducing environment.

5.4. Summary.

The significance of this genetic model may be summarized by the following set of exploration criteria:

a) The primary distribution of good quality brick clay deposits in the areas north of Cape Town is related to areas where the Malmesbury shales were retained as a relative thin cover (cupola) above intrusive syn tectonic granites.

b) The earliest clay formation phase is most probably controlled by hydrothermal cells that formed during the cooling phase of the granite when hydrothermal fluids migrated along aquifers formed by structurally formed zones of weakness.

c) The subsequent weathering phase resulted from denudation of the altered zones in the Malmesbury shales and a prolonged period of weathering under subtropical to the present day mediterranean climatic conditions.

d) The formation of ball clay deposits, in restricted lakes, signifies the end of the formation of clay deposits in this area.

CHAPTER 6 – VALUATION

The valuation of brick clay deposits in South Africa has, to date, received very little attention in the public domain literature due to:

a) The limited number of larger local producers and an apparent lack in the trade of these deposits.
b) The relative low capital expenditure required to acquire and evaluate such a deposit compared to the large capital investment required to construct a modern state of the art, brick plant.
c) The lack of geological and ceramic information available on such deposits prior to construction of brick plants.
d) The general belief is that due to the perceived abundance of brick clay deposits such deposits have very little intrinsic value.

Brick clay is exclusively used for the manufacturing of clay brick products, and must therefore derive its value from the sales revenue generated from these products. The information presented in the two exploration case studies, suggests that the two clay deposits evaluated have no value as individual deposits as the clay from both deposits lack specific ceramic properties to successfully manufacture quality clay face bricks if used in isolation. It is however clear that if the clay from the two deposits is mixed in specific proportions; body mixes with ceramic properties suitable for light coloured clay face brick manufacturing is possible. The value of the beneficiated product, clay face brick, can thus be used to determine the value of both clay deposits, based on the percentage (volume) of clay used from the individual deposits in the manufacturing process.

This chapter will describe the fundamental valuation (Kernot, 1999) of the two brick clay deposits, by generating discounted cash flow (DCF) models and net present values (NPV), for two different scenarios:

Scenario 1: The erection and running of a Clamp operation at Deposit One, using clay from both deposits.

Scenario 2: Supplying an existing Transverse Arch (TVA) plant with clay from both deposits.

All the South African brick manufacturers are privately owned companies or closed corporations that do not publish annual financial statements. This made it difficult to obtain meaningful financial information to valuate the clay deposits explored. Two local bricks manufacturers were however willing to divulge cost estimates for a Clamp and TVA operation. The accuracy of these costs could not be verified resulting in estimated accuracy levels of between 65% and 75%, comparable to accuracy levels acceptable for scoping and pre-feasibility studies.

6.1 Discounted Cash Flow Model.

Kernot (1999) and Rudenno (1998) argues that the calculation of the Discounted Cash Flow Model (DCFM) and Net Present Value (NPV) is the most frequent method used to determine the fundamental value of a project or company as it determines the time value of money.

The input parameters used for this valuation will be based on the requirements for the DCF as presented by Kernot, 1999. The confidence levels of the different input parameters used determines the overall accuracy of the results and will be specified when describing individual input parameters. Generic models for the calculations were set up in Microsoft Excel spreadsheets.

6.1.1 Revenue.

Selling prices were determined by contacting different clay brick manufacturers in the Western Cape during the first quarter of 2005. Average prices were calculated and summarized per clay brick category (SABS 227, 2002) as shown in Table 30. All prices shown are ex-works, excluding VAT.

Table 30 clearly shows that the pricing of the various categories of clay brick reflects the increasing value added to the end user in moving from non-face plaster brick (NFP) and non-face extra (NFX), requiring the walling to be plastered and painted (ongoing maintenance), to face brick standard (FBS), yielding low maintenance, aesthetic and durable walling. Prices within categories are fairly variable and stronger market demand for a specific face brick will enable a higher selling price to be achieved. It has been found that a popular face brick aesthetic (FBA) product can be more expensive than a FBS product. Face brick extra (FBX), is not produced in the Western Cape region.

Table 30 - Average clay brick prices, (Imperial size) for the Western Cape, first quarter 2005.

Category	NFP	NFX	FBA	FBS	FBX
R per 1000 bricks	890.00	990.00	2100.00	2616.00	Not Available

Quarterly statistics, national averages (Figure 49), released by the Clay Brick Association (CBA) show a steady increase in clay brick prices since 1990, with a sharper rise from 2000. Comparative prices, with the main competitors of clay brick, clearly show that clay brick are still the most affordable method of construction.

Trend lines, AB and EF, were fitted to the BER-CBA curve, Figure 49, to model past price tendencies in order to attempt estimates of future price increases. Inflation has not been stripped out of these prices and whereas the earliest rising tendency (AB) could be ascribed to inflation (1990-2000), the dramatic increase in price since 2000 (EF) took place under a much lower inflation regime. This indicates a marked increase in prices, reflecting on demand increases and supply shortages.

The line AB, ranging from 1990 to 2000, is defined by:

$y = 27.575x + 287$ were x = number of years and y = brick price.

The line EF, ranging from 2000 to September 2005, is defined by:

$y = 81.957x + 562.75$ were x = number of years and y = brick price.

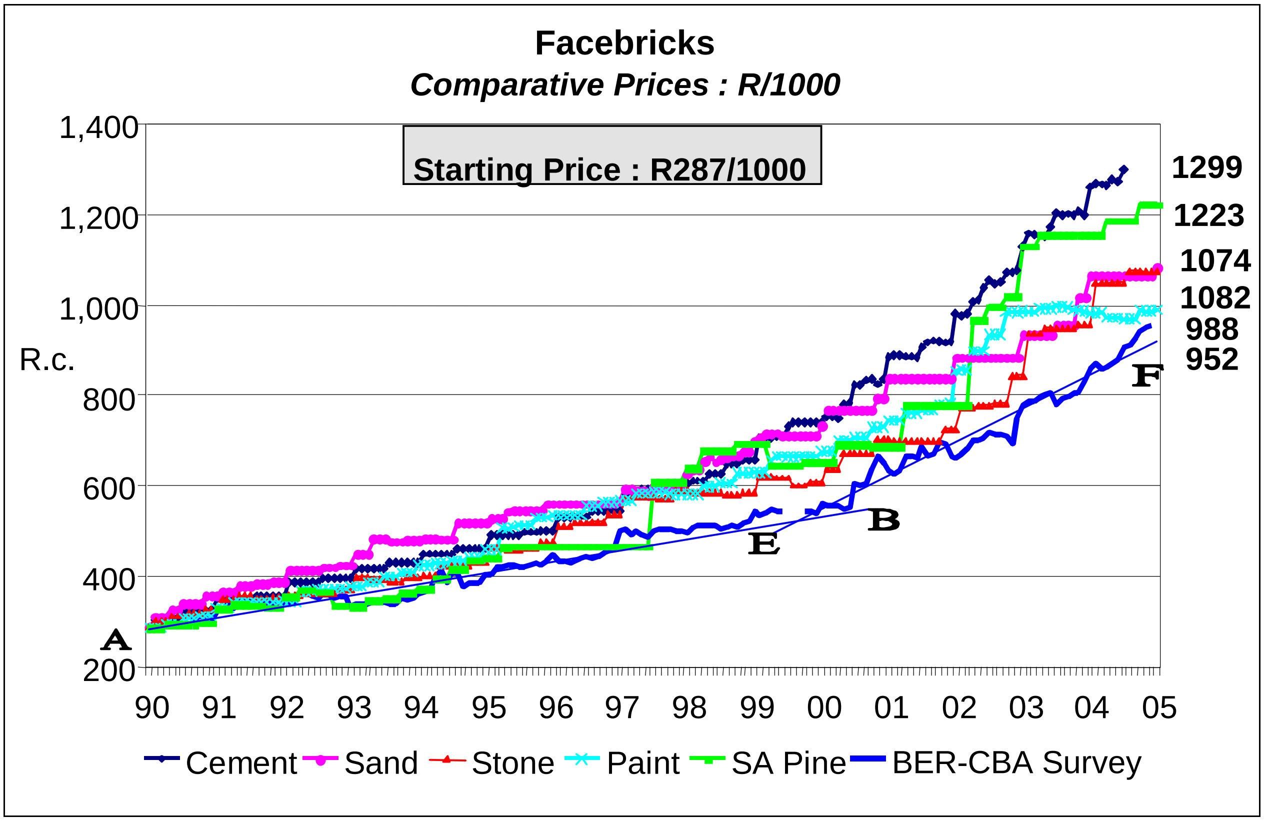


Figure 49 - Comparative prices for clay face brick and main competitors. (CBA)

Future price increases of 9.5%, from 2006 to 2010, and 6% there after is envisaged as:

a) The average, year on year, calculated price increase of 14.56%, since 2000, would not be sustainable as brick producers have steadily increased production capacity to meet demand thereby steadily increasing availability of their product. The average year on year price increase of 9.5% chosen, consist of a 4.8% inflation component and a 4.7% increase linked to reducing stock shortages.

b) The current high demand for clay brick should continue until 2010, after the hosting of the Soccer World Cup in South Africa, where after demand should drop, possibly resulting in an over supply of bricks negatively impacting on pricing. Price increases should, from after 2010, be limited to inflation (estimated at 6%) unless new local growth opportunities are initiated.

The costs of transporting the finished product is not included in the prices shown above as the industry often uses transport contractors for this purpose. This cost is for the account of the client and has been excluded from all calculations.

6.1.2 Production.

Smith (1997) argues that the best method of selecting optimum production rates for a mining project is to determine maximum value curves associated with the project by plotting the discounted cash flow rate of return for a series of production rates. By adopting this method, the following three significant characteristics, with respect to determining a production rate for a mining project are taken into account:

a) The production rate for an individual mining project is generally not limited to supply-demand considerations for the total market as a single project has little effect on the metal price or metal supply to the overall market.
b) The owner's financial resources may limit the production rate, as the initial investment tends to be very large and are directly related to the production rate.
c) The life of the project is determined as soon as the production rate is selected, as there is a physical limit to the size of the reserve for each mineral deposit.

The selection criteria for determining optimal production rates for the manufacturing of clay bricks differ significantly from the above due to the following characteristics:

a) Clay brick, unlike commodities, are not traded on the open market and the sales thereof are generally geographically restricted to local markets. Supply-demand considerations are therefore crucial and totally dependent on the local economic climate and business confidence levels.
b) Although the initial investment of a clay brick manufacturing facility can be very large and is limited by the owner's financial resources, production rate is restricted by the capacity of the extruder, driers and kiln.
c) The physical size of a brick clay deposit generally limits the life of a product range and not the life of a manufacturing facility. The cost associated with developing new brick clay deposits and the associated transportation costs of the raw materials to existing manufacturing facilities are small when compared to the costs associated with the erection of new manufacturing facilities.
d) The ceramic properties of a brick clay deposit determine the drying and firing cycles (time periods) and constrain the production capacity to an upper limit for the manufacturing technology used at existing brick plants.

Based on the high levels of activity prevailing in the Western Cape construction industry, it was assessed that switching the TVA's production from low margin 35 million NFP clay brick per annum to a raw material mix yielding a mix of non face plaster (NFP, NFX) and higher margin face brick (FBA, FBS) with a simultaneous increase in capacity of 15 million bricks per annum to 50 million bricks per annum, would yield an attractive investment opportunity.

To be able to compare the results of the two scenarios the selected annual gross green production of fifty million brick would be used for valuating both the TVA kiln and clamp kiln operations, as well as similar product mixes consisting of 80% of the white clay from Deposit One and 20% of the ball clay from Deposit Two. The resultant 42.86% production increase, dependant on the upgrading of the existing TVA plant, should meet increased demand as indicated by the increase in building plans passed and the decrease in clay brick stock holdings.

This planned production will yield 41096 bricks per day more than the current daily production of 95890. This means that, in order to prevent stock build-up, 136986 bricks have to be sold and delivered to site every day.

Local industry guidelines have been used to estimate the expected average yield per product category (Table 31) for the different operations.

Table 31 - Budgeted Product Yields.

Product Category	**CLAMP Yield %**	**TVA Yield %**
FBS	0.0	5.0
FBA	20.0	40.0
NFX	15.0	20.0
NFP	50.0	25.0
WASTE	15.0	10.0

All other production input parameters used will be typical for the technology level of the manufacturing facility. These are summarized in Table 32.

Table 32 - Production costs statistics.

Cost Item	**Clamp Kiln**		**TVA Kiln**	
	(R / 1000 bricks)	**%**	**(R / 1000 bricks)**	**(%)**
Overheads	166	26	166	27
Labour	210	32	165	26
Maintenance	36	6	62	10
Fuels	233	36	233	37

The Producer Price Index (PPI), currently lags the Consumer Price Index (CPIX) inflation by roughly 0.8%. This tendency was used to estimate future production price increases. An average annual increase of 4% has been chosen for the period up to 2010 and 5.2% for the period thereafter.

6.1.3 Resource Life Estimations.

Table 33 is a summary of the clay volumes required for the production of the fifty million green bricks. It has been assumed that 2,1 Spm^3 (stockpile cubic meter) of clay is required to extrude one thousand bricks.

Table 33 - Resource estimations based on annual production of fifty million bricks.

	Measured Resource Bm^3	**Swell Factor Bm^3 to Spm^3**	**Annual Consumption Spm^3**	**Resource Life Years**
Deposit One	3766538	1.07	84000	47.97
Deposit Two	242395	1.20	21000	13.85

It is also clear from the above table that the clay from Deposit Two will only last for 13.85 years. This figure excludes any indicated resources in the area and all NPV calculation will be limited to a thirteen-year life of mine estimate. This should however highlight the need to replace the ball clay resource in due time as it is a critical component for clay brick manufacturing in the area.

6.1.4 Mining and Transportation Costs.

Mining and stockpiling of the clay are done once a year. Sufficient clay is excavated and stockpiled at the individual clay quarries for one years production and transported to the manufacturing facilities where a minimum of 2000 Spm^3 is kept for any individual clay.

Average prices (Table 34) for the mining, stockpiling and transportation of the clay were obtained, May 2005, from mining and transport contractors in the Western Cape.

6.1.5 Costs of Sales.

The costs of sales vary considerably from operation to operation dependant mainly on the total production (quality and category) output and size of the company or closed corporation. An average of 11 % has been decided on for both operations.

Table 34 - Clay mining and transportation rates.

Activity	Unit	Deposit One	Deposit Two
Clay Mining and Stockpiling			
Establishment	**R. c.**	8000.00	8500.00
Overburden	**R / Bm^3**	9.25	9.25
Clay	**R / Spm^3**	10.50	10.50
Clay Transportation			
Traveling distance to Clamp	**Km**	0	31.6
Transportation cost to Clamp	**R / Spm^3**	0.00	33.45
Traveling distance to TVA	**Km**	6.3	33.2
Transportation cost to TVA	**R / Spm^3**	23.75	34.00

6.1.6 Capital Costs.

Estimated capital expenditure, for the two different scenarios, is summarized in Table 35.

Table 35 - Estimated Capital Expenditure.

Activity	Clamp (Rand)	TVA (Rand)
Exploration	1,500,000.00	1,500,000.00
Land Acquisition	4,500,000.00	4,500,000.00
Legal Fees	150,000.00	150,000.00
Environmental	500,000.00	500,000.00
New Construction	10,000,000.00	0.00
Plant Expansion	0.00	17,000,000.00
TOTAL	16,650,000.00	23,650,000.00

6.1.7 DCF Models.

Discounted cash flow models were drawn up to calculate the net present value (NPV), internal rate of return (IRR) and payback period for the two projects taking all the factors described above into consideration, at a discount rate of 11% (Government bonds of 7.87%, 11 August 2005, and 3.13% project risk).

No royalties were included in the calculations as clay brick manufactures have been exempted from the proposed 1% royalty rate (local sales only) that holders of industrial mineral rights would have to pay for the extraction and transfer of South African mineral resources (Mineral & Petroleum Royalty Bill 2003).

Rehabilitation provision and the final rehabilitation of the Deposit Two would not exceed five hundred and fifty thousand rand during the duration of the 13-year project. This is possible by adopting a mine plan where rehabilitation will be done concurrently during the annual mining program. Mined out sections of the previous year will be backfilled and sloped for revegetation with seed bearing soil that will be stripped the following year, keeping un-rehabilitated sections of the quarry and the stockpiling of seed bearing soil to a minimum. This amount has been inflated with PPI, as discussed under paragraph 5.2, and was included as a cost during year thirteen.

No rehabilitation provision for Deposit One has been included in the calculations as the life of this deposit exceeds 13 years. Bank guarantees will however be issued for rehabilitation provisions (updated annually) to the DME as prescribed by the Minerals and Petroleum Resources Development Act, 2002 (Act 28 of 2002).

The DCFM for the clamp operation, Table 36, shows a NPV of one hundred and forty one million rand, an IRR of 61% and a 2.26-year payback period. In contrast to this the DCFM for the TVA operation, Table 37, shows a NPV of four hundred and ten million rand, an IRR of 128% and a 0.79-year payback period.

The huge difference in NPV, calculated for the two operations, is a direct result of the higher income envisaged for the TVA operations due to increased quality and face brick yields.

It is further evident that the NPV of the two clay deposits, calculations based on apportionment of the proposed product mix on 80% (Deposit One clay) and 20% (Deposit Two Clay), varies significantly for the different operations. The value calculated for Deposit Two varies between twenty eight million rand and eighty two million rand and for Deposit One from one hundred and twelve million rand and three hundred and twenty eight million rand, for the Clamp and TVA operations respectively. These calculations do not reflect the true value of the clay from Deposit Two as the ceramic superiority and strategic importance (limited abundance) of this raw material is not accounted for.

Table 36 -DCF model for Clamp Operation. (See file valuationprint.xls)

Table 36 - DCF model for Clamp Operation.

			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6-13
Income		**Selling Price**	11,097,825.00	42,532,414.31	66,532,411.03	72,853,468.69	79,774,548.20	676,488,168.55
FBS	R / 1000 bricks	2616.00	0.00	0.00	0.00	0.00	0.00	0.00
FBA	R / 1000 bricks	2100.00	4,599,000.00	17,625,667.50	27,571,398.75	30,190,879.97	33,059,013.56	280,340,434.92
NFX	R / 1000 bricks	990.00	1,626,075.00	6,231,932.44	9,748,458.84	10,674,632.56	11,688,722.65	99,120,368.06
NFP	R / 1000 bricks	890.00	4,872,750.00	18,674,814.38	29,212,553.44	31,987,956.16	35,026,811.99	297,027,365.57
Costs of Sales		11.00%	1,220,760.75	4,678,565.57	7,318,565.21	8,013,881.56	8,775,200.30	74,413,698.54
Expenditure		%	6,978,630.00	25,001,936.13	37,120,247.74	38,605,057.65	40,149,259.96	338,486,443.51
Overheads	R / 1000 bricks	23.79	166.00	172.64	179.55	186.73	194.20	204.29
Labour	R / 1000 bricks	30.09	210.00	218.40	227.14	236.22	245.67	258.45
Maintenance	R / 1000 bricks	5.16	36.00	37.44	38.94	40.50	42.11	44.30
Fuels	R / 1000 bricks	33.39	233.00	242.32	252.01	262.09	272.58	286.75
Raw materials Clay	R / 1000 bricks	7.57	52.86	43.54	44.77	46.56	48.43	52.42
Clay Deposit One	R / 1000 bricks	80.00	24.60	20.83	21.56	22.42	23.32	25.18
Clay Deposit Two	R / 1000 bricks	20.00	28.27	22.71	23.21	24.14	25.11	27.24
Profit/Loss			2,898,434.25	12,851,912.60	22,093,598.08	26,234,529.48	30,850,087.94	263,588,026.50
Capital Expenditure			15,000,000.00	1,650,000.00	0.00	0.00	0.00	0.00
Sub Total			-12,101,565.75	11,201,912.60	22,093,598.08	26,234,529.48	30,850,087.94	263,588,026.50
Tax (29%)			0.00	3,248,554.66	6,407,143.44	7,608,013.55	8,946,525.50	76,440,527.68
Net Profit/Loss			-12,101,565.75	7,953,357.95	15,686,454.63	18,626,515.93	21,903,562.44	187,147,498.81
Net Profit/Loss (Deposit One)	80%	-13,320,000.00	-9,681,252.60	6,362,686.36	12,549,163.71	14,901,212.75	17,522,849.95	149,717,999.05
Net Profit/Loss (Deposit Two)	20%	-3,330,000.00	-2,420,313.15	1,590,671.59	3,137,290.93	3,725,303.19	4,380,712.49	37,429,499.76
Cumulative Net Profit/Loss	Deposit One	-13,320,000.00	-9,681,252.60	-3,318,566.24	9,230,597.47	24,131,810.21	41,654,660.16	191,372,659.21
Cumulative Net Profit/Loss	Deposit Two	-3,330,000.00	-2,420,313.15	-829,641.56	2,307,649.37	6,032,952.55	10,413,665.04	47,843,164.80
Cumulative Net Profit/Loss	Clamp Project	-16,650,000.00	-12,101,565.75	-4,148,207.80	11,538,246.83	30,164,762.77	52,068,325.20	239,215,824.02
Payback (Years)	2.26	85.00						
		%						
Product Yields	FBS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FBA	20.00	2,000.00	7,000.00	10,000.00	10,000.00	10,000.00	80,000.00
	NFX	15.00	1,500.00	5,250.00	7,500.00	7,500.00	7,500.00	60,000.00
	NFP	50.00	5,000.00	17,500.00	25,000.00	25,000.00	25,000.00	200,000.00
Production Volumes (x 1000 units)	Gross Green	100.00	10,000.00	35,000.00	50,000.00	50,000.00	50,000.00	400,000.00
	Waste	15.00	1,500.00	5,250.00	7,500.00	7,500.00	7,500.00	60,000.00
	Saleable	85.00	8,500.00	29,750.00	42,500.00	42,500.00	42,500.00	340,000.00
Stripping Ratio's	Deposit One	Clay:Waste	15.00	18.00	19.25	19.25	19.25	19.25
	Deposit Two	Clay:Waste	1.00	2.10	2.56	2.56	2.56	2.56
Mining Volumes	Deposit One	Clay (Spm3)	16,800.00	58,800.00	84,000.00	84,000.00	84,000.00	672,000.00
		Waste (Bm3)	1,120.00	3,266.67	4,363.64	4,363.64	4,363.64	34,909.09
	Deposit Two	Clay (Spm3)	4,200.00	14,700.00	21,000.00	21,000.00	21,000.00	168,000.00
		Waste (Bm3)	4,200.00	7,000.00	8,203.13	8,203.13	8,203.13	65,625.00
Royalties		R/Spm3	0.00	0.00	0.00	0.00	0.00	0.00
Transport Cost	From Deposit One	R/Spm3	0.00	0.00	0.00	0.00	0.00	0.00
	From Deposit Two	R/Spm3	33.45	34.79	36.18	37.63	39.13	41.17
Mining Costs	Deposit One	R/Spm3	14.64	12.40	12.83	13.35	13.88	14.99
	Deposit Two	R/Spm3	33.85	19.28	19.09	19.85	20.65	23.69
Mining Rate Waste		R/Bm3	9.25	9.62	10.00	10.40	10.82	11.25
Mining Rate Clay		R/Spm3	10.50	10.92	11.36	11.81	12.28	12.77
Establishment		Sum	8,000.00	8,320.00	8,652.80	8,998.91	9,358.87	9,733.22
Stockpile pad preperation		Sum	5,000.00	5,200.00	5,408.00	5,624.32	5,849.29	6,083.26
Plant Hire		Sum	5,000.00	5,200.00	5,408.00	5,624.32	5,849.29	6,083.26
Pit Dewatering		Sum	0.00	5,200.00	5,408.00	5,624.32	5,849.29	6,083.26
Rehabilitation		Sum	41,215.00	31,663.60	55,466.14	57,684.79	59,992.18	1,066,930.52
Survey Costs		Sum	8,215.00	8,543.60	8,885.34	9,240.76	9,610.39	10,110.13
Closure		Sum	0.00	0.00	0.00	0.00	0.00	1,003,818.75
Signs		Sum	3,000.00	3,120.00	3,244.80	3,374.59	3,509.58	3,692.07
Grassing		Sum	0.00	0.00	5,480.00	5,699.20	5,927.17	6,235.38
Vegetation		Sum	0.00	0.00	27,040.00	28,121.60	29,246.46	30,767.28
Fencing		Sum	30,000.00	20,000.00	0.00	0.00	0.00	0.00
Profiling		Sum	0.00	0.00	10,816.00	11,248.64	11,698.59	12,306.91

Summary of DCFM statistics for base case scenario

	NPV	IRR	Discount rate
Deposit One	R 112,564,039.72	61%	11%
Deposit Two	R 28,141,009.93	61%	11%
Project	R 140,705,049.65	61%	11%

Table 37 - DCF model for TVA Operation. (See file valuationprint.xls)

CHAPTER 7 – RISK MANAGEMENT

Both Rudenno (1998) and Kerzner (2001) agree that financial evaluation of a project is based on estimations, each with a certain degree of accuracy. The financial estimations calculated for the base case scenarios, in Chapter 6, is meaningless if not accompanied by a statement of the reliability and uncertainty of the estimate.

This chapter will define the reliability of the estimate by analysing the sensitivity of different variables used to identify and access the risks associated with the project.

7.1 Sensitivity Analysis.

The sensitivity of the base case to the following variables were tested:

a) Brick price
b) Cost of fuel
c) Transportation costs of clay
d) Brick Yields
e) Production volume variation
f) Effect of production waste

The sensitivities were tested by taking one variable at a time and changing its values in the DCFM's systematically by –20%, -15%, –10%, -5%, 0%, +5%, +10%, +15% and +20%, keeping all other variables constant.

The variability in brick yields and production waste were used as indicators to model the effect of variability in raw material quality, assuming that all production variables are constant. It is important to remember that these calculations were based on the assumption that the raw materials used for production, complies with the quality parameters identified for the individual clays as described in Chapters 4 and 5, and that this analysis tests quality variation for the raw materials and not compliance to set quality parameters. The use of raw materials of unspecified quality will result in the production of brick not complying with SABS 227 standards, resulting in massive yield losses and project failure.

It stands to reason that if the raw material quality is consistent it would then be possible to access and optimize production variables such as drying rates, kiln draft, push rates, firing curves and many others, all of which have to be designed to best fit the ceramic properties of a specific raw material mix.

Table 38 and Figure 50 below show the results of the sensitivity analysis for the Clamp operation. The results clearly show that brick price, production volume variation and NFP yield have the biggest influence on the profitability of the project, to the extent that the project could fail if the anticipated brick price reduces by more than 20%.

Table 38 - Sensitivity of NPV for Clamp Operation.

Sensitivity	Bricks price	Fuel	Clay Transport	NFP Yield	Prod Qty's	Waste
-20%	31,731,217	162,960,041	142,046,940	175,918,597	97,024,888	162,101,984
-15%	58,974,675	157,396,293	141,711,467	167,115,210	107,944,928	156,752,750
-10%	86,218,133	151,832,545	141,375,995	158,311,823	118,864,969	151,403,517
-5%	113,461,592	146,268,798	141,040,522	149,508,436	129,785,009	146,054,283
0%	140,705,050	140,705,050	140,705,050	140,705,050	140,705,050	140,705,050
5%	167,948,508	135,141,302	140,369,577	131,901,663	151,625,090	135,355,816
10%	195,191,966	129,577,554	140,034,105	123,098,276	162,545,131	130,006,583
15%	222,435,424	124,141,302	139,698,632	114,294,889	173,465,131	124,657,649
20%	249,678,882	118,450058	139,363,160	105,491,597	184,385,212	119,308,116

To a lesser degree, similar trends can be identified for the cost of fuel and production waste variations indicating that the success of clamp operations are totally dependent on being a high volume, low cost producer extremely sensitive to pricing.

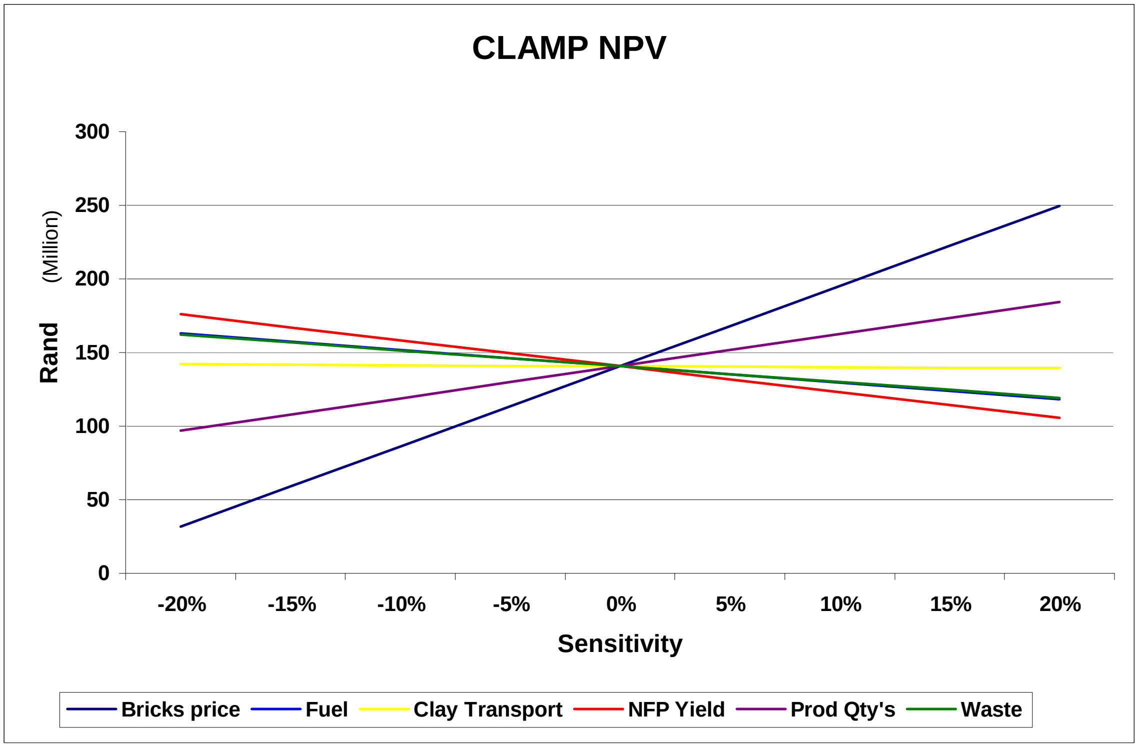


Figure 50 - Graphical representation showing sensitivity of NPV for Clamp Operation.

The analysis clearly shows that the landed costs of raw materials have very little influence on the profitability of a clamp operation as displayed by the clay transportation variable. It would thus be less risky to use the clay from these deposits as raw materials at existing clamp operations rather than constructing a new clamp yard at Deposit One.

Although the results of the sensitivity analysis for the TVA operation show similar trends, Table 39 and Figure 51, to that of the Clamp operation for the variables tested, it is less risky to pursue as displayed by the higher NPV's. Added advantages would be that new products introduced into the market would be limited to fifteen million brick and the flexibility of being able to produce all clay brick products, specified by SABS 227, on demand.

Table 39 - Sensitivity of NPV for TVA Operation.

Sensitivity	Bricks price	Fuel	Clay Transport	FBA Yield	Prod Qty's	Waste
-20%	225,062,688	438,633,794	416,889,735	348,458,071	310,804,269	430,177,442
-15%	271,372,412	431,550,741	415,242,697	363,918,949	335,678,598	425,208,477
-10%	317,682,136	424,467,689	413,595,659	379,379,827	360,552,927	420,239,513
-5%	363,991,860	417,384,636	411,948,621	394,840,706	385,427,255	415,270,548
0%	410,301,584	410,301,584	410,301,584	410,301,584	410,301,584	410,301,584
5%	456,611,308	403,218,531	408,654,546	425,762,462	435,175,912	405,332,619
10%	502,921,031	396,135,479	407,007,508	441,223,340	460,050,241	400,363,655
15%	549,230,755	389,052,426	405,360,471	456,684,218	484,924,569	395,394,690
20%	595,540,479	381,969,374	403,713,433	472,145,196	509,798,898	390,425,726

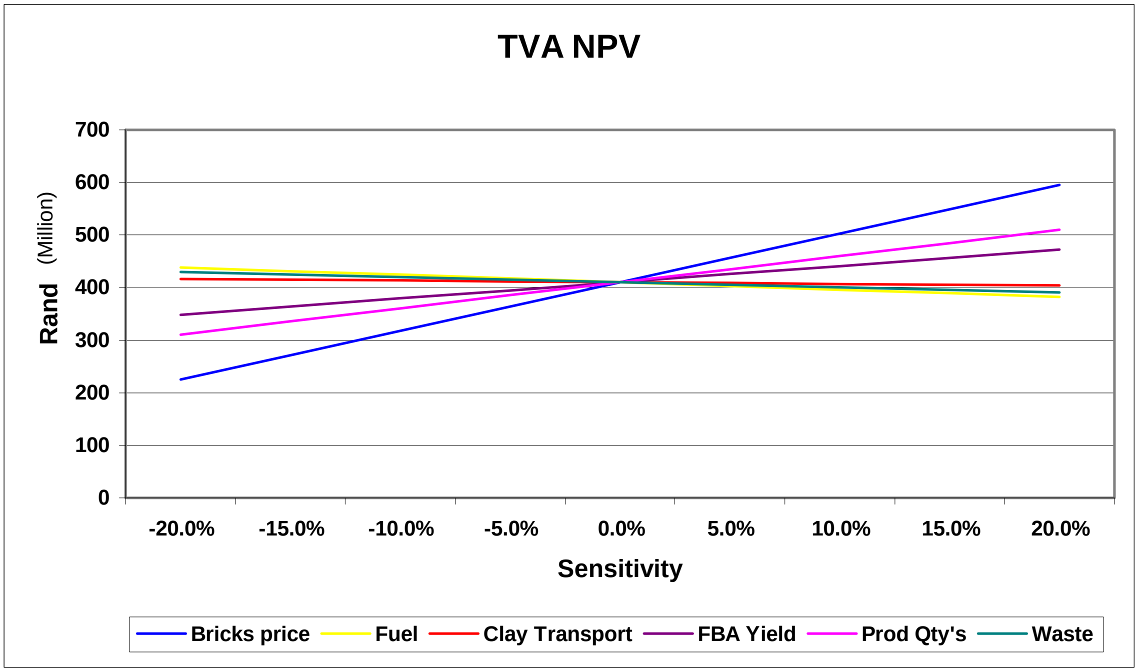


Figure 51 - Graphical representation showing sensitivity of NPV for TVA Operation.

It is further evident that brick pricing, yields and production volumes have the biggest influence on the profitability of this operation followed by waste levels and the impact of fuel prices.

The cost of transporting clay show a slight impact on NPV, again showing the potential of extending the life of current brick manufacturing facilities by upgrading existing facilities and importing the raw materials rather than constructing manufacturing facilities closer to new clay deposits. The impact on raw material haul distance versus brick quality and uniqueness should however be considered before any decisions are made.

Optional benefits to this strategy would be the ability to design new unique product ranges increasing profitability even more and the potential of realizing huge savings in capital expenditure, and the associated cost of capital, allowing brick manufacturers to rather update and improve existing operations.

Although the impact of the cost of transportation of the finished product to the consumer falls outside the scope of this treatise it might be beneficial to brick manufacturers, in the event of constructing new manufacturing facilities, to research the impact of clay transportation versus finished goods transportation before deciding on the location of the facility. A reduction in the cost of transporting the finished product would allow brick manufacturers flexibility in pricing, giving them huge advantages over their competitors.

7.2 A qualitative risk assessment and quarry management strategy.

It is important that the raw materials to be processed are strictly managed and controlled during quarrying and stockpiling operations, as well as during winning from stockpiles to feed the plant. Fluctuations in concentrations of identified quality parameters of the raw materials will cause colour variation and other ceramic defects in the product resulting in poor first grade yields. It is therefore essential to establish raw material management procedures in order to achieve consistency, year on year, to ensure the production and marketing of products of premium quality.

As the project depends entirely on the availability of quality raw materials, a qualitative risk analysis had been undertaken to identify possible threats and associated vulnerabilities for the five critical areas identified and described below:

a) Quarry Development Planning

   i. Insufficient geological, chemical, ceramic and survey data resulting in poor or no quarry development planning leading to:

      Increase costs due to excessive overburden stripping, increased rehabilitation liabilities and non-compliance to statutory requirements.

      Over or under supply of raw materials resulting in over expenditure or insufficient raw materials.

      Raw material quality not complying to set standards.

   ii. Inadequate raw material stock control and production planning measures resulting in:

      Insufficient raw material stock levels.

      Unplanned clay mining and construction of small stockpiles

      Increased quality variability between stockpiles

b) Quarrying

   i. Selection of mining equipment and methods unsuitable for material to be mined:

      Mining equipment not able to break material into small lumps to assists with blending of material in individual stockpile layers

      Unable to mine material selectively by separate removal of overburden, internal waste and clay

      Use of old, inefficient equipment resulting in increased mining costs and environmental damage caused by fuel/oil spillages.

ii. Inclement weather conditions

Wet weather causes bad underfoot conditions unsuitable for clay mining resulting in possible depletion of stockpiled material before mining can resume

Constructing of smaller more variable stockpiles.

iii. Ineffective quarry management

Stockpiling clay of unsuitable quality

Clay stockpiles not completed when required for production

Increasing rehabilitation liability by ignoring concurrent rehabilitation

Over or under mining of required clay volumes

Non-compliance with statuary requirements

Over paying mining contractors

c) Stockpiling

i. Incorrect stockpile location

Clay used most frequently not stockpiled closest to bin feeder resulting in high plant feeding costs

ii. Incorrect stockpile construction methods

Increase the risk of raw material variability by not controlling the layer thickness and material lump size when constructing stockpiles.

Incorrect size, shape and drainage of stockpiles increases the chance of stockpiled material becoming wet during bad weather.

Positive identification of individual stockpiles required as a reference for identification of samples taken from stockpile for quality assessment and for identification to ensure that clay is won from the correct stockpile.

d) Sampling

i. Ineffective quality control procedures

Sampling methods not standardized, all samples are not representative of the location.

Labelling of individual samples not systematic resulting in incorrect interpretation of chemical and ceramic results

Response to individual layer results not standardized, might result in construction of stockpiles of unsuitable quality

e) Reclaiming stockpiles

i. Inclement weather conditions

Material too wet for processing when required

ii. Material spillage

Material not available/accessible when required

7.3 Risk Amelioration:

The implementation of deterrent, preventative, corrective and detective controls to ensure the reduction and removal of possible threats discussed above are critical management tools in ensuring the delivery of quality raw material to the manufacturing process.

a). Quarry development planning and mining.

Some 3-months prior to commencement of any mining the raw material requirements for the forthcoming 15 months have to be determined to formulate a Quarry Development Plan and Contract Tender Document.

It is suggested that a dedicated manager be appointed and that the following protocol be followed in developing the quarrying programme.

i. The raw materials to be mined for the coming year should be based on the current and forecast sales plan, taking the capacity of the manufacturing facility and the current in stock raw material volumes into account.

ii. Formulation of a one-year Quarry Development Plan for each quarry using applicable geological and ceramic data obtained from boreholes drilled, ahead of the quarry face, and the latest digital terrain model obtained by surveying the quarry after the last quarrying operation. This will limit the required overburden volume that has to be stripped resulting in a lower landed clay prices.

iii. If mining contractors are used a mining contract documents calling for tenders should be drawn up requesting contractors to tender followed by adjudication and awarding of the mining contract.

iv. The mining method has strategic significance in terms of the finished product, and thus the applicable machinery to be used will be based on successful past practice.

v. Special attention need to be given to rehabilitation of worked out sections of the quarry during overburden stripping to minimize the rehabilitation liability required in terms of the Minerals and Petroleum Development Act of 2002 (Act 38 of 2002).

vi. Statutory requirements related to the quarry, is the responsibility of the appointed manager and include:

Return of statistics

Safety

Correct mining practice
Updating of quarry plans
Statutory appointments

vii. Progressive payments to mining contractors based on work done are the sole responsibility of the appointed manager. Interim payments should only be made on receipt of verified invoices and limited to 90 % of claimed amounts to provide for unforeseen events.

viii. Reconciliation of the mining contract after completion should include:
The survey of the "air space" created in the quarry and the volumes of the raw materials stockpiled, preferably by an independent mine surveyor.

Reconciling the mining contract in conjunction with the mining contractor based on the results of the above-mentioned survey.

Followed by the calculation of the actual landed cost for the clay stockpiled and the assigning of a value to each stockpile based on its volume. This value should be zero when the stockpile has been totally consumed.

To maximize the utilizations of earthmoving equipment and reduce the risk of not being able to supply raw materials when needed, mining operations should only be conducted during the dry summer months between early October and April as the rainfall patterns, shown in Figure 52, clearly indicate. Sufficient materials must be extracted and stockpiled during this period, allowing a three months souring (natural breakdown of material when exposed to the atmosphere) period before use, to ensure the uninterrupted continuation of production until raw materials are extracted during the next mining season.

Construction of large raw material stockpiles is recommended as it decreases variability of all the identified quality parameters. Variation in colour occurs with small fluctuations in iron concentrations due to the natural low concentrations of iron and the extreme weathered state of the shales.

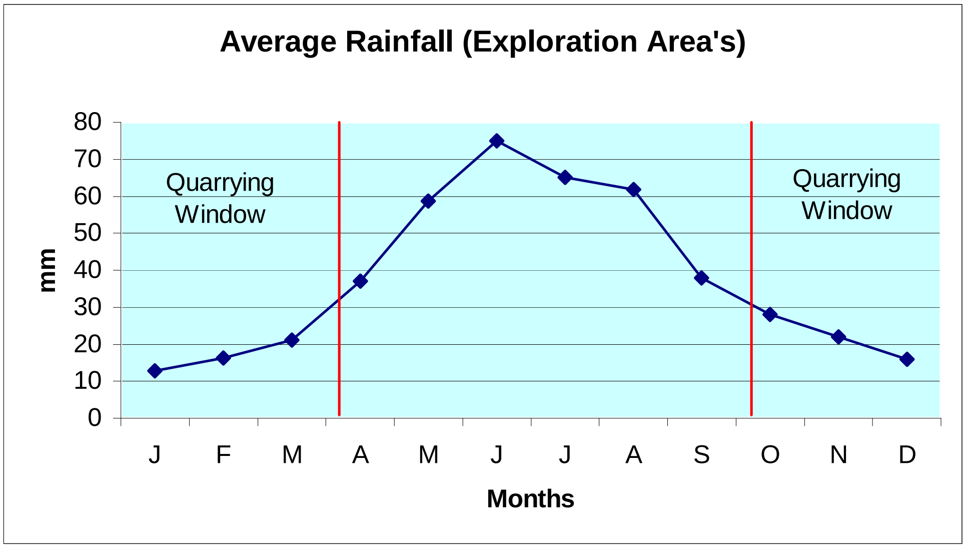


Figure 52 - Rainfall statistics for the Western Cape, exploration area's.

b). Stockpile Construction.

In most applications the use of stockpiles seldom makes economic sense as unnecessary costs are incurred with double handling of the material. The use of layered stockpiles in clay brick manufacturing is strategic as it is the primary method of eliminating variation over the life of the clay deposit thus ensuring consistency of raw materials for production. A secondary function is souring or weathering of the material resulting in improved ceramic properties with the increase of surface area as the material breaks down.

After raw materials have been excavated from the quarry, it is important that they are properly stockpiled so as to ensure that:

i. Production output from the factory is not disrupted because of a lack of suitable material.

ii. The moisture content of the stockpiled material is maintained to the in-situ moisture content of the raw material (i.e. stockpiles must be built to prevent either the ingress or evaporation of moisture).

iii. The material contained in a stockpile complies with agreed ceramic specifications.

iv. The lump size in the stockpiles does not exceed a ring gauge size of 150mm.

Prior to mining the clay, a stockpile pad has to be constructed, which shall cover an area exceeding the dimensions of the planned stockpile by 5m on all sides. Clearing the area by grader or bulldozer should suffice. The whole stockpiling area should be levelled to facilitate water run-off away from the stockpiling area as shown in Figure 53 below. The graded surface should be to within an accuracy of 200mm at any point on the pad.

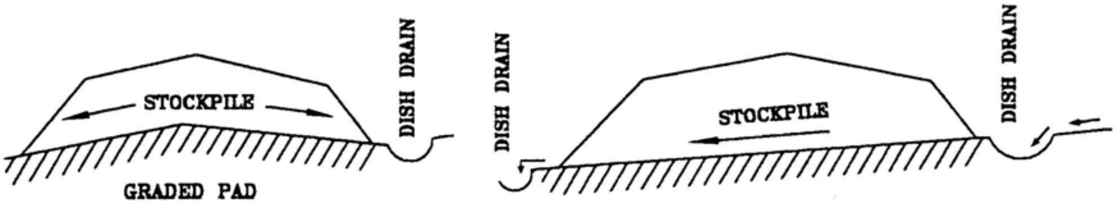


Figure 53 - Illustration of graded stockpile pad and dish drains.

The average height of a stockpile should not exceed 5,5 meters bearing in mind that the height must not exceed 1.5m above the reach of the front-end loader or any machine reclaiming the raw material from the stockpile.

The haul trucks or scrapers must always deliver their loads from one direction and in alternating sequence as indicated in Figure 54. When all the required loads for a layer have been delivered, a front-end loader or bulldozer must spread the heaps so as to form a 300mm thick layer. Under no circumstances may a new layer be deposited until the previous layer has been sampled and approved in accordance with the procedures outlined in section 7.3.c; Sampling Stockpiles.

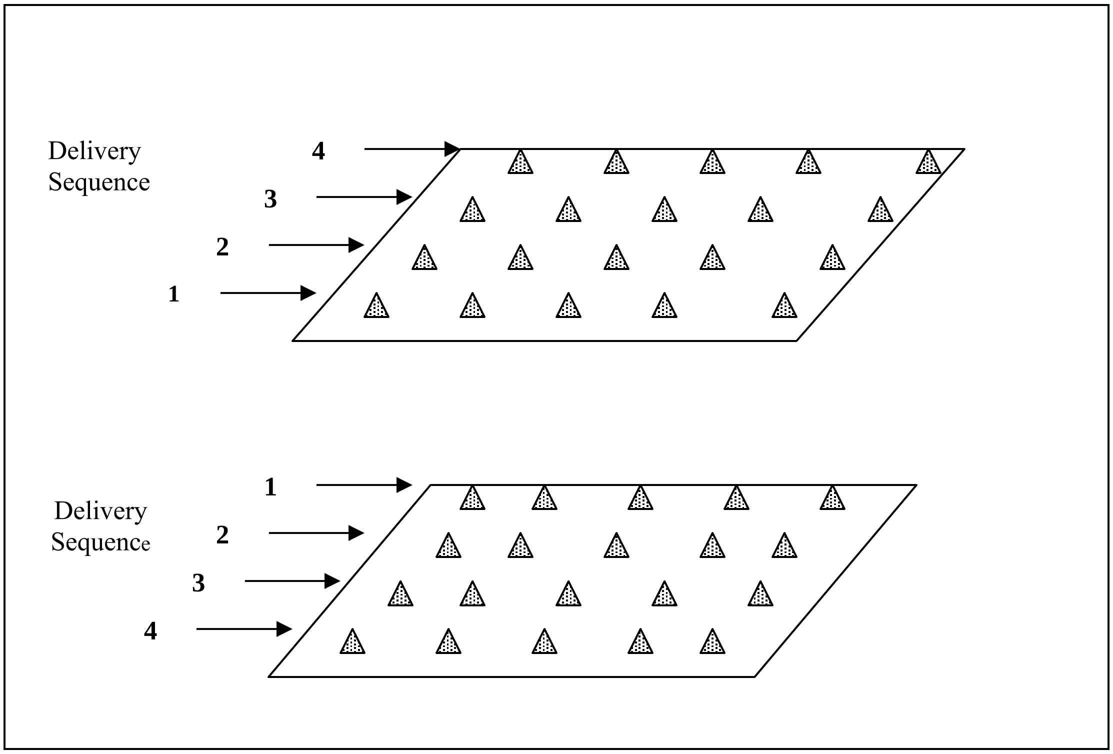


Figure 54 - Showing sequence of delivering raw material loads when constructing a layered stockpile.

When a height of approximately 5,5m is attained and hand sampling is completed, the stockpile must be profiled into a 'roof' shape as illustrated in Figure 55. This can be accomplished by using a front-end loader, dozer or grader.

In the event of eminent bad weather during the construction stage of a stockpile, when the profiling of a stockpile has been accomplished, its top surface should be rolled and compacted, Figure 56. The profiling and compacting of the stockpile will facilitate water run-off and minimize infiltration of moisture into the clay. The presence of dish-drains at the base of the stockpile will also assist in improving drainage by channeling water away from the stockpile. Dish-drains need to be regularly maintained to prevent blockages.

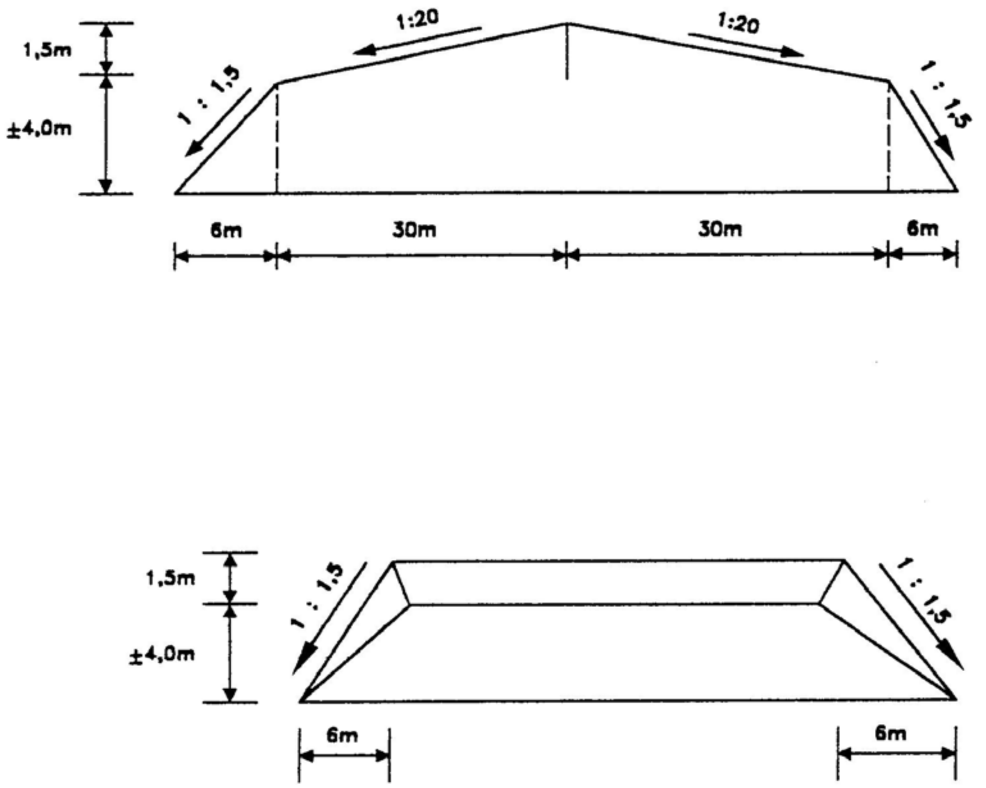


Figure 55 - Profile configuration of a layered stockpile.

The naming of stockpiles is important, as it would be used as a reference for identification of samples taken from the stockpile and for identification when clay is won from it.

A sign indicating the type of raw material with the month and the year of construction should be placed on each completed stockpile, e.g.

MS 5/04 indicates:
MS - Malmesbury Shale
5 - Month of May
04 - Year 2004

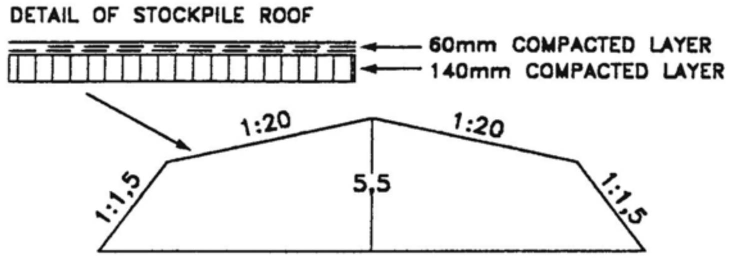


Figure 56 - Typical cross section through stockpile showing roof details.

When deciding on the location of a stockpile at the manufacturing facility consideration needs to be given to the consumption rate of the raw material in question and whether the clay has to be transported from quarry stockpiles a distance away. Raw material stockpiles with high consumption rates should be placed nearer the intake hoppers to reduce utilization of the loading equipment to keep plant-feeding costs to an absolute minimum.

A balance should be reached for the clay imported from quarry stockpiles as the additional capital outlay incurred during the transportation of the raw material might influence the raw material volumes held at the manufacturing facility leading to possible variation in quality if just in time delivery method is adopted. This will obviously be dependent on the consumption rate of the raw material in question and the availability of stockpiling space at the manufacturing facility.

c). Sampling Stockpiles.

Hand sampling of each layer must be undertaken during construction of a stockpile. After completion of an individual layer it should be sampled as shown in Figure 57.

The largest possible area of each section must be covered by bulking numerous samples taken across the entire area of a section during the sampling exercise for the sample to be fully representative of that section. If the samples are taken by means of a shovel care should be taken that every scoop across the section is equal in volume. Lumps exceeding the size of approximately 50mm in diameter must be excluded.

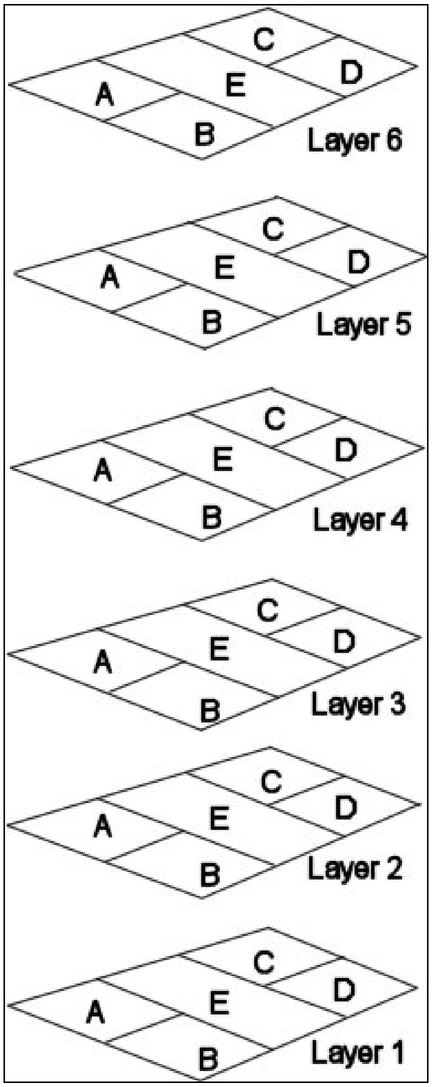


Figure 57 - Showing how each individual layer is divided into sections.

Each section sample must weigh about 4kg and be placed in a strong plastic bag from which all surplus air be preferably removed before sealing the bag. Each sample bag shall be code labelled by indicating material type, stockpile number, sample number and layer number. For example, sample bag 8 taken from the third layer of the first stockpile should be labelled as follows:

MS 5/04 - 8/3
Material Type : MS (Malmesbury Shale)
Stockpile No. : 5/04
Sample No. : 8
Layer No. : 3

These samples must be tested for identified chemical attribute(s) with the results available before completion of construction of the following layer to allow sufficient time to make adjustments to subsequent layers where necessary so as to bring the completed stockpile into specification. The results of each stockpile layer tested have to be recorded and weighted averages calculated based on loads dumped per layers.

After completion of the stockpile, all the samples representing the layer sections are combined to produce composite samples for full chemical and physical analysis.

d). <u>Reclaiming Stockpiles.</u>

Material must be won from stockpiles in a manner that will ensure that its moisture content will not be affected by inclement weather. There should, therefore, be adherence to the following procedures:

i. To attain consistent moisture content, materials should only be won from the vertical faces of the stockpile using a front-end loader as illustrated in Figure 58. Under no circumstances should the material be ‘bulldozed’ on a top-to-bottom basis.

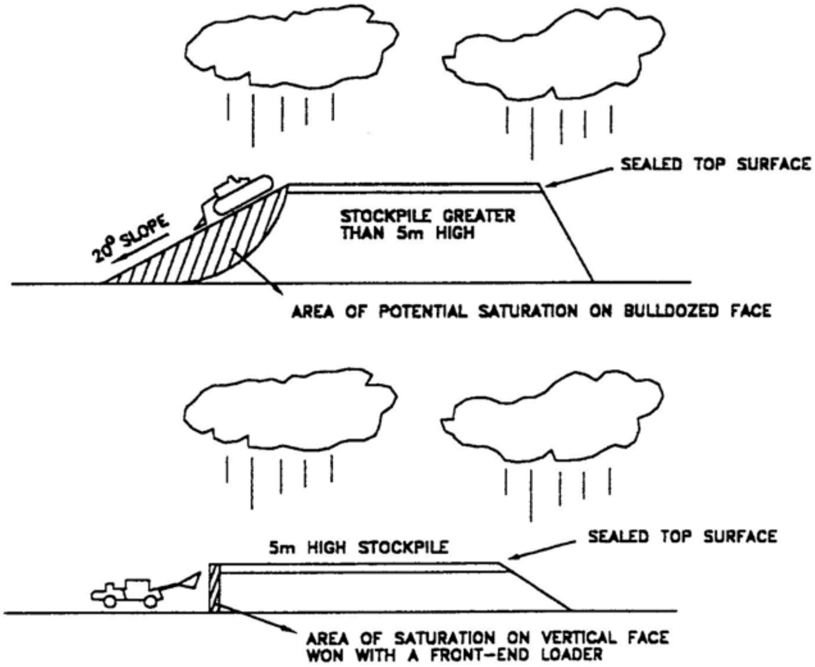


Figure 58- Illustrating the importance of using a front-end loader rather than a bulldozer to minimize moisture saturation when winning from a stockpile.

ii. Whenever possible, the largest faces of a stockpile should be aligned normal to the prevailing wind/rain direction.

iii. To optimise raw material consistency, winning operations should be confined to the shorter faces rather than the longer faces of a stockpile except during wet weather when winning should be concentrated on the largest face of the stockpile closest to the intake hopper. Reclaim against water flow to avoid the accumulation of water at the base of the reclaimed stockpile face; do not allow depressions to form that could lead to the 'pooling' of rainwater. This will minimise the risk of the clay in the front-end loader bucket from becoming saturated and also reduce the distance of travel over muddy surfaces. During dry conditions the converse 'modus operandi' should be practiced.

iv. Spillage from the front-end loader bucket must be cleared regularly. If not, mud is created during the wet weather and will deny access to the stockpiles although the clay is dry.

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