REFRACTORY CLAYS IN THE TRANSVAAL : EXPLORATION, GENESIS AND PROPERTY INTERRELATIONSHIPS

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Typical South African flint refractory clay

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Dedicated to
Rina, Marina and Peter
for their patience and support during
the compilation of this work.

"We shall not cease from exploration
And the end of our exploring
Will be to arrive where we started
And know the place for the first time."

T.S. Eliot

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ABSTRACT

Refractory clay is defined for the purposes of this study as having a fusion temperature of at least 1 605°C (Seger cone 27). It can be regarded as one of the most important industrial raw materials in view of its impact on virtually all high-temperature industries. Long-term statistics reveal the somewhat alarming trend that more flint than non-flint refractory clay will be consumed in South Africa over the next 20 years in spite of the much more limited reserves of the former. The basic aims of the study were to locate sufficient resources of refractory clay and to investigate aspects which could serve as an aid in future exploration.

All deposits of refractory clay in South Africa are confined to the basal part of the Ecca Group in the Transvaal. An inventory containing particulars of all known deposits and occurrences is included. Exploration for these clays has to be guided almost exclusively by geological interpretation and each area requires a different approach to finding new deposits. On the East Rand an isopach map has proved to be a valuable aid in selecting exploration targets, but contrary to the common belief, the pre-Karoo geology cannot be used as a reliable guide for exploration. Three potentially mineable deposits containing 8,3 Mt of clay with a good refractoriness (PCE 34 to 35) were discovered in this area. Delineation of Ecca outliers on the West Rand was accomplished by using the combined results of drilling and gravity surveys. Up to 40 m of refractory clay was intersected in reconnaissance boreholes and these abnormal thicknesses are attributed to gradual synsedimentary subsidence of the basins. Total inferred clay resources on the West Rand probably exceed 200 Mt of which about 70 per cent can be expected to have a good refractoriness. In the Pretoria – Belfast area, refractory clays occupy different stratigraphic horizons and no practical exploration guide can be suggested. Indicated resources amounting to 18,22 Mt of clay with a good refractoriness were found during the investigation in this region and exploitation has commenced at one of these sites. In the large Nooitgedacht outlier north of Bronkhorstspruit, refractory clays form the tops of successive upward-fining cycles which are interpreted as the result of waning floods during the retreat of Dwyka glaciation. The study has accentuated the need for a better knowledge of the configuration of the pre-Ecca floor, particularly in the area west of Witbank which is considered to have excellent potential for further exploration. It is estimated that total measured reserves of grade I flint clay in South Africa are only about 3,4 Mt.

The genesis of the clays is described in terms of a pH-controlled differentiation process. In smaller proximal basins at a low pH, kaolinite particles flocculated selectively from a mixed

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clay-mineral suspension in an edge-to-face manner, giving rise to small flint-clay deposits (Pretoria – Belfast area). Under higher pH conditions in larger, more distal brackish basins, flocculation was less selective and essentially face-to-face, forming more extensive deposits of plastic clay (Witwatersrand). Refractory clays from different regions are characterised by differences in their Rb and Sr concentrations. By comparison with residual kaolinite developed on pre-Karoo rocks, it is tentatively concluded that the West Rand clays were principally derived from Halfway House Granite and partially from Witwatersrand shale, clays on the East Rand received kaolinite from both Halfway House Granite and Bushveld granite, while the latter served as the main source for refractory clays in the Pretoria – Belfast area.

A study of the interrelationships between physical and chemical properties illustrates the limitations of such measurements in assessing the quality of refractory clays. Several useful trends do, however, emerge and a good positive correlation between particle size (as determined from scanning electron micrographs) and refractoriness is also indicated.

Refractory clay is one of the most promising locally available non-bauxitic raw materials for the production of alumina. Recent discoveries of low-grade bauxite in Natal have, however, largely eliminated the need for further research on aluminium-silicate substitutes.

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SAMEVATTING

Vuurvaste klei word vir die doel van hierdie studie beskou om 'n smelttemperatuur te hê van minstens 1 605°C (Segerkeël 27). Dit kan as een van die vernaamste industriële grondstowwe gereken word weens die benutting daarvan in feitlik alle hoë-temperatuur industrieë. Langtermynstatistiek bring die ietwat ontstellende tendens aan die lig dat meer flint as nieflint vuurvaste klei oor die volgende 20 jaar in Suid-Afrika verbruik sal word, ten spyte van die baie meer beperkte reserwes van eersgenoemde. Die basiese oogmerke van die studie was om genoegsame bronne van vuurvaste klei te vind en om aspekte te ondersoek wat as hulpmiddel sou kon dien vir toekomstige eksplorasie.

Alle afsettings van vuurvaste klei in Suid-Afrika is beperk tot die basale gedeelte van die Groep Ecca in die Transvaal. 'n Inventaris met besonderhede oor alle bekende afsettings en voorkomste word ingesluit. Eksplorasie vir hierdie kleie berus feitlik uitsluitlik op geologiese interpretasie en elke gebied verg 'n ander benadering tot die opsporing van nuwe afsettings. Op die Oos-Rand het 'n isopagkaart 'n waardevolle hulpmiddel geblyk te wees in die keuse van eksplorasieteikens, maar strydig met die algemene opvatting, kan die voor-Karoo geologie nie dien as 'n betroubare gids vir eksplorasie nie. Drie potensieel-mynbare afsettings wat 8,3 Mt klei met 'n goeie vuurvastheid (PKE 34 tot 35) bevat, is in hierdie gebied ontdek. Omlyning van Ecca-loslappe op die Wes-Rand is bewerkstellig deur gebruik te maak van die gekombineerde resultate van boorwerk en gravitasie-opnames. Tot 40 m vuurvaste klei is in verkenningsboorgate aangetref en hierdie abnormale diktes word toegeskryf aan geleidelike versakking van die komme tydens afsetting. Totale afgeleide kleibronne op die Wes-Rand oorskry waarskynlik 200 Mt waarvan sowat 70 persent na verwagting oor 'n goeie vuurvastheid beskik. In die Pretoria – Belfastgebied kom vuurvaste kleie op verskillende stratigrafiese vlakke voor en geen praktiese eksplorasiegids kan voorgestel word nie. Totale aangeduide bronne van 18,22 Mt klei met 'n goeie vuurvastheid is tydens die ondersoek in hierdie streek gevind en daar is reeds met ontginning by een van hierdie lokaliteite begin. In die groot Nooitgedachtloslap noord van Bronkhorstspruit vorm vuurvaste kleie die boonste gedeeltes van opeenvolgende opwaartsfynerwordende siklusse wat waarskynlik ontstaan het as gevolg van kwynende vloede tydens die terugtrekking van Dwyka-vergletsering. Die ondersoek het die behoefte aan meer kennis oor die konfigurasie van die voor-Ecca vloer beklemtoon, veral in die gebied wes van Witbank wat uitstekende potensiaal inhou vir verdere eksplorasie. Daar word beraam dat die totale gemete reserwes van graad I flintklei in Suid-Afrika slegs sowat 3,4 Mt beloop.

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Die ontstaan van die kleie word beskryf in terme van 'n pH-beheerde differensiasieproses. In kleiner proksimale komme teen 'n lae pH het kaolinietpartikels selektief uit 'n gemengde kleimineraalsuspensie geflokkuleer op 'n kant-tot-vlak wyse en sodoende aanleiding gegee tot klein flintkleiafsettings (Pretoria – Belfastgebied). Onder toestande van hoër pH in groter, meer distale brakkerige komme, was flokkulasie minder selektief en hoofsaaklik vlak-tot-vlak, met die gevolglike vorming van groter afsettings plastiese klei (Witwatersrand). Vuurvaste kleie van verskillende streke word gekenmerk deur verskille in Rb- en Sr-konsentrasies. Deur vergelyking met residuele kaoliniet wat op voor-Karoogesteentes ontwikkel is, word daar tentatief tot die gevolgtrekking gekom dat die Wes-Randkleie hoofsaaklik afkomstig is van Halfweghuisgraniet en gedeeltelik van Witwatersrandskalie, dat kleie op die Oos-Rand kaoliniet ontvang het van beide Halfweghuisgraniet en graniet van die Bosveldkompleks, en dat laasgenoemde as hoofbron gedien het vir vuurvaste kleie in die Pretoria – Belfastgebied.

Bestudering van die tussenverwantskappe van fisiese en chemiese eienskappe illustreer die beperkinge van hierdie bepalings in die beoordeling van die kwaliteit van vuurvaste kleie. Verskeie bruikbare tendense kom egter na vore en 'n goeie positiewe korrelasie tussen partikelgrootte (soos bepaal vanaf aftaselektronmikrofoto's) en vuurvastheid word ook aangedui.

Vuurvaste klei is een van die mees belowende plaaslik-beskikbare nie-bauxitiese grondstowwe vir die produksie van alumina. Onlangse ontdekkings van laegraadse bauxiet in Natal het egter in 'n groot mate die behoefte aan verdere navorsing op aluminiumsilikaatsubstitute uitgeskakel.

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1. INTRODUCTION

1.1 TERMINOLOGY AND CLASSIFICATION

Although the use of clay in manufacturing ceramic articles ranks as one of man's earliest technological achievements (Searle and Grimshaw, 1959), there is still no general concensus on clay terminology, and refractory-clay terminology in particular. Even fundamental terms such as *clay* or *clay mineral* cannot be closely defined to satisfy all the contradictory meanings attached to them by, for example, the farmer, potterer, brickmaker, soil scientist, mineralogist, civil engineer, geologist or the legal profession. Firebricks capable of withstanding high temperatures have been in use since about 2000 B.C. and it is certainly not the author's intention to try and formulate universally acceptable definitions for basic concepts after all these years. It is, however, essential at this stage to discuss the meaning of the term *refractory clay* and to present a clear statement on the interpretation that will be attached to it in the context of this study.

Refractory clay is used by the author in preference to the more popular but ambiguous term *fireclay* for reasons which will become obvious from the discussion that follows. The American Geological Institute (1980) regards refractory clay as synonymous with fireclay and defines the latter as:

> *A siliceous clay rich in hydrous aluminium silicates, capable of withstanding high temperatures without deforming and useful for the manufacture of refractory ceramic products. It is deficient in iron, calcium and alkalies and approaches kaolin in composition, the better grades containing at least 35% alumina when fired.*

Although quite comprehensive, this definition lacks one important detail, namely a definite lower limit of refractoriness. The United States Bureau of Mines (1968) deals with this aspect more specifically and describes refractory clay as:

> *Any clay showing a pyrometric cone equivalent* of not less than (Seger) cone 27.* (This lower limit was originally suggested by Ries, 1927).

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* A measure of the refractoriness of a clay determined by comparison with a series of numbered standard cones of which the bending temperatures have been predetermined at a specific heating rate.

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The U S B M seems, however, to contradict itself by giving the following definitions for fireclay:

> *A clay that is high in alumina or silica; diffusion* is not less than (Seger) cone 19 (1 515°C). Fireclays may be sedimentary or residual, plastic or non-plastic, and are dominantly composed of kaolinite.* (This limit of cone 19 was, as far as the author could establish, first suggested by Bates, 1960).
> Alternatively: *An earthy or stoney mineral aggregate which is composed essentially of hydrous silicates of aluminium with or without free silica. It is plastic when sufficiently pulverized and wetted, rigid when subsequently dried and of sufficient purity and refractoriness for use in commercial refractory products.*

Somewhat puzzling is a statement by Searle and Grimshaw (1959): *Refractory clays are those with a high resistance to heat without loss of shape. This group includes many clays, but the most important are the fireclays.* This obviously implies that they do not regard refractory clay and fireclay as synonymous, but unfortunately no explanation is presented and no refractory clays other than fireclay are mentioned. They do not stipulate a definite lower fusion limit but suggest that a softening point of 1 500°C is usually regarded as a minimum for fireclay and that one of more than 1 600°C is generally required.

Adding to the confusion are the following misapplications of the term fireclay, some of which are still in common use:

(1) A term formerly used for underclay or seat clay underlying coal seams. Not all underclays are, however, refractory and many refractory clays do not have a roof of coal (A G I, 1980).

(2) A stratum of rock found in anthracite mines which disintegrates on exposure to air (U S B M, 1968).

(3) As used in the quarterly information circular *Minerals* issued by the Department of Mineral and Energy Affairs of South Africa, fireclay is meant to include all non-flint refractory clay types (Bredell, 1979).

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* Diffusion is the mechanism through which solid-state reactions take place, but although temperature-dependent, this process is not directly related to deformation and it is therefore suspected that what is in fact meant here is *fusion* or melting.

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(4) A term used locally in South Africa by some producers, denoting a non-plastic refractory clay (Bredell, 1979).

The author therefore prefers the term refractory clay which, apart from being more descriptive, is much less prone to ambiguous interpretation. It is further recommended that formal usage of the term fireclay be avoided unless properly defined in its context. Based partly on the definitions quoted above and partly from personal observations, the author would like to define refractory clay as follows for the purposes of this study:

> Any clay which has a fusion temperature of at least 1 605°C (Seger cone* 27) and which is suitable or potentially suitable for use in the manufacturing of ceramic refractory products. Kaolinite is the main clay mineral constituent but small amounts of other clay minerals such as illite, sericite (hydromuscovite) or montmorillonite are usually present; the quartz content may be as high as 55 per cent. It is deficient in iron, calcium and alkalies and these components do not exceed 10 per cent in total. The alumina content on a calcined basis is at least 22 per cent. If sufficiently moistened, different types may range from very plastic to entirely non-plastic depending on their bulk density. It is of sedimentary origin, usually associated with coal measures, and may be laminated or massive but is invariably non-fissile.

An effective and practical classification of refractory clay is subject to the same inherent problems as that of fine-grained sedimentary rocks (mudrocks) in general, *viz.* the relative difficulty in obtaining quantitative data on characteristic criteria such as mineral composition and grain-size distribution. No concise and widely accepted classification for mudrocks has been developed, but recent attempts by Spears (1980) and Lundegard and Samuels (1980) appear to be a step in the right direction. Spears proposes a classification based on quartz content and suggests that non-fissile mudrocks be classified as follows:

More than 40% quartz	:	Massive siltstone
30 – 40% quartz	:	Very coarse mudstone
20 – 30% quartz	:	Coarse mudstone
10 – 20% quartz	:	Fine mudstone
Less than 10% quartz	:	Very fine mudstone

---

* The series of standard cones (devised by Seger) most commonly used for determining the refractoriness of clay samples by way of comparing deformation at a controlled rate of heating.

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As far as refractory clays are concerned, this is perhaps an unfortunate choice of terminology, as some of the lower-quality clays will have to be classed as *very coarse mudstone* or even *massive siltstone.* The field classification of Lundegard and Samuels (1980) is more satisfactory in the sense that refractory clays can easily be accommodated in the system (Fig. 1.1). All refractory clays should plot in either the *claystone* or *clayshale* fields but whether these terms should be adopted in refractory-clay terminology is debatable. Although technically more correct, it is doubtful whether a term such as *refractory claystone* will ever gain popularity in favour of *refractory clay.* The author will therefore only use *claystone* or *clayshale* when it is specifically necessary to distinguish between non-laminated and laminated varieties of refractory clay.

The industrial application of refractory clay requires, however, a more detailed classification which should be based on one or more quality-determining parameters. There is at present no internationally accepted classification and the numerous published proposals, of which only a few will be quoted here, differ widely due to varying local requirements. Ries (1927) suggested the following:

Highly refractory clay	:	fusing above (Seger) cone 33
Refractory clay	:	cone 31 to 33
Semi-refractory clay	:	cone 27 to 30
Clay of low refractoriness	:	cone 20 to 26

The South African Bureau of Standards (1949) has laid down the following specifications:

Super-duty fireclay bricks	:	at least Seger cone 34 (1 750°C)
High-duty fireclay bricks	:	at least Seger cone 31 (1 690°C)
Normal-duty fireclay bricks	:	at least Seger cone 28 (1 630°C)

Bates (1960) suggests that the following subdivision is generally accepted:

Super-duty fireclay	:	cone 32–35 (1 700–1 775°C)
High-duty fireclay	:	cone 30–32 (1 650–1 700°C)
Intermediate-duty fireclay	:	cone 28–30 (1 615–1 650°C)
Low-duty fireclay	:	cone 19–28 (1 515–1 615°C)

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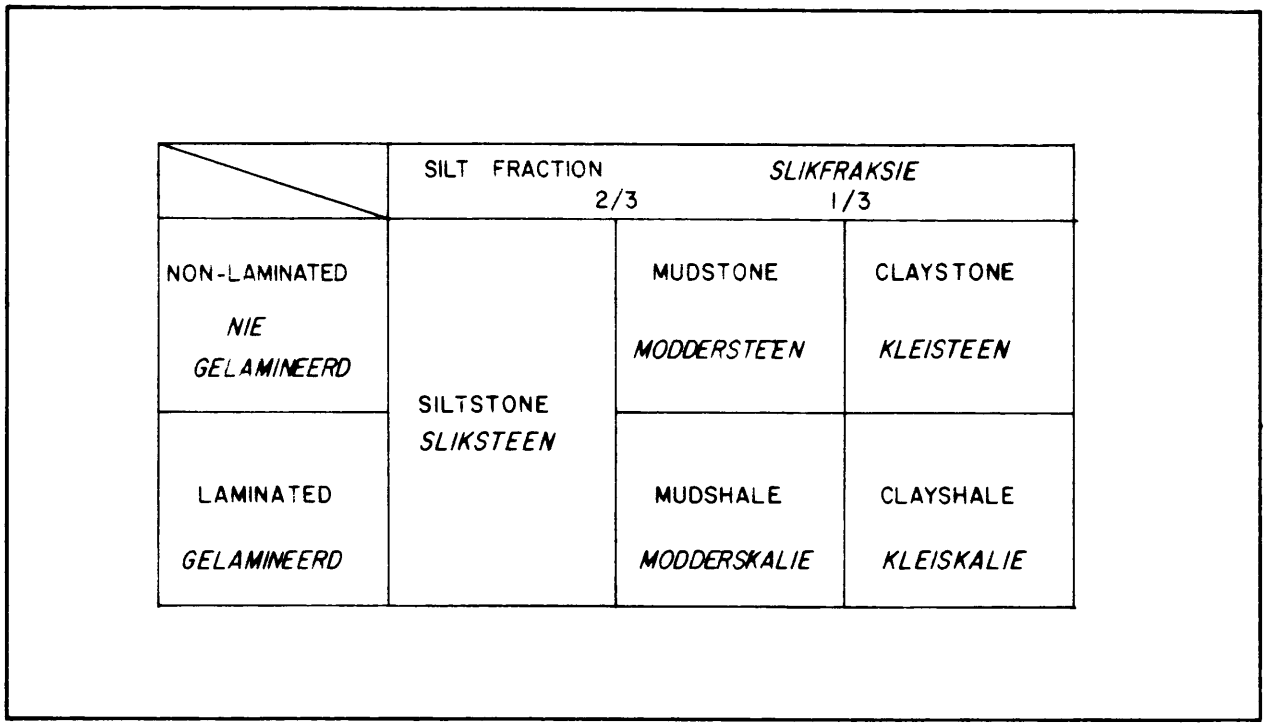

Fig. 1·1

Field classification of mudrock (after Lundegard and Samuels, 1980)

Veldklassifikasie van moddergesteentes (volgens Lundegard en Samuels, 1980)

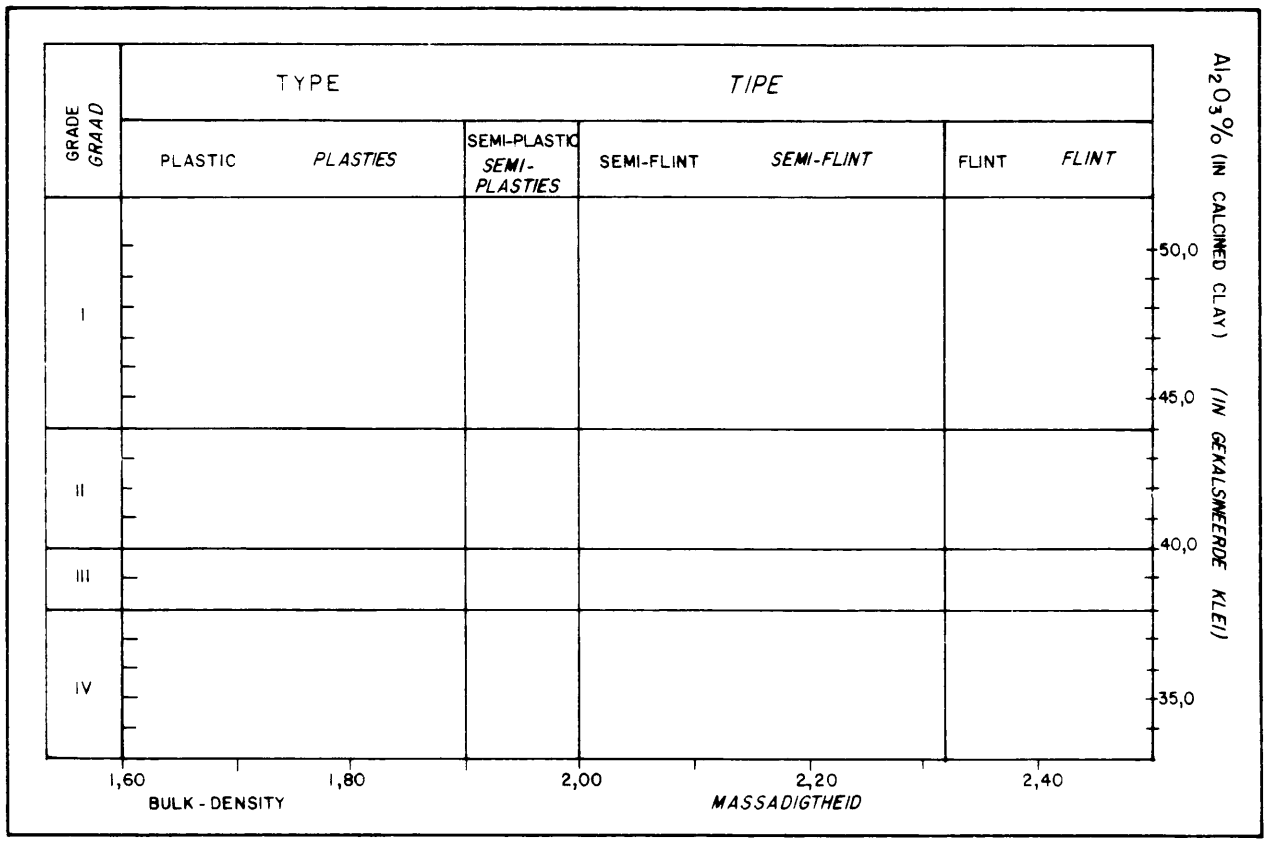

Fig. 1 2

Classification of refractory clay (after Bennetts, 1965)

Klassifikasie van vuurvaste klei (volgens Bennetts, 1965)

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The classification which has been adopted for this study is one which was developed by Vereeniging Refractories Ltd. and which was first published by Bennetts (1965). It is based on two most important quality-determining parameters, *viz.* bulk density and alumina content on a calcined basis (Fig. 1.2). The alumina content gives a good indication of the purity and refractoriness of the clay while the bulk density, being inversely related to porosity, reflects to some extent the plasticity of the clay as well as the resistance of the fired product against slag attack. From a geologist's point of view the main advantage of this system is, however, that at least the type classification can, with a bit of experience, be readily established in the field or while doing core-logging. The macroscopical characteristics and identification of the various types of refractory clay will be discussed in Chapter 3.

1.2 THE ECONOMIC IMPORTANCE OF REFRACTORY CLAY IN SOUTH AFRICA

Exploitation of refractory clay in South Africa dates back to 1891 when the first refractory bricks were manufactured at Vereeniging (Warde, 1949). Refractory bricks were also produced at Olifantsfontein before 1900 but the output was small and most of the refractory products required by early industries on the Witwatersrand were imported. The two world wars and particularly the expansion of the steel industry greatly stimulated demand for local refractories, and not only have most industries using high temperatures become vitally dependent on locally manufactured refractory-clay products, but the export trade in high-grade calcined flint clay has become a significant earner of foreign exchange over the last decade.

Refractory-clay products comprise more than half of all refractories produced in the country and possible substitutes such as silica or high-alumina materials may cost up to five times as much (Heckroodt, 1967). In spite of their low unit cost, refractory-clay bricks are extremely versatile and they are only substituted by more expensive products in cases where a higher performance under specific conditions is essential. The economic significance of the refractory-clay industry should, however, rather be measured in terms of its interrelationship with other industries than the value of its own output. Used mostly in furnaces, kilns, boilers, ovens, casting pits, crucibles, nozzles, etc., refractory-clay products have become indispensable in industries such as iron and steel, power-generating, non-ferrous metals, ceramics, glass and cement. It is therefore important to have a closer look at some long-term trends in production and sales statistics of refractory clay in order to evaluate available resources in the proper context.

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Some of the more important economic aspects for the 20-year period 1961-80 are illustrated in Figures 1.3–1.8 which were compiled from information published in *Minerals* (Republic of South Africa, Department of Mineral and Energy Affairs). Although rather erratic, the cyclic nature of the refractory-clay industry is clearly reflected in both production and sales, indicating its intimate dependence on the national economy. However, the demand for refractory clay appears to be generally declining due to the use of higher-duty refractories (Dr. P.L.C. Grubb, pers. comm.).

Corresponding to the economic boom of the early seventies, output reached unprecedented levels for the period 1970–75 with an all-time maximum of 636 000 t during 1974 (Fig. 1.3). At present, production is more or less back to the levels attained during the early sixties and the whole refractories industry is going through a very difficult period. Assuming that this general cyclic trend is going to repeat itself over the next 20 years, an average total annual production of approximately 500 000 t of refractory clay can be expected. This means that from 1981 to the year 2000, an estimated 10 Mt of refractory clay will be produced. From a total resources point of view, this is no cause for concern, but somewhat alarming is the fact that flint and non-flint types are being produced in roughly equal amounts in spite of the far more limited known reserves of the former.

Total local sales follow the production trend rather closely, reaching a maximum of 438 000 t in 1974 (Fig. 1.4). The local demand for both calcined and raw flint clay has been rising steadily since 1970 and if this trend persists, annual sales of around 160 000 t and 210 000 t can be expected by the year 2000 for these two commodities respectively. Sales of non-flint clay on the other hand, appear to be generally declining and by the year 2000 it could be down to about 150 000 t/year, i.e. less than that of calcined flint clay. Of the total expected local sales of about 7,5 Mt of refractory clay for the period 1981–2000, some 4 Mt could therefore be flint and 3,5 Mt non-flint clay.

With the exception of minor amounts of non-flint refractory clay during 1965–69 and a shipment of 1 698 t of calcined non-flint clay in 1977, exports have been restricted to high-grade flint clay. After a steady increase since 1961, the total flint clay exports reached a peak of 263 000 t in 1970 but shortly afterwards the export market declined rapidly to an average of around 78 000 t/year since 1976 (Fig. 1.5). As the local demand for high-grade flint clay increases and resources are being depleted, it can be expected that exports of this valuable material will further decline in future. An encouraging trend is the fact that exports of raw flint clay have become insignificant since 1972 and ceased altogether in 1978. In view of limited resources, it is definitely not considered in the national interest to resume export of this unprocessed material at relatively low unit cost.

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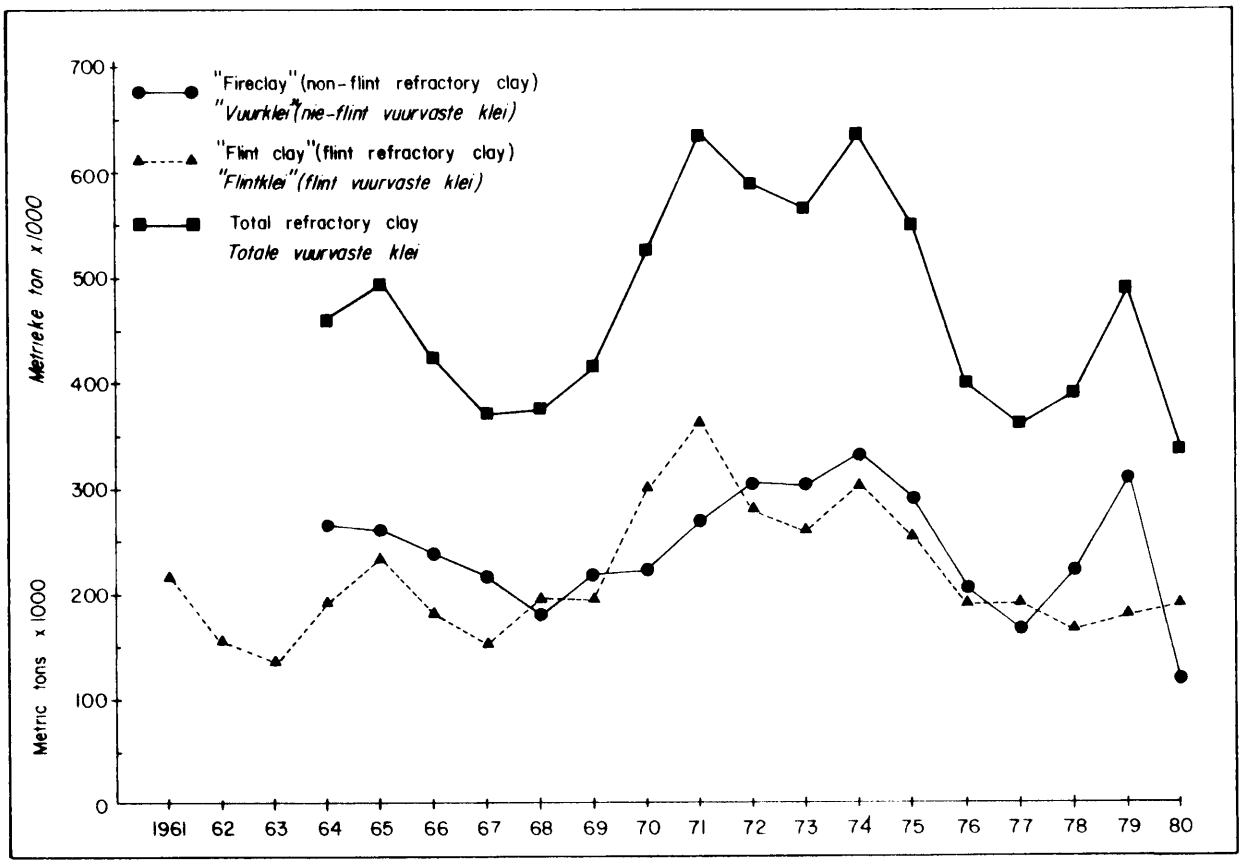

Fig. 1·3 Production of refractory clay in South Africa for the period 1961 - 1980

Produksie van vuurvaste klei in Suid-Afrika vir die tydperk 1961-1980

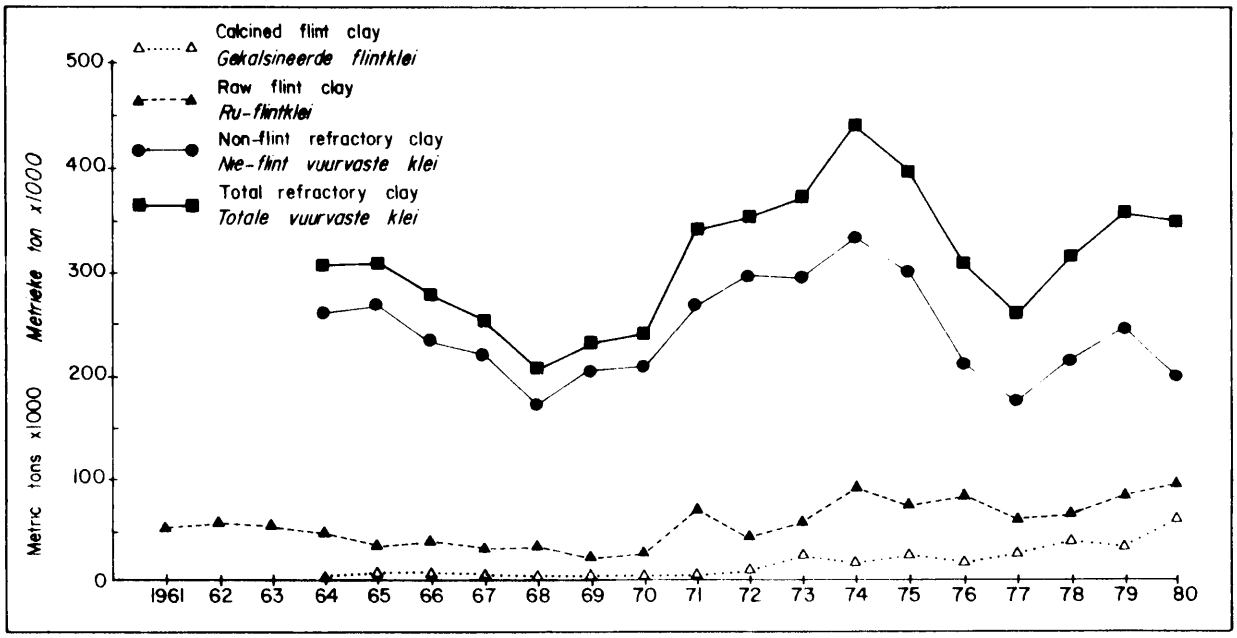

Fig. 1·4 Local sales of refractory clay in South Africa for the period 1961 - 1980

Plaaslike verkope van vuurvaste klei in Suid-Afrika vir die tydperk 1961-1980

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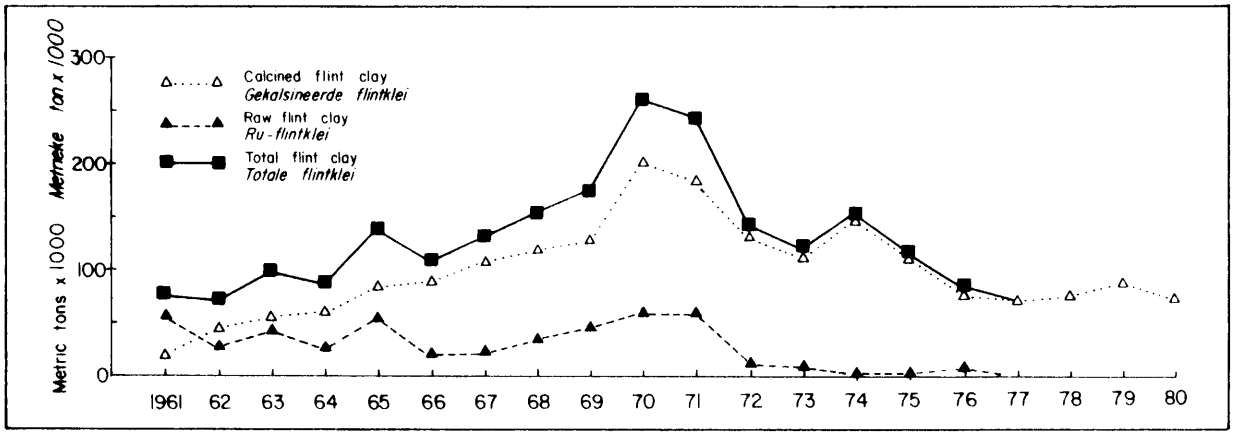

Fig. 1·5 Exports of South African flint clay for the period 1961 - 1980

Uitvoere van Suid-Afrikaanse flintklei vir die tydperk 1961 - 1980

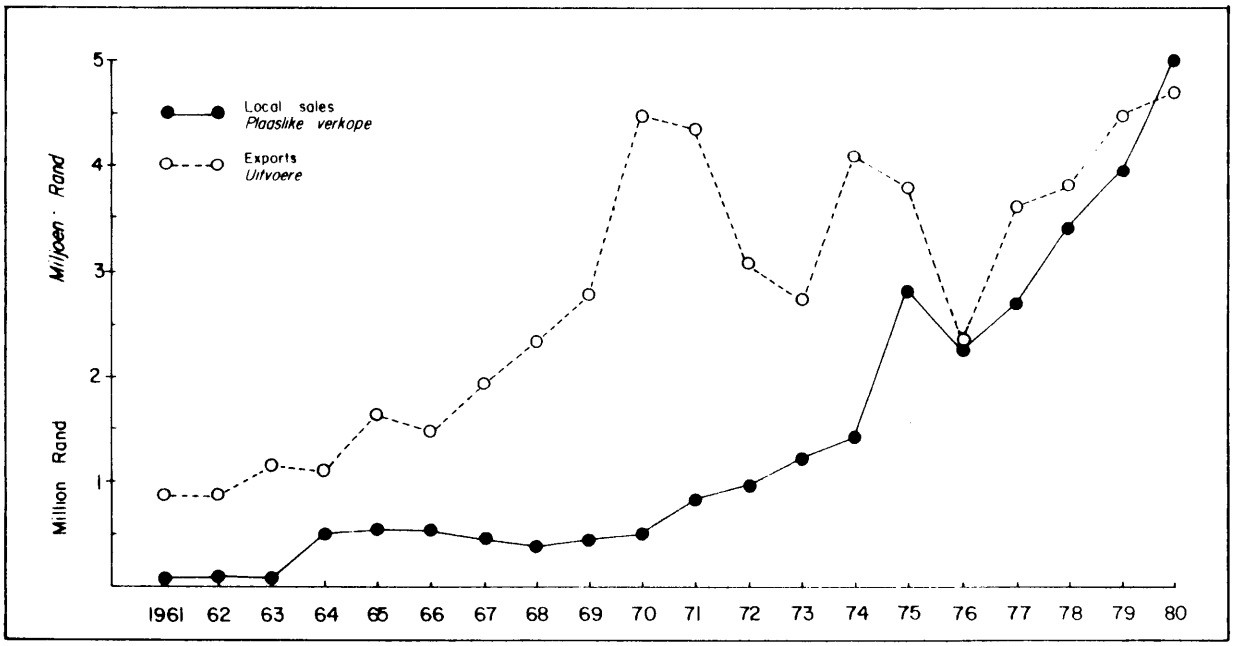

Fig. 1·6 Sales value of South African refractory clay for the period 1961 - 1980

Verkoopwaarde van Suid-Afrikaanse vuurvaste klei vir die tydperk 1961 - 1980

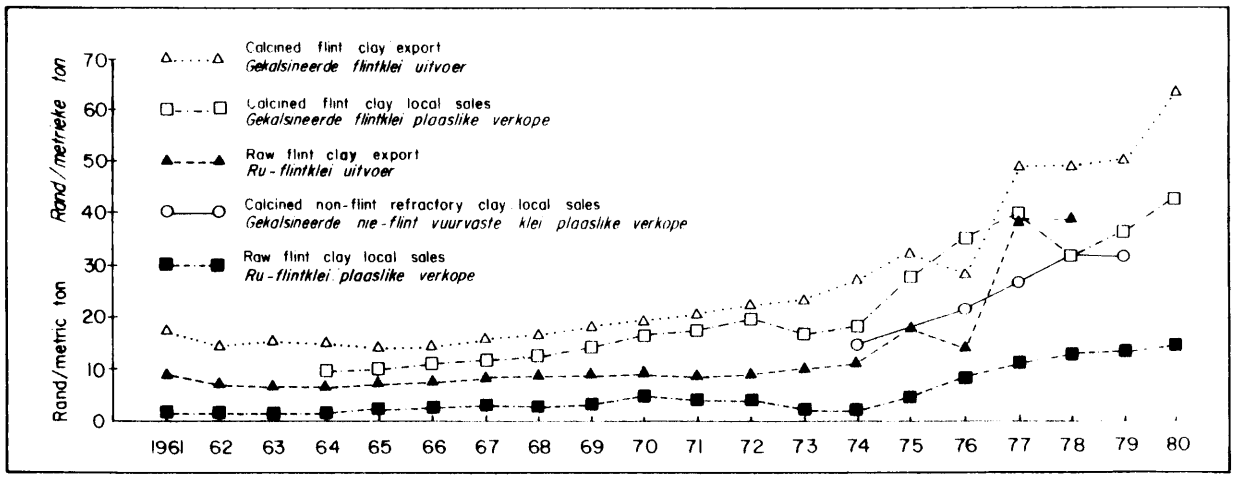

Fig. 1·7 Unit value of South African refractory clay

Eenheidswaarde van Suid-Afrikaanse vuurvaste klei

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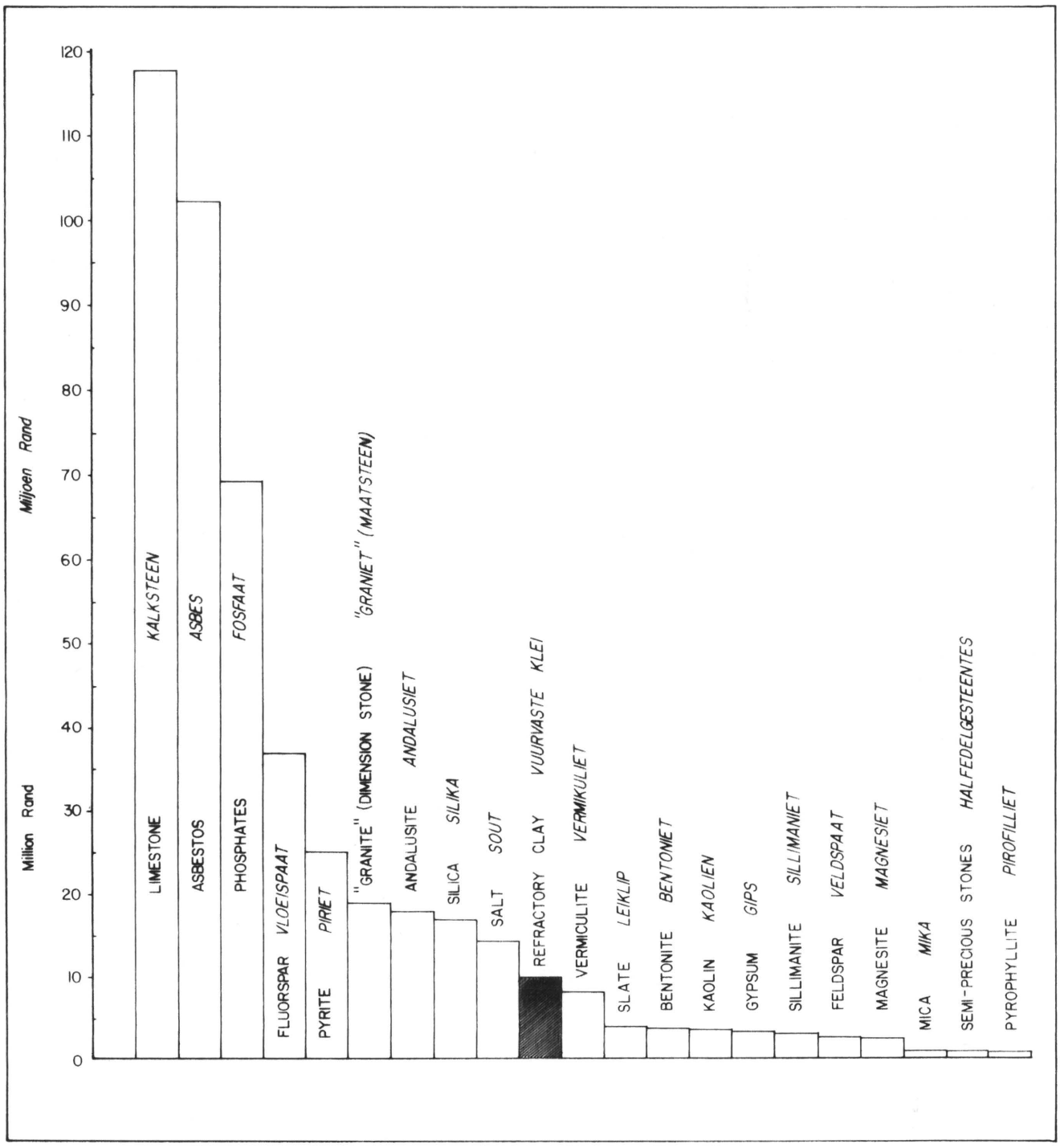

Fig. I·8 Comparison of the total sales value (1980) of refractory clay and some of the other more important South African non-metallic mineral commodities (coal and diamonds excluded).

Vergelyking van die totale verkoopswaarde van vuurvaste klei en sommige van die ander meer belangrike Suid-Afrikaanse nie-metaal delfstofkommoditeite gedurende 1980 (steenkool en diamante uitgesluit)

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The total local sales value of refractory clays has risen dramatically since 1970 and in 1980 it reached more than R5 million, for the first time exceeding the value of exports (Fig. 1.6). Although largely attributable to inflation, this reflects to some extent the increase in local consumption of flint clay.

The relative economic importance of the various types of refractory clay is illustrated in terms of unit values in Fig. 1.7. According to the latest available sales figures, the following order can be established:

Calcined flint clay, exported	:	R63,64/t	(1980)
Calcined flint clay, locally sold	:	R42,77/t	(1980)
Raw flint clay, exported	:	R39,03/t	(1978)
Calcined non-flint clay, locally sold	:	R32,05/t	(1979)
Raw flint clay, locally sold	:	R14,74/t	(1980)
Raw non-flint clay, locally sold	:	R 6,20/t	(1980)

Judged purely on sales value, the contribution of refractory clay to the South African mineral industry is rather insignificant; during 1980 it amounted to R9,69 million, i.e. only about 0,06 per cent of the total mineral sales. As illustrated in Fig. 1.8, refractory clay ranks only tenth in terms of sales value amongst locally produced non-metallic mineral commodities with the exception of coal and diamonds. In spite of this, however, it can certainly be regarded as one of the most strategic industrial minerals if measured in terms of its direct and indirect impact on so many other industries.

1.3 PREVIOUS INVESTIGATIONS

In his well-known work *Sedimentary Rocks,* Pettijohn (1957) states that although substantial progress has already been made in the field of clay mineralogy, the geology of clays is still far from understood. Today, more than a quarter of a century later, this statement is unfortunately still valid, particularly as far as South African refractory clays are concerned. Considering the fact that a nearly R10 million per year primary industry has evolved from the exploitation of these clays, the number of published works on this subject has been strikingly few. Only publications dealing specifically with South African refractory clays will be briefly reviewed in this chapter, while works on general and indirectly related aspects will more appropriately be referred to at relevant places in the text.

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Wagner (1916) made the first substantial contribution on the subject in the earlier literature by describing the occurrence of plastic refractory clay in the outlier of Karoo sediments at Olifantsfontein. A discussion of this paper was published in the same year by Holford (1916) but the work of these pioneers was not followed up until more than 20 years later when Bosazza reported on the geological setting, physical and chemical properties and possible origin of refractory clays of the Witwatersrand area in a number of publications (Bosazza, 1941, 1943, 1943a, 1945). His work culminated in a somewhat philosophical Ph.D. thesis on the petrography and petrology of South African clays which was published by the author himself in 1946. Bosazza can rightfully be regarded as the father of South African refractory-clay geology and although limited by analytical techniques and equipment available at the time, his efforts provided a sound base and also stimulated interest for further research. This is borne out by the work of Ahrens (1945) on the trace-element composition of South African clays (including refractory clay) as well as that of Warde and Denysschen (1949) on the differential thermal analysis of local refractory clays. Warde (1949), in his own right, made a major contribution in the form of a Ph.D. thesis dealing with the occurrence, nature, properties and utilisation of refractory clays in South Africa; a summary of this thesis was subsequently published (Warde, 1950). In 1953 Heysteck and Chase published the results of a study on the brown or *chocolate* refractory clays in the Transvaal, a paper which concluded an era during which virtually all the attention was devoted to clays in the Witwatersrand area. After that, the accent shifted to the recently discovered flint-clay deposits in the region between Pretoria and Belfast which became the subject of substantial investigation during the early sixties. Behr (1960) examined and reported on the flint clays near Bon Accord and a summary of this excellent survey was subsequently published in Bennetts (1965). The first description of the flint-clay deposits in the Bronkhorstspruit area appeared in print as part of the explanation of geological sheets 2528 D and 2529 C (Visser *et al.*, 1961). In 1963, Bennetts published the results of orientation-index measurements on local flint clays, proving the random orientation of kaolinite crystals by means of X-ray diffraction. In the same year, Bennetts and Pieterse (1963) reported on the linear relationship between bulk-density and apparent porosity in Transvaal flint clays, an observation which has proved to be a most valuable initial identification method which is still being applied today. During 1962 and 1963 Bennetts conducted an extensive survey of all the flint-clay deposits in the Pretoria – Belfast area and subsequently published the results in a comprehensive and authoritative work (Bennetts, 1965).

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Hammerbeck (1972) investigated the extension of refractory clay from the deposit of Boksburg Brick and Fire Clay Co. Ltd. onto the adjoining Westwood Small Holdings in Boksburg North. This investigation accentuated the very real threat of urban expansion to the future exploitation of unexplored but potentially viable refractory-clay deposits, one of the main aspects which shortly afterwards led to the initiation of the present study.

1.4 MOTIVATION, OBJECTIVES AND SCOPE OF THE PRESENT STUDY

As mentioned in the previous chapter, this investigation was triggered in the early seventies by realisation of the fact that potentially valuable but undiscovered deposits of refractory clay were being sterilised by rapid urban expansion, particularly on the Witwatersrand. In order to put this motivation into proper perspective, the role of the Geological Survey (in which employ the author carried out this study) has to be explained briefly as far as conservation of mineral deposits in the national interest is concerned.

To ensure proper co-ordination of the very often conflicting land-use claims in respect of the same area, all proposals for major surface developments such as townships, dams, roads, railway lines, etc. are circulated for comment to the various Government departments. In this regard, the Department of Mineral and Energy Affairs is particularly concerned with the safeguarding and optimum utilisation of the country's mineral resources, and in all cases where the proposed developments are likely to restrict or prevent exploitation of known or potential deposits, the Geological Survey is consulted, normally via the Government Mining Engineer. It is obvious, therefore, that in order to make a meaningful contribution, the Geological Survey has to acquire and maintain a comprehensive data base on the distribution, resources and the grade or quality of all the various mineral commodities. Furthermore, although it is undoubtedly not the aim of the State to compete with the private sector in the search for new deposits, it is clear that for purposes of long-term or regional planning, it is sometimes essential for the Geological Survey to conduct exploration on a reconnaissance basis. Refractory clay is a very good example of such a case. Being a comparatively low-priced commodity which can only be exploited economically by open-cast methods within reasonable distance from the major consumer industries, it is particularly vulnerable to sterilisation by any surface development. At the same time, although vitally important, the demand for these clays is relatively small, offering little incentive for private companies to carry out extensive regional exploration programmes. The basic aims of the author's investigation were therefore in the first place to find sufficient resources of

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refractory clay in areas where these deposits could be reserved, and secondly to delineate areas underlain by potential resources which could, as far as practically possible, be protected from sterilisation.

In order to accomplish these aims, it was first of all necessary to develop sound, regional exploration concepts to select target areas in each of the regions which had to be investigated (see Fig. 1.9). The first part of this thesis deals therefore with the regional setting of known refractory-clay deposits, the various approaches followed during the exploration phase, the delineation of potential refractory-clay areas as well as the results of the subsequent reconnaissance and follow-up drilling programmes. From the mass of data gathered during these initial stages, it was possible to propose genetic and depositional models for the various types of refractory clay, and this forms the topic of the second basic part of this work. In the third instance, an attempt was made to establish meaningful interrelationships between the physical and chemical properties of the clays in order to provide a more quantitative basis for evaluating the raw material from parameters which can be measured in the laboratory. Finally, both the genetic model and the property interrelationships are related back to exploration and proposals are made to improve the concepts which have originally been adopted.

It is sincerely hoped that, in addition to achieving the primary aims set out above, this work will also be of guidance to exploration geologists in their search for and evaluation of refractory clays and that it will stimulate further research on this fascinating commodity.

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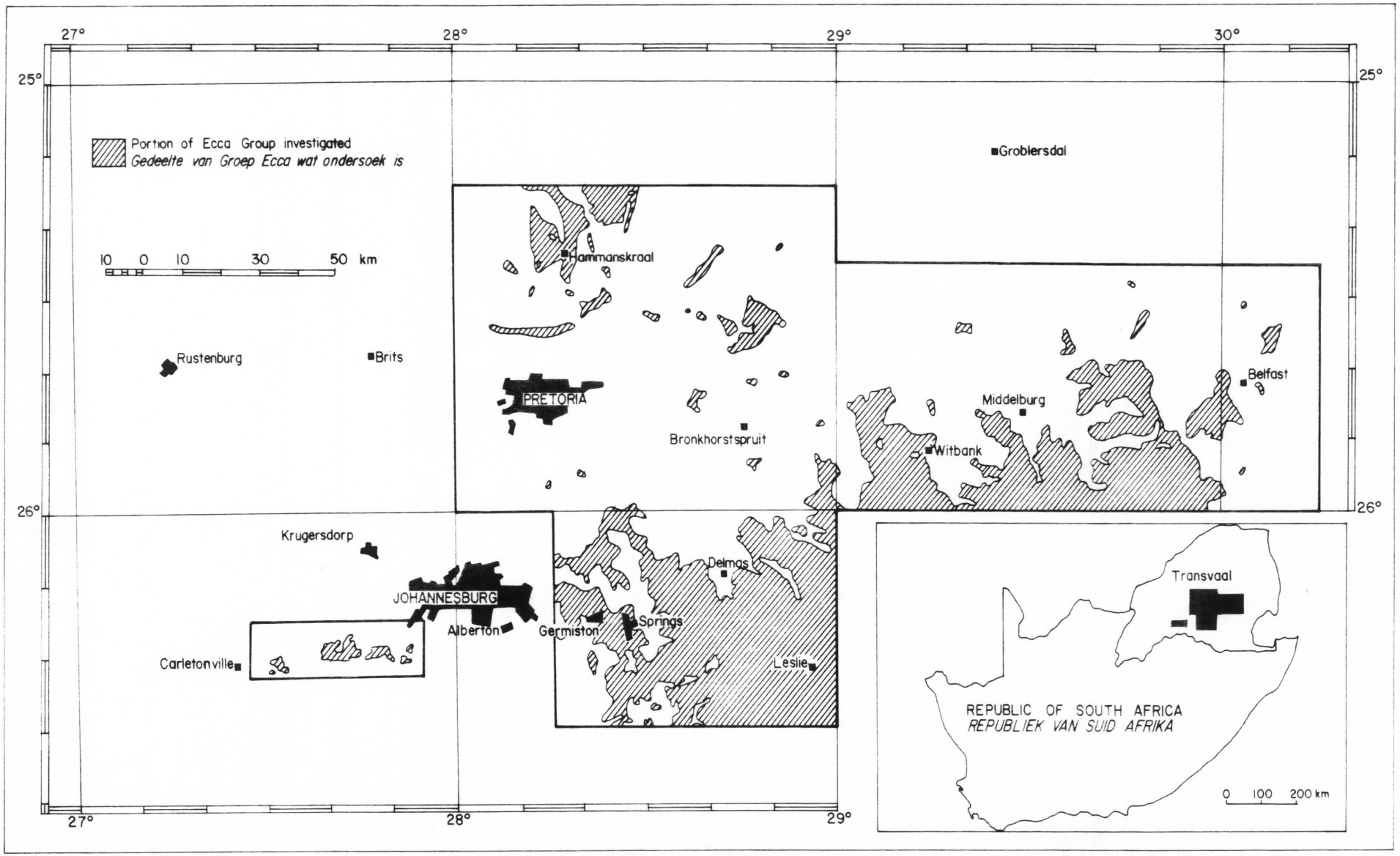

Fig. 1 9 Setting of the study areas and portions of the Ecca Group which were investigated

Ligging van die studiegebiede en gedeeltes van die Groep Ecca wat ondersoek is

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2. THE REGIONAL SETTING OF REFRACTORY-CLAY DEPOSITS IN THE TRANSVAAL

All deposits of refractory clay in South Africa are confined to the Ecca Group of the Karoo Sequence in the Transvaal. More specifically, their occurrence is limited to the basal part of what used to be called the Middle Ecca (coal measure) Stage, a sedimentary succession of Permian age consisting of grit, sandstone, shale, coal seams and occasional lenses of clay, siltstone and conglomerate. In some cases the clays occur directly on pre-Karoo rocks or tillite of the Dwyka Formation, while in other areas they are underlain by coal or carbonaccous shale (see Fig. 2.1).

According to the latest proposals of the South African Committee for Stratigraphy (SACS, 1980), the basic concept, distinguishing features and boundaries of the Middle Ecca Stage correspond to what is now termed the Vryheid Formation. It is suggested by SACS, however, that the formational subdivision of the Ecca Group as applicable to the main Karoo basin, should not be extended to the detached outliers of this Group in the central Transvaal. For the purposes of this thesis, these outliers will therefore be assigned to the Ecca Group (undifferentiated), while sediments forming part of the main sheet of Ecca rocks on the East Rand will be referred to as belonging to the Vryheid Formation.

The 26^{o} line of latitude roughly subdivides the known refractory-clay deposits into two provinces according to type. To the north of this latitude, flint clays predominate in the form of comparatively small deposits which are largely confined to Ecca outliers, while to the south much more extensive deposits of essentially plastic clay are located along the margins of the main sheet of Ecca sediments (East Rand) as well as in exceptionally thick outliers situated on dolomite (West Rand).

Although the present investigation was mainly concentrated on the East and West Rand and in the Pretoria – Belfast area (Fig. 1.9), it is regarded appropriate to include here an inventory of all the refractory-clay deposits in the Transvaal which were known to the author at the time of writing (Table 2.1). The data presented were obtained from published sources, unpublished Geological Survey reports, personal investigation and through the kind cooperation of various mining companies. In order to protect the interests of individual companies, some deposits are not listed and for the same reason reserve or resources figures are not included. Nevertheless, this inventory should serve as a useful reference as well as a basis to which future discoveries could be added.

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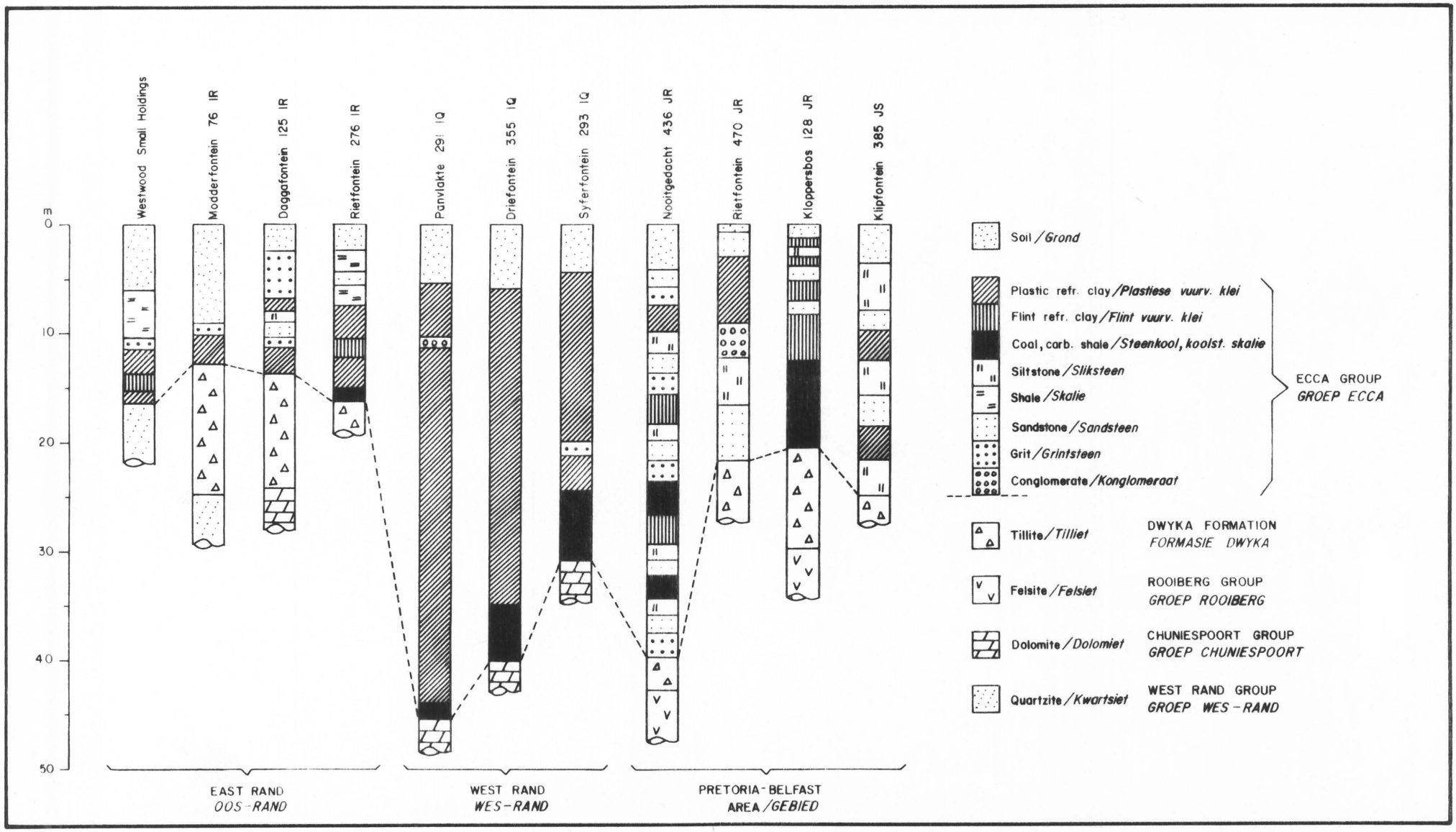

Fig 2.1 Schematic profiles from various parts of the area investigated, indicating typical stratigraphic settings of refractory clay deposits within the Ecca Group.

Skematiese profiele van verskillende gedeeltes van die ondersoekte gebiede om tipiese stratigrafiese liggings van vuurvaste kleiafsettings in die Groep Ecca aan te dui.

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TABLE 2.1: INVENTORY OF REFRACTORY-CLAY DEPOSITS AND OCCURRENCES IN THE TRANSVAAL

Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Badfontein 438 IR	Vereeniging	SF	I	M	Verref Mining (Pty) Ltd.	1. Nel and Jansen (1957) 2. Sampling by the author
Blesbokfontein 459 JR	Bronkhorst-spruit	F	I	M	Chamotte Holdings (Pty) Ltd and Cullinan Holdings Ltd.	Bennetts (1965)
Boekenhout-kloof 129 JR	Pretoria	F	N.A.	m	Small reserves, largely exhausted	1. Bennetts (1965) 2. Bredell (1976b)
Boekenhouts-kloofdrift 286 JR	Bronkhorst-spruit	F,SF	I–III	M	Metramco (Pty) Ltd. Several abandoned quarries and numerous prospecting pits	Bennetts (1965)
Boschbult 432 JR	Bronkhorst-spruit	SF	I	N	Exposed in prospecting pits. Small reserves	Bennetts (1965)
Boschfontein 447 JS	Middelburg	F	I–II	M	Stoctz Clay Minerals Ltd.	Sampling by the author
Cavan 508 MS	Soutpansberg	F	II	m	Estimated reserves about 12 000 t	De Villiers (1966)
Cyfer-fontein 457 KR	Waterberg	P,SF	I–II	m	Unmapped outlier. Associated with excellent brick clay	Sampled by the author
Dagga-fontein 125 IR	Springs	P,SP, SF	II–IV	N	Indicated resources about 12,2 Mt	Bredell (1978)
Doornrug 302 JS	Witbank	P	IV	N	Intersected in Geological Survey boreholes. True extent not established	This study

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Driefontein 355 IQ	Oberholzer	P,SP, SF	I–IV	M	Exploited for face-brick manufacture	Bredell (1979)
Elands-fontein 309 JS	Witbank	P	III	N	Sandy, ferruginous clay in small excavation	Sampling by the author
Elands-fontein 322 JT	Belfast	F	I	M	Otavi Mining Co. (Pty.) Ltd.	Bennetts (1965)
Elands-fontein 412 IR	Heidelberg	P	N.A.	N	Exact locality unknown	Lovell (1952)
Frans-poort 332 JR	Cullinan	F	I–II	M	Cullinan Holdings Ltd.	Sampling by the author
Gemsbok-fontein 231 JR	Bronkhorst-spruit	SF	I	M	Metramco (Pty Ltd.	Bennetts (1965)
Gemsbok-fontein 411 JR	Middelburg	N.A.	N.A.	N	Slightly sandy, possibly extensive	Bennetts (1965)
George 749 MS	Soutpans-berg	F	I	N	Up to 4 m thick. Extent unknown	Wilke (1962)
Glasgow 750 MS	Soutpans-berg	F	I	N	Part of the same deposit occurring on George 749 MS	Wilke (1962)
Groen-fontein 331 JS	Witbank	SP	II	N	Sandy clay as float on surface	Sampling by the author
Groot-fontein 394 JR	Pretoria	SF	I	M	Cullinan Holdings Ltd.	Sampling by the author
Haak-doorn-boom 267 JR	Pretoria	SF	I	M	Raulpel Brickworks	Bennetts (1965)

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Haakdoorn-fontein 119 JR	Pretoria	SF	I	m	Locally carbonaceous and sulphide-bearing	Bennetts (1965)
Hanglip 508 LQ	Waterberg	N.A.	N.A.	M	African Mining and Trust Co. Ltd.	Minerals Bureau (List of operating mines, 1982)
Hamans-kraal 112 JR	Pretoria	F	I–II	m	Several abandoned quarries. Excessive overburden and variable quality	Bennetts (1965)
Hartbeest-laagte 325 JS	Witbank	F	I	M	About 1 m of white flint and 5 m of carbonaceous flint clay Exploited by M. Krüger	M. Krüger (Personal communication)
Hartebeest-spruit 235 JR	Bronkhorst-spruit	SF	N.A.	N	Silty clay in boreholes	Collins, Verref Mining (Personal communication)
Honing-nestkrans 269 JR	Pretoria	SF	I	m	About 2 m thick in abandoned quarry	Bennetts (1965)
Katbosch-fontein 22 IR	Delmas	SF	II	N	Thin layer (1,0 m) found at a depth of 11 m in a borehole sited by the author	Bredell (1975a)
Kleinwater 301 JS	Witbank	F	I	M	Cullinan Holdings Ltd.	Bennetts (1965)
Klipdrift 116 JR	Pretoria	F	I	M	Verref Mining (Pty) Ltd.	Bennetts (1965)
Klipdrift 121 JR	Pretoria	F	I	M	Verref Mining (Pty) Ltd.	Sampling by the author
Klipfontein 83 IR	Boksburg	P,SP, SF	I–II	M	Indicated resources of 8 Mt reported on Westwood Small Holdings adjacent to mining properties of Boksburg Brick and Fireclay Co.Ltd. and Union Fireclay Works (Pty) Ltd.	Hammerbeck (1972)

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Klipfontein 256 JS	Witbank	F	I–III	N	Some flint-clay float on surface. Very small outlier of Ecca Group	Sampling by the author
Klipfontein 268 JR	Pretoria	F	I	m	Previously mined by Cullinan Holdings Ltd.	Bennetts (1965)
Klipfontein 385 JS	Belfast	SF,P	II–III	N	Intersected in Geological Survey boreholes. True extent not established	1. This study 2. Bennetts (1965)
Kloppersbos 128 JR	Pretoria	F,SF, SP	II–IV	N	Indicated resources of 1,62 Mt reported	Bredell (1976b)
Kookfontein 545 IQ	Vereeniging	SF	N.A.	m	Several thin layers of carbonaceous clay interbedded with coal seams	Warde (1949)
Koppermyn 435 JS	Middelburg	F	I	M	Cullinan Holdings Ltd.	Sampling by the author
Kranspoort 448 JR	Bronkhorstspruit	F	I–III	N	Some flint-clay float on surface. Very small outlier of the Ecca Group	Sampling by the author
Kromdraai 115 JR	Pretoria	F	I	m	Excessive overburden	Bennetts (1965)
Kromdraai 279 JS	Witbank	SF	II	m	Soft and sandy	Bennetts (1965)
Lakenvalei 355 JT	Belfast	F	II	N	Small occurrence of sandy clay	Bennetts (1965)
Langkloof 356 JT	Belfast	F	I	M	Deimbez (Pty) Ltd.	Bennetts (1965)

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Leeuw-kraal 92 JR	Pretoria	F	N.A.	N	Sandy and thin (0,3 m)	Bennetts (1965)
Leeuw-kuil 596 IQ	Vanderbijl-park	P,SF	I	M	Verref Mining (Pty) Ltd.	1. Nel and Jansen (1957) 2. Warde (1949) 3. Sampling by the author
Lemoen-fontein 436 JS	Middelburg	F	I–II	M	Stoctz Clay Minerals Ltd.	Sampling by the author
Loop-spruit 435 JR	Bronkhorst-spruit	F,SF, P	I–III	m	Flint clay sandy and carbonaceous, partly underlain by coal. Only semi-flint clay exploited in northern outlier	1. Bennets (1965) 2. Bredell (1980)
Modderbult bult 511 JR	Heidelberg	F	II	m	About 5 m thick in small abandoned quarry	Sampling by the author
Modder-fontein 76 IR	Brakpan	P,SP, SF	III–IV	N	Indicated resources amount to 11,6 Mt of low-grade refractory clay	Bredell (1978)
Nanescol 582 IQ	Vanderbijl-park	P	I	M	Verref Mining (Pty) Ltd.	Sampling by the author
Nooit-gedacht 300 JS	Witbank	SF	N.A.	N	Sandy clay in prospecting pits	Bennetts (1965)
Nooit-gedacht 436 JR	Bronkhorst-spruit	P,SP, SF,F	I–IV	M	Otavi Mining Co. (Pty) Ltd. and Cullinan Holdings Ltd. Indicated resources of 11,8 Mt Gr.I–II carbonaceous flint clay reported outside mining areas	1. Bennetts (1965) 2. Bredell (1980)

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Olifants-fontein 410 JR	Pretoria	P,SF	I	M	Cullinan Holdings Ltd.	1. Warde (1949) 2. Sampling by the author
Ontevreden 358 JS	Belfast	F,SF	I	M	Otavi Mining Co. (Pty) Ltd.	Bennetts (1965)
Paarde-fontein 282 JR	Pretoria	F	IV	N	Siliceous clay of low refractoriness in Dwyka Formation	Bredell (1976c)
Paarde-plaats 380 JT	Belfast	SF,C	I	N	Thin but apparently extensive deposit	Bennetts (1965)
Pan-vlakte 291 IQ	Randfontein	P,SP, SF	I–IV	N	Located in recon-naissance boreholes drilled by Geological Survey. Up to 40 m thick	Bredell (1979)
Portland 753 MS	Soutpansberg	F	I	N	Preserved in a down-faulted block of the Ecca Group. Total thickness of flint clay and alternating ferru-ginous shale is esti-mated at 10 m	De Villiers (1968)
Rhenoster-fontein 304 JP	Marico	SF	I	M	Marico Fluorspar (Pty) Ltd.	Sampling by the author
Rietfon-tein 115 IR	Brakpan	P	N.A.	m	About 4 m of clay overlain by 3 m of soil and ferricrete near Range View Station	Warde (1949)
Riet-fontein 128 IR	Springs	P,SP, SF	I–IV	M	Verref Mining (Pty) Ltd.	1. Bredell (1978) 2. Sampling by the author
Riet-fontein 276 IR	Springs	P,SP, SF	I–IV	N	Indicated resources amount to 6,5 Mt of predominantly semi-flint clay	Bredell (1978)

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Riet-fontein 314 JS	Middelburg	SP,SF, F	I–IV	M	Intersected in Geological Survey boreholes. Limited reserves	This study
Riet-fontein 364 IR	Vereeniging	SF	II	m	Thickly bedded siliceous clay	1. Nel and Jansen (1957) 2. Sampling by the author
Riet-fontein 470 JR	Bronkhorst-spruit	P,SP, SF	I–II	M	Indicated resources of 215 000 t (Gr I–II) reported from the area north of the Leolorde Farming & Mining quarry	Bredell (1976a)
Riet-spruit 583 IQ	Vanderbijl-park	P	N.A.	M	Verref Mining (Pty) Ltd.	Nel and Jansen (1957)
Riet-valei 195 IR	Delmas	P,SF	N.A.	N	Predominantly plastic clay under-lain by dolomite	Pers. comm.: J.C. Siebert, Cullinan Minerals Ltd
Riet-valley 387 JS	Belfast	F	II	N	Small deposit, difficult to mine	Bennetts (1965)
Riet-vlei 397 JS	Middelburg	SF	I	N	Variable quality	Bennetts (1965)
Ronde-bult 136 IR	Boksburg	P	I	M	Rondebult Fireclay (Pty) Ltd.	Sampling by the author
Roode-poort 302 IQ	Roodepoort	SP,SF, F	I–IV	M	Exploited for manu-facture of facebricks and tiles	Sampling by the author
Roode-poort 439 JR	Bronkhorst-spruit	F	I	M	Otavi Mining Co. (Pty) Ltd., Cullinan Holdings Ltd and Metramco (Pty) Ltd.	Sampling by the author

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Rooi-poort 440 JR	Bronkhorst-spruit	SF	II	m	Two apparently small deposits	1. Bennetts (1965) 2. Bredell (1980)
Schoon-gezicht 308 JS	Witbank	SP	II	m	Silty clay in small abandoned quarry	Sampling by the author
Taai-fontein 461 JR	Bronkhorst-spruit	SF	II	m	Sandy and imper-sistent	Bennetts (1965)
Twee-fontein 220 JR	Pretoria	F	I	M	Metramco (Pty) Ltd.	Sampling by the author
Uitge-vallen 432 IR	Vereeniging	SP	II	m	Thinly bedded siliceous clay	1. Nel and Jansen (1957) 2. Sampling by the author
Van Dykspruit 431 JR	Bronkhorst-spruit	SF	I	N	Exposed in pros-pecting pits	Bennetts (1965)
Verbrick 118 JR	Pretoria	F	I–II	M	Verref Mining (Pty) Ltd.	Bennetts (1965)
Vlak-drift 163 IQ	Krugersdorp	P	I	N	Exposed in brick-clay quarry. Ex-tent unknown	Pers. comm.: Gordon Boucher
Vlak-fontein 161 IR	Nigel	P,SF	I–II	M	Verref Mining (Pty) Ltd.	Sampling by the author
Vlak-plaats 317 JT	Belfast	F	I	m	Very limited reserves	Bennetts (1965)
Vogel-fontein 84 IR	Boksburg	P	I	M	Economic Fireclay Works (Pty) Ltd.	1. Warde (1949) 2. Sampling by the author
Vrisge-waag 501 IR	Nigel	SF	I	m	Worked during 1977-78 by Verref Mining (Pty) Ltd.	

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Farm	District	Type *	Grade	Mining Status **	Remarks	Reference
Waterpan 292 IQ	Randfontein	P	IV	N	Intersected in reconnaissance borehole drilled by the Geological Survey (± 20 m thick)	Bredell (1979)
Weltevreden 118 IR	Brakpan	P,SF	N.A.	m	About 3 m of plastic clay overlying 0,5 m of carbonaceous semi-flint clay	Warde (1949)
Weltevreden 386 JS	Belfast	F	N.A.	N	Reported occurrence	Bennetts (1965)
Wildebeestfontein 327 JS	Witbank	F	I	N	Substantial deposit of high-density flint clay outlined by drilling	Pers. comm. : M. Krüger
Yzervarkfontein 467 JR	Bronkhorstspruit	SF	I	N	Exposed in prospecting pits	Bennetts (1965)

* P = plastic
SP = semi-plastic
SF = semi-flint
F = flint
C = naturally calcined flint (chamotte)

** N = Occurrence or prospect where no exploitation has taken place
m = Exploited in the past but now abandoned (1982)
M = Producing mine (1982)

N.A. = Data not available

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3. EXPLORATION

3.1 GENERAL PRINCIPLES AND PROBLEMS

In contrast to prospecting which only refers to the *search* for mineral deposits, exploration also includes the *assessment* of a deposit after discovery. Both these concepts will be dealt with in this chapter, using as an example the exploration program conducted by the author during the period 1973–79. It needs to be pointed out, however, that it was not the intention of this exercise to establish *measured reserves** of refractory clay at any particular site, but rather to identify potential areas on a regional basis and to determine *identified resources** in cases where promising material was located.

Being non-metallic, stratiform sedimentary deposits, refractory clay and coal have much in common as far as the basic approach to exploration is concerned. Practically the only differences are in the evaluation of the material and the fact that the clay deposits are much more limited in extent and therefore more difficult to locate. As in the case of coal, techniques such as geochemistry and geophysics have no or very limited application in the search for refractory clays and exploratory drilling has to be guided almost exclusively by geological interpretation.

One of the fundamental problems in searching for refractory clay is the fact that natural outcrops of the material are virtually non-existent and sub-outcrops do not reveal themselves by a characteristic surface expression of any kind. In the rare cases where outcrops do occur, the exposed material is normally so contaminated by secondary enrichment in iron and silica that no reliable conclusions can be drawn regarding the nature of the possibly underlying deposit. Considering in addition the vast extent of the host formation, i.e. the Ecca Group, it is no wonder that almost all the known refractory-clay deposits in South Africa have originally been found by mere coincidence, and not by the application of geological principles.

Once the presence of refractory clay has been established at a particular site, an assessment of the extent and quality-distribution within the deposit can only be made by means of de-

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* All resources-terminology in this chapter refers to the definitions proposed by McKelvey (1974).

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tailed drilling or pitting and sampling. This is necessitated by the lenticular nature of the clay beds as well as unpredictable lateral variations in composition or physical properties within the same bed. After having analysed his samples, the exploration geologist is faced with the task of predicting the quality of the material from these results. This is no simple matter because of the almost total lack of practically usable data on the interrelationship of the physico-chemical properties of refractory clays. Initial analytical procedures are therefore usually supplemented by direct testing under commercial conditions. Although this offers a sound practical solution, it certainly contributes very little to the understanding of the parameters which control refractoriness (see Chapter 5).

Apart from quality and lateral extent, the most important constraint on the exploitability of a refractory-clay deposit is the overburden/clay ratio. During reconnaissance exploration, this factor should already be considered while planning the search-phase, i.e. the selection of target areas. The cut-off for the stripping ratio at any particular deposit is, however, largely determined by economical considerations and it is therefore a variable constraint.

It should be made quite clear at this stage that there is no fixed set of procedures which can be universally applied to locate new deposits of refractory clay. The three regions referred to in this study (East Rand, West Rand and Pretoria – Belfast) will serve to illustrate that each area requires a different approach to identify target sites. The following most basic principles can, however, be used as a guide:

(1) Establish the exact extent of the host formation.

(2) Determine the stratigraphic position of the clay from available exposures or boreholes.

(3) Eliminate areas of excessive overburden.

(4) Eliminate areas covered by existing or planned surface developments.

(5) Reconnaissance drilling.

(6) Follow-up drilling.

(7) Quality and resources assessment.

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3.2 DRILLING, SAMPLING AND ANALYTICAL METHODS

3.2.1 Drilling Technique and Core Description

Although pitting can be applied with great success and at relatively low cost in areas of shallow overburden, diamond-drilling is by far the best technique for the subsurface sampling of refractory clay. However, due to the rather exorbitant cost of this type of drilling, mining companies often resort to percussion or air-drilling for reconnaissance purposes or for preliminary delineation of a deposit. Unfortunately, samples obtained by these methods are unavoidably mixed or contaminated while the small size of the fragments makes physical-property testing almost impossible. Seeing that it was the specific intention of the present investigation to study the composition and physical properties of the clays, diamond-drilling was used throughout the exploration programme. The core diameter was NX (54,86 mm) on the East and West Rand and TNW (60,8 mm) for holes drilled in the Pretoria – Belfast area. Smaller-diameter drilling (BX – 41,3 mm or TBW – 45,2 mm) was also locally attempted but although it proved quite satisfactory for flint and semi-flint clays, the thin core of very plastic clay tends to be stretched considerably during transfer from the core barrel to the core box, resulting in an overestimation of the thickness. As both plastic and non-plastic clay types may be intersected in the same borehole, it is therefore advisable to rather use the larger diameter in unexplored areas. In order to prevent excessive core loss in the softer clays, drilling should be done at high revolutions, low water pressure and low hydraulic pressure on the drilling rods.

Description of the core was done by recording macroscopically distinguishable features and was as far as possible standardised according to the following general pattern:

(1) Rock name according to grain size:

Conglomerate	:	>4 mm
Grit	:	2–4 mm
Sandstone	:	1/16–2 mm
Siltstone	:	1/256–1/16 mm
Clay	:	<1/256 mm

(2) Physical or textural characteristics, e.g. weathered, plastic, flint, silty, unconsolidated, cross-bedded, laminated, fissile, etc.

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(3) Mineralogical characteristics, e .g. micaceous, feldspathic, ferruginous, carbonaceous, lateritic, etc.

(4) Colour of the dry material according to standard colours presented in the "Rock-color Chart" of the Geological Society of America (1963).

As mentioned in Chapter 1, the type classification of refractory clays can be predicted with a reasonable degree of assurance after a "feeling" for the material has been developed through experience. However, each geologist normally develops his own personal technique, using methods which may seem rather odd and subjective to the uninitiated, e.g. rubbing, moulding, rolling, scratching, licking or even chewing the material! The following description may nevertheless be useful as a guide for classifying refractory-clay core or hand samples by inspection:

Plastic clays are soft, even when dry, and become completely plastic when saturated with water. They are commonly bedded or laminated and have a weakly developed fissility, giving rise to a typical blocky fracture. Rubbing a dry sample with a thumbnail produces a characteristic shiny surface, indicating a low silt or sand content. Even minor amounts of silt can be detected by chewing a small piece of the clay – good-quality clay should feel completely smooth between the teeth. Plastic refractory clay is normally easily distinguishable from weathered shale or siliceous non-refractory-clay by its poor fissility, the lack of visible mica on bedding planes and the almost total absence of silt or sand-sized particles.

Semi-plastic clay is harder than the plastic type but can still be scratched quite easily with a fingernail. It has to be broken down into small pieces and soaked in water for quite a while before it becomes plastic. Laminations are rare and the material is normally non-fissile. The fracture is essentially blocky but weakly conchoidal in places. The silt content can be tested in the same way as for plastic clays.

Semi-flint clay is considerably harder than semi-plastic clay and can only just be scratched with a fingernail. It is completely non-plastic and retains this property even after prolonged soaking in water. It is normally massive and non-fissile and has a predominantly conchoidal fracture but subordinate blocky fractures are generally developed on each sample. Some idea of the silt content can be obtained by running the sharp point of a geological hammer along the core – even thin layers of more silty material can be detected in this manner by the contrast in sound.

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South African *flint clays* are very hard and cannot be scratched with a fingernail; they can be scratched quite easily with a knife, however. (Flint clay from Missouri is markedly softer and can be compared with South African semi-flint clays as far as scratch hardness is concerned). True flint clay is massive, totally non-fissile, completely non-plastic and has a characteristic conchoidal fracture, even on the smallest pieces. The silt content can be estimated in the same way as for semi-flint clay.

3.2.2 Sampling Procedure

Because of the diversity of analyses and tests which had to be carried out simultaneously by different laboratories and apparatus, and the fact that conventional splitting of the borehole core proved to be impractical in the case of most of the clays, the following sampling procedure was developed:

(1) Sample intervals were selected on the basis of lithological differences but with due regard to the selective exploitability of that particular layer.

(2) The entire length of core within a sample interval was broken up into roughly 100 mm lengths and every alternate length was gathered and grouped together as a composite sample for physical tests and determination of mineralogical composition.

(3) Small fragments were chipped from opposite sides of each of the remaining lengths of core and submitted for major and trace-element analysis.

(4) Samples for pH determinations were obtained by chipping off the remaining two sides of the core lengths mentioned in step (3).

(5) The remainder of the material was used for electron-microscope studies and also served as a control in cases where resubmission was required.

3.2.3 Physical-Property Tests

All determinations of bulk density (B D), apparent porosity (A P) and pyrometric cone equivalent (P C E) were performed by the National Building Research Institute of the C S I R. The method for determining B D and A P is described by Bennetts and Pieterse (1963) and is based on procedures which are comprehensively dealt with in Searle and

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Grimshaw (1959). Samples are dried at 110°C for 24 hours, put in a vacuum desiccator for 2 hours to evacuate open pores, and then immersed in a liquid (paraffin) under vacuum for a further 2 hours. The mass of the samples are determined after drying, saturated with and suspended in paraffin, and saturated with paraffin in air. The B D and A P are then calculated as follows:

$$\text{B D} = \frac{m_1 \times \rho}{m_2 - m_3}$$

$$\text{A P} = \frac{m_2 - m_1}{m_2 - m_3} \times 100\%$$

where m_1 = mass dry (110°C)

m_2 = mass saturated with liquid in air

m_3 = mass saturated with, and suspended in liquid

ρ = relative density of liquid

Measurements of the B D and A P were done in triplicate for each sample and an average value was then calculated. This procedure is also commonly used in industry and in view of the high cost involved, no attempt was made to compare these results with measurements made by means of more sophisticated equipment such as a porosimeter.

The refractoriness of the clay samples was determined by means of the well-known pyrometric cone equivalent method, following the procedures laid down in British Standard No. 1092 of 1952. Samples were prepared by crushing in a hammer mill to minus 1 mm and molding the specimens in brass molds using water as bonding agent. Comparison with standard Seger cones was made in an oxy-acetylene furnace on a rotating stage and from about 200°C below the expected fusion point, the temperature was raised at a steady rate of 5°C per minute until the test cones bent to touch the cone holder. It is important to note here that the small type of Seger cone was used in respect of all samples investigated for this study. The equivalent temperatures of these cones differ somewhat from those of the corresponding larger Seger cones which are in more common use, particularly in the United States. In order to avoid confusion, the equivalent temperatures of both types of cone are listed below:

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	Equivalent temperature (°C)	
Cone No.	Small cone	Large cone
26	1 585	1 580
27	1 605	1 610
28	1 635	1 630
29	1 655	1 650
30	1 680	1 670
31	1 695	1 690
32	1 710	1 710
33	1 730	1 730
34	1 755	1 750
35	1 780	1 770
36	1 805	1 790

3.2.4 Major-Element Analysis

During the data-gathering phase of this investigation which lasted about seven years, several different techniques and instruments had been used to analyse the clay samples for major elements. With increasing experience and the improvement of analytical equipment in the Geological Survey Laboratory over these years, more reliable results could be obtained and procedures were eventually standardised. For the purposes of this thesis it was therefore decided to re-analyse all the more important samples in order to obtain comparable results. Analyses presented here will consequently differ somewhat from, and can be considered more accurate than, the results which appear in previous reports and publications by the author. The method summarised below was specially adapted and optimised for these refractory clays by staff of the Geological Survey Laboratory.

Most of the components (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5) were determined by means of X-ray fluorescence, using a Rigaku Denki sequential X-ray spectrometer at 50 kV and 50 mA. With the exception of Na_2O for which better results were obtained on powder pellets, the other elements mentioned above were all deter-

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mined on samples prepared in the form of glass discs. These discs are made up of 1 g of sample calcined at 1 000°C and 6 g of Li-metaborate dried at 450°C. One gram of Na-tetraborate is added to avoid crystallisation of excess Al in the glass and during fusion,and a drop of HBr is added to ensure a uniform distribution of material in the melt and to reduce viscosity. In order to cope with the rather wide compositional range of the samples, five international and six local standards were used for calibration purposes. These included flint clay, plastic clay, ferruginous bauxite, andalusite, sillimanite, kinzingite and an aluminous refractory product. The apparent concentrations were calculated using the method of Haukka and Thomas (1977) and mass-absorption tables provided by the NBS in Washington. Apparent concentration was plotted against counts per second and calibration constants were determined by weighted least-squares regression. The calibration curves presented in Appendix 1 give an indication of the reliability of results at various concentration levels. During analysis, drift was monitored by including reference samples.

H_2O^+, H_2O^-, CO_2 and FeO were determined separately, using gravimetric methods for H_2O^+ and H_2O^-, gas chromatography for CO_2 and volumetric titration with K-dichromate for FeO. Organic carbon was determined on 20 randomly selected samples after leaching with diluted HCl. This indicated that there are virtually no carbonates present in these clays and that the CO_2 determined by gas chromatography can for all practical purposes be regarded as representing organic carbon.

Since the XRF analyses were performed after calcining at 1 000°C, the concentrations reported for constituents so determined were subsequently adjusted to accommodate H_2O^+ and CO_2. In order to eliminate the effect of a varying H_2O^- content as determined on air-dried samples, all the results are presented on a moisture-free (H_2O^--free)basis.

3.2.5 Trace-Element Analysis

With the exception of sulphur which was done by gas chromatography on a Leco simultaneous C – S analyser, all the other minor constituents were determined by means of X-ray fluorescence spectrometry. All analyses were performed by the Geological Survey Laboratory. Two different instruments were used; a simultaneous spectrometer for V, Co, Sn, Sb, W, U and a secondary-target spectrometer for Ni, Cu, Zn, Ga, Ge, Rb, Sr, Y, Zr, Nb, Mo, Pb, Se, Th and As. Samples were prepared as pressed powder pellets, using polyvinyl alcohol/distilled water as a binding agent and drying the pellet afterwards at 100°C

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for 2 hours. Background and matrix correction of spectral peaks was done according to the method described by Feather and Willis (1976). These authors claim that relative accuracies of 2 to 5 per cent are obtainable with this technique.

3.2.6 pH

In preparing samples for fossil-pH determinations, a method described by Bennetts (1965) was employed. This method was preferred as it was intended to compare the values obtained with those determined by him during his survey of flint clays in the Pretoria – Belfast area. An Orion pH-meter with glass electrode was used for all the measurements. Samples were prepared by adding 25 ml of deionised water to 10 g of pulverised sample and shaking it vigorously for about one minute. Bennett's method involves shaking the mixture for half an hour, but as no difference in pH was noted between a sample shaken for 1 minute or 30 minutes, the shorter time was used throughout.

Immediately after the sample had been shaken, the electrode was immersed in the suspension. Equilibrium was usually established within 30 – 60 seconds, during which time the electrode was kept in constant motion in order to keep the clay particles in suspension. Once equilibrium was reached, a reading was taken, taking care that the electrode was not moved during this process. Three readings were taken of each sample at about 5-minute intervals. Values so determined usually did not drift significantly in either direction, indicating that the suspensions were reasonably well buffered. Some of the samples did, however, show a drift in pH of up to 0,2 after a period of 24 hours. In these cases an average pH value was calculated using the three initial readings and three subsequent values obtained after 24 hours. Values were found to be reproducible to within 0,1 pH unit on duplicate samples. During measuring operations the instrument was standardised every hour against buffered solutions of known pH.

3.2.7 Mineralogy

Semi-quantitative mineralogical analyses were carried out on contract by the National Building Research Institute, using a Philips X-ray diffractometer with Cu radiation and a Ni filter at a potential of 40 kV and a current of 20 mA. Samples were pulverised in a mortar and pestle and brought into suspension by addition of water. A few drops of the suspension were transferred to a glass plate by means of a medicine dropper and subsequently dried under infra-red light. The approximate percentage quartz was calculated from

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the diffraction peaks for each sample but the rest of the mineral components were only listed as major or minor constituents. Quantitative determinations were subsequently performed by applying the technique developed by Pearson (1978) to samples of which the clay-mineral fraction largely consists of kaolinite and illite. This method involves the calculation of clay-mineral abundance from the bulk chemical composition of a sample by using qualitative XRD results and the compositional range of the clay mineral as obtained from Deer, Howie and Zussman (1962). According to Pearson, the technique gives results which are more accurate than those obtained by XRD and equally precise, provided that the material does not contain clay minerals other than kaolinite, illite, mica and chlorite.

3.2.8 Grain-size Analysis and Particle Orientation

Conventional methods of grain-size measurement such as sieving, sedimentation analysis, centrifugal separation, elutration, etc. cannot be applied successfully to refractory clays because the size distribution so determined would only be a measure of the efficiency of the dispersion method used (Griffiths, 1967). An attempt was made to deflocculate some of the more plastic clays by using various dispersion agents (sodium carbonate, sodium oxalate, ammonium hydroxide) as well as prolonged shaking. Subsequent inspection under the scanning electron microscope showed, however, that the material still consists almost entirely of aggregates. As it was one of the aims of this study to investigate the effect of grain size on refractoriness of the material, measurement of individual particles in their undisturbed state was considered essential. It was consequently decided that the most practical procedure would be the direct assessment of size from scanning electron micrographs. Although there seems to be general agreement that X-ray diffraction, and in some cases optical birefringence, are the most reliable techniques for measuring particle orientation in clays, an attempt was made during this investigation to quantify the degree of preferred orientation from electron micrographs. This is after all the only technique whereby the actual clay particles can be observed and the electron-microscope study had to be conducted in any case for grain-size determination. According to Tchalenko, Burnett and Hung (1971), direct observation of particles by electron microscopy is inadequate for the assessment of orientation, mainly because of the apparent insensitivity of this method and the difficulty in obtaining representative micrographs. The author believes, however, that by following the procedure described below, meaningful results can be obtained which can be related to other clay properties (see Chapter 5).

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The preparation and mounting of specimens were found to be most important in obtaining satisfactory results and the technique which was finally adopted, is therefore described here in some detail. From each sample, two orientated chips were obtained; one parallel to the macroscopical bedding of the clay (for grain-size measurements), and one perpendicular thereto (for orientation studies). These chips were then trimmed to a thickness of about 5 mm and a diameter of 6–8 mm, after which the lower surface was flattened on fine emery paper. The upper surface, i.e. the surface to be studied, can then be prepared by careful chipping or flaking, making sure that a clean, natural break is obtained with as little relief as possible. After this, care must be taken not to touch this surface during subsequent handling. Specimens were mounted on standard 10-mm diameter brass studs, and after experimenting with various types of adhesives, a quick-drying, two-component liquid-paste epoxy was found to give the best results. The liquid should be applied sparingly to the stud and the paste to the specimen; if applied the other way around or if too much liquid is used, the latter tends to be absorbed by the specimen, giving a glazed appearance to the upper surface and rendering it useless for examination. Coating was done under vacuum, first with carbon and then with Au – Pd. After coating, specimens should be stored in a desiccator to prevent absorption of moisture.

After scanning each sample to obtain a general idea of its texture and to identify minerals by means of the microprobe attachment, an average of four photographs were taken to record the predominant or typical size distribution and orientation. The sharpest images and best photographs were obtained at a potential of 20 kV. At least 100 measurements were made per photograph so that on average, about 400 grain-size and 400 orientation measurements were obtained for each sample. The grain sizes were converted to phi values and the phi arithmetic means and phi arithmetic standard deviations were calculated to serve as a measure of average grain size and grain-size distribution respectively (Griffiths, 1967) for comparison with other properties. In the case of orientation measurements, the general bedding pattern was first observed under low magnification and the image was then rotated to bring the overall bedding direction parallel to the frame of the observation tube. The orientation of particle edges could consequently be measured from $+90^{o}$ to -90^{o} with reference to this bedding direction which coincided with the side of the micrograph. Assuming the surface studied to be a random sample of the aggregate perpendicular to the bedding, standard deviations were subsequently calculated as an expression of the degree of preferred orientation (Griffiths, 1967).

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3.2.9 Tests adopted by Industry

Although testing procedures have largely been standardised, the type of tests conducted on refractory clays by industry varies considerably from company to company and even within the same company, depending on the wide and changing range of applications. While some companies find it quite adequate to determine only the major chemical composition, bulk density and quartz content of a clay on a routine basis, others resort to much more comprehensive testing, adding measurements of apparent porosity, PCE, linear stability, slakability and occasionally pH and green strength. The value of particularly linear stability, slakability and green strength as well as density and porosity measurements on fired products are, however, of doubtful value if conducted on small samples collected during exploration. These properties can only be meaningfully interpreted if performed on actual blends and under the conditions prevailing in a particular plant. The author is therefore convinced that the tests and analyses conducted during this study provides the basic information required to evaluate these clays for exploration purposes.

3.3 EAST RAND

The part of the East Rand which was selected for exploration purposes is situated between 28^{o} 15' and 29^{o} 00'E, and between 26^{o} 00' and 26^{o} 30'S (Fig. 1.9). As far as surface distribution is concerned, the Karoo Sequence is by far the most widespread geological unit in the area. Represented by essentially the Vryheid Formation to which deposits of refractory clay are known to be confined, and to a much lesser extent the Dwyka Formation, the Karoo Sequence covers about 3 100 km^2 or 75 per cent of the study area (Bredell, 1979). These sediments were deposited on an uneven floor of older rocks of which the Chuniespoort Group of the Transvaal Sequence predominates. The Vryheid Formation on the East Rand consists mostly of shale, siltstone and sandstone with subordinate grit, carbonaceous shale, coal and sedimentary clay. Over the greater part of the area these rocks are underlain by a relatively thin layer of tillite or reworked tillite of the Dwyka Formation, but in some isolated areas the Vryheid Formation was deposited directly on pre-Karoo rocks. The scarcity of natural outcrops due to the predominantly argillaceous nature of the Karoo sediments and extensive urban and agricultural developments, renders accurate surface mapping virtually impossible and this proved to be a major handicap in selecting exploration targets.

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3.3.1 Selection of Target Areas

At the start of the investigation, the only established fact as to the distribution of possible refractory clay deposits was that they are confined to the Vryheid Formation. As a first step, the distribution of the Karoo Sequence was therefore revised by making use of all available information, including the logs of some 1 500 boreholes previously drilled in the area in search of gold, coal and ground-water. This exercise resulted in quite a few minor but important alterations to the boundaries of the Vryheid and Dwyka Formations as indicated on the published 1:250 000 geological map, Sheet 2628 (East Rand) (see Bredell, 1978). However, at that stage only the non-Vryheid Formation rocks, i.e. pre-Vryheid units and post-Karoo dolerite could be eliminated as target areas. A vast area still remained which could only be reduced by further information, especially regarding the stratigraphic position of the clay deposits.

3.3.1.1 An Isopach Map of the Karoo Sequence as a Guide to the Distribution of Exploitable Refractory-Clay Deposits

Examination of the existing quarries and available borehole data revealed that the clays do in fact occupy a specific stratigraphic position. They occur at or very near the base of the Vryheid Formation, irrespective of whether this unit had been deposited on Dwyka Formation or on pre-Karoo rocks. Areas where the base of the Vryheid Formation exceeds the limit at which open-cast mining for refractory clay is considered to be economically feasible can therefore be eliminated. If an overburden/clay ratio of 6 is considered to be the limit of economic exploitation, and if an average thickness of 4 m of refractory clay is assumed, it is clear that only areas where the Vryheid Formation is less than about 30 m thick need to be considered for exploration. An isopach map was therefore required to delineate these potential zones. Unfortunately the construction of a reliable isopach map of only the Vryheid Formation was not possible owing to the lack of detail in many of the borehole logs, and as an alternative an isopach map of the total Karoo Sequence was compiled (Fig. 3.1). Seeing that the Dwyka Formation seldom exceeds 5 m in thickness over most of the area, this map is considered to be quite adequate for selecting target areas. Figure 3.2 is a simplified map indicating favourable areas within the Vryheid Formation alone. It was constructed by extrapolation from the isopach map of the total Karoo Sequence and illustrates the regional setting of areas where refractory clay may be expected to be present at mineable depth in relation to infrastructure and existing refractory clay mines. The fact

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FIGURE 3-1

ISOPACH MAP OF KAROO SEQUENCE ON THE EAST RAND

LEGEND

- Boundary of the Karoo Sequence (including Karoo dolerite)
- Thickness contour (metres)
- 146 Borehole which intersected Karoo rocks (with thickness in metres)
- Borehole which did not intersect Karoo rocks
- Farm boundaries
- Boundaries of gold mining leases

Metres 1000 0 1000 2000 3000 4000 5000

HARTBEEST-FONTEIN 17
ELANDSFONTEIN 412
TWEEFONTEIN 213
ELANDSVALLY 414
KNOPPIESFONTEIN 549
BRONKHORSTFONTEIN 20
WIT-FONTEIN 16
WIT-FONTEIN 15
TWEEFONTEIN 19
RIETFONTEIN 21
YZERVARKFONTEIN 194
VARKFONTEIN 5
WITFONTEIN 15
ZESFONTEIN 27
KNOPPIESFONTEIN 23
KATBOSCHFONTEIN 22
RIETVALEI 195
RIETFONTEIN 32
RIETFONTEIN 31
PETIT 28
PUTFONTEIN 6
OLIFANTSFONTEIN 196
VLAKFONTEIN 30
RIETPAN 66
MODDERFONTEIN 236
HOLFONTEIN 71
RIETKOL 237
WITKOPPIE 64
VLAKFONTEIN 69
KLIPFONTEIN 70
MODDERFONTEIN 5
Van Ryn
Modder East
KLIPFONTEIN 83
KLEINFONTEIN 67
New Modder
Modder B
CLOVERFIELD 75
WELGEDACHT 74
Welgedacht
BENONI 77
Modder Deep
Govt G.M. Areas
New Kleinfontein
GEDULD 123
Geduld
East Geduld
VOGELFONTEIN 84
WELTEVREDEN OR BRAKPAN 118
RIETFONTEIN 115
Van Dyk
Brakpan
Grootvalei
Govt Gold Areas
THE SPRINGS
LEEUWPOORT 113
KOOLBULT 122
PALMIETKUIL 241
WITPOORTJE 117
Van Dyk
S.A. Lands
Daggafontein
DAGGAFONTEIN 125
RIETFONTEIN 128
Springs
RIETFONTEIN 276
VISCHKUIL 274
FINAALSPAN 114
KLIP-BULT 134
WITHOK 131
Withok
VLAKFONTEIN 130
Vlakfontein
VOGELSTRUISBULT 127
Vogelstruisbult
ROOIKRAAL 156
GLENROY 132
BLEMENDAL 283
MAPLETON 135
VLAKFONTEIN 281
Marievale
West Vlakfontein
GROOTFONTEIN 165
Sub-Nigel
ROODEKRAAL 133
VLAKFONTEIN 161
DRAAIKRAAL 166
Nigel
Spaarwater
LEEUWENFONTEIN 284
VARKENSFONTEIN 169
HOLGATFONTEIN 326
UIT-KYK 159
RIETVALEI 172
SPAARWATER 171
DROOGE BULT 170
KOPPIESKRAAL 157
BULTFONTEIN 192
MARAISDRIFT 190
KLIPPOORTJE 187
NOYCEDALE 191
EENDRACHT 185
UITKYK 327
RIETPOORT 193
LANGLAAGTE 186
VALSFONTEIN 183
BOSCHHOEK 385
BOSCHFONTEIN 386
KLIPPOORTJE 188
POORTJE 389
VRISGEWAAG 501
WITKOP 330
GROOTVALY 124
STRYDPAN 243
DROOGEFONTEIN 242
OLIFANTSFONTEIN 196
GELUK 234
LEEUWPOORT 205
MIDDELBULT 235
WITKLIP 232
WITKLIP 229
MIDDELBURG 231
GOEDGEDACHT 228
GROENFONTEIN 206
DWAALFONTEIN 565
KLIPFONTEIN 568
VLAKFONTEIN 569
BANK-FONTEIN 216
DWARSFONTEIN 209
VAN CYKSPUT 214
HEUVELFONTEIN 215
BOSCHPOORT 211
HEKPOORT 207
RONDEVLY 208
VLAKVARKFONTEIN 213
ZONDERFOUT 226
SCHOONGEZICHT 225
SCHOONGEZICHT 218
WELGELEGEN 221
WELTEVREDEN 227
LEEUWFONTEIN 219
MOABSVELDEN 248
VANGGATFONTEIN 250
ZONDAGSFONTEIN 253
STRAFFONTEIN 252
VANGGATFONTEIN 251
WOLVENFONTEIN 224
LEEUWPAN 246
RIETKUIL 249
DIEPLAAGTE 262
BRAKFONTEIN 264
UIT-VLUGT 255
STREHLA 261
KRAMERTAAI 254
WEILAAGTE 271
VLAKPLAATS 268
MIDDELBURG 266
HAVERKLIP 265
KORTLAAGTE 67
STOMPIESFONTEIN 273
WELGEVONDEN 272
GOEDE HOOP 300
COUWENBURG 290
SPRINGBOKLAAGTE 306
WELTEVREDEN 307
MOEDVERLOREN 68
SYFERFONTEIN 288
ENKELDEBOSCH 301
STEENKOOLSPRUIT 302
HET BLOK 287
NOOITGEDACHT 286
BRAKFONTEIN 310
LEEUWKOP 299
HOLSPRUIT 303
GOEDEHOOP 308
BLESBOK-SPRUIT 90
BOSMANSKOP 293
NOOITGEDACHT 294
POT-FONTEIN 285
WINTERHOEK 314
RIETFONTEIN 313
GROOTLAAGTE 311
PALMIETFONTEIN 316
LANGZEEKOEGAT 323
PALMIETKUIL 322
ROLSPRUIT 127
MALKOP 317
SALPETERKRANZ 351
GRUISFONTEIN 344
WATERVALSHOEK 350
KLIPPAN 324
LANGZEEKOEGAT 325
GROENKUIL 321
WONDERFONTEIN 341
MOREA 331
HONIGFONTEIN 339
KULWATER 347
KLIPFONTEIN 357
KAFFERSKUILEN 349
GROUWATER 353
PALMIETFONTEIN 337
WOLVENBANK 338
WITBANK 340
VLAKPLAAS 348
WILDEBEESTSPRUIT 356
BRAKSPRUIT 359

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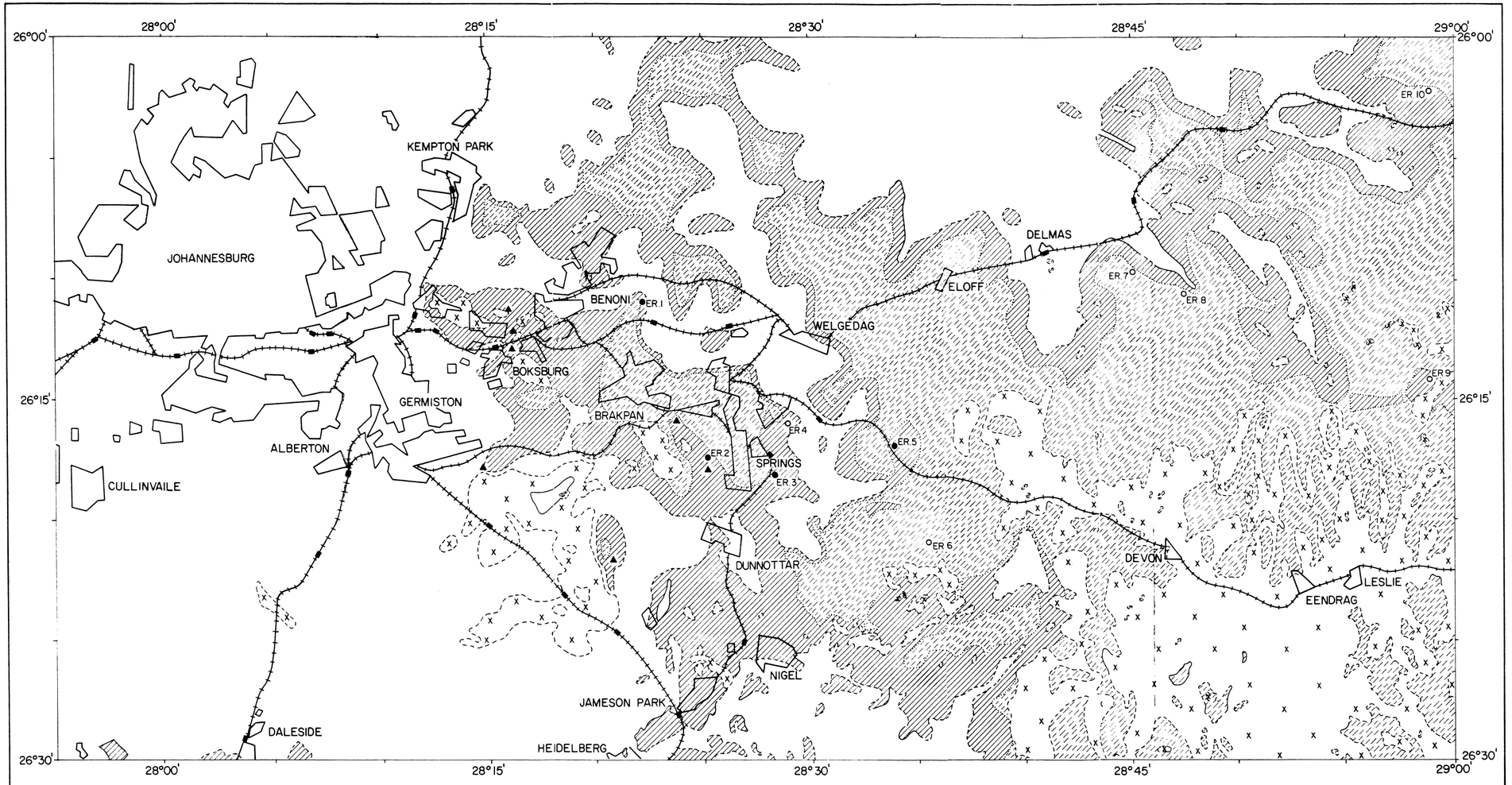

FIG. 3·2 - Target areas for refractory clay prospecting on the East Rand
Teikengebiede vir vuurvaste-kleiprospektering aan die Oos-Rand

Favourable areas / Gunstige gebiede

- Working refractory clay mines
  Werkende vuurvaste-kleimyne
- ER.5 Presence of refractory clay proved in boreholes
  Aanwesigheid van vuurvaste klei in boorgate bewys
- Areas where refractory clay may occur at mineable depth (less than 30 m)
  Gebiede waar vuurvaste klei op mynbare diepte (minder as 30m) mag voorkom

Unfavourable areas / Ongunstige gebiede

- Built-up areas
  Beboude gebiede
- ER.7 Absence of refractory clay proved by boreholes
  Afwesigheid van vuurvaste klei deur boorgate bewys
- Areas covered by post-Karoo dolerite
  Gebiede bedek deur na-Karoodoleriet
- Areas where refractory clay may occur, but below mineable depth (plus 30 m)
  Gebiede waar vuurvaste klei mag voorkom, maar nie op mynbare diepte nie (dieper as 30m)
- Areas occupied by pre-Vryheid rocks
  Gebiede beslaan deur voor-Vryheidgesteentes
- Main railways
  Hoofspoorlyne

5 0 5 10 km

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that all the refractory clay mines are situated within the predicted zones established a fair amount of confidence in the proposed exploration concept and served as a strong motivation for the next phase, i.e. reconnaissance drilling.

As to be expected, the 0 – 30 m zones are largely restricted to the perimeter of the Karoo Sequence. Exceptions to this pattern are, however, frequent in the western part of the study area, particularly around Springs, Boksburg and Benoni, and also in the area about 15 km north of Leslie. According to available borehole data, the Karoo rocks attain a maximum thickness of 316 m in the south-eastern part of the area on the farm Grootlaagte 311 IR near Leslie. From this point, the thickness decreases fairly rapidly to less than 60 m in a northerly and westerly direction over a distance of about 25 km (Bredell, 1979). Towards the north-west, however, a prominent channel, in which the Karoo rocks are more than 60 m thick, extends up to Holfontein 71 IR immediately north of Welgedag. Except for a few isolated areas around Springs, Benoni and north of Leslie, the thickness over most of the remaining area is less than 60 m.

Apart from the original purpose for which the isopach map was constructed, it may also be of assistance in town and regional planning. A thickness of less than 30 m indicates potential clay-mining land, whereas the thickness of the Karoo cover in dolomitic areas is an important factor in determining the relative safety of a specific area with respect to subsidence or sinkhole formation. It must be emphasised, however, that this map should not be used for more exact purposes than as a general planning guide; its accuracy depends solely on the concentration of data points, and contours in some areas are highly conjectural as a result of a paucity of borehole information.

3.3.1.2 The Influence of Pre-Karoo Rocks on the Distribution of Refractory-Clay Deposits

There is a strong belief among some mining companies that deposits of particularly plastic refractory clay occur preferentially in areas which are underlain by dolomite. In order to test this idea, a generalised pre-Karoo geological map (Fig. 3.3) was constructed from the same borehole data used for the compilation of the isopach map. This indeed revealed a strong tendency for known deposits to be underlain by dolomite of the Chuniespoort Group. All the sites at which refractory clay was found during reconnaissance drilling (see paragraph 3.3.2) also overlie dolomite, and the same applies to the deposits on the West Rand and those at Olifantsfontein to the north of the study area. This could probably be

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FIGURE 33

GENERALISED PRE-KAROO GEOLOGICAL MAP OF THE EAST RAND

LEGEND

Pre-Karoo formation not covered by Karoo rocks

Inferred distribution of pre-Karoo formation below Karoo cover

- Granite, granophyre — BUSHVELD COMPLEX
- Felsite, breccia, agglomerate — Rooiberg Group
- Shale, quartzite, andesite intrusive diabase — Pretoria Group
- Dolomite, chert, quartzite, shale, grit, conglomerate — Chuniespoort Group — TRANSVAAL SEQUENCE
- Lava, flow-breccia, tuff — VENTERSDORP SUPERGROUP
- Qucrtzite, conglomerate, slate grit greywacke, lava — WITWATERSRAND SUPERGROUP
- Granite, gneiss — FUNDAMENTAL COMPLEX

Boundary of the Karoo Sequence including Karoo dolerite

Geological boundary not covered by Karoo rocks

Inferred geological boundary below the Karoo cover

Fault not covered by Karoo rocks

Inferred continuation of fault below the Karoo cover

Farm boundaries

Boundaries of gold mining leases

Borehole which penetrated pre-Karoo rocks

Scale 1000 0 1000 2000 3000 4000 5000 metres

TWEEFONTEIN 413 · ELANDSVALLEY 414 · KNOPPIESFONTEIN 549 · HARTEBEESTFONTEIN 17 · ELANDSFONTEIN 412 · BRONKHORSTFONTEIN 20 · TWEEFONTEIN 19 · RIETFONTEIN 21 · WITFONTEIN 16 · VARKFONTEIN 25 · WITFONTEIN 15 · ZESFONTEIN 27 · KNOPPIESFONTEIN 23 · KATBOSCHFONTEIN 22 · RIETFONTEIN 32 · RIETFONTEIN 31 · PUTFONTEIN 26 · PETIT 28 · VLAKFONTEIN 30 · RIETPAN 66 · WITKOPPIE 64 · VLAKFONTEIN 69 · MODDERFONTEIN 236 · HOLFONTEIN 71 · KLIPFONTEIN 70 · MODDERFONTEIN 76 · KLEINFONTEIN 67 · New Modder · Modder B · Modder East · CLOVERFIELD 75 · WELGEDACHT · Welgedacht · BENONI 77 · KLIPFONTEIN 83 · New Kleinfontein · Govt G.M. Areas · GEDULD 123 · Geduld · East Geduld · VOGELFONTEIN 84 · RIETFONTEIN 115 · WELTEVREDEN 118 · GROOTVALY 124 · LEEUWPOORT 113 · Brakpan · New State Areas · THE SPRING 129 · Grootvlei · PALMIETKUILEN 241 · KOOLBULT 121 · WITPOORTJE 117 · S.A. Lands · Van Dyk · RIETFONTEIN 128 · Daggafontein · DAGGAFONTEIN 125 · RIETFONTEIN 276 · East Daggafontein · Springs · FINAALSPAN 114 · KLIPBULT 134 · WITHOK 131 · VLAKFONTEIN 130 · VOGELSTRUISBULT 127 · Vogelstruisbult · Withok · Vlakfontein · ROOIKRAAL 156 · GLENROY 132 · MARPLETON 135 · GROOTFONTEIN 165 · Sub-Nigel · West Vlakfontein · ROODEKRAAL 133 · VLAKFONTEIN 161 · DRAAIKRAAL 166 · Spaarwater · Nigel · VARKENSFONTEIN 169 · UITKYK 159 · RIETVALLEI 172 · SPAARWATER 171 · DROOGEBULT 170 · HOLGATFONTEIN 326 · KOPPIESKRAAL 157 · BULTFONTEIN 192 · MARAISDRIFT 190 · EENDRACHT 185 · KLIPPOORTJE 187 · UITKYK 327 · LANGLAAGTE 186 · TULPVALE 188 · RIETPOORT 193 · VALSFONTEIN 183 · BOSCHHOEK 385 · BOSCHFONTEIN 386 · POORTJE 389 · VRISGEWAAG 501 · VLAKVARKFONTEIN 213 · LEEUPOORT 205 · MIDDELBURG 231 · GOEDGEDACHT 228 · WELTEVREDEN 227 · WITKLIP 229 · GELUK 234 · RIETKOL 237 · WITKLIP 232 · MIDDELBULT 235 · GEIGERLE 238 · DROOGEFONTEIN 242 · WOLVENFONTEIN 224 · LEEUWPAN 246 · STRYDPAN 243 · WEILAAGTE 271 · WELGEVONDEN 272 · STOMPIESFONTEIN 273 · VISCHKUIL 274 · HET BLOCK 287 · SYFERFONTEIN 288 · BLOEMENDAL 283 · NOOITGEDACHT 286 · VLAKFONTEIN 281 · Marievale · LEEUWENFONTEIN 284 · POTFONTEIN 285 · BOSMANSKOP 293 · LANGZEEKOEGAT 323 · PALMIETKUIL 322 · LANGZEEKOEGAT 325 · KLIPPAN 324 · MOREA 331 · UITKYK 327 · RIETPOORT 193 · WITKOP 330 · PALMIETFONTEIN 337 · WOLVENBANK 338 · VLAKPLAATS 348 · WITBANK 340 · WONDERFONTEIN 341 · HONIGFONTEIN 339 · KUILWATER 347 · KAFFERSKUILEN 349 · GROUWWATER 353 · WILDEBEESTSPRUIT 356 · BRAKSPRUIT 359 · KLIPFONTEIN 357 · WATERVALSHOEK 350 · SALPETERKRANZ 351 · ROLSPRUIT 127 · MALKOP 317 · GRUISHOEK 344 · GROENKUIL 321 · PALMIETFONTEIN 316 · GROOTLAAGTE 311 · WINTERHOEK 314 · NOOITGEDACHT 294 · LEEUWKOP 299 · BRAKFONTEIN 310 · GOEDEHOOP 308 · BLESBOKSPRUIT 90 · RIETFONTEIN 313 · WELTEVREDEN 307 · SPRINGBOKLAAGTE 306 · ENKELDEBOSCH 301 · STEENKOOLSPRUIT 302 · COUWENBURG 300 · GOEDE HOOP 290 · HAVERKLIP 265 · KORTLAAGTE 67 · KROMDRAAI 263 · STREHLA 261 · DIEPLAAGTE 262 · BRAKFONTEIN 264 · MIDDELBURG 266 · VLAKPLAATS 268 · VANGGATFONTEIN 251 · RIETKUIL 249 · MOABSVELDEN 248 · VANGGATFONTEIN 250 · STRAFFONTEIN 252 · ZONDAGSFONTEIN 253 · LEEUWFONTEIN 216 · WELGELEGEN 221 · SCHOONGEZICHT 225 · ZONDERFOUT 226 · RONDEVLY 208 · BOSCHPOORT 211 · HEKPOORT 207 · DWARSFONTEIN 209 · VAN DYKSPRUIT 214 · HEUVELFONTEIN 215 · BANKFONTEIN 216 · KLIPFONTEIN 568 · DWAALFONTEIN 565 · VLAKFONTEIN 569 · GROENFONTEIN 206

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attributed to the fact that the pre-Karoo dolomite surface was more susceptible to the formation of isolated depressions which subsequently developed into shallow swampy lakes, offering an ideal environment for the deposition of these clays (Bredell, 1974).

On the other hand there are notable exceptions on the East Rand which indicate that the apparent preference for a dolomite floor might be purely coincidental. The deposits of Boksburg Brick and Fireclay, Union Fireclay and Economic Fireclay on Klipfontein 83 IR and Vogelfontein 84 IR are for example all underlain by quartzite and shale of the Witwatersrand Supergroup. The fact that most deposits are located over dolomite could therefore just as well be ascribed to the subsurface predominance of this rock type, particularly in areas covered by less than 30 m of Karoo sediments. From an exploration point of view, it would appear therefore that the pre-Karoo geology cannot be used as a reliable guide in the selection of target sites. The most useful application of the pre-Karoo map turned out to be for town-planning purposes where it has been used in conjunction with the isopach map to identify areas underlain by dolomite at shallow depth and which therefore require special attention with respect to the possibility of subsidence.

3.3.2 Reconnaissance Drilling

In selecting the sites for the first 10 reconnaissance boreholes, the following factors were taken into account:

(1) The distribution of the Vryheid Formation.

(2) The thickness of overburden, i.e. the areas depicted in Fig. 3.2.

(3) The presence of possible refractory clay as described in the logs of boreholes drilled for coal and gold.

(4) The location of existing and planned townships.

(5) The proximity to railways and existing refractory-clay kilns.

The positions of these initial 10 boreholes (ER 1 to ER 10) are indicated on Fig. 3.2 and a description of the cores is presented in Appendix 2. The most promising intersections of refractory clay were obtained from boreholes ER 1 on Modderfontein 76 IR, ER 3 on Daggafontein 125 IR and ER 5 on Rietfontein 276 IR. Borehole ER 2 on Rietfontein

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128 IR also intersected refractory clay at mineable depth but as this merely indicated the extension of a deposit which was being mined immediately to the south, it was decided to rather concentrate follow-up drilling on the newly discovered sites mentioned above. No Karoo sediments were found in borehole ER 4 on Daggafontein 125 IR, indicating the presence of a small window of dolomite at this locality. No clay of any significance was intersected in borehole ER 6 on Bloemendal 283 IR, ER 8 on Rietkuil 249 IR, ER 9 on Strehla 261 IR and ER 10 on Heuvelfontein 215 IR; the normal stratigraphic position of refractory clay, i.e. just above carbonaceous sediments at the base of the Vryheid Formation, is mostly occupied by shale and sandstone in these areas, pointing to higher-energy conditions which inhibited clay deposition.

Of all the boreholes which were not subsequently followed up by additional drilling, ER 7 on Moabsvelden 248 IR is probably the most significant. As indicated in Appendix 2, 1,7 m of semi-flint and plastic clay was intersected beneath an overburden of 13,8 m. No further investigations were carried out because of the distance from kilns on the near-East Rand and the excessive overburden. This site could, however, become a promising target in future, especially in the event of the underlying coal being extracted by open-cast methods. The entire intersection of coal and carbonaceous shale from borehole ER 7 was submitted to the Fuel Research Institute for analysis and the results indicate that a 4,77 m thick seam of fairly good quality steam coal is present at a depth of between 32,46 and 37,23 m. The ash content varies between 19,3 and 26,2 per cent but the material can be upgraded to 16,0 and 21,9 per cent ash respectively at a yield of between 85,9 and 76,1 per cent. It is therefore recommended that further drilling be carried out, particularly in the area immediately to the north of ER 7 where the clay could be expected to occur at shallower depth.

3.3.3 Follow-up Drilling

Before follow-up drilling commenced, the feasibility of using geophysical methods to assist in delineating the clay deposits was investigated in an attempt to reduce the high costs involved in this part of the project. An experiment was conducted with electrical resistivity measurements on the plastic refractory-clay deposit on Vlakfontein 161 IR where the distribution of the clay and the over and underlying rock types had been well established by drilling. The results were, however, disappointing as this technique could not distinguish between refractory clay and the overlying weathered shale. Not even the pre-Karoo contact could be detected because of the deeply weathered nature of the underlying lava of the

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Ventersdorp Group. This left no alternative but to use core drilling for further investigation of the clay indicated by reconnaissance boreholes on Modderfontein 76 IR, Daggafontein 125 IR and Rietfontein 276 IR.

3.3.3.1 Modderfontein 76 IR

The area investigated is situated on Portion 1 of the farm, about 6 km due east of Benoni and on the old New Modder gold-mining lease area. A total of 13 boreholes were drilled around the initial borehole ER 1; ten of the holes were sited south of the road between Benoni and the old Modder B gold mine, while the other three were sunk immediately to the north of this road (Fig. 3.4). The latter three holes were drilled as a result of a township application on this particular piece of land shortly after the discovery of clay in ER 1. As only one of these three holes (ER 1/3) intersected a thin layer of impure clay (see Appendix 2), permission for township establishment was granted on the area to the north of the Modder B road.

As indicated by the geological sections (Fig. 3.5), the clay deposit pinches out towards the north and west but extends further to the south and east. The probable extension towards the east beyond borehole ER 1/6 is unfortunately rather limited due to the proximity of the Vryheid Formation contact, while in a southerly direction the clay can be expected to occur at increasing depths. The extent of the deposit has therefore been fairly well established, although further drilling will be required prior to exploitation in order to obtain a more accurate idea of variations in thickness and quality. The thickness of the clay as indicated by the boreholes varies between 1,1 and 10 m with an average of 4,5 m. Over most of the area it is directly overlain by lateritic soil but in the central and south-western parts a capping of soft weathered shale is present in addition to the soil cover. The thickness of the overburden varies between 8,4 and 18,6 m with an average of 11,5 m. Although this appears to be somewhat excessive in places, the soft nature of the overburden should render its removal a relatively inexpensive operation. The few thin partings of siltstone, shale, sandstone and grit which occur within the clay zone in parts of the deposit should not cause serious exploitation problems, as they can easily be distinguished from the clay and it should therefore be possible to strip off these unwanted layers as mining progresses.

The clay was deposited on an apparently undulating floor of Dwyka tillite after the most prominent irregularities had been filled up in the central part of the area by one upward-fining cycle of grit, sandstone and siltstone. From borehole ER 1 eastwards, there is a marked

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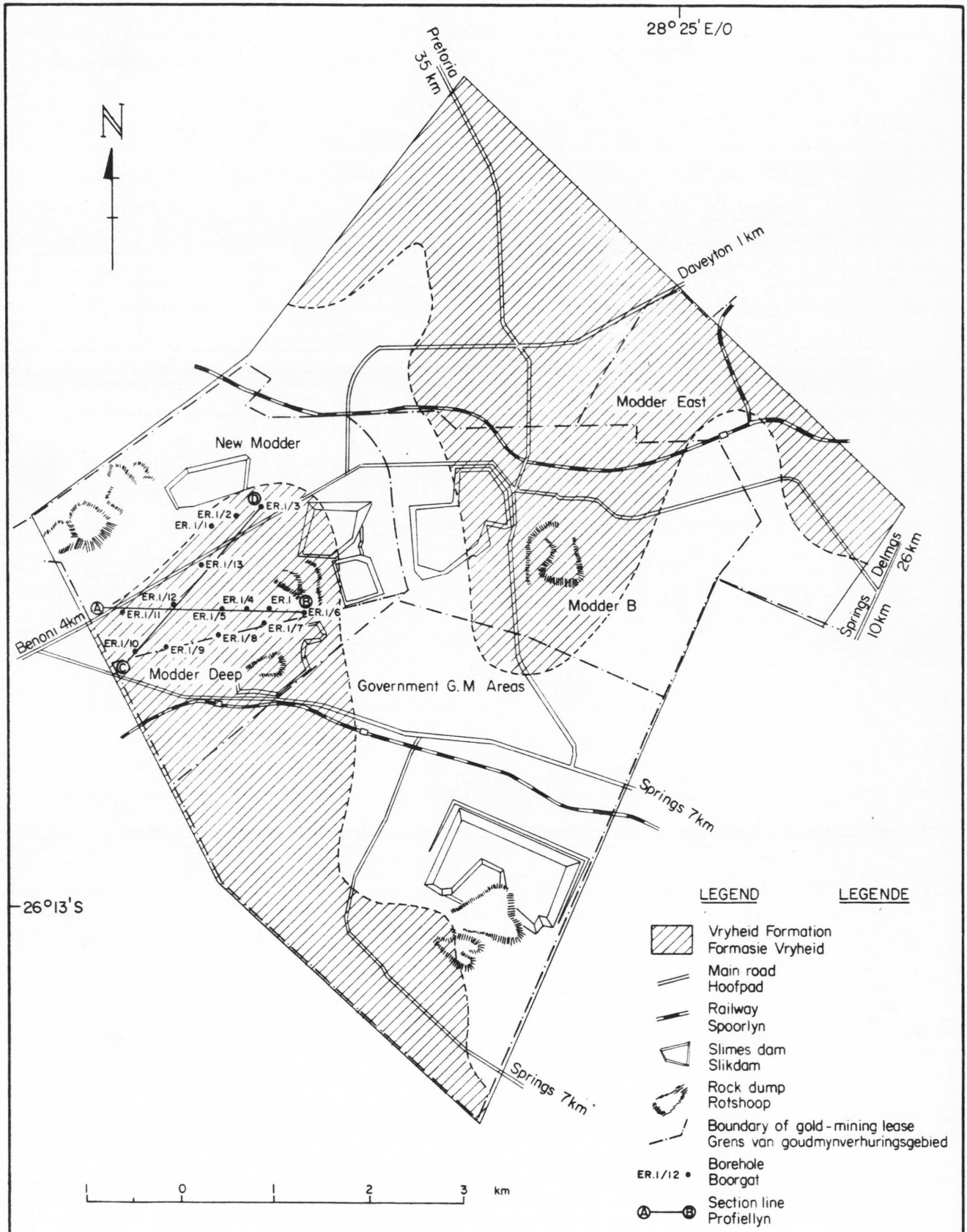

FIG. 3·4 - Location of boreholes on Modderfontein 76 IR.
Posisies van boorgate op Modderfontein 76 IR.

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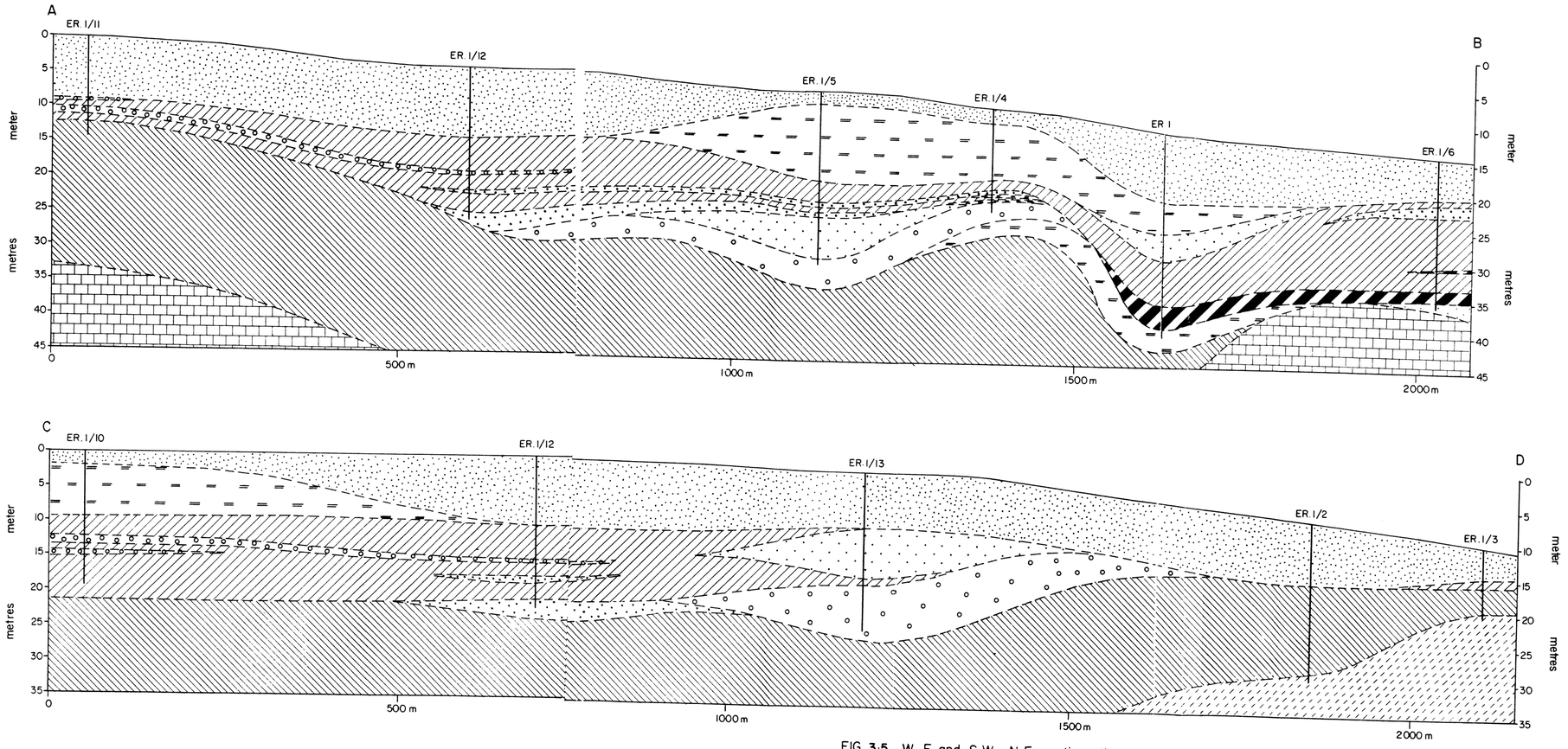

LEGEND

LEGENDE

- Soil / Grond
- Shale / Skalie
- Refractory clay / Vuurvaste klei
- Carbonaceous clay / Koolstofhoudende klei
- Sandstone / Sandsteen
- Grit / Grintsteen
- Siltstone / Sliksteen
- Tillite / Tilliet
- Dolomite / Dolomiet
- Quartzite / Kwartsiet

VRYHEID FORMATION / FORMASIE VRYHEID

DWYKA FORMATION / FORMASIE DWYKA

KAROO SEQUENCE / OPEENVOLGING KAROO

CHUNIESPOORT GROUP / GROEP CHUNIESPOORT

TRANSVAAL **SEQUENCE** / **OPEENVOLGING TRANSVAAL**

WITWATERSRAND SUPERGROUP / SUPERGROEP WITWATERSRAND

FIG. 3·5 -W.-E. and S.W. - N.E. sections through boreholes on Modderfontein 76 IR
W.-O. en S.W. - N.O. profiele deur boorgate op Modderfontein 76 IR

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deepening of the pre-Vryheid Formation floor and the refractory clay is here underlain by carbonaceous clay and shale, indicating the development in these parts of an initially isolated basin where predominantly argillaceous and carbonaceous material accumulated under swampy conditions. This must have offered an excellent environment for refractory clay deposition (Bredell, 1974) and, as will be pointed out below, the best quality clay was indeed proved to be located in this part of the deposit. Cross-bedded sandstone which supposedly overlies the clay deposit stratigraphically is exposed in a few shallow excavations near the railway line on Modder Deep. The cross-beds indicate palaeocurrents in a direction between 98^{o} and 112^{o}, pointing to a possible provenance for the clay situated towards the west and west north-west.

With the exception of sample 114, all the samples tested proved to be refractory clay as defined in Chapter 1 (see Table 3.1). This sample is a composite representing material from five boreholes (ER 1/4, 1/5, 1/7, 1/8 and 1/9) which was grouped together on the basis of striking lithological similarity. As shown in Table 3.2, the reason for the low refractoriness (Seger cone 26^{-}) of the clay intersected in these boreholes is clearly its high iron content (17,29%, Fe_2O_3). The ferruginous nature of these clays is probably largely due to post-depositional contamination but their trace-element composition (Table 3.3) indicates that a different provenance for this part of the deposit could also have been a contributing factor. This is suggested by a higher Ni and Co content which might be the result of material partly derived from a lateritically weathered ultramafic source.

The clays intersected in the remainder of the boreholes can all be classified as low-grade plastic, semi-plastic and semi-flint refractory (Table 3.1). The best quality material is evidently situated in the eastern and western extremities of the deposit around boreholes ER 1/6 and ER 1/11 and having yielded Serger-cone values in the range of 34^{-} to 35, these clays could, according to the generally accepted norm, be regarded as having a good refractoriness. As indicated by their chemical composition, the high fusion temperatures of these samples are not so much due to a high alumina content, but rather to the low percentage of fluxes (iron oxide and alkalies).

Mineralogically, all the samples analysed consist essentially of kaolinite with illite, montmorillonite, sericite and alunite occurring in minor amounts (Table 3.1). Quartz is invariably present in rather high quantities for refractory clay (between 9 and 20 per cent). The presence of alunite in two of the samples (120 and 124) needs special mention because as

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TABLE 3.1 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON MODDERFONTEIN 76 IR

			Physical properties				Classification		Mineralogical composition (Kaolinite is the major constituent of all samples)	
Sample No.	Borehole No.	Depth (m)	PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
19	ER 1	18,60–20,60	31	1,75	33,60	N8–5Y8/4	Plastic	IV	Illite, montmorillonite	10
20	ER 1	20,60–25,20	33	1,62	37,30	5YR6/1–N7	Plastic	IV	Illite, montmorillonite	15
21	ER 1	25,20–28,00	32$^-$	1,68	32,70	N3	Plastic	IV	None	15
	ER 1/4	10,30–11,70								
	ER 1/5	13,10–16,00								
114	ER 1/7	11,10–14,30	26$^-$	1,86	30,60	10YR7/4–10YR8/2	N.r.**	–	Illite	18
	ER 1/8	10,40–13,40								
	ER 1/9	10,40–12,70								
115	ER 1/6	9,10–15,10	28	1,77	32,70	5YR8/1–5YR7/2	Plastic	IV	Illite	12
116	ER 1/6	15,10–15,80	35	2,15	16,80	N7–5YR8/1	Semi-flint	III	None	15
117	ER 1/6	16,25–18,10	34$^-$	1,97	24,10	5YR8/1–5YR7/2	Semi-plastic	IV	Illite	15
118	ER 1/6	18,10–18,90	34	2,14	20,00	N7	Semi-flint	IV	None	14
119	ER 1/10	13,40–14,40	33$^+$	1,84	29,50	N7	Plastic	IV	Sericite	20
120	ER 1/10	15,10–20,00	33	1,71	34,80	N7–10YR7/4	Plastic	IV	Illite, alunite	14
121	ER 1/11	9,50–10,20	34	n.d.	n.d.	N8	Plastic	IV	Sericite, montmorillonite	12
122	ER 1/11	11,45–12,30	33	n.d.	n.d.	5R 8/2	Plastic	IV	Illite, montmorillonite	18
123	ER 1/12	18,20–19,20	30$^-$	1,98	24,30	10YR7/4	Semi-plastic	IV	None	15
124	ER 1/12	19,20–20,80	33$^+$	1,65	37,20	10YR8/2–5YR8/4	Plastic	IV	Montmorillonite, alunite	9

*PCE = Pyrometric cone equivalent **N.r. = Non-refractory n.d. = Not determined

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TABLE 3.2 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON MODDERFONTEIN 76 IR

Sample No.*	19	20	21	114	115	116	117	118	119	120	121	122	123	124
SiO_2	56,26	54,99	49,92	50,89	52,52	51,22	54,96	49,93	52,78	50,25	52,65	52,90	50,82	49,48
TiO_2	0,85	1,58	1,28	0,73	1,28	1,20	1,11	1,06	0,91	0,86	0,87	2,40	1,40	1,55
Al_2O_3	28,87	30,05	30,47	20,05	28,13	33,83	30,43	31,17	32,12	32,39	31,90	33,40	29,22	30,33
Fe_2O_3	<0,10	0,67	0,38	17,29	3,11	<0,10	0,65	1,51	1,09	1,37	1,39	0,77	3,63	1,44
FeO	<0,15	<0,15	<0,15	<0,15	<0,15	0,04	<0,10	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15
MnO	0,01	0,02	0,02	0,10	0,03	0,01	0,01	0,02	0,01	0,03	0,02	0,02	0,01	0,01
MgO	0,92	0,91	0,82	0,53	0,89	0,71	0,84	0,72	0,89	0,85	0,89	0,30	0,78	0,72
CaO	0,11	0,12	0,31	0,09	0,12	0,06	0,13	0,10	0,09	0,04	0,04	0,09	0,08	0,11
Na_2O	0,08	0,08	0,07	0,05	0,06	0,03	0,06	0,05	0,07	0,07	0,07	0,05	0,06	0,08
K_2O	0,81	0,41	0,23	0,72	0,36	<0,01	0,41	0,21	1,15	0,91	0,90	0,39	0,38	0,95
P_2O_5	0,07	0,12	0,06	0,08	0,11	0,11	0,07	0,06	0,07	0,07	0,07	0,09	0,07	0,31
CO_2	0,47	1,25	7,90	0,40	1,16	0,35	1,43	0,81	0,24	0,66	0,21	0,38	0,24	1,02
H_2O^+	9,85	10,04	7,14	9,46	10,72	11,73	9,93	12,96	10,73	11,09	10,51	9,68	12,97	12,77
Total	99,31	100,24	98,60	100,39	98,49	99,26	100,03	98,61	100,15	98,60	99,53	100,62	99,66	98,78
H_2O^- on air-dried sample	1,00	0,88	1,14	1,31	0,02	0,88	0,96	1,11	0,90	0,77	0,55	0,61	0,97	0,60
Al_2O_3 on a calcined basis	32,27	33,84	35,90	22,23	31,98	38,51	34,31	36,21	36,08	36,75	35,75	37,12	33,69	35,26
pH	6,6	6,8	6,3	6,30	6,4	6,4	6,2	5,9	6,8	6,2	6,3	5,9	6,7	6,7

*See Table 3.1 for sample positions

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TABLE 3.3 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON MODDERFONTEIN 76 IR

Sample No.*	19	20	21	114	115	116	117	118	119	120	121	122	123	124
V	104	89	70	66	123	91	96	193	142	169	137	169	126	120
Co	16	15	20	39	35	32	18	19	18	32	31	31	18	14
Ni	56	24	26	116	59	12	27	37	57	55	58	22	62	111
Cu	49	88	77	71	74	37	81	33	54	90	45	69	90	85
Zn	55	48	53	118	131	84	182	222	47	59	43	39	61	55
Ga	29	34	30	27	34	35	32	31	32	35	29	36	32	35
Ge	< 5	6	10	< 5	5	6	5	< 5	5	11	6	10	7	8
Rb	65	42	33	65	43	22	65	40	91	37	81	24	36	34
Sr	33	131	39	25	74	40	24	23	21	658	23	448	30	1 124
Y	47	67	53	46	88	44	51	32	41	75	45	87	42	87
Zr	259	401	339	259	534	339	289	276	293	600	319	557	262	522
Nb	21	36	29	26	31	33	25	25	27	46	25	40	28	34
Mo	11	6	13	12	14	< 5	10	10	11	5	< 5	19	21	20
Sn	10	10	5	1	32	35	8	5	13	19	26	12	< 1	< 1
Sb	9	4	< 1	1	32	34	5	3	8	15	31	5	< 1	< 1
W	< 1	< 1	< 1	1	1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	19	33	29	43	31	15	17	33	24	45	22	72	12	124
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	21	32	38	14	49	42	40	27	22	88	16	75	18	59
U	< 1	6	2	1	8	4	< 1	< 1	< 1	19	< 1	13	3	31
As	< 5	< 5	< 5	5	< 5	< 5	< 5	< 5	< 5	22	< 5	7	26	45
S	30	10	30	98	368	155	<10	<10	175	5 293	219	1 085	145	7 769

*See Table 3.1 for sample positions

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far as could be established, this mineral has not previously been identified in South African refractory clays. It is represented by only a few peaks on the X-ray diffraction diagram (at 2,99 Å, 3,50 Å, 4,98 Å and 5,75 Å) but its presence was subsequently verified by means of differential thermal analysis and it is also reflected in the relatively high sulpur content of the two samples concerned. According to Searle and Grimshaw (1959), alunite is formed through hydrothermal alteration of igneous rocks which are rich in alkalies and it is commonly found associated with halloysite clays. The latter clay mineral has, however, not been identified in any of the local refractory clays in spite of extensive electron-microscope studies. Clays containing small amounts of alunite are used in the U.S.A. for the manufacture of ladle bricks because the liberation of sulphur dioxide at the temperature of service gives rise to expansion which seals the joints between adjacent bricks, preventing the penetration of molten metal (Searle and Grimshaw, 1959). It might therefore be worthwhile to investigate the possibility of utilising some of the Modderfontein clays for this specialised purpose.

A study of the microstructure of the clays by means of electron microscopy revealed that the plastic types consist mainly of well-orientated, anhedral flakes of kaolinite varying in size from about 0,9 to 5,5 μm in diameter (Fig. 3.6). In rare cases, curved kaolinite booklets of up to 50 μm long were observed (Fig. 3.7). Well-developed booklets of kaolinite as well as occasional hexagonal plates are, however, commonly present in the non-refractory clays (Fig. 3.8). By virtue of their fragility, these structures could not have been transported and must have grown *in situ,* indicating that a substantial proportion of the kaolinite in this part of the deposit was probably formed by post-depositional weathering of originally detrital feldspar grains. The semi-flint clay from borehole ER 3/6 exhibits a particle-size distribution similar to that of the plastic clays but the orientation is more random and there is a clear tendency towards an edge-to-face type of arrangement in places (Fig. 3.9). The significance of texture as related to the bulk physical properties of the clays will be dealt with in Chapter 5.

The total indicated clay resources in the Modderfontein deposit amount to 11,6 Mt as reported by Bredell (1978). These resources can be further subdivided as follows:

(1) Semi-flint, semi-plastic and plastic clay of good refractoriness (PCE 34^- to 35) : 1,2 Mt.

(2) Semi-plastic and plastic clay of low refractoriness (PCE 28 to 33^+) : 8,8 Mt.

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Fig. 3.6 Typical fine-grained, well-orientated kaolinite in plastic refractory clay on Modderfontein 76 IR. Magnification 1 800X.

Tipiese fynkorrelrige, goedgeoriënteerde kaoliniet in plastiese vuurvaste klei op Modderfontein 76 IR. Vergroting 1 800X.

Fig. 3.7 A rare, curved kaolinite booklet in plastic refractory clay on Modderfontein 76 IR. Magnification 1 500X.

'n Skaars, geboë kaolinietboekie in plastiese vuurvaste klei op Modderfontein 76 IR. Vergroting 1 500X.

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Fig. 3.8 A typical kaolinite booklet in non-refractory clay on Modderfontein 76 IR. Magnification 4 000X.

'n Tipiese kaolinietboekie in nie-vuurvaste klei op Modderfontein 76 IR. Vergroting 4 000X.

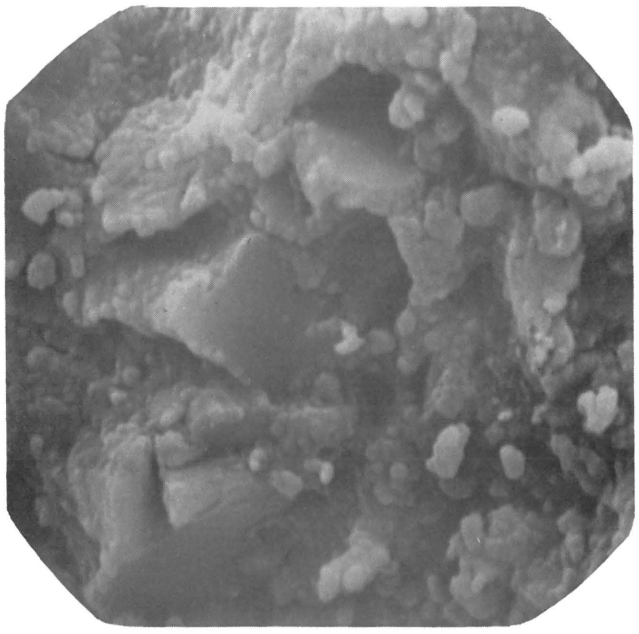

Fig. 3.9 Tendency to edge-to-face orientation of kaolinite plates in semi-flint clay on Modderfontein 76 IR. Magnification 3 600X.

Neiging tot kant-tot-vlak oriëntasie van kaolinietplaatjies in semi-flintklei op Modderfontein 76 IR. Vergroting 3 600X.

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(3) Ferruginous, non-refractory plastic clay (PCE 26⁻) : 1,6 Mt.

The main attraction of the Modderfontein deposit is its favourable setting with regard to infrastructure. It could probably be best exploited in the form of a joint venture between the refractories and brick-making industries, utilising the non-refractory and part of the low-refractory clays for the manufacture of possibly face bricks, while extracting the better-quality refractory clay at the same time. The deposit has been reserved for clay-mining purposes and is therefore safeguarded against urban development.

3.3.3.2 Daggafontein 125 IR

The area concerned is located about 7 km south-east of Springs near Daggafontein siding. Thirteen follow-up holes were drilled around reconnaissance borehole ER 3 on Portions 101, 112 and 113 of the farm within the old Daggafontein and Vogelstruisbult gold-mining lease areas (Fig. 3.10). Descriptions of the borehole core are presented in Appendix 2.

As illustrated in the geological sections (Fig. 3.11), the clay deposit appears to extend in all directions beyond the area covered by follow-up drilling. Towards the south and south-west, however, the thickness of the overburden increases rapidly, ruling out open-cast exploitation to the south of a line running approximately through boreholes ER 3/10 and ER 3/12. The true extent of this deposit has therefore not been established during the present investigation and further drilling, particularly to the north, might delineate substantial additional resources. In the south-western part of the area (boreholes ER 3/10 and 3/11), two clay layers have been indicated of which the lower one is not regarded as economically exploitable due to excessive overburden. The thickness of the clay, excluding the lower layer in the south-west, varies from 1,2 to 10,7 m with an average of 3,6 m. It attains a maximum in the south-east (borehole ER 3/6) and in contrast to the thicker parts of the Modderfontein deposit, no interbedded non-clay material is present. The overburden consists predominantly of soil and soft weathered shale, except in the north-west (boreholes ER 3/7, 3/8 and 3/9) where the clay is capped by weathered grit and sandstone. The thickness of the overburden varies from 3,5 to 15,9 m with an average of 8,8 m. As shown in Fig. 3.10, part of the deposit is overlain by an old slimes dam. This should, however, pose no serious problems to possible future mining of the clay, as the dump is on average only about 2 m high. In constructing Fig. 3.11, the slimes were included in the soil layer.

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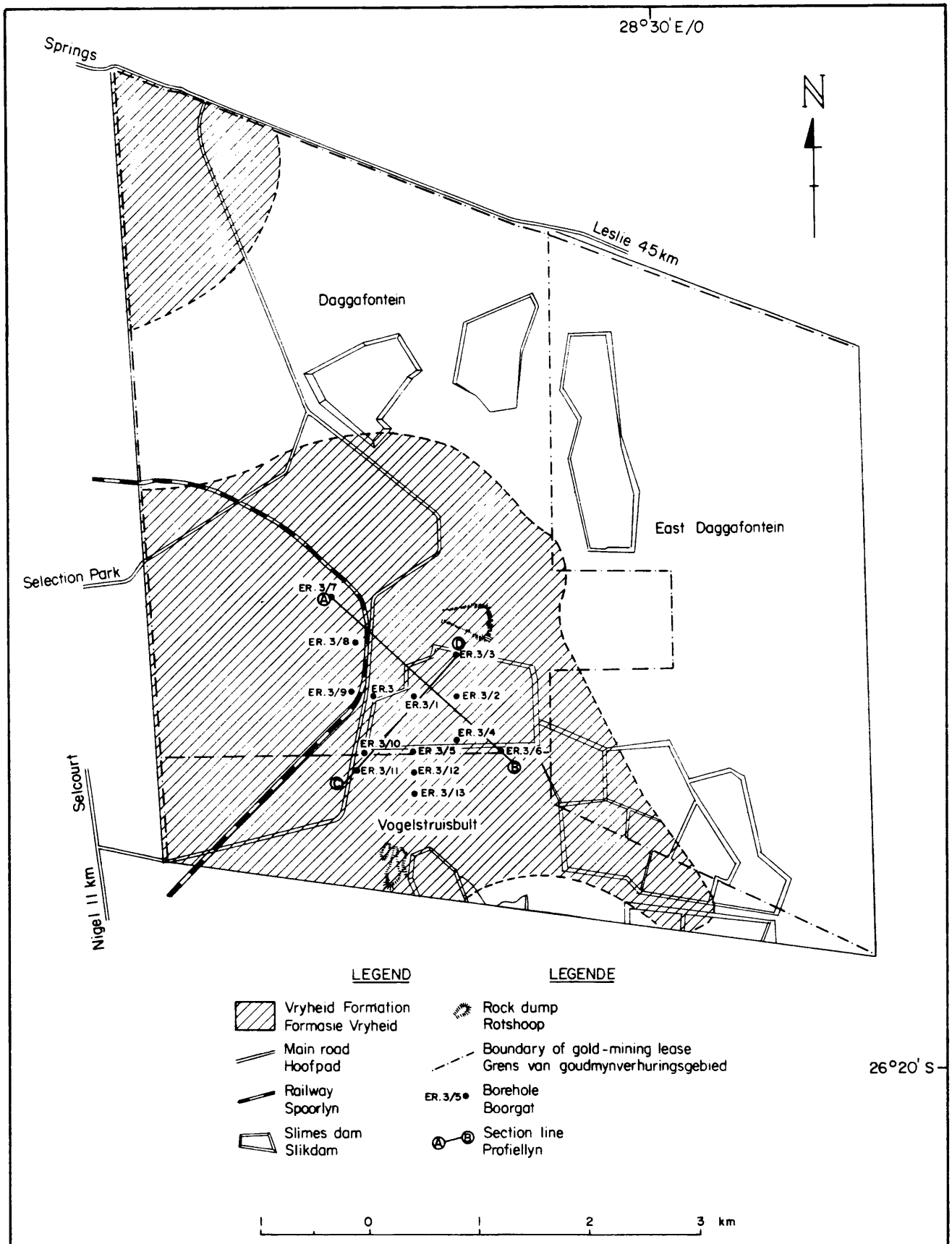

FIG. 3·10 Location of boreholes on Daggafontein 125 IR.
Posisies van boorgate op Daggafontein 125 IR.

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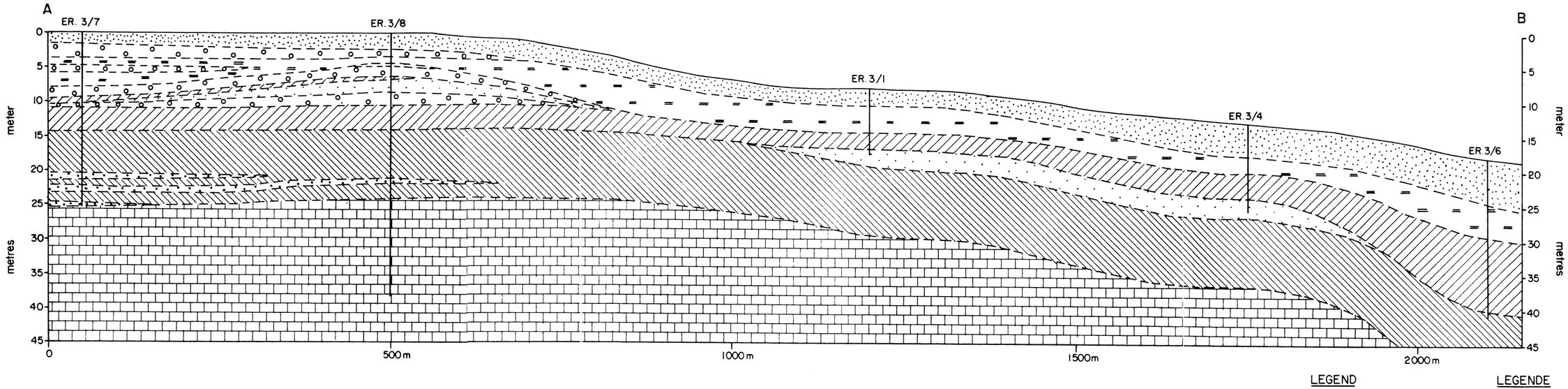

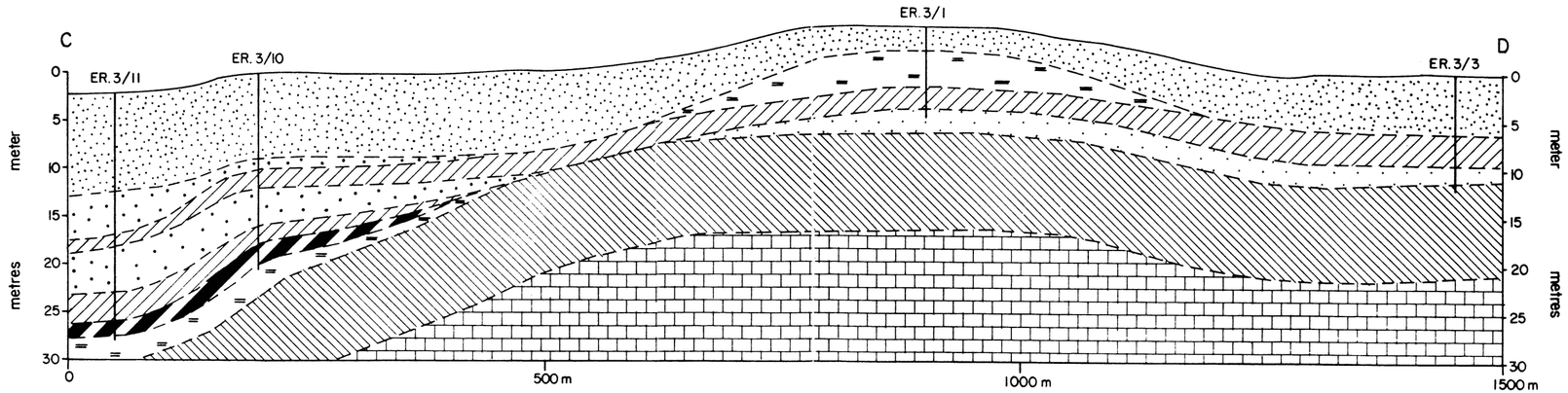

LEGEND LEGENDE

- Soil / Grond
- Grit / Grintsteen
- Shale / Skalie
- Sandstone / Sandsteen
- Siltstone / Sliksteen
- Refractory clay / Vuurvaste klei
- Carbonaceous clay / Koolstofhoudende klei
- Tillite and siltstone / Tilliet en sliksteen
- Dolomite / Dolomiet

VRYHEID FORMATION / FORMASIE VRYHEID

DWYKA FORMATION / FORMASIE DWYKA

CHUNIESPOORT GROUP / GROEP CHUNIESPOORT

KAROO SEQUENCE / OPEENVOLGING KAROO

TRANSVAAL SEQUENCE / OPEENVOLGING TRANSVAAL

FIG. 3·11.- N.W.- S.E. and S.W.- N.E. sections through boreholes on Daggafontein 125 IR
N.W.- S.O. en S.W.- N.O. profiele deur boorgate op Daggafontein 125 IR

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In the north-eastern part of the deposit, the clay was deposited on an almost flatlying floor of Dwyka Formation and the clay itself appears to maintain a very constant thickness in this area. Along the gentle south-easterly slope of the Dwyka Formation further to the south, a lenticular layer of sandstone was deposited, separating the clay from the underlying tillite. In the extreme south-eastern,southern and south-western parts of the area drilled, the pre-Vryheid Formation floor deepens steeply into what might have been a rather extensive, initially isolated, swampy basin as evidenced by the presence of carbonaceous clay and shale in its lower parts (see boreholes ER 3/6, 3/10, 3/11, 3/12 and 3/13 in Appendix 2). Unlike the Modderfontein deposit, the better-quality clays are not confined here to areas underlain by carbonaceous material, showing that a low-energy, acid environment suitable for refractory-clay deposition also existed beyond the limits of the deeper parts of a swampy basin. Cross-bedded sandstone and grit exposed along the railway line to the south-west of the deposit indicate palaeocurrents from the north-west in a direction between 123^{o} and 136^{o}.

As shown in Table 3.4, all the boreholes intersected clay which can be classified as refractory, ranging in type from predominantly plastic through semi-plastic to semi-flint. The better-quality clays, i.e. those with PCE values of between 34^{-} and 35, are more abundant in the western part of the area drilled with seemingly isolated occurrences around boreholes ER 3/3 and ER 3/6 in the north and south-east. The thickest succession of these more refractory clays was intersected in the latter borehole where they constitute the lower 3,6 m of a 10,7 m thick clay zone. By close comparison of the major-element compositions presented in Table 3.5 in conjunction with the mineralogical compositions (Table 3.4), clays with a higher refractoriness can in most cases be readily distinguished from their less refractory counterparts. The former invariably contain either more alumina, less iron oxide, less alkalies or less quartz than the latter. The trace-element composition on the other hand seems to have no direct bearing on the refractoriness of the clays (Table 3.6). A very interesting observation is, however, that samples with PCE values in the range 34^{-} to 35 generally have a lower Rb content than those which proved to be less refractory. This relationship is particularly distinct when comparing adjacent samples from the same borehole, e.g. sample 25 from borehole ER 3 has a PCE of 34^{+} and contains 16 ppm Rb in contrast to the over and underlying material (PCE 32 and 31) with Rb contents of 58 and 27 ppm respectively. As these low concentrations of Rb can obviously not affect the fusion temperatures of the clays to a noticeable degree, it is more logical to assume that the bulk Rb content reflects the relative abundance of less refractory minerals such as illite and mixed-layer clays which have been shown by Horstman (1957) to contain generally more Rb than kaolinite (see Chapter 5).

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TABLE 3.4 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON DAGGAFONTEIN 125 IR

			Physical properties				Classification		Mineralogical composition (Kaolinite is the major constituent of all samples)*	
Sample No.	Borehole No.	Depth (m)	PCE**	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
24	ER 3	3,50–5,30	32	1,74	34,20	N8–10YR8/2	Plastic	IV	Montmorillonite, illite	10
25	ER 3	5,30–5,80	34+	2,27	12,50	N8–N7	Semi-flint	I	None	1
26	ER 3	5,80–7,00	31	1,87	28,20	N7–N8	Plastic	IV	Illite	35
28	ER 3/1	6,30–8,60	33-	2,08	20,40	N8	Semi-flint	IV	Illite, montmorillonite	20
29	ER 3/2	9,40–9,90	33-	1,90	26,50	N8	Semi-plastic	IV	Illite, montmorillonite	20
30	ER 3/2	10,20–10,60	33	1,90	26,20	N8–N7	Semi-plastic	IV	Illite, montm., illite-montm.	15
31	ER 3/3	6,60–7,00	30	1,74	34,30	N8	Plastic	II	Illite, montmorillonite	3
32	ER 3/3	7,00–9,10	34-	1,99	22,90	N8	Semi-plastic	IV	Illite	10
33	ER 3/4	7,00–8,30	30-	1,87	28,60	N9–5Y8/1	Plastic	IV	Illite, montmorillonite	10
34	ER 3/4	8,30–9,70	31	1,67	35,90	5 RP 8/2	Plastic	IV	Illite, montmorillonite	8
35	ER 3/4	9,80–10,20	33	1,74	33,60	5 RP 8/2	Plastic	IV	Illite, montm., illite-montm.	1
36	ER 3/5	5,20–7,40	30-	2,09	17,30	Multi-coloured	Semi-flint	IV	Illite, montm.,illite-montm.	15
37	ER 3/6	11,20–11,80	31	1,79	30,80	N9–5YR8/1	Plastic	IV	Illite, montmorillonite	15
38	ER 3/6	11,80–12,90	30-	2,15	10,30	5Y8/1–5Y6/4	Semi-flint	IV	Illite, montmorillonite	22
39	ER 3/6	13,50–14,00	33	1,99	21,90	5YR8/1–N8	Semi-plastic	IV	Illite, montmorillonite	8
40	ER 3/6	14,10–16,20	32	1,86	28,00	N8–5YR6/1	Plastic	II	Illite, montm., illite-montm.	1
41	ER 3/6	16,20–17,40	34	1,88	26,40	N8–5YR6/1	Plastic	II	Illite, montm., illite-montm.	1
42	ER 3/6	17,50–19,30	35-	1,88	27,50	5YR6/1–5YR8/1	Plastic	II	Illite, montmorillonite	1
43	ER 3/6	19,30–19,80	34-	1,77	32,00	5YR4/1	Plastic	II	Illite, montmorillonite	0

*Samples 42 and 43 also contain illite-montmorillonite as major constituent in addition to kaolinite.

**PCE = Pyrometric cone equivalent

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TABLE 3.4 (Continued)

			Physical properties				Classification		Mineralogical composition (Kaolinite is the major constituent of all samples)	
Sample No.	Borehole No.	Depth (m)	PCE	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
97	ER 3/7	9,50–9,95	33⁻	2,06	21,40	N9–10YR8/2	Semi-flint	IV	Sericite	15
98	ER 3/7	10,80–12,20	31	1,66	36,40	N9–10YR7/4	Plastic	III	None	2
99	ER 3/7	12,20–12,50	35	2,10	18,20	N8	Semi-flint	II	Illite	<1
100	ER 3/7	12,50–14,20	34	1,83	29,50	N8	Plastic	III	Illite	10
101	ER 3/8	10,30–11,00	34	1,68	34,90	N9	Plastic	II	Vermiculite, alunite	4
102	ER 3/8	11,00–11,80	32⁻	1,76	32,10	10YR8/2–5YR7/2	Plastic	II	Montmorillonite, illite	2
103	ER 3/8	11,80–12,65	35	1,88	26,30	N8–10YR8/2	Plastic	II	Illite	<1
104	ER 3/8	12,65–13,50	35⁻	1,85	28,30	N8	Plastic	IV	Illite	20
105	ER 3/9	6,00–7,70	33	1,99	21,20	N8–N7	Semi-plastic	IV	Sericite	10
106	ER 3/9	7,70–9,50	33	2,05	20,80	10YR8/2–N7	Semi-flint	IV	Montmorillonite, sericite	10
107	ER 3/9	9,50–10,80	35⁻	2,27	12,10	N7	Semi-flint	II	None	<1
108	ER 3/9	10,80–11,50	33⁺	1,85	27,10	N7	Plastic	III	Montmorillonite, illite	10
125	ER 3/10	16,00–17,00	32⁻	1,98	24,60	5YR5/6–5YR6/1	Semi-plastic	IV	Montmorillonite, illite, alunite	35
126	ER 3/10	17,00–17,90	33	1,93	25,60	5YR5/2	Semi-plastic	IV	Montmorillonite, illite, alunite	20
127	ER 3/11	20,80–22,90	32⁻	1,71	33,40	5YR5/5–5YR6/1	Plastic	IV	Montmorillonite, illite	30
128	ER 3/11	22,90–24,00	34⁻	1,49	40,60	10YR6/2	Plastic	II	Montmorillonite, illite, alunite	4
129	ER 3/12	20,60–23,00	33	1,74	32,50	5YR5/6–5YR6/1	Plastic	IV	Montmorillonite, illite	20
130	ER 3/13	15,90–17,40	33	2,13	18,00	5R4/2–5YR5/2	Semi-flint	IV	Montmorillonite, illite	20

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TABLE 3.5 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON DAGGAFONTEIN 125 IR

Sample No.*	24	25	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
SiO_2	48,26	44,14	52,09	55,40	53,94	51,98	45,50	51,58	51,31	48,21	43,84	50,64	49,07	54,46	51,14	42,01	45,80	44,32	42,94
TiO_2	1,54	1,55	1,76	0,91	0,85	1,06	1,43	2,08	1,22	1,85	1,58	1,44	0,95	1,43	1,46	1,81	2,35	1,50	1,73
Al_2O_3	32,09	38,60	32,62	32,30	30,36	32,22	34,90	32,13	30,42	31,10	32,11	28,64	31,73	26,64	28,91	37,08	36,30	36,88	36,25
Fe_2O_3	4,16	1,16	0,45	0,90	0,73	0,98	3,20	1,23	3,07	2,18	2,57	2,28	2,00	2,42	0,11	0,67	1,02	0,15	0,67
FeO	< 0,15	< 0,15	< 0,15	<0,15	<0,10	<0,15	< 0,15	< 0,15	< 0,15	1,19	0,75	1,21	0,82	0,88	1,41	<0,15	<0,15	0,25	< 0,01
MnO	0,03	0,07	0,01	0,02	0,01	0,02	0,03	0,02	0,09	0,02	0,03	0,03	0,02	0,01	0,01	0,03	0,03	0,01	0,01
MgO	0,92	0,69	0,77	0,25	0,90	0,96	0,78	0,79	0,96	0,07	1,19	1,04	1,04	1,05	1,06	1,03	0,22	1,19	0,97
CaO	0,11	0,08	0,08	0,12	0,10	0,11	0,11	0,11	0,23	0,21	0,38	0,25	0,15	0,16	0,22	0,31	0,23	0,78	0,99
Na_2O	0,06	0,05	0,05	0,06	0,12	0,10	0,10	0,08	0,13	0,14	0,36	0,21	0,09	0,09	0,13	0,36	0,06	0,85	0,44
K_2O	0,51	<0,01	0,08	0,82	0,83	0,89	0,16	0,13	1,01	0,75	1,17	0,76	0,56	0,75	1,09	0,89	0,80	0,49	0,58
P_2O_5	0,12	0,07	0,07	0,23	0,06	0,06	0,21	0,50	0,31	0,32	0,32	0,23	0,07	0,06	0,34	0,35	0,07	0,13	0,09
CO_2	1,07	0,33	0,75	0,41	0,47	0,63	0,43	0,57	1,16	1,14	4,00	1,26	0,97	0,47	1,09	1,32	0,85	2,02	1,66
H_2O^+	11,66	13,35	11,73	8,00	10,37	10,90	13,16	11,26	10,46	12,81	11,88	11,61	11,30	10,00	12,22	13,34	12,11	11,22	13,88
Total	100,53	100,09	100,75	99,57	98,73	99,91	99,99	100,08	100,38	99,98	100,17	99,61	98,65	98,43	99,18	99,19	99,99	99,78	100,21
H_2O^- on air-dried sample	1,10	0,49	0,77	0,70	0,71	1,06	0,80	0,84	1,17	0,90	1,94	1,45	1,18	1,26	0,96	1,53	1,80	2,25	2,12
Al_2O_3 on a calcined basis	36,72	44,71	37,24	35,28	34,10	36,42	40,39	36,41	34,38	36,13	37,60	32,89	36,20	29,81	33,39	43,51	41,71	42,52	42,92
pH	6,4	6,0	6,7	6,0	6,1	6,3	6,8	6,1	6,1	6,1	6,1	6,1	6,2	6,3	6,3	6,3	6,3	6,2	6,2

*See Table 3.4 for sample positions

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TABLE 3.5 (Continued)

Sample No.*	97	98	99	100	101	102	103	104	105	106	107	108	125	126	127	128	129	130
SiO_2	51,34	42,16	45,12	47,91	43,06	42,85	45,04	51,36	52,10	47,60	44,82	49,85	59,12	50,69	57,14	38,52	54,00	60,70
TiO_2	1,39	1,46	1,15	2,49	1,27	1,72	1,25	2,31	1,22	1,59	1,15	1,71	1,60	1,53	1,46	1,17	1,07	0,97
Al_2O_3	32,97	33,35	37,74	33.37	36,53	34,70	37,81	32,56	32,20	31,58	37,45	33,79	25,25	29,82	27,37	31,97	30,88	26,10
Fe_2O_3	0,51	5,02	1,24	1,58	1,95	4,43	1,14	0,34	2,13	4,27	1,12	0,69	1,71	1,95	1,45	1,79	1,24	1,60
FeO	0,86	0,99	<0,10	<0,15	<0,15	1,53	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15
MnO	<0,01	0,02	0,03	0,01	0,02	0,01	0,02	0,01	0,07	0,03	0,01	0,02	0,02	0,02	0,01	0,01	0,02	0,04
MgO	0,36	0,75	0,65	0,80	0,72	0,87	0,69	0,75	0,42	0,91	0,71	0,80	0,98	0,95	0,93	0,79	1,01	0,36
CaO	0,16	0,10	0,06	0,07	0,12	0,11	0,07	0,05	0,17	0,13	0,09	0,09	0,20	0,28	0,20	0,85	0,19	0,21
Na_2O	0,20	0,11	0,04	0,05	0,09	0,06	0,05	0,06	0,04	0,09	0,01	0,07	0,08	0,09	0,09	0,13	0,07	0,10
K_2O	1,28	0,17	0,01	0,15	0,49	0,20	<0,01	0,05	1,00	0,75	0,01	0,20	0,51	0,59	0,49	0,94	0,49	0,47
P_2O_5	0,07	0,20	0,07	0,08	0,49	0,18	0,06	0,08	0,15	0,19	0,06	0,10	0,09	0,16	0,08	0,47	0,06	0,23
CO_2	0,22	1,02	0,41	0,41	0,78	0,51	0,22	0,35	0,30	0,58	0,31	0,64	0,64	2,29	0,78	14,00	0,64	0,65
H_2O^+	10,67	13,47	13,44	12,06	13,84	12,82	13,46	10,95	10,44	11,41	13,43	11,16	9,28	11,23	9,72	8,81	9,47	7,79
Total	100,05	98,83	99,96	98,98	99,37	100,00	99,81	99,88	100,39	99,14	99,17	99,11	99,48	99,61	99,72	99,46	99,14	99,37
H_2O^- on air-dried sample	0,53	0,97	1,02	0,81	0,82	0,75	0,89	0,71	0,81	0,75	0,90	0,97	0,15	1,08	0,21	1,17	0,78	0,81
Al_2O_3 on a calcined basis	37,00	39,08	43,81	38,18	42,83	40,04	43,82	36,71	36,06	35,92	43,47	38,36	28,05	34,17	30,59	40,96	34,39	28,52
pH	6,3	6,5	6,1	6,3	6,3	6,2	6,1	6,2	6,2	6,3	5,8	6,4	6,8	6,6	6,3	7,0	6,4	6,0

*See Table 3.4 for sample positions

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TABLE 3.6 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON DAGGAFONTEIN 125 IR

Sample No.*	24	25	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
V	149	98	104	106	131	158	91	124	176	142	228	107	137	151	134	137	106	121	123
Co	28	22	34	35	17	16	27	43	24	32	42	20	21	29	16	20	17	42	19
Ni	93	24	103	104	75	82	33	48	65	39	59	51	56	48	26	22	11	23	27
Cu	98	50	64	66	56	67	55	43	94	75	128	85	62	45	75	82	36	90	75
Zn	52	29	37	38	71	50	42	42	67	54	61	54	55	54	45	43	40	49	58
Ga	34	37	36	40	27	29	37	30	40	35	41	31	32	33	32	35	36	33	37
Ge	10	6	7	6	6	6	8	7	7	9	14	10	7	6	9	9	6	7	6
Rb	58	16	27	28	69	64	35	21	78	41	72	51	62	61	47	43	50	35	52
Sr	181	16	22	23	28	29	522	35	859	1 120	1 628	968	43	31	1 168	1 669	65	485	198
Y	109	38	105	106	44	47	45	121	96	62	217	118	69	34	63	86	78	197	145
Zr	504	395	535	541	247	255	392	593	314	506	559	432	348	336	439	640	456	517	591
Nb	37	38	39	41	21	24	32	45	31	33	43	38	24	33	30	37	51	38	40
Mo	20	< 5	7	6	7	9	15	24	9	15	6	14	9	15	13	16	19	19	22
Sn	6	10	10	12	9	8	5	43	3	30	31	8	9	32	9	10	19	32	17
Sb	< 1	4	5	5	6	1	1	36	2	29	33	5	7	33	4	5	< 1	29	8
W	< 1	< 1	< 1	< 1	< 1	< 1	1	1	1	1	1	1	1	1	1	1	< 1	< 1	< 1
Pb	37	24	30	32	21	25	41	32	116	48	59	30	31	6	90	66	44	64	48
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	57	34	65	66	16	15	20	60	32	59	53	52	38	32	66	83	68	73	81
U	7	3	5	5	< 1	1	9	11	11	21	30	12	1	4	22	24	19	38	17
As	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	11	10	25	10	< 5	< 5	11	13	< 5	< 5	< 5
S	147	80	10	91	96	104	1 356	492	360	5 443	5 220	2 046	170	126	5 997	6 123	5 134	6 314	120

*See Table 3.4 for sample positions

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TABLE 3.6 (Continued)

Sample No.*	97	98	99	100	101	102	103	104	105	106	107	108	125	126	127	128	129	130
V	134	257	99	158	108	228	115	106	124	119	113	91	180	104	132	133	83	109
Co	33	40	34	31	22	36	36	35	41	36	34	22	14	17	25	35	29	31
Ni	64	75	17	73	43	89	17	46	15	92	11	57	14	27	14	40	23	19
Cu	60	72	36	56	72	94	34	58	29	107	31	62	50	80	53	100	23	25
Zn	51	54	28	38	42	63	31	35	32	67	33	42	37	35	37	47	37	34
Ga	29	37	34	38	38	38	35	38	37	37	31	37	33	35	33	36	31	30
Ge	5	9	< 5	7	8	10	< 5	8	10	8	7	11	7	7	6	8	6	5
Rb	70	26	16	27	26	25	18	24	22	60	18	31	43	40	42	32	45	47
Sr	63	367	56	43	1 414	280	16	34	17	650	20	121	89	432	67	2 226	29	31
Y	31	119	33	95	116	113	38	117	42	89	37	99	33	47	31	70	19	22
Zr	305	504	365	682	458	559	382	883	356	447	321	661	328	369	287	379	219	259
Nb	24	40	31	49	29	38	31	62	26	36	30	38	36	30	31	25	26	24
Mo	< 5	< 5	< 5	8	< 5	< 5	15	6	13	13	10	12	15	12	13	< 5	8	10
Sn	26	1	19	23	1	23	35	41	19	27	30	9	9	8	52	17	25	22
Sb	32	1	15	14	1	21	34	31	32	39	37	1	< 1	3	36	18	29	31
W	1	1	1	1	1	3	1	1	1	1	1	1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	21	83	16	38	89	64	19	33	21	69	17	32	45	60	39	52	43	41
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	14	63	29	82	82	60	33	125	29	54	32	73	19	38	20	63	16	19
U	1	10	1	8	24	13	5	16	5	4	3	9	2	6	1	38	< 1	< 1
As	< 5	13	< 5	< 5	8	10	< 5	< 5	< 5	15	< 5	< 5	< 5	< 5	< 5	26	< 5	< 5
S	15	401	20	26	166	149	34	78	56	107	240	396	697	2 266	478	10174	192	212

*See Table 3.4 for sample positions

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The main mineralogical difference between the Daggafontein clays and those at Modderfontein is the presence of the mixed-layer clay mineral illite – montmorillonite which, in the case of two samples, was found to be a major constituent in addition to kaolinite. Both these samples proved to have a good refractoriness, however, showing that an overall favourable chemical composition is the predominant factor determining fusion temperature in these cases. The approximate free quartz content was found to be as high as 35 per cent in some samples, but this is obviously compensated for by relatively low alkali and iron-oxide contents which still render them refractory as per definition. Vermiculite was detected as a minor constituent in one of the samples with good refractoriness but seeing that its presence could not be verified during subsequent electron-microscope investigations, it probably occurs in such small quantities that the firing properties of the clay are unlikely to be affected detrimentally. Alunite was again identified in some of the clays from this deposit and it seems to be predominantly associated with material from the deeper part of the basin in the south-west.

The microtextures of the clays are generally very similar to those at Modderfontein, showing predominantly well-orientated anhedral kaolinite flakes in the case of the plastic types (Fig. 3.12) and less well orientated particles in the semi-flint varieties. The main difference seems to be in grain size, with kaolinite particles commonly attaining diameters of up to 50 μm compared to a maximum size of about 5 μm for clays from Modderfontein (see Chapter 5). Kaolinite booklets are very scarce in the semi-flint clays and are much more compact (Fig. 3.13) than the often deformed booklets found in the plastic types (Figs. 3.14 and 3.15). The genetical significance of this difference is discussed in Chapter 4. Although most of the samples have a relatively high zirconium content, zircon crystals were seldom observed on the electron microscope; Fig. 3.16 shows a rare example of a perfectly preserved zircon crystal. Quartz grains are invariably well rounded and up to about 1 mm in diameter; a typical example is shown in Fig. 3.17.

Total indicated clay resources, with the exclusion of the lower layer in the south and south-west, amount to 12,2 Mt (Bredell, 1978). In terms of refractory quality, these resources can be subdivided as follows:

(1) Semi-flint, semi-plastic and plastic clay of good refractoriness (PCE 34^- to 35) : 4,1 Mt.

(2) Semi-flint, semi-plastic and plastic clay of low refractoriness (PCE 30 to 33^+) : 8,1 Mt.

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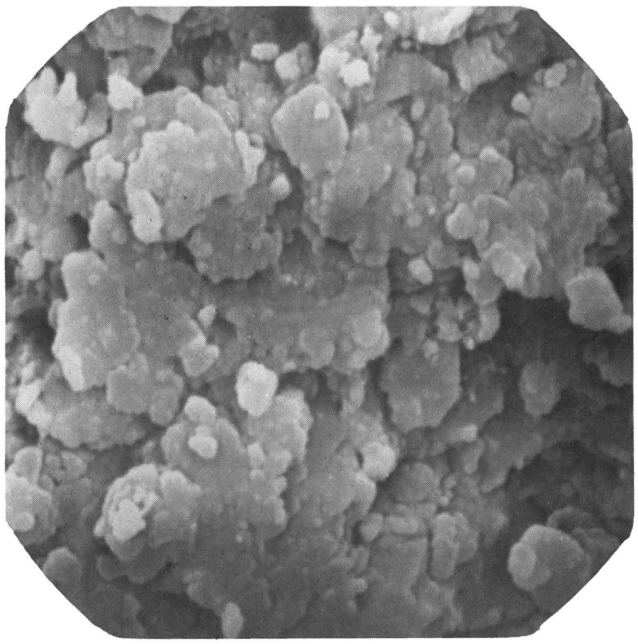

Fig. 3.12 Typical well-orientated kaolinite flakes in plastic refractory clay from Daggafontein 125 IR. Magnification 3 600X.

Tipiese goedgeoriënteerde kaolinietvlokkies in plastiese vuurvaste klei van Daggafontein 125 IR. Vergroting 3 600X.

Fig. 3.13 Compact kaolinite booklet in semi-flint clay from Daggafontein 125 IR. Magnification 1 100X.

Kompakte kaolinietboekie in semi-flintklei van Daggafontein 125 IR. Vergroting 1 100X.

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Fig. 3.14 Completely deformed kaolinite booklet in plastic refractory clay from Daggafontein 125 IR. Magnification 2 600X.

Geheel vervormde kaolinietboekie in plastiese vuurvaste klei van Daggafontein 125 IR. Vergroting 2 600X.

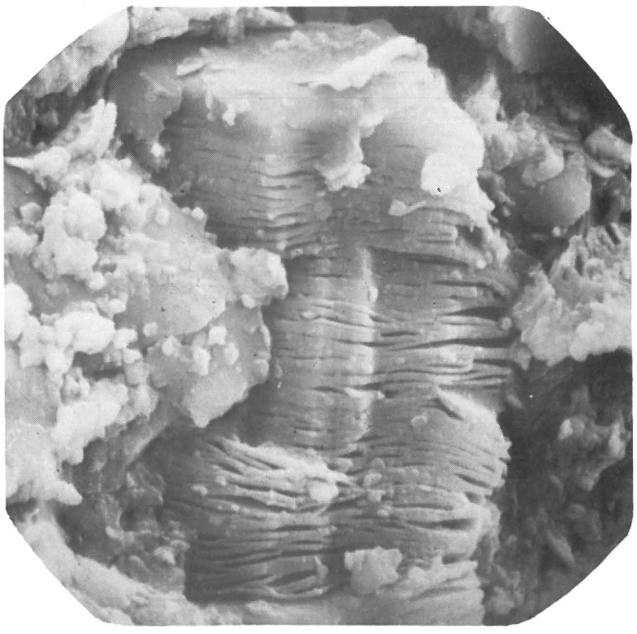

Fig. 3.15 Partly dislocated kaolinite booklet in plastic clay from Daggafontein 125 IR. Magnification 1 800X.

Gedeeltelik verplaasde kaolinietboekie in plastiese klei van Daggafontein 125 IR. Vergroting 1 800X.

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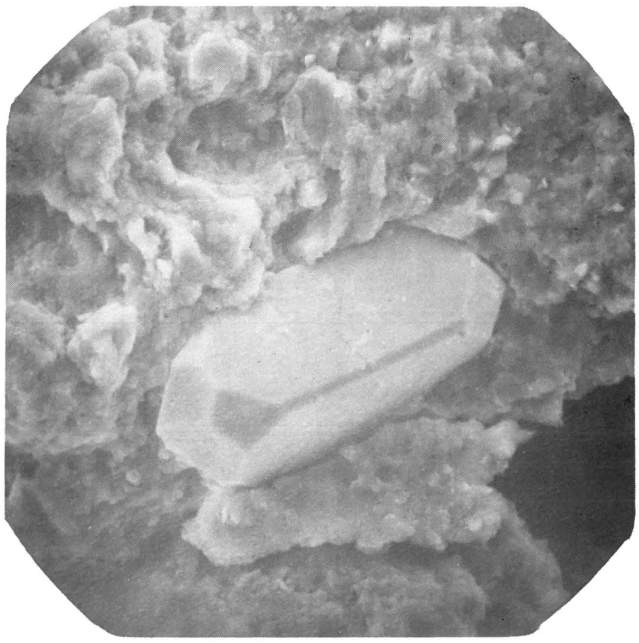

Fig. 3.16 A rare, perfectly preserved zircon crystal in plastic clay from Daggafontein 125 IR. Magnification 780X.

'n Skaars, perfekbewaarde sirkoonkristal in plastiese klei van Daggafontein 125 IR. Vergroting 780X.

Fig. 3.17 Well-rounded quartz grain in plastic clay from Daggafontein 125 IR. Magnification 1 300X.

Goedafgeronde kwartskorrel in plastiese klei van Daggafontein 125 IR. Vergroting 1 300X.

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In the author's opinion, the Daggafontein deposit is a most attractive proposition for future refractory-clay exploitation. It is well situated with respect to infrastructure, the quality of the clay compares favourably with material mined elsewhere on the East Rand, and as a result of the investigation discussed above, this area has been reserved for clay mining.

3.3.3.3 Rietfontein 276 IR

The area investigated is situated about 12 km due east of Springs and 3 km north-west of Endicott Station. A total of 11 boreholes, including the reconnaissance borehole ER 5, were drilled on Portion 3 of the farm (Fig. 3.18); core descriptions are presented in Appendix 2.

As shown in Fig. 3.18, the eastern and northern limits of the clay deposit were delineated with a fair amount of certainty. It pinches out towards the north-west and east and is bordered in the north-east and south-east by increasing overburden. A westerly dipping dolerite dyke cuts through the sediments as illustrated in Fig. 3.19. Further drilling towards the west and south-west might prove a continuation of the deposit but the siliceous, non-refractory nature of the clay mined for brick manufacturing immediately to the west (see Fig. 3.18) suggests a deterioration of refractory quality in the latter direction. In the north-eastern part of the deposit, two clay layers separated by a layer of carbonaceous clay were indicated. Partial analysis of the carbonaceous clay at this locality and also from further to the south proved this material to be non-refractory, and it is therefore doubtful whether the lower of the two clay layers mentioned above would be economically exploitable. Excluding this layer and the carbonaceous clay, the thickness of the intersected clay zone varies between 0,7 and 7,4 m with an average of 3,5 m . The entire deposit is overlain by soft weathered shale which is covered by a relatively thin layer of mainly clayey to sandy soil. This overburden varies in thickness from 7,0 to 11,3 m with an average of 9,2 m.

The drilling indicated that the area is situated on a pre-Vryheid Formation ridge between two adjoining proto-basins in which predominantly coal and carbonaceous shale accumulated before clay deposition commenced (Fig. 3.19). After filling up of the basins, deposition of clay continued and later transgressed onto the surrounding higher ground, in places interconnecting the two initially isolated basins. Subsequently slightly higher-energy sedimentation prevailed and the whole area was covered by shale. The clay succession intersected in borehole ER 5 serves as a very good example to illustrate the depositional model discussed in Bredell (1974). Comparing the physical properties, mineralogy and chemical composition

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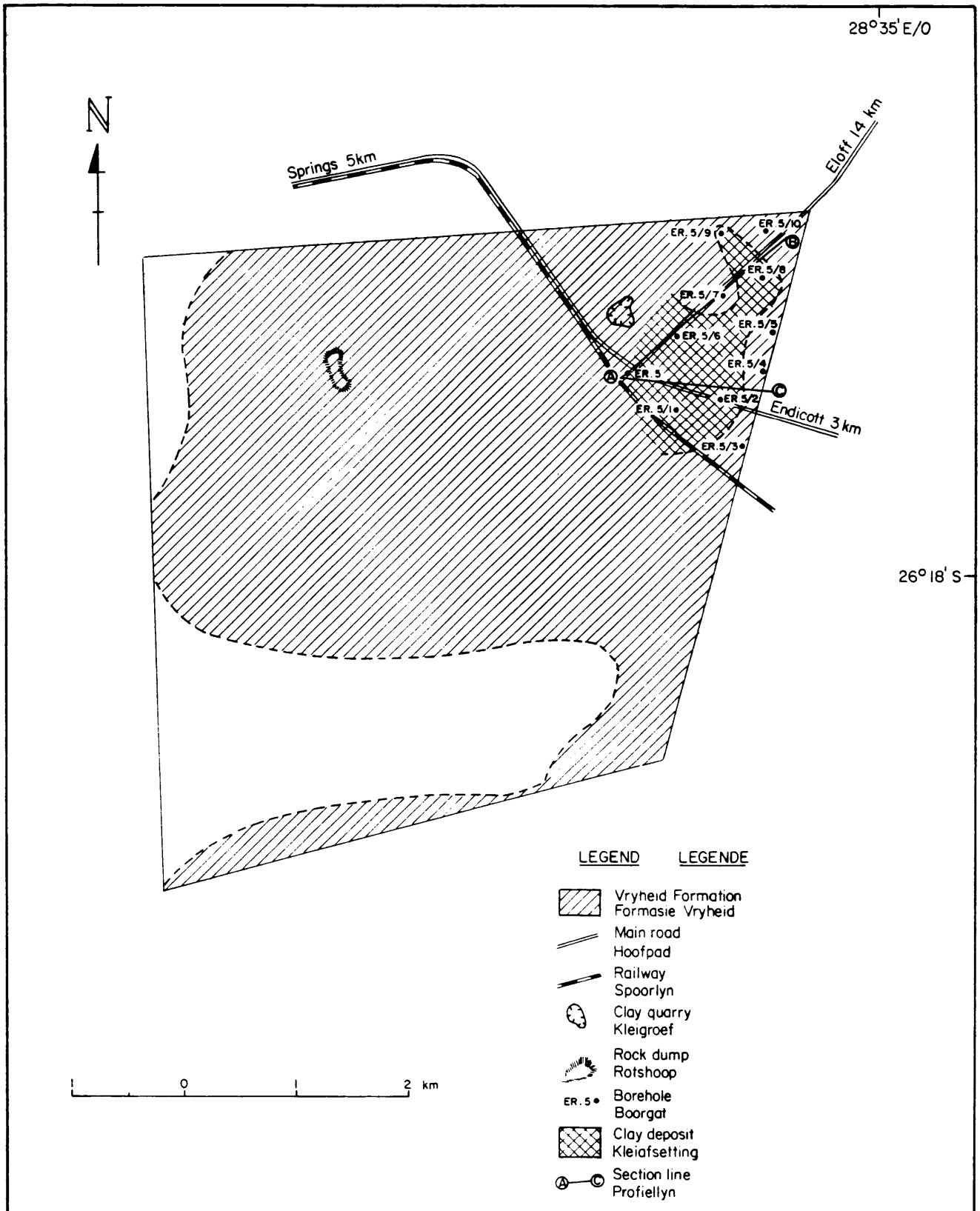

FIG. 3·18 - Location of boreholes on Rietfontein 276 IR.
Posisies van boorgate op Rietfontein 276 IR.

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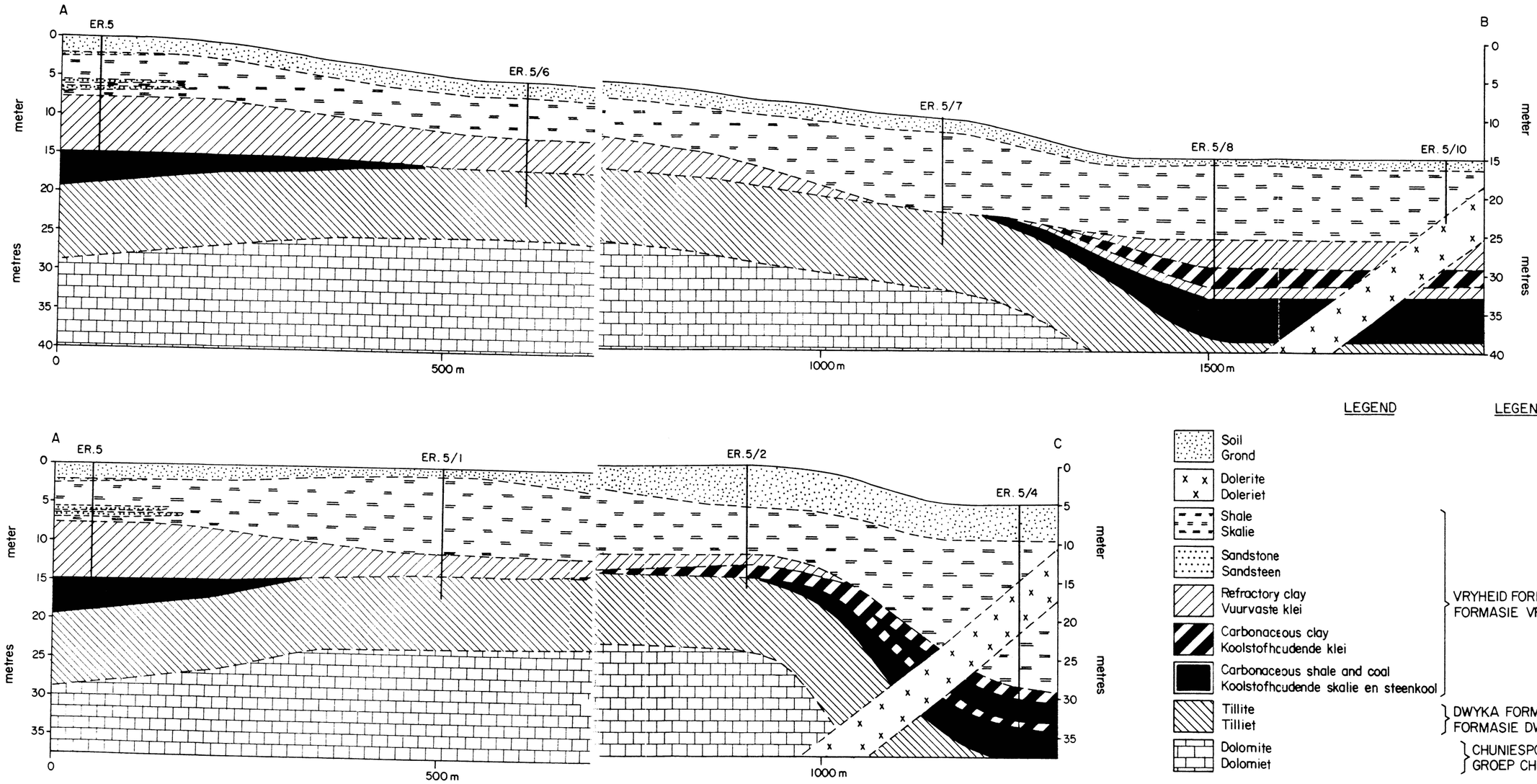

FIG. 3·19 - S.W.-N.E. and W.-E. sections through boreholes on Rietfontein 276 IR
S.W.-N.O. en W.-O. profiele deur boorgate op Rietfontein 276 IR

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presented in Table 3.7 and 3.8, it is evident that the lower part of the succession consists almost of pure kaolinite, deposited under relatively acid conditions (fossil pH 5,8 to 6,1). Higher up in the sequence, progressively more other clay minerals and detrital material were introduced as a result of the increasing volume of water and a consequent lowering of the acidity (fossil pH 6,3 to 6,5). Poorly developed cross-beds in sandstone exposed in the brick-clay quarry next to the deposit indicate palaeocurrents in a direction between 115° and 126°.

All the samples tested proved to be refractory clay with semi-flint being the predominant type and one sample (133) almost meeting the bulk-density requirements for a flint clay (Table 3.7). The best development of clay with a higher refractoriness is in the south-western part of the deposit around boreholes ER 5 and 5/6 where 3,7 and 4,4 m of material with PCE values in the range 34 to 35 was intersected respectively. As mentioned in the case of Daggafontein, the better-quality clays are also here characterised by a distinctly lower Rb content (see Table 3.9).

In contrast to both the Modderfontein and Daggafontein deposits, no alunite was identified in any of the samples, suggesting that these clays were derived from different source rocks or from soil profiles which had not been hydrothermally altered. Considering the general similarity in trace-element composition, the latter possibility seems to be the more likely. As shown in Table 3.7, potassium feldspar was identified in a sample from the upper part of the clay zone intersected in borehole ER 5. This could be indicative of a depletion of the soil profile in the provenance, resulting in the erosion of partly unweathered rock during the final stages of clay deposition. Unfortunately, no feldspar could be detected during electron-microscope studies and an analysis of this mineral could therefore not be obtained.

The grain size and general texture of these clays are very similar to those at Daggafontein with the semi-flint types showing a strong tendency towards an edge-to-face orientation of kaolinite particles (Fig. 3.20). No well-developed booklets of kaolinite were observed, but subhedral flakes of up to about 50 μm in diameter are frequently present in both the plastic and semi-flint clays (Fig. 3.21).

Bredell (1978) reported indicated resources of 6,5 m Mt, excluding non-refractory carbonaceous clay and the lower layer of refractory clay in the north-east. Based on refractory properties, the following subdivision of resources can be made:

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TABLE 3.7 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 276 IR

			Physical properties				Classification		Mineralogical composition (Kaolinite is the major constituent of all samples)	
Sample No.	Borehole No.	Depth (m)	PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
44	ER 5	7,60–8,90	32	2,07	23,00	10YR6/6–5B9/1	Semi-flint	IV	Illite, montmorillonite	20
45	ER 5	8,90–9,55	32	2,02	23,30	N8–5YR6/1	Semi-flint	IV	K-feldspar, illite, montm.	20
46	ER 5	9,55–10,55	32	1,84	29,20	5YR6/1–5Y6/4	Plastic	IV	Illite, montmorillonite	15
47	ER 5	10,55–11,20	33	1,97	24,80	N7–5YR6/1	Semi-plastic	IV	Montmorillonite	10
48	ER 5	11,20–13,20	34^{+}	1,82	29,30	5R8/2–5YR6/1	Plastic	II	Illite, montmorillonite	2
49	ER 5	13,20–14,40	35^{-}	1,94	24,50	N9	Semi-plastic	II	Montmorillonite	0
50	ER 5	14,40–14,90	34^{+}	1,77	31,30	5YR8/1–5YR6/1	Plastic	II	Montmorillonite	0
131	ER 5/1	11,00–12,00	35	2,19	16,60	5YR8/1–N9	Semi-flint	II	Montmorillonite	trace
132	ER 5/1	12,00–14,00	33	2,15	17,50	5YR8/1	Semi-flint	IV	Montmorillonite	10
133	ER 5/2	11,30–12,80	35	2,30	17,50	N7–N8	Semi-flint	II	Montmorillonite, illite	0
134	ER 5/6	7,00–11,40	34	2,05	20,60	5Y8/1–5YR8/2	Semi-flint	II	Montmorillonite	4
135	ER 5/8	10,30–14,20	32^{-}	1,87	28,00	5YR8/1	Plastic	IV	Montmorillonite, illite	20
136	ER 5/8	16,50–18,00	34^{+}	2,13	17,50	10YR6/2	Semi-flint	II	Montmorillonite	0

*PCE = Pyrometric cone equivalent

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TABLE 3.8 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 276 IR

Sample No.*	44	45	46	47	48	49	50	131	132	133	134	135	136
SiO_2	53,72	52,91	55,40	51,56	46,40	45,20	46,20	47,80	53,50	45,03	44,70	49,57	45,20
TiO_2	2,20	1,50	0,93	2,12	1,88	1,91	1,86	1,36	2,15	1,53	1,67	1,48	1,87
Al_2O_3	28,36	29,42	32,20	31,12	37,10	38,10	38,30	36,30	32,00	37,40	37,10	32,15	37,14
Fe_2O_3	1,40	1,39	0,75	0,60	0,42	0,40	0,40	1,51	0,83	0,39	1,68	1,31	0,40
FeO	< 0,15	< 0,15	< 0,15	< 0,15	< 0,15	< 0,15	< 0,15	< 0,15	< 0,15	< 0,15	< 0,10	0,40	< 0,15
MnO	0,04	0,05	0,02	0,03	0,02	0,01	0,03	0,00	0,07	0,02	0,16	0,02	0,02
MgO	0,21	0,20	0,24	0,51	0,89	0,35	0,86	0,16	0,49	0,76	0,01	1,86	0,87
CaO	0,41	0,43	0,13	0,26	0,31	0,36	0,31	0,22	0,25	0,44	0,22	0,38	0,28
Na_2O	0,05	0,05	0,06	0,15	0,02	0,08	0,04	0,11	0,14	0,09	0,17	0,00	0,02
K_2O	1,70	1,04	0,81	0,32	0,35	0,40	0,32	0,21	0,34	0,03	0,24	0,51	0,34
P_2O_5	1,24	0,04	0,24	0,13	0,07	0,04	0,09	0,16	0,14	0,18	0,20	0,08	0,08
CO_2	1,23	1,31	0,51	1,01	1,01	1,61	1,52	0,15	0,25	0,81	0,60	0,65	0,84
H_2O^+	9,62	10,53	8,60	12,40	11,60	11,01	10,05	12,02	10,30	13,30	13,12	11,22	13,01
Total	100,33	99,02	100,04	100,36	100,22	99,62	100,13	100,15	100,41	99,98	99,87	99,63	100,07
H_2O^- on air-dried sample	1,72	1,31	1,43	1,69	0,91	0,97	1,04	0,21	0,31	0,72	0,75	1,79	0,02
Al_2O_3 on a calcined basis	31,80	33,42	35,43	35,92	42,44	43,62	43,30	41,32	35,76	43,55	43,01	36,50	43,11
pH	6,5	6,4	6,4	6,3	6,1	5,8	6,0	5,5	5,7	5,0	6,2	6,4	6,0

*See Table 3.7 for sample positions

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TABLE 3.9 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 276 IR

Sample No.*	44	45	46	47	48	49	50	131	132	133	134	135	136
V	141	136	131	128	114	106	118	103	114	151	111	117	103
Co	32	34	31	42	36	37	39	35	38	33	37	31	27
Ni	29	41	46	31	26	21	28	18	29	6	29	16	12
Cu	30	32	37	40	31	27	34	26	36	26	30	38	33
Zn	47	66	73	68	64	51	62	48	49	47	51	66	67
Ga	37	38	46	49	45	42	39	36	38	37	37	47	39
Ge	< 5	< 5	< 5	< 5	< 5	6	< 5	6	< 5	< 5	5	5	< 5
Rb	81	76	73	61	17	16	20	17	69	22	20	84	24
Sr	162	129	119	106	91	78	211	87	98	47	203	167	211
Y	41	39	41	48	50	45	48	46	52	53	37	43	39
Zr	477	471	412	396	449	391	413	332	358	477	374	397	448
Nb	40	39	37	43	40	36	41	31	42	39	32	38	40
Mo	< 5	< 5	< 5	< 5	11	< 5	6	11	10	< 5	12	9	6
Sn	10	11	10	18	15	16	19	43	29	31	10	16	14
Sb	16	20	18	21	17	21	20	38	42	29	2	5	2
W	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	26	39	33	29	36	28	33	32	41	21	51	36	42
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	34	36	32	41	31	36	44	43	47	46	34	39	36
U	< 1	< 1	3	5	6	11	10	7	< 1	6	< 1	6	11
As	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
S	319	327	139	186	216	411	416	126	136	198	264	374	562

*See Table 3.7 for sample positions

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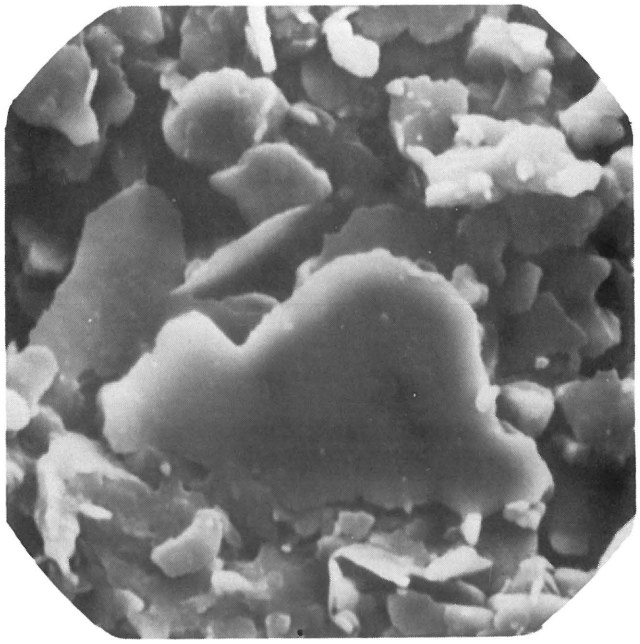

Fig. 3.20 Randomly orientated kaolinite flakes in semi-flint clay from Rietfontein 276 IR. Magnification 1 800X.

Wanordelik georiënteerde kaolinietvlokkies in semi-flintklei van Rietfontein 276 IR. Vergroting 1 800X.

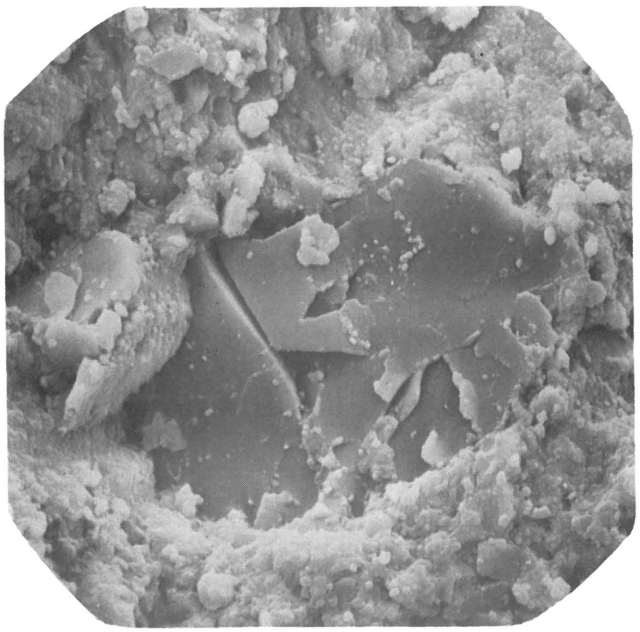

Fig. 3.21 Subhedral kaolinite plate in plastic clay from Rietfontein 276 IR. Magnification 1 300X.

Subhedrale kaolinietplaat in plastiese klei van Rietfontein 276 IR. Vergroting 1 300X.

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(1) Semi-flint, semi-plastic and plastic clay of good refractoriness (PCE 34 to 35) : 3,0 Mt.

(2) Semi-flint, semi-plastic and plastic clay of low refractoriness (PCE 32⁻ to 33) : 3,5 Mt.

This deposit contains a high proportion of clay with a good refractoriness and the grade of this material as based on the alumina content is generally higher than that of similar clays at Modderfontein and Daggafontein. It is slightly less favourably situated with regard to existing kilns but should nevertheless be considered as a promising target for further exploration and possible exploitation. This area has also been reserved for clay mining as a result of this investigation.

3.3.4 Total Resources of Refractory Clay on the East Rand

Information on refractory-clay resources is very difficult to obtain and is often conflicting as a result of inadequate drilling and the confidential nature of company data. No estimate for total resources on the East Rand has therefore ever been published. The following broad summary of resources is partly based on information supplied by mining companies, but largely on the author's own calculations from borehole data:

(1) Indicated resources of semi-flint and plastic clay with a good refractoriness (PCE 34⁻ to 35) within the boundaries of presently active mining areas : **10,5 Mt.**

(2) Indicated resources of semi-flint, semi-plastic and plastic clay with a good refractoriness (PCE 34⁻ to 35) in areas where mining is potentially feasible (including the three deposits discovered during the present investigation) : **11,3 Mt.**

(3) Indicated resources of semi-flint, semi-plastic and plastic clay with a low refractoriness (PCE 26 to 33) in areas where mining is potentially feasible (including the three deposits discovered during the present investigation) : **22,4 Mt.**

(4) Approximate amount of refractory clay which has already been sterilised by urban development : **26,6 Mt.**

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3.4 WEST RAND

The investigation on the West Rand was confined to the tract of dolomite and chert of the Chuniespoort Group situated between Bank Station and Lawley (Fig. 1.9). The dolomite is bounded in the north by the Black Reef Formation and the Witwatersrand and Ventersdorp Supergroups; in the south it is overlain by the Pretoria Group. Extensive geophysical and drilling programmes carried out by the Geological Survey since publication of the 1 : 250 000 Geological Series Sheet 2626 West-Rand in 1967, have indicated that the extent and distribution of the Karoo outliers on the dolomite differ markedly from those presented on that map. Revising and updating the Karoo geology was therefore considered an essential prerequisite to the clay investigation.

Knowledge of the Karoo outliers has a two-fold application in this area:

(1) **Safety considerations.** Dewatering of the different ground-water compartments in the dolomite has serious complications in the form of sinkhole formation. Depending on its thickness, a remnant of Karoo rocks on the dolomite constitutes an area of comparative or even absolute safety in this respect. Future expansion of towns or other surface developments in the area will therefore depend to a large extent on the distribution and nature of these "safe areas".

(2) **Economic importance.** The Karoo Sequence in this area has been known to host two commodities of economic significance, viz. coal and clay. The potential for coal is rather small, but the Karoo clays have supported a thriving brick-making industry on the West Rand for many years. Sampling at two of Corobrik's major quarries revealed that most of the clay which is currently being used for face-brick manufacture is in fact plastic to semi-flint clay with a good refractoriness (see Tables 3.10, 3.11 and 3.12). It was reasonable to assume, therefore, that exploitable deposits of refractory clay could be found somewhere within these Karoo outliers.

3.4.1 Mapping the Karoo Outliers

Owing to the total absence of natural exposures of Karoo rocks in the area, conventional surface mapping was only of limited use in the delineation of the outliers. The main source of information was the numerous boreholes drilled by the Geological Survey during sinkhole investigations. Corobrik kindly provided additional borehole information and full use was

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TABLE 3.10 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF SAMPLES FROM TWO BRICK-CLAY QUARRIES ON THE WEST RAND

		Physical Properties				Classification		Mineralogical Composition (Kaolinite is the major constituent of all samples)	
Location of quarries	Sample No.*	PCE**	Bulk density	Apparent porosity	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
Roodepoort 302 IQ	7	35^-	2,04	22,2	10YR8/2	Semi-flint	I	None	1
	8	33^-	2,27	15,8	5Y8/1	Semi-flint	IV	Sericite	20
	9	32^-	2,34	13,5	5Y8/1	Flint	IV	Sericite	20
	10	35^-	2,01	19,4	N8	Semi-flint	I	None	0
	11	35^-	1,93	25,0	N7	Semi-plastic	I	None	0
	12	34^+	1,92	25,4	N7	Semi-plastic	II	None	2
Driefontein 355 IQ	13	34^+	1,95	25,8	5YR8/1	Semi-plastic	II	Sericite	5
	14	34^+	1,92	26,4	N9	Semi-plastic	II	Sericite	6
	15	32	2,01	23,4	5Y8/1	Semi-flint	III	Sericite	6
	16	35	1,79	30,6	N8	Plastic	I	None	0
	17	35	1,97	24,3	N8	Semi-plastic	I	Sericite	0
	18	34^-	1,92	26,6	Multi col.	Semi-plastic	II	None	trace

*Samples were taken at 2 m intervals from top to bottom across the clay zone

**Pyrometric cone equivalent

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TABLE 3.11 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF SAMPLES FROM TWO BRICK-CLAY QUARRIES ON THE WEST RAND

Sample No. *	7	8	9	10	11	12	13	14	15	16	17	18
SiO_2	45,2	55,70	56,90	44,60	44,90	45,30	47,51	48,12	45,41	44,30	44,20	48,10
TiO_2	1,12	0,92	0,91	1,10	1,12	1,01	1,29	1,30	1,45	1,07	1,10	1,31
Al_2O_3	38,20	31,25	30,04	38,70	38,50	37,80	36,07	36,10	33,51	37,60	37,80	35,91
Fe_2O_3	0,45	0,10	0,15	0,42	0,44	0,78	0,91	0,89	3,62	0,36	0,34	0,93
FeO	n.d.	0,89	0,86	n.d.	n.d.	n.d.	0,83	0,84	<0,15	n.d	n.d.	0,81
MnO	<0,05	<0,01	<0,01	<0,05	<0,05	<0,05	0,01	0,01	0,02	<0,05	<0,05	0,01
MgO	<0,05	0,87	0,86	<0,05	<0,05	<0,05	0,89	0,91	0,90	0,10	0,11	0,90
CaO	0,07	0,15	0,15	0,06	0,05	0,06	0,12	0,14	0,18	0,07	0,08	0,16
Na_2O	0,06	0,31	0,34	0,05	0,06	0,05	0,11	0,10	0,10	0,01	0,01	0,15
K_2O	0,28	2,03	1,94	0,27	0,26	0,25	0,98	0,96	0,92	0,47	0,46	0,85
P_2O_5	0,05	0,07	0,05	0,05	0,05	0,05	0,08	0,08	0,21	<0,05	<0,05	0,09
CO_2	0,15	0,16	0,18	0,20	0,24	0,91	0,38	0,40	2,02	0,70	0,72	0,43
H_2O^+	13,51	8,01	7,96	13,71	13,69	12,70	10,91	10,95	11,01	13,94	13,96	11,01
Total	99,19	100,47	100,41	99,26	99,41	99,01	100,09	100,80	99,50	98,77	98,88	100,66
H_2O^- on air-dried sample	0,72	0,69	0,74	0,70	0,73	1,01	0,72	0,75	0,93	1,10	1,12	0,76
Al_2O_3 on a calcined basis	44,30	34,02	32,69	45,01	44,77	43,82	40,66	40,68	38,56	44,14	44,39	40,51
pH	6,2	5,3	5,0	6,4	6,1	6,5	6,2	6,6	6,6	6,7	6,3	6,2

*See Table 3.10 for sample localities

n.d. = not determined

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TABLE 3.12 TRACE-ELEMENT COMPOSITION IN PPM) OF SAMPLES FROM THE BRICK-CLAY QUARRIES ON THE WEST RAND

Sample No.*	7	8	9	10	11	12	13	14	15	16	17	18
V	190	112	106	185	191	181	153	156	191	191	187	185
Co	35	6	10	31	28	33	25	27	22	34	36	41
Ni	93	40	26	99	106	103	66	65	66	102	101	115
Cu	61	51	76	72	70	73	65	68	75	78	83	92
Zn	54	32	26	53	57	61	79	81	91	56	59	61
Ga	30	29	28	30	28	31	34	31	35	32	34	36
Ge	< 5	5	5	< 5	< 5	< 5	5	5	5	< 5	< 5	< 5
Rb	59	131	134	58	61	65	90	88	96	61	63	66
Sr	34	145	150	34	35	37	45	42	406	36	37	45
Y	36	42	64	35	36	32	51	52	72	32	29	28
Zr	291	221	216	289	293	296	368	371	525	292	289	306
Nb	22	19	16	20	16	18	28	26	36	18	20	21
Mo	10	< 5	< 5	8	10	12	< 5	< 5	< 5	6	5	6
Sn	26	< 1	< 1	28	26	28	10	11	8	26	28	29
Sb	31	< 1	< 1	33	31	30	8	9	< 1	32	30	27
W	2	< 1	< 1	3	5	5	< 1	< 1	< 1	5	5	5
Pb	44	42	41	46	51	53	61	58	63	45	47	41
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	36	21	17	35	31	33	38	36	53	36	38	40
U	1	< 1	< 1	1	1	1	< 1	< 1	10	1	1	1
As	< 5	< 5	< 5	< 5	< 5	< 5	5	5	8	< 5	< 5	< 5
S	106	115	121	136	142	189	146	152	206	187	193	172

*See Table 3.10 for sample localities

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also made of the logs of prospecting boreholes which had been drilled for gold and coal. All these boreholes were plotted on gravity contour maps that had been prepared for the sinkhole investigation; wherever a clear correlation could be detected between "Karoo boreholes" and the gravity contours, the latter were used to determine the shape and size of the outliers. This method proved to be quite successful for most of the outliers in the Bank compartment where the Karoo sediments usually coincide with well-defined gravity lows. In the vicinity of Westonaria the relationship is less clear, and the boundaries of the outliers were obtained mainly by extrapolation, taking into account the thickness of the Karoo rocks and the distance to the nearest "dolomite borehole".

A compilation indicating the distribution of the outliers is presented in Fig. 3.22. This map has many shortcomings and no claim is made for its absolute accuracy. It is in fact doubtful whether it would be at all possible to construct a true picture of all the remnants of Karoo rocks in this area. This is due firstly to the lack of outcrop and secondly to the irregular and unpredictable nature of the pre-Karoo surface. As an extreme example, a particular borehole intersected 55 m of Karoo sediments, whereas another borehole, only 25 m distant, passed directly into leached dolomite (Bredell, 1979).

If the map is to be used for more exacting purposes than as a general guide for clay prospecting, the following points should be considered:

(1) In areas where borehole information is inadequate, the size and shape of the outliers may differ considerably from those shown on the map. It is possible that the small isolated outliers indicated between Bank Station and Westonaria are actually wholly or partly interconnected to form one or more continuous outliers. It is equally possible that the larger outliers shown at Westonaria and Lawley are in fact composed of a series of smaller isolated or partly interconnected outliers.

(2) In some areas the coincidence of "Karoo boreholes" with gravity lows is incidental, as most of the holes were drilled subsequent to the gravity surveys and were positioned on the anomalies.

(3) Gravity lows do not necessarily indicate the presence of Karoo rocks; they may delineate areas of thick alluvium or deep leaching of the dolomite. For this reason, gravity lows where the presence of Karoo sediments had not been verified by drilling, were not taken into account in the compilation of the map.

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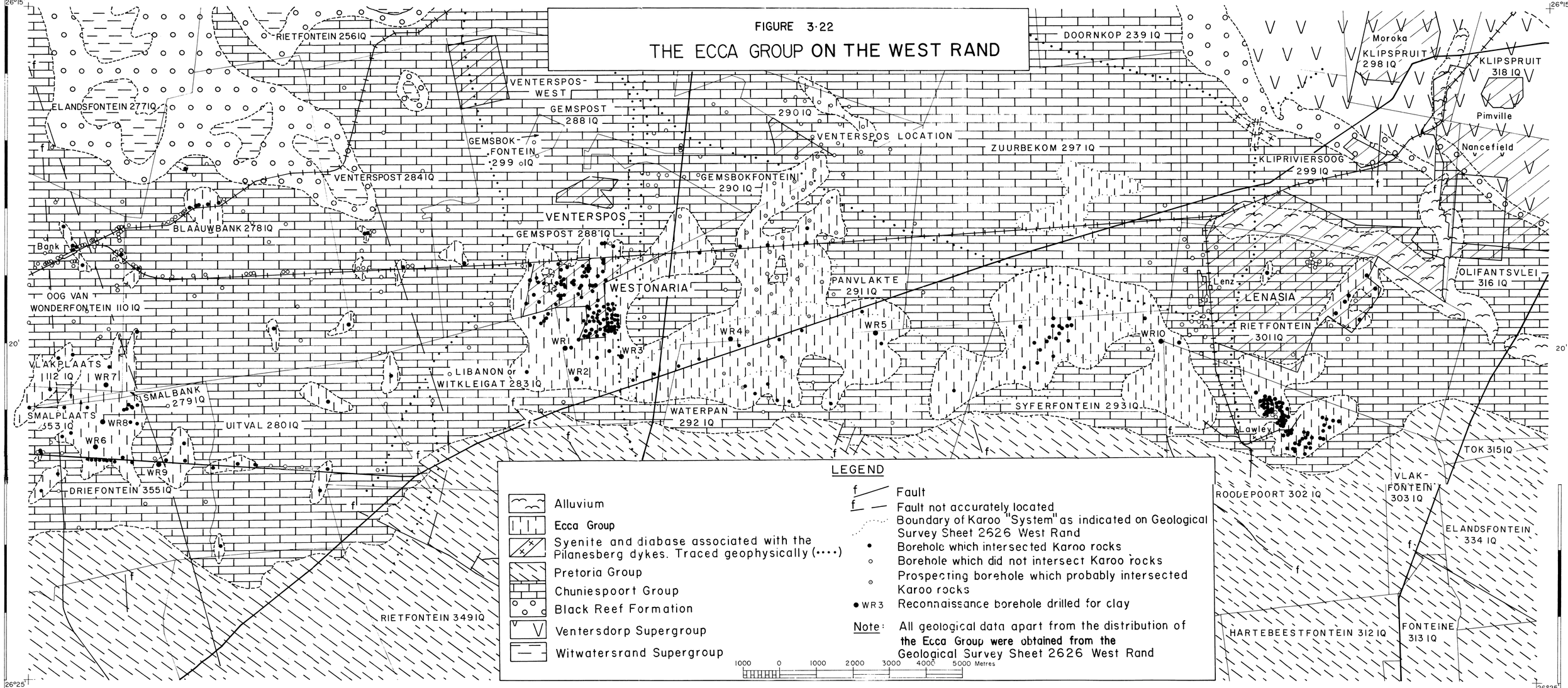
FIGURE 3·22

THE ECCA GROUP ON THE WEST RAND



LEGEND

- Alluvium
- Ecca Group
- Syenite and diabase associated with the Pilanesberg dykes. Traced geophysically (····)
- Pretoria Group
- Chuniespoort Group
- Black Reef Formation
- Ventersdorp Supergroup
- Witwatersrand Supergroup

- f —— Fault
- f —— Fault not accurately located
- Boundary of Karoo "System" as indicated on Geological Survey Sheet 2626 West Rand
- Borehole which intersected Karoo rocks
- Borehole which did not intersect Karoo rocks
- Prospecting borehole which probably intersected Karoo rocks
- ● WR3 Reconnaissance borehole drilled for clay

Note: All geological data apart from the distribution of the Ecca Group were obtained from the Geological Survey Sheet 2626 West Rand

1000 0 1000 2000 3000 4000 5000 Metres

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(4) Logs of boreholes drilled for gold provided little or no information on strata overlying the dolomite. Many of them indicate an "overburden" of 60 m or more, and if shales or sandstones are described, they are usually assigned to the Pretoria Group. In cases where an "overburden" of more than 30 m was indicated or where shale and sandstone were described in the logs of these boreholes at positions where Pretoria Group rocks are unlikely,it was assumed, for purposes of constructing the map, that Karoo rocks are present.

3.4.2 Subsurface Studies

Isopach maps of the outliers at Westonaria and Bank Station are presented in Figs. 3.23 and 3.25(a). The thickness indicated on these maps includes the soil cover on top of the Karoo sediments. Thicknesses of up to 100 m are indicated in the Bank outliers, while a maximum of 155 m has been recorded approximately 2 km south of Westonaria. In north-east-trending patches to the east south-east and east of Westonaria, thicknesses of up to 120 m are attained. As mentioned before, isopach maps proved to be a valuable guide to clay prospecting on the East Rand. On the West Rand, however, these maps cannot be used for this purpose to the same extent because the clay layer is much thicker and starts immediately below the soil cover. Although it is therefore not possible to eliminate areas of excessive overburden like on the East Rand, the West Rand isopach maps are nevertheless very useful as a rough guide to the thickness distribution of potential clay deposits. During the preliminary stages of town planning, these maps may also serve as a valuable aid.

Pre-Karoo topographical maps of the Westonaria and Bank outliers are shown in Figs. 3.24 and 3.25(b). The pre-Karoo surface reaches a depth of 1 440 m above sea level to the south of Westonaria and forms the deepest point of a north north-east-trending asymmetrical elongated basin. Shallower basins trend around a high in the pre-Karoo topography to the east and east south-east of Westonaria. In the Bank area, the pre-Karoo surface is generally in the order of 100 m lower than at Westonaria. Only major subsurface features such as these can be resolved because of the limitations imposed by the available borehole data. There is nevertheless a remarkable correspondence between the strike directions of the elongated pre-Karoo valleys and the bimodal palaeocurrent pattern derived from cross-bedding measurements in the brick-clay quarries. These measurements revealed two distinct current directions; one to just west of south (182^{o} to 196^{o}) and the other to the south-west (223^{o} to 230^{o}).

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FIGURE 3·23

ISOPACH MAP OF THE KAROO OUTLIER AT WESTONARIA

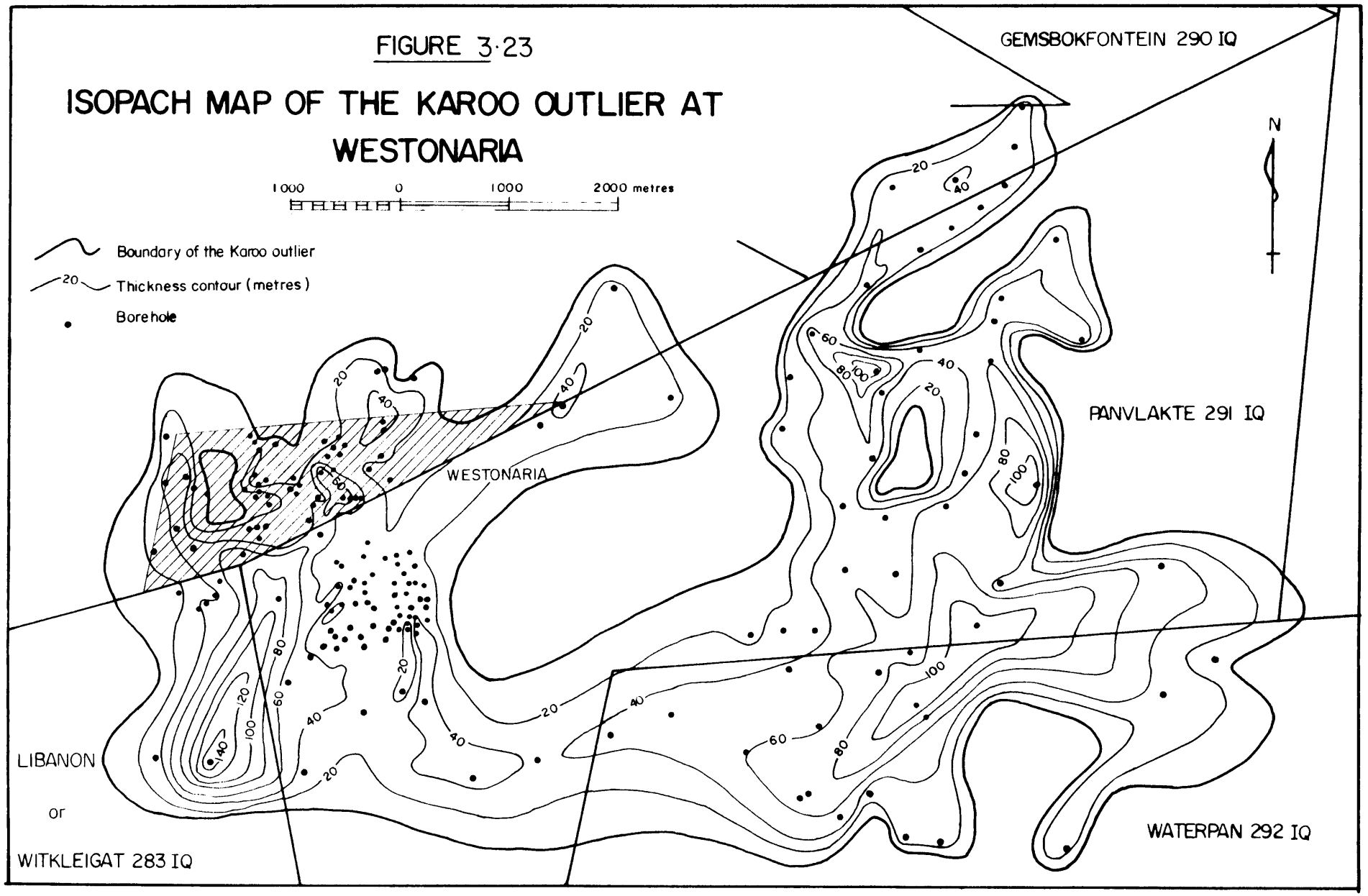

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FIGURE 3·24

PRE-KAROO TOPOGRAPHY OF THE KAROO OUTLIER AT WESTONARIA

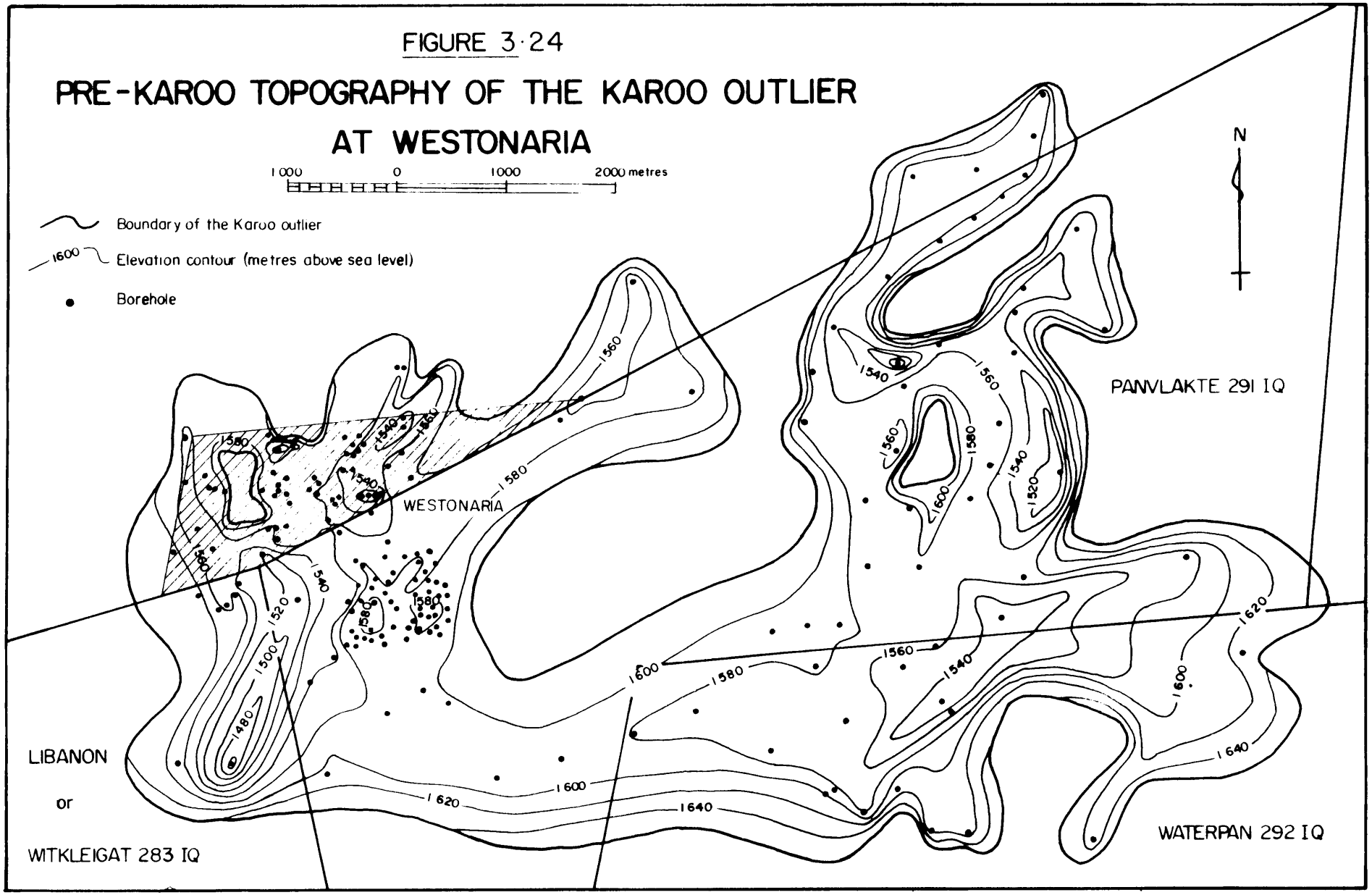

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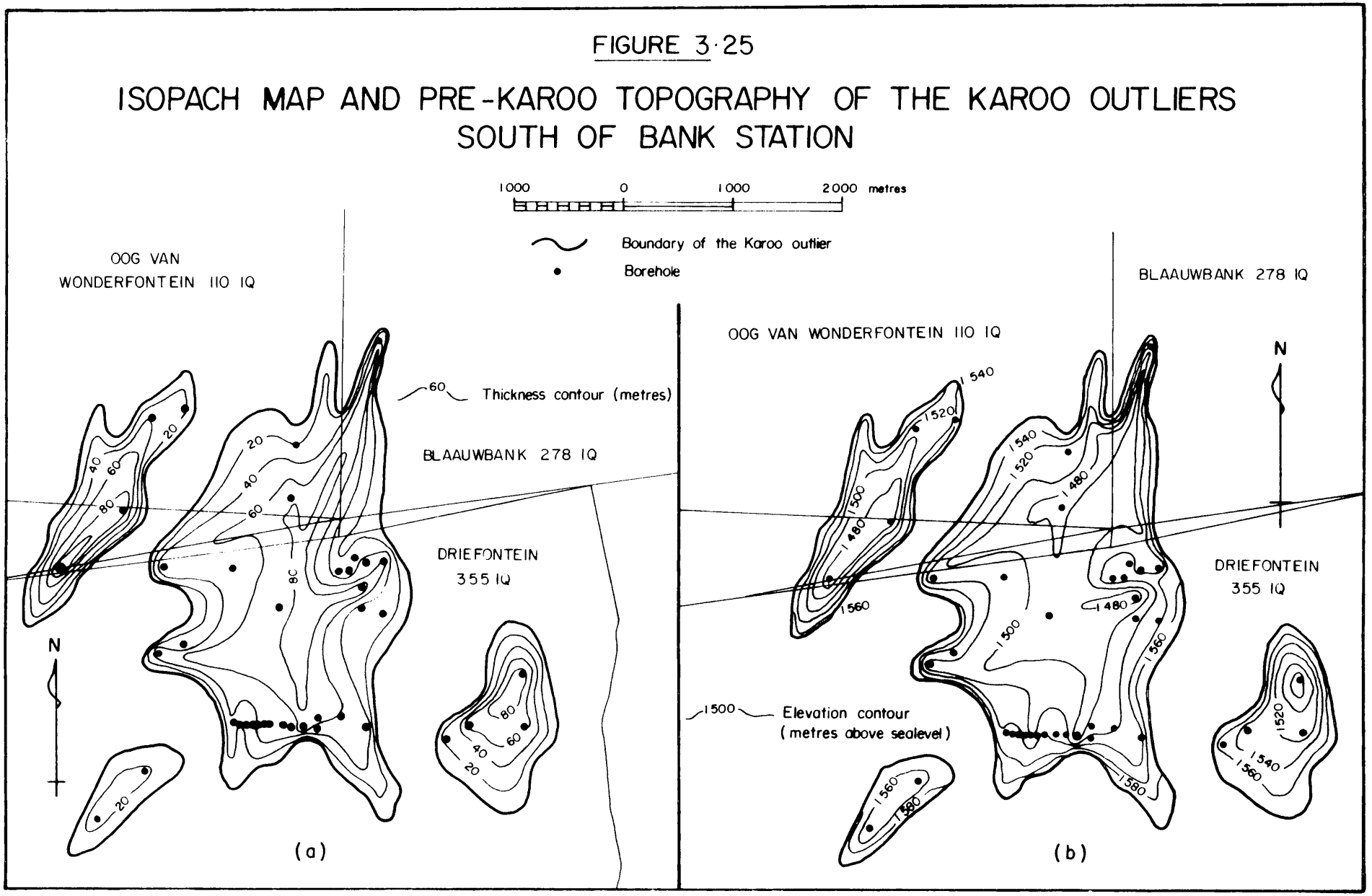
FIGURE 3·25

ISOPACH MAP AND PRE-KAROO TOPOGRAPHY OF THE KAROO OUTLIERS SOUTH OF BANK STATION



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The configuration of the pre-Karoo surface was also found to have a definite bearing on the distribution of clay deposits in these outliers. Although the Karoo sediments are predominantly argillaceous everywhere in this area, the thickest accumulations of clay are located in the pre-Karoo valleys and an inspection of samples from the percussion boreholes drilled for the sinkhole investigation also indicated that the more pure kaolinitic clays occur in these valleys and around their perimeters. Furthermore, the distribution of coal and carbonaceous shale is clearly displayed by the pre-Karoo surface maps. These materials are only present in areas where the pre-Karoo surface is lower than 1 560 m above sea level, i.e. in the deeper basins of the Westonaria outlier and in the greater part of the Bank outliers. Of particular interest in this regard is the outlier to the west of Lawley where coal was discovered on the farm Syferfontein 293 IQ as long ago as 1887 (see Fig. 3.22). A shaft was sunk, but after about 1 300 t of coal had been extracted, mining operations were stopped (Wybergh, 1928). Interest in this deposit renewed from time to time but no further mining has been attempted. From the results of several boreholes put down in the area, it has been proved that the coal occurs interbedded with highly carbonaceous shales in an elongated basin, some 1 200 m long and 300 m wide. The maximum thickness of the coal-bearing strata is just over 60 m with an overburden of between 45 and 90 m. The uppermost 20 to 30 m of this overburden consist of sedimentary kaolinitic clay which is largely refractory and very similar to the material which is being exploited by Corobrik at Lawley. Should mining of this clay deposit be considered in future, it might become economically viable to extract the underlying coal by open-cast methods. After the last exploration boreholes were drilled in 1932, it was estimated that the tonnage available in this deposit amounts to 6 Mt of "better class coal" and 11 Mt of "lower-grade" material (Anon., 1932).

A geological and gravity profile (Fig. 3.26) was compiled from information gathered along provincial road P111-1 in the western part of the Bank compartment. The profile illustrates the correlation between gravity data and the occurrence of Karoo rocks, as well as the cross-sectional shape of the outliers. Three distinctly different types of Karoo deposits can be recognised in the profile (Bredell, 1979):

(1) The occurrences marked I, IV and V have similar characteristics, namely an undulating pre-Karoo floor with the leached dolomite and wad zone following the undulations. The near-parallelism of these two surfaces, i.e. the pre-Karoo surface and the lower contact of the leached zone, seems to indicate that the depressions had formed well before deposition of the Karoo sediments. This allowed the leached zone to reflect the new topography. The presence of carbonaceous

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shale, indicative of swampy conditions, supports the hypothesis that the depressions already existed at the time of deposition. Some degree of subsidence must have taken place during and after deposition, as evidenced by the slightly anomalous attitude of strata exposed in clay quarries immediately north of the section line on outlier IV; there are definitely no indications of a post-depositional collapse of the sediments into a sinkhole-like depression.

(2) The occurrence marked III can be explained best by assuming deposition along a leached pre-Karoo fault zone. No carbonaceous material is present in this case.

(3) The outlier marked II differs markedly from the others in that the leached zone does not extend into the solid dolomite to follow the pre-Karoo surface. One possible explanation for this is that an erosional valley had been cut into the leached zone shortly prior to deposition of the Karoo sediments and that these sediments retarded subsequent leaching of the dolomite below the deposit.

3.4.3 Reconnaissance Exploration

In view of the information gained from previously drilled percussion boreholes and from the sampling of quarries, it was decided to restrict further investigations on the West Rand to reconnaissance drilling. In order to test the thickness and refractory properties of the clay in various parts of the outliers, ten diamond boreholes (WR 1 – WR 10) were drilled at positions indicated on Fig. 3.22. With the exception of WR 7 and WR 8 which were stopped in thick alluvium on the Bank outlier, all the boreholes intersected sedimentary kaolin of the Karoo Sequence. Only three of the holes penetrated the pre-Karoo basement, but no Dwyka Formation was intersected. Descriptions of the borehole core are presented in Appendix 3. The general succession indicated by the boreholes is as follows:

Reddish-brown lateritic soil:	2,5 – 12,5 m
Chert and quartzite pebbles in a matrix of clay and soil:	0,2 – 1,1 m
Light-coloured kaolinitic clay, predominantly plastic, with local red or yellow iron-oxide staining along joints. Subordinate interbeds of sandstone, conglomerate or shale are developed locally near the middle of the succession:.	15,4 – 40,6 m
Sandstone or grit (only locally developed):	0,2 m
Black carbonaceous clay:	5, 7 m
Leached dolomite and wad	

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In spite of the scarcity of sandstone and grit which are characteristic of the Vryheid Formation in the main Karoo basin, the sediments in the West Rand outliers could probably be correlated with this Formation on account of the presence of refractory sedimentary kaolin as well as carbonaceous shale and coal. Following the proposals of SACS (1980), these rocks are, however, for the present only assigned to the Ecca Group. Possible correlation with the Dwyka Formation as implied by Plumstead (1969) does not seem feasible in terms of a lithostratigraphic subdivision. According to SACS (1980), only rocks of probable glacial origin, e.g. "diamictite, varved shale and mudstone with dropped pebbles, fluvioglacial gravel, conglomerate, etc." should be incorporated in the Dwyka Formation. Plumstead (1969) regarded the West Rand clays as representing "glacial flour", an assumption which seems highly unlikely in view of the essentially mono-mineralic nature of the material as well as textural and chemical features which are discussed later in this chapter. During March 1983, the author had the opportunity to study the clay profile in several large-diameter auger holes immediately south-east of Westonaria, and particular attention was paid to the possible presence of till stones. Angular granules, blocks and slabs of chert which are locally present in the clay could of course be interpreted as rafted material which had dropped from an ice sheet, but their apparent restriction to the edges of the clay deposit as well as the absence of other supporting evidence of glaciation suggest that they were more likely derived from outcrops around the perimeter of the basin through a process of slumping.

The stratigraphic position of the clay horizon at or close to the base of the sedimentary succession, and overlying a carbonaceous zone in places, corresponds to that of the refractory-clay deposits on the East Rand. There is, however, one very important difference; the clay layer in the West Rand outliers is approximately 5 times thicker than any other known deposit of sedimentary kaolin in the country. This phenomenon can probably be best explained in terms of gradual subsidence of the depressions in which the clays were deposited, a condition which evidently did not prevail during deposition of the clays on the dolomite areas of the East Rand. This gradual subsidence of the basins would have ensured the existence of swampy conditions for a much longer period than would have been the case had deposition taken place on a rigid floor. Acidic conditions (caused by organic acids in the swampy basins) which are necessary for the differential flocculation of kaolinite (Bredell, 1974) therefore prevailed for an unusually long time-span, thus leading to the formation of these unique deposits. The acidic water probably also enhanced solution and decomposition of the underlying dolomite, thereby ensuring a continuous process of subsidence.

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The analytical and test results of borehole samples are presented in Tables 3.13 to 3.16. All except two of the samples can be regarded as refractory clay with Seger-cone values ranging between 29$^-$ and 35 (Table 3.13). Of the 33 samples of refractory clay for which bulk densities were determined, 13 can be classified as semi-plastic, 10 as plastic and 10 as semi-flint clays. This probably represents a rough indication of the proportion of the different types present in these outliers. The distribution of clays with a good refractoriness (Seger cone 34$^-$ to 35) is summarised below:

Borehole	Depth interval (m)	Thickness (m)
WR 1	8,25–15,8; 17,8–20,85; 21,15–31,4; 32,3–41,06	29,71
WR 2	8,5–45,0	36,5
WR 3	3,8–6,6; 7,7–10,9; 14,8–24,0	15,2
WR 4	16,7–18,6	1,9
WR 9	13,35–19,5; 22,0–26,5	10,65
WR 10	4,4–20,0	15,6

It is clear that, as far as refractory clay is concerned, the prime targets for further exploration are the areas around boreholes WR 2 and WR 1, i.e. the deeper part of the outlier due south of Westonaria. An investigation in the vicinity of boreholes WR 3, 9 and 10 (Fig. 3.22) might also be rewarding.

As mentioned before, the West Rand clays have not yet been utilised as a refractory raw material and it is therefore significant to compare them generally with clays which are being mined for this purpose. To avoid using a presently operating mine as an example, reference is made here to the deposit at Westwood Small Holdings on the East Rand which, according to Hammerbeck (1972), is generally similar to the plastic and semi-flint clay quarried on the adjacent property by Boksburg Brick and Fire Clay Company. The PCE range of 29$^-$ to 35$^+$ obtained for borehole samples from Westwood Small Holdings is almost identical to that of the West Rand clays, while the average alumina content (calculated on a calcined basis) of 36 per cent in respect of refractory clays from the latter area compares favourably with a corresponding average of about 35 per cent obtained for 25 samples from the East Rand deposit. Average percentages of some of the other constituents are

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TABLE 3.13 PHYSICAL PROPERTIES AND CLASSIFICATION OF CLAY SAMPLES FROM RECONNAISSANCE BOREHOLES ON THE WEST RAND

Sample No.	Borehole No.	Depth (m)	Physical properties				Classification	
			PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade
52	WR 6	16,40–18,50	29⁻	n.d.	n.d.	N8	n.d.	IV
53	WR 6	18,50–21,50	30⁻	1,96	25,00	10YR8/2	Semi-plastic	IV
54	WR 6	21,50–24,40	30⁻	1,87	26,20	5YR6/1–N7	Plastic	IV
55	WR 6	24,40–27,00	33⁻	1,75	32,80	5YR8/1–5YR6/1	Plastic	III
57	WR 9	13,35–19,50	34	2,07	21,90	10YR8/2–N7	Semi-flint	IV
58	WR 9	19,50–22,00	33	2,06	20,70	N8–5YR6/1	Semi-flint	IV
59	WR 9	22,00–26,50	34	2,08	21,30	N8–5YR6/1	Semi-flint	III
60	WR 9	26,50–30,80	31	1,98	25,50	10YR8/2–5YR8/1	Semi-plastic	IV
61	WR 9	30,80–33,40	33⁻	2,07	20,60	10YR6/2–5YR6/1	Semi-flint	III
64	WR 5	9,55–12,85	17	1,87	29,60	10YR7/4	N.r.	–
65	WR 5	12,85–33,00	30⁻	1,81	31,60	N7–5Y8/1	Plastic	IV
68	WR 4	10,50–11,50	30⁻	1,99	23,90	N8–5YR8/1	Semi-plastic	IV
69	WR 4	11,50–12,00	33⁺	2,00	20,30	N8	Semi-flint	IV
70	WR 4	12,00–16,50	30⁻	1,87	27,20	5YR8/1–5YR7/2	Plastic	IV
71	WR 4	16,70–18,60	34⁺	1,80	28,30	10R6/2–5YR7/2	Plastic	III
73	WR 3	3,80–4,40	34	1,98	23,00	N8–5YR8/1	Semi-plastic	IV
74	WR 3	4,40–6,60	35	1,94	24,80	N8–10YR7/4	Semi-plastic	II
75	WR 3	7,70–10,90	34⁻	2,29	13,70	10YR8/2–10YR7/4	Semi-flint	IV

*PCE = Pyrometric cone equivalent n.d. = Not determined N.r. = Non-refractory

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TABLE 3.13 (Continued)

Sample No.	Borehole No.	Depth (m)	Physical properties				Classification	
			PCE	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade
76	WR 3	11,60–12,20	30^-	2,06	22,90	10YR7/4	Semi-flint	IV
77	WR 3	14,80–24,00	34^-	2,27	13,80	Multi-coloured	Semi-flint	IV
81	WR 2	7,20–8,50	18	1,99	25,00	10YR8/2	N.r.	–
82	WR 2	8,50–11,20	34	1,95	25,50	10YR8/2–5YR8/4	Semi-plastic	III
83	WR 2	11,20–16,00	34	1,98	24,50	N8–10YR8/2	Semi-plastic	II
84	WR 2	16,00–20,50	34^-	1,99	26,20	5YR6/4–10YR8/2	Semi-plastic	IV
85	WR 2	20,50–45,00	34	1,87	28,80	N8	Plastic	IV
87	WR 1	5,00–8,25	33^-	1,87	28,40	10YR8/2–N8	Plastic	IV
88	WR 1	8,25–10,40	34	1,76	34,00	5YR8/1	Plastic	IV
89	WR 1	10,40–15,80	34^+	2,00	24,20	N8–5YR8/1	Semi-flint	III
90	WR 1	17,80–20,85	34^-	2,16	20,60	N8–5YR8/1	Semi-flint	IV
91	WR 1	21,15–23,65	34	1,85	31,50	N8–5YR8/1	Plastic	III
92	WR 1	23,65–31,40	34^+	1,91	27,00	5YR6/1–5YR8/1	Semi-plastic	III
93	WR 1	32,20–41,06	35	1,83	29,10	5YR6/1	Plastic	I
109	WR 10	4,40–10,40	34^+	1,96	24,70	N8	Semi-plastic	II
110	WR 10	10,40–11,00	34	1,92	25,70	10R 4/6	Semi-plastic	III
111	WR 10	11,00–11,50	34^+	1,98	24,60	10YR6/6–N7	Semi-plastic	II
112	WR 10	11,50–20,00	34^-	1,91	26,90	Multi-coloured	Semi-plastic	IV

*PCE = Pyrometric cone equivalent n.d. = Not determined N.r. = Non-refractory

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TABLE 3.14 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM RECONNAISSANCE BOREHOLES ON THE WEST RAND

Sample No.*	52	53	54	55	54+55	57	58	59	60	61	58+59	59+60	64	65	64+65	68	69	70
SiO_2	57,79	52,43	52,33	47,26	46,40	50,21	49,92	48,71	46,33	44,19	49,60	46,89	56,61	58,87	56,78	61,60	52,67	52,11
TiO_2	0,88	0,98	1,61	1,51	1,90	1,22	1,38	1,36	1,54	1,49	1,38	1,35	0,87	0,66	0,81	1,33	1,28	1,95
Al_2O_3	25,41	26,80	29,78	33,92	33,47	33,06	32,69	34,06	32,89	33,89	31,96	32,55	20,52	19,64	20,42	22,79	29,78	30,04
Fe_2O_3	3,60	6,65	2,28	0,55	0,88	1,83	1,99	0,95	5,16	3,58	1,09	4,13	8,41	5,47	7,18	2,28	2,36	1,26
FeO	<0,15	<0,15	<0,15	<0,15	1,38	< 0,15	< 0,15	0,85	<0,15	<0,15	1,31	<0,15	<0,15	<0,15	<0,15	<0,15	0,15	1,27
MnO	0,01	0,03	0,01	0,03	<0,01	0,02	0,01	0,01	0,01	0,02	0,02	0,02	0,43	0,03	0,03	0,01	0,01	0,01
MgO	0,98	0,92	1,08	0,90	0,94	0,95	0,75	0,92	0,90	0,89	0,81	0,83	1,06	2,19	1,46	1,01	0,81	0,98
CaO	0,07	0,11	0,16	0,19	0,14	0,11	0,11	0,10	0,10	0,17	0,11	0,10	0,29	0,42	0,44	0,09	0,08	0,12
Na_2O	0,17	0,14	0,09	0,11	0,14	0,13	0,15	0,13	0,12	0,10	0,11	0,10	0,07	0,07	0,08	0,08	0,05	0,08
K_2O	2,01	2,00	0,88	0,95	1,04	1,53	1,15	1,04	1,02	0,93	1,13	1,12	2,18	2,02	2,26	0,55	0,08	0,51
P_2O_5	0,07	0,15	0,14	0,24	0,21	0,08	0,79	0,08	0,11	0,23	0,09	0,10	0,08	0,07	0,08	0,08	0,10	0,12
CO_2	016	0,20	0,76	1,04	0,34	0,35	0,48	0,50	0,70	1,95	0,22	0,56	0,17	0,21	0,33	0,33	0,47	0,69
H_2O^+	7,75	8,83	10,00	12,02	12,43	10,60	11,55	10,82	10,93	11,02	11,10	11,38	9,04	9,31	9,63	8,76	11,32	9,95
Total	98,91	99,25	99,14	98,87	99,26	100,10	100,26	99,53	99,81	98,46	98,93	99,15	99,74	98,98	99,50	98,92	99,02	99,10
H_2O^- on air-dried sample	0,61	0,69	1,11	1,07	1,06	0,63	0,72	0,66	0,55	0,88	0,80	0,62	2,36	3,33	4,29	0,71	0,75	1,19
Al_2O_3 on a calcined basis	27,62	29,48	33,41	38,63	38,41	37,12	37,15	38,43	37,23	39,03	36,09	37,01	22,61	21,73	22,69	25,10	33,81	33,65
pH	6,8	6,1	6,3	6,6	6,4	6,2	6,0	5,8	6,4	6,0	5,9	6,1	6,8	6,5	6,6	6,4	6,4	6,6

*See Table 3.13 for sample positions

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TABLE 3.14 (Continued)

Sample No.*	71	68,69,70	73	74	75	76	77	73,74	81	82	83	84	85	81,82	87	88	89	90
SiO_2	49,13	55,82	50,62	45,82	55,95	50,12	52,46	46,23	54,87	46,75	44,05	49,53	47,98	46,91	59,75	55,22	50,23	49,24
TiO_2	1,33	1,45	1,23	1,43	0,99	1,96	1,33	1,46	1,09	1,51	1,40	1,35	1,56	1,31	0,87	1,29	1,30	1,07
Al_2O_3	33,59	28,40	33,47	36,36	29,03	30,09	30,53	34,33	26,92	35,40	35,73	30,88	32,89	34,02	27,15	30,16	33,79	32,80
Fe_2O_3	0,76	2,34	0,85	1,36	0,48	3,26	0,72	1,24	4,76	2,51	2,77	4,18	2,75	2,23	0,09	0,70	0,76	1,74
FeO	<0,15	<0,10	<0,15	<0,15	1,59	1,30	<0,10	1,57	0,68	<0,15	<0,15	<0,15	<0,15	0,87	0,90	<0,15	<0,15	0,69
MnO	0,06	0,02	0,01	0,01	0,01	0,01	0,01	0,03	0,05	0,02	0,02	0,02	0,03	0,02	<0,01	0,02	0,01	0,01
MgO	1,10	0,97	0,82	0,77	0,81	0,96	0,95	0,83	0,89	0,76	0,79	0,82	0,77	0,76	0,86	0,81	0,82	0,80
CaO	0,16	0,13	0,07	0,10	0,06	0,11	0,15	0,11	0,16	0,13	0,14	0,16	0,14	0,14	0,16	0,09	0,12	0,14
Na_2O	0,07	0,10	0,09	0,12	0,14	0,09	0,10	0,10	0,26	0,17	0,14	0,24	0,16	0,17	0,31	0,16	0,17	0,28
K_2O	0,43	0,47	0,51	0,59	1,78	0,55	0,56	0,66	1,61	0,76	0,68	1,14	0,78	0,99	2,05	0,89	1,06	1,75
P_2O_5	0,07	0,16	0,06	0,08	0,07	0,10	0,08	0,08	0,07	0,06	0,08	0,07	0,08	0,07	0,08	0,09	0,07	0,06
CO_2	0,47	0,50	0,22	0,28	0,19	0,71	0,34	0,34	0,20	0,28	0,31	0,27	0,30	0,22	0,20	0,25	0,22	0,15
H_2O^+	12,43	9,93	10,99	12,11	8,12	9,98	11,83	12,10	8,46	11,05	12,68	10,49	12,12	10,80	7,59	9,70	10,88	10,21
Total	99,62	100,28	98,95	100,29	99,23	99,24	99,07	99,10	100,05	99,42	98,78	99,16	99,55	98,52	100,01	99,38	99,44	98,96
H_2O^- on air-dried sample	0,82	1,04	0,41	0,82	0,41	0,96	0,77	1,09	0,80	1,12	0,79	0,58	0,59	1,34	0,68	0,82	0,68	0,71
Al_2O_3 on a calcined basis	38,59	31,70	37,75	41,49	31,68	33,72	34,81	39,26	29,47	39,95	41,14	34,64	37,58	38,30	29,44	33,52	38,04	36,64
pH	6,1	6,4	5,9	6,0	5,6	6,1	5,7	5,9	6,7	6,3	6,0	6,1	6,4	6,5	6,5	6,6	6,1	5,8

*See Table 3.13 for sample positions

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TABLE 3.14 (Continued)

Sample No.*	91	92	93	87,88	90,91	109	110	111	112
SiO_2	49,16	47,69	41,59	55,45	50,54	44,42	44,28	41,72	46,25
TiO_2	1,49	1,97	1,45	1,34	1,39	1,72	1,46	1,38	1,28
Al_2O_3	34,61	34,45	39,59	29,95	33,03	36,78	34,51	37,75	30,70
Fe_2O_3	1,05	0,66	0,24	1,50	1,42	1,19	<0,15	2,94	5,12
FeO	<0,15	<0,15	<0,15	<0,10	<0,15	1,29	<0,15	<0,15	<0,15
MnO	0,02	0,01	0,01	0,02	0,01	0,03	0,05	0,02	0,08
MgO	0,84	0,86	0,78	0,85	0,81	0,89	1,21	0,83	2,17
CaO	0,16	0,14	0,20	0,10	0,16	0,08	0,15	0,05	0,37
Na_2O	0,18	0,12	0,10	0,18	0,20	0,08	0,05	0,04	0,04
K_2O	1,10	0,62	0,73	1,08	1,32	0,68	0,65	0,12	0,42
P_2O_5	0,07	0,07	0,08	0,09	0,08	0,07	0,07	0,05	0,07
CO_2	0,34	1,23	2,40	0,35	0,26	0,26	0,14	0,19	0,20
H_2O^+	10,50	11,06	11,23	8,69	10,43	12,69	13,04	13,61	13,25
Total	99,52	98,89	98,41	99,61	9,66	100,18	99,33	98,70	99,96
H_2O^- on air-dried sample	0,98	0,83	1,04	0,75	0,93	1,37	1,79	0,71	4,13
Al_2O_3 on a calcined basis	38,84	39,34	45,95	32,94	37,00	42,24	37,79	43,89	35,47
pH	6,5	6,0	6,1	6,6	6,2	6,0	6,3	6,1	6,2

*See Table 3.13 for sample positions

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TABLE 3.15 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM RECONNAISSANCE BOREHOLES ON THE WEST RAND

Sample No.*	52	53	54	55	54, 55	57	58	59	60	61	58, 59	59, 60	64	65	64, 65
V	125	200	139	231	223	161	216	158	181	187	192	212	131	81	93
Co	10	30	14	34	27	25	43	21	27	21	26	30	35	18	21
Ni	41	64	32	43	39	88	33	65	86	64	78	91	231	57	76
Cu	49	60	106	106	106	88	43	69	91	70	82	86	103	63	67
Zn	55	55	62	36	40	96	31	82	95	89	110	120	129	116	123
Ga	27	30	38	39	39	33	39	33	34	34	35	34	26	25	26
Ge	6	6	9	10	10	5	8	5	<5	5	<5	7	<5	6	<5
Rb	134	123	98	71	79	139	105	91	99	94	90	90	159	127	140
Sr	89	256	252	629	593	63	45	44	47	405	43	46	65	62	56
Y	31	35	87	54	60	58	45	49	53	70	42	49	61	37	46
Zr	230	244	571	453	489	329	323	373	469	523	316	354	349	232	238
Nb	18	17	13	58	40	25	26	31	33	35	28	26	22	18	21
Mo	<5	<5	7	<5	<5	<5	<5	<5	7	<5	15	15	<5	10	9
Sn	<1	13	4	16	11	10	32	11	<1	6	<1	<1	3	<1	<1
Sb	<1	26	<1	6	4	6	39	9	<1	<1	<1	<1	17	<1	<1
W	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb	37	54	30	74	67	39	24	58	71	61	74	76	42	23	36
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Th	25	21	56	81	70	38	31	40	44	51	47	31	22	25	22
U	<1	5	6	17	14	<1	<1	<1	7	10	<1	5	<1	<1	<1
As	<5	16	<5	21	17	9	<5	5	11	7	10	12	12	<5	7
S	<10	<10	106	154	129	56	61	76	104	243	14	<10	13	<10	<10

*See Table 3.13 for sample positions

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TABLE 3.15 (Continued)

Sample No.*	68	69	70	71	68,69,70	73	74	75	76	77	73,74	81	82	83	84
V	128	79	165	131	125	193	184	226	169	150	207	174	183	193	199
Co	23	30	32	30	33	34	25	29	20	35	24	19	26	24	22
Ni	38	41	22	32	28	94	82	89	110	74	103	75	79	64	67
Cu	58	51	82	70	78	60	82	94	80	91	88	70	78	70	74
Zn	48	42	52	53	55	54	98	112	71	82	108	63	90	89	83
Ga	30	30	38	34	34	31	34	27	31	33	34	30	34	34	33
Ge	9	8	8	8	7	<5	<5	<5	5	6	<5	5	<5	5	6
Rb	59	23	57	53	48	60	66	109	90	70	68	116	81	71	106
Sr	100	84	145	31	318	33	46	73	53	71	45	86	63	50	71
Y	58	27	103	67	82	35	57	33	32	88	56	41	48	52	58
Zr	583	256	660	433	533	285	358	253	261	491	339	317	362	364	508
Nb	34	26	40	31	33	21	30	19	19	27	27	20	32	29	31
Mo	8	8	11	9	21	11	13	8	<5	<5	12	<5	<5	<5	<5
Sn	21	24	30	31	31	25	1	28	10	22	<1	1	5	4	1
Sb	21	29	30	30	31	29	1	38	11	26	<1	1	2	1	1
W	<1	<1	1	<1	<1	1	1	1	<1	1	<1	1	1	1	1
Pb	36	32	66	39	61	42	56	47	34	35	64	51	59	61	55
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Th	41	27	85	42	53	37	38	24	20	52	40	36	45	44	56
U	4	<1	34	5	21	1	1	1	<1	10	2	3	1	1	6
As	<5	<5	12	<5	<5	<5	<5	<5	<5	<5	9	<5	7	7	9
S	15	34	104	51	80	<10	<10	<10	150	31	<10	<10	15	15	<10

*See Table 3.13 for sample positions

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TABLE 3.15 (Continued)

Sample No.*	85	81,82	87	88	89	90	91	92	93	87,88	90,91	109	110	111	112
V	219	189	107	120	228	216	189	159	241	133	215	129	129	95	119
Co	33	24	5	11	28	34	29	19	23	13	18	18	32	25	30
Ni	84	85	38	24	66	81	57	37	96	41	72	25	24	17	40
Cu	81	73	52	68	56	64	81	167	127	62	63	44	69	48	89
Zn	79	96	33	52	46	50	48	55	71	37	50	47	81	66	125
Ga	38	34	27	33	32	32	33	40	34	33	33	37	30	31	25
Ge	7	<5	7	7	6	6	5	9	5	8	6	8	5	5	<5
Rb	85	81	128	74	106	132	101	74	67	83	105	73	64	23	49
Sr	59	57	142	107	83	99	79	46	63	143	81	36	43	30	51
Y	51	41	40	73	63	33	54	122	70	67	47	73	43	38	61
Zr	464	312	217	554	326	304	345	1 036	336	542	305	518	295	361	246
Nb	34	26	18	29	28	21	27	41	28	28	25	36	30	38	25
Mo	<5	10	<5	9	<5	<5	5	5	<5	<5	<5	23	<5	<5	<5
Sn	29	<1	<1	<1	26	14	18	21	2	<1	<1	1	3	8	1
Sb	30	<1	<1	<1	29	19	12	6	<1	<1	<1	1	1	1	1
W	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	1	1	1
Pb	58	58	39	37	28	41	63	66	43	55	58	35	44	27	45
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Th	55	40	23	33	40	28	46	68	48	40	41	53	39	39	28
U	5	<1	<1	2	<1	2	10	22	5	6	5	8	1	1	1
As	8	7	<5	<5	<5	<5	<5	110	<5	<5	7	<5	<5	<5	<5
S	21	11	<10	<10	<10	<10	22	156	364	<10	22	19	<10	<10	<10

*See Table 3.13 for sample positions

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TABLE 3.16 MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM RECONNAISSANCE BOREHOLES ON THE WEST RAND

Sample No.*	Major Constituents	Minor Constituents	Approximate percentage quartz
52	Kaolinite and sericite	montmorillonite	25
53	Kaolinite and sericite	montmorillonite and illite-montmorillonite mixed layer	15
54	Kaolinite and sericite	montmorillonite and illite-montmorillonite mixed layer	20
55	Kaolinite	sericite, alunite, montmorillonite and illite-montmorillonite mixed layer	12
57	Kaolinite	sericite and illite-montmorillonite mixed layer	12
58	Kaolinite	sericite and illite-montmorillonite mixed layer	12
59	Kaolinite	illite-vermiculite mixed layer, sericite, vermiculite and alunite	7
60	Kaolinite	sericite and illite-montmorillonite mixed layer	7
61	Kaolinite and montmorillonite	sericite	5
64	Kaolinite, montmorillonite, sericite and feldspar		20
65	Montmorillonite, kaolinite and sericite	feldspar	20
68	Kaolinite	montmorillonite, illite and illite-montmorillonite mixed layer	40
69	Kaolinite	montmorillonite and illite	22
70	Kaolinite	montmorillonite, illite and illite-montmorillonite mixed layer	20

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TABLE 3.16 (Continued)

Sample No.*	Major Constituents	Minor Constituents	Approximate percentage quartz
71	Kaolinite	very little montmorillonite and illite	10
73	Kaolinite	illite and very little montmorillonite and illite-montmorillonite mixed layer	20
74	Kaolinite	illite (very little	4
75	Kaolinite	sericite	22
76	Kaolinite (badly crystallized)	illite (very little)	7
77	Kaolinite	montmorillonite and illite (very little)	10
81	Kaolinite and sericite	illite-montmorillonite mixed layer	20
82	Kaolinite	montmorillonite, sericite and illite-montmorillonite mixed layer	5
83	Kaolinite	montmorillonite, sericite and illite-montmorillonite mixed layer	3
84	Kaolinite and sericite	montmorillonite and illite-montmorillonite mixed layer	12
85	Kaolinite	sericite and little montmorillonite	8
87	Kaolinite and sericite	montmorillonite and illite-montmorillonite mixed layer	25
88	Kaolinite	illite and illite-montmorillonite mixed layer	25
89	Kaolinite	sericite	10
90	Kaolinite		25

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TABLE 3.16 (Continued)

Sample No.*	Major Constituents	Minor Constituents	Approximate percentage quartz
91	Kaolinite	sericite and illite-montmorillonite mixed layer	7
92	Kaolinite	montmorillonite, illite and illite-montmorillonite mixed layer	10
93	Kaolinite	illite (very little)	7
109	Kaolinite	montmorillonite and illite	<1
110	Kaolinite	illite	<1
111	Kaolinite	–	<1
112	Kaolinite and morillonite	illite	1

*See Table 3.13 for sample positions

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listed below with the corresponding values of samples from Westwood Small Holdings given in brackets for comparison*:

SiO_2	49,89	(53,4)
TiO_2	1,37	(1,64)
Fe_2O_3	2,12	(2,35)
MgO	0,96	(0,21)
CaO	0,14	(0,13)
Na_2O	0,13	(0,25)
K_2O	0,96	(0,21)

Based on chemical composition, the West Rand clays therefore appear to be generally of better quality, but samples from Westwood Small Holdings do contain significantly less MgO and K_2O.

The TiO_2 content of the West Rand clays is generally of the same order of magnitude as that of refractory clays elsewhere in the Ecca Group. On the other hand, siliceous mudstone which resembles flint refractory clay and which occurs interbedded with tillite of the Dwyka Formation in the Pretoria – Belfast area, has been found to contain significantly less TiO_2 (in the order of 0,5 per cent). Although not conclusive by itself, this certainly tends to support correlation of the West Rand clays with the Ecca Group rather than with the Dwyka Formation.

On average, these clays have a higher rubidium content than their East Rand counterparts, but the previously mentioned tendency of the more refractory types to contain relatively less Rb is clearly discernible. The overall trace-element composition is, however remarkably similar to that of clays from the East Rand.

As shown in Table 3.16, the most common mineralogical constituents apart from kaolinite and quartz are montmorillonite, mixed layer illite-montmorillonite, illite and sericite. Rare constituents are alunite, vermiculite, mixed layer illite-vermiculite and feldspar. The only

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* The values listed here differ somewhat from those presented in a similar comparison in Bredell (1979) because more samples from the West Rand have since been analysed.

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mineral present here which has not been detected in any of the East Rand clays is the mixed-layer variety illite-vermiculite. This is probably not of much significance as it was only found in one sample. Of more importance is the greater tendency of other minerals (sericite, montmorillonite and feldspar) to occur together with kaolinite as major constituents. Seeing that there is no significant difference between the fossil pH of clays from the East and West Rand, the greater abundance of non-kaolinite minerals in the latter area can probably be attributed to relatively poorer leaching conditions in the provenance. The quartz content is highly variable and of particular interest is the fact that sample 68 yielded an unexpectedly high fusion temperature (Seger cone 30$^-$) despite a quartz content of about 40 per cent. This serves to illustrate the often misleading impression which can be gained from routine analytical results, an aspect which is dealt with in Chapter 5.

The difference in texture between semi-plastic and semi-flint clay from the promising south-western part of the Westonaria outlier is shown in Figs. 3.27 and 3.28. The close resemblence with corresponding types on the East Rand is obvious and strongly suggests a similar genesis for clays from these two areas. The kaolinite particles are typically detrital and kaolinite booklets are very scarce, indicating an almost complete absence of post-depositional kaolinisation. This, together with the absence of small angular rock and mineral fragments, can in the author's opinion be regarded as conclusive evidence that these clays neither represent, nor have been derived from glacial flour as proposed by Plumstead (1969). As in the case of the East Rand clays, the quartz grains are typically well-rounded but some rare subangular grains were also observed (Fig. 3.29). Sericite is commonly present as comparatively large booklets of up to about 200 μm across (Fig. 3.30). The very small particle size of montmorillonite (0,15 to 0,8 μm) is illustrated in Figs. 3.31 and 3.32.

3.4.4 Inferred Resources

Owing to the fact that only reconnaissance drilling was attempted, no reliable estimate of resources can be made. Boreholes which had been drilled for other purposes do, however, indicate that the clay horizon persists over large areas and for all practical purposes, the areas delineated as Ecca Group on Fig. 3.22 can be regarded as potentially clay-bearing. The properties of the clay and the thickness of the deposits can be expected to vary roughly within the limits established by the reconnaissance boreholes. Assuming an average bulk density of 2,0 and an average thickness of 20 m, the amount of clay per hectare would be in the order of 400 000 t, and total inferred resources in the area could be in excess of

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Fig. 3.27 Well-orientated kaolinite flakes in semi-plastic clay from borehole WR 2 on Panvlakte 291 IQ. Magnification 2 000X.

Goedgeoriënteerde kaolinietvlokkies in semi-plastiese klei uit boorgat WR 2 op Panvlakte 291 IQ. Vergroting 2 000X.

Fig. 3.28 Typical texture of semi-flint clay from borehole WR 3 on Panvlakte 291 IQ. Magnification 2 200X.

Tipiese tekstuur van semi-flintklei uit boorgat WR 3 op Panvlakte 291 IQ. Vergroting 2 200X.

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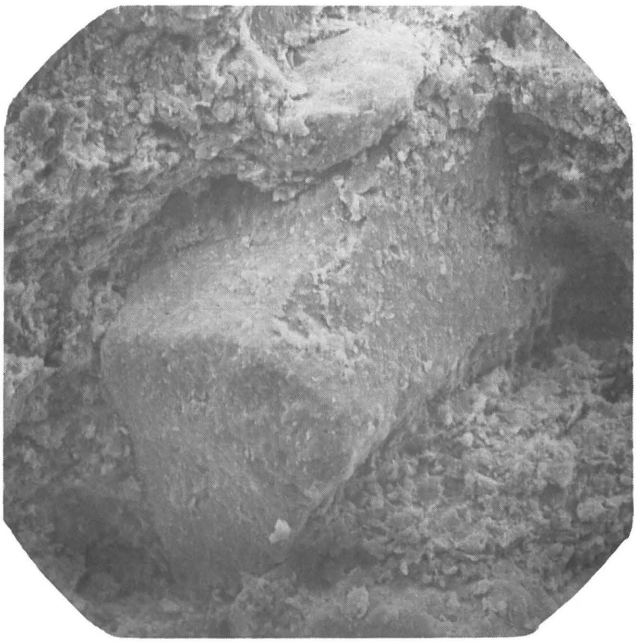

Fig. 3.29 Subangular quartz grain in semi-flint clay from borehole WR 1 on Panvlakte 291 IQ. Magnification 360X.

Effens hoekige kwartskorrel in semi-flintklei uit boorgat WR 1 op Panvlakte 291 IQ. Vergroting 360X.

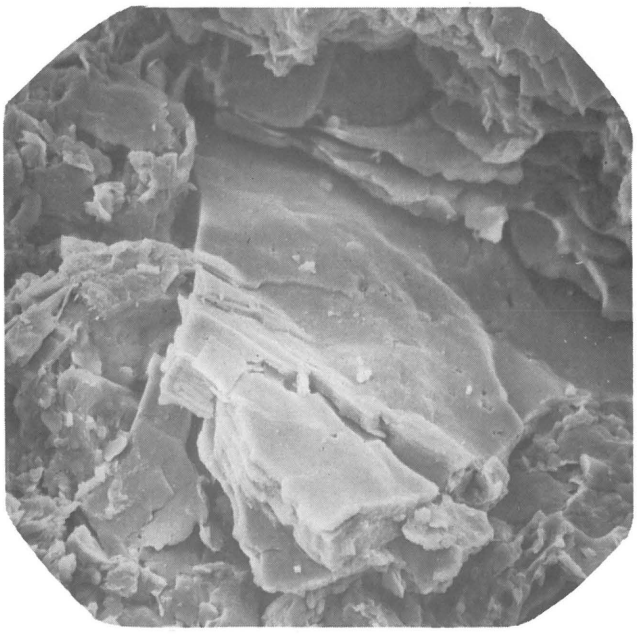

Fig. 3.30 Sericite booklet in non-refractory clay from borehole WR 5 on Waterpan 292 IQ. Magnification 440X.

Serisietboekie in nie-vuurvaste klei uit boorgat WR 5 op Waterpan 292 IQ. Vergroting 440X.

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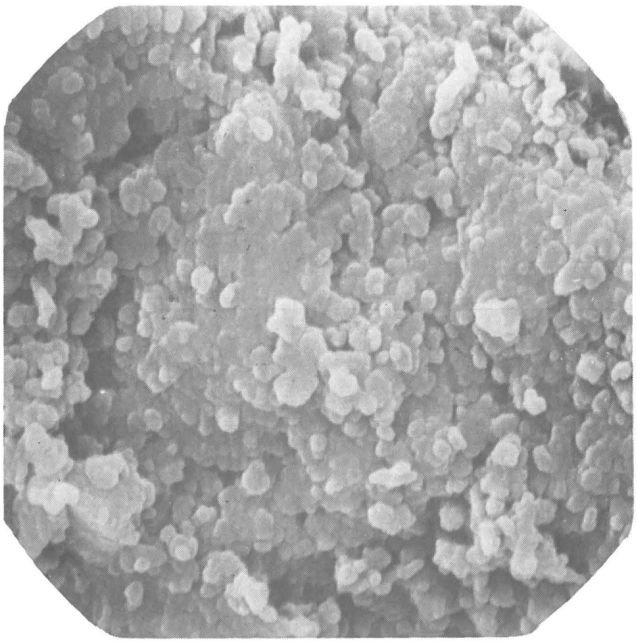

Fig. 3.31 Montmorillonite in semi-flint clay from borehole WR 9 on Driefontein 355 IQ. Magnification 4 800X.

Montmorilloniet in semi-flintklei uit boorgat WR 9 op Driefontein 355 IQ. Vergroting 4 800X.

Fig. 3.32 Kaolinite plate covered by montmorillonite in semi-flint clay from borehole WR 9 on Driefontein 355 IQ. Magnification 3 200X.

Kaolinietplaatjie bedek deur montmorilloniet in semi-flintklei uit boorgat WR 9 op Driefontein 355 IQ. Vergroting 3 200X.

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200 Mt. If the reconnaissance boreholes are considered to represent a fair reflection of the quality distribution within the West Rand outliers, about 70 per cent of the total resources can be expected to consist of clay with a good refractoriness (PCE 34^- to 35), while clay with a low refractoriness (PCE 29^- to 33^+) and non-refractory clay constitute approximately 27 and 3 per cent respectively.

In the somewhat unlikely event of the production of alumina from silicate sources ever becoming economically competitive with conventional alumina extraction from low-grade bauxite, the West Rand clays would undoubtedly become of prime importance in view of the size of these deposits. However, in the short term it is probably more realistic to predict that exploitation of these vast resources for the refractories industry would commence in the near future, and that the production of face bricks and other structural clay products would continue to expand to satisfy growing demand in the Pretoria – Witwatersrand – Vereeniging region. It is therefore strongly recommended that these unique clay deposits be safeguarded from sterilisation as far as possible, even in areas which have not formally been reserved for clay mining as a result of this investigation.

3.5 THE PRETORIA – BELFAST AREA

All production of proper flint clay and a large proportion of semi-flint clay production in South Africa have come from small outliers and tongues of the Ecca Group in the area between Pretoria and Belfast. Approximately 45 erosional outliers of the Ecca Group are scattered in this area between the vast sheet of Karoo rocks to south and the detached Karoo basin to the north around Warmbad. From an economic point of view, this can certainly be regarded as the most important refractory-clay producing region in the country. The area considered for exploration purposes during the present study is depicted on Fig. 1.9.

The distribution of the Ecca Group in this area has been adequately displayed on several maps published by the Geological Survey, viz. Sheets 1 (Pretoria), 2 (Pienaars River), 3 (Middelburg), 11 (Lydenburg), 16 (Belfast), 18 (Moos River), 2528D (Bronkhorstspruit) and 2529C (Witbank). More recently, the area has also been covered partly by the series of 1 : 50 000 maps around Pretoria and the 1 : 250 000 Sheet 2528 (Pretoria). Descriptions of the physiography of the area and the general lithology and stratigraphy of the Ecca Group have been presented by *inter alia* Wybergh (1922) and Visser, *et al.* (1961). By far

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the most comprehensive account of the distribution and geological setting of the refractory-clay deposits has been given by Bennetts (1965) who conducted a detailed survey of all quarries, prospecting pits and trenches which existed at the time. He also made a valuable contribution on the mineralogy, origin and depositional environment of the clays and this work is still regarded as the most authoritative on these subjects. The present study was not aimed at duplicating this excellent investigation on known deposits, but rather to complement it by attempting to find and evaluate new deposits.

3.5.1 Selection of Drilling Targets

As mentioned above, general exploration targets in the form of areas underlain by the Ecca Group have been fairly well established. Further reduction of these areas as was done in the case of the East and West Rand, proved to be practically impossible because of the much smaller, lenticular nature of the deposits, the general lack of subsurface data and the fact that these clays have been proved to occur at different stratigraphic levels. Some exploration companies have reported an apparent correlation between altitude and the presence of clay, an observation which was also made by Bennetts (1965) in respect of the Belfast area. This aspect has been thoroughly investigated by the author in order to assess its potential as an exploration aid, but it can be concluded that, although interesting, there is very little merit in applying this relationship in an area where the host formation has already been dilineated. Known deposits of refractory clay are indeed found at progressively lower altitudes from north to south and from east to west in the area, but this is obviously merely a reflection of the general trend in the topography.

The final choice of drilling targets was made after eliminating all areas which have already been investigated by mining companies and by selecting the most promising of the remaining sites during a field survey. All borehole descriptions are presented in Appendix 4.

3.5.2 Paardefontein 282 JR

Four boreholes were drilled on Portion 32 of this farm which is situated on the central part of an Ecca Group outlier that strikes for about 12 km across Wallmannsthal 278 JR, Paardefontein 282 JR and Kloppersbos 128 JR, approximately 30 km north-east of Pretoria (Fig. 3.33). The area seemed to be an obvious choice for refractory-clay prospecting because it lies on strike with the outlier around Pyramid Station which is known to host several flint-

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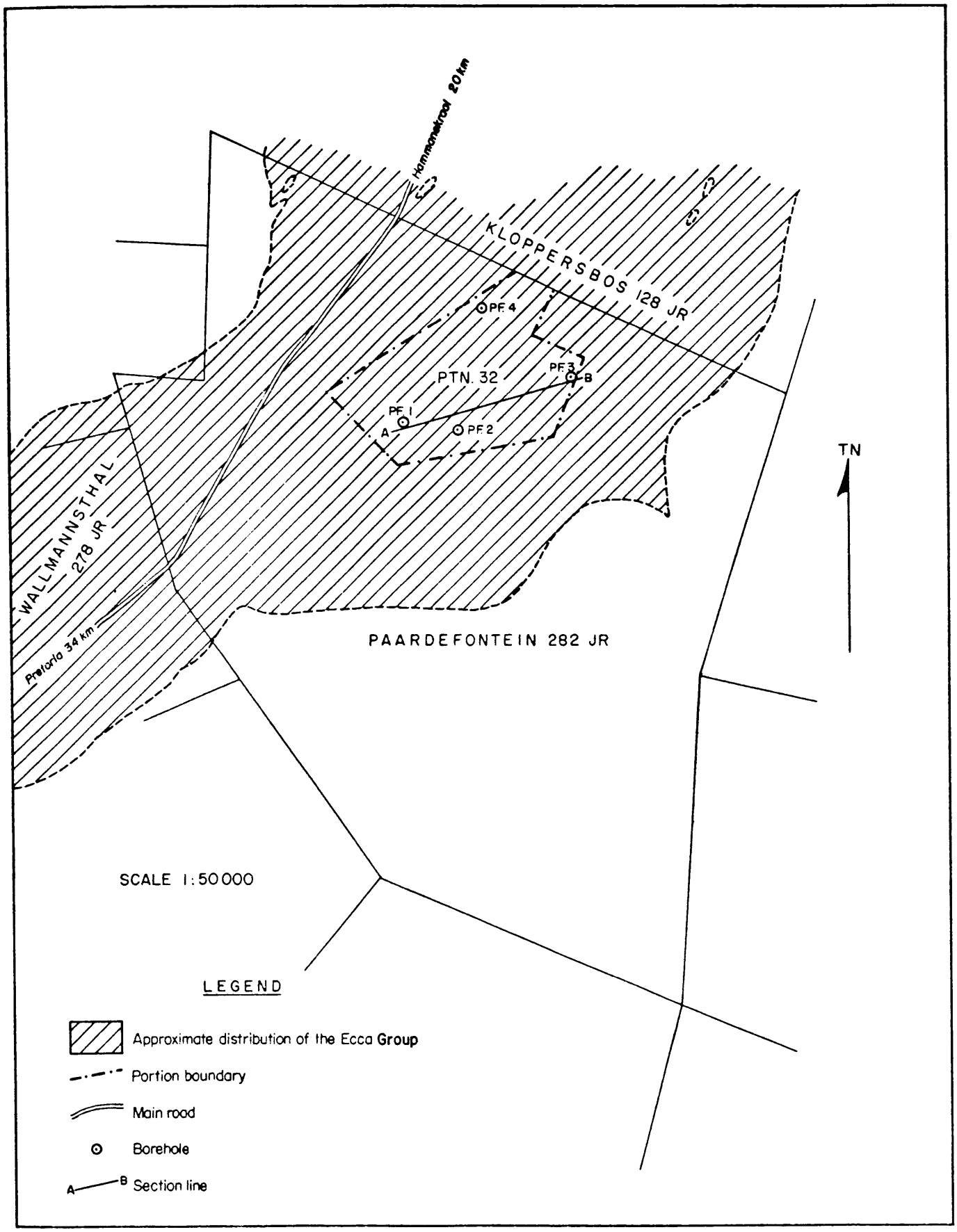

Fig. 3·33 Positions of boreholes drilled for refractory clay on Paardefontein 282 JR

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clay deposits, and it is located only 15 km south-east of the well-known deposits at Hammanskraal.

The general succession indicated by the boreholes is as follows (Bredell, 1976c):

Soil (0,6 – 1,5 m).	ECCA GROUP
Siltstone and sandstone (5,45 m).	
Grit with layers and lenses of sandstone, siltstone and silty plastic clay (10,45 – 13,05 m).	
Tillite with a gritty matrix (1,75 – 5,8 m).	DWYKA FORMATION
Siltstone (0,5 – 4,9 m).	
Tillite with a silty matrix (2,8 – 6,1 m).	
Silty flint clay (0,15 – 2,6 m).	
Tillite with a sandy matrix (3,9 – 9,45 m).	
Felsite.	ROOIBERG GROUP

The usual stratigraphic position of refractory clay is occupied in this case by predominantly poorly rounded grit which probably resulted from rapid erosion in the source area and quick deposition in a proximal basin. These high-energy conditions prevented the separation of the clay-mineral fraction during transportation as well as differential flocculation of kaolinite. The thin layers and lenses of silty clay probably represent relatively short periods of quiet sedimentation, but seeing that the preceeding cycle prevented plant accumulation and an increase in organic acids, kaolinite particles could not be separated properly from the clay-silt suspension. The extent of these immediately post-Dwyka depositional conditions is not accurately known, but from available evidence it appears to be fairly localised. Such conditions evidently did not prevail towards the south south-west (Pyramid outlier), the north (Hammanskraal area and the northern outlier on Kloppersbos) or to the east in the outlier on Boekenhoutskloofdrift 286 JR. Similar conditions might, however, have predominated towards the east north-east in the large outlier on the farms Enkeldoorn 217 JR and Hartebeestspruit 235 JR, where drilling by Marico Mineral Co. (Pty) Ltd. also proved only silty clay to be present (Collins, pers. comm.).

The distinct and persistent grading displayed in the Dwyka Formation, not only in the tillite matrix, but also in the form of layers and lenses of siltstone and siliceous flint clay (Fig. 3.34), indicates that these rocks were probably deposited under fluvio-glacial conditions. Evidence from other localities in the Pretoria – Belfast area suggests that this applies to most of the Dwyka Formation in this region.

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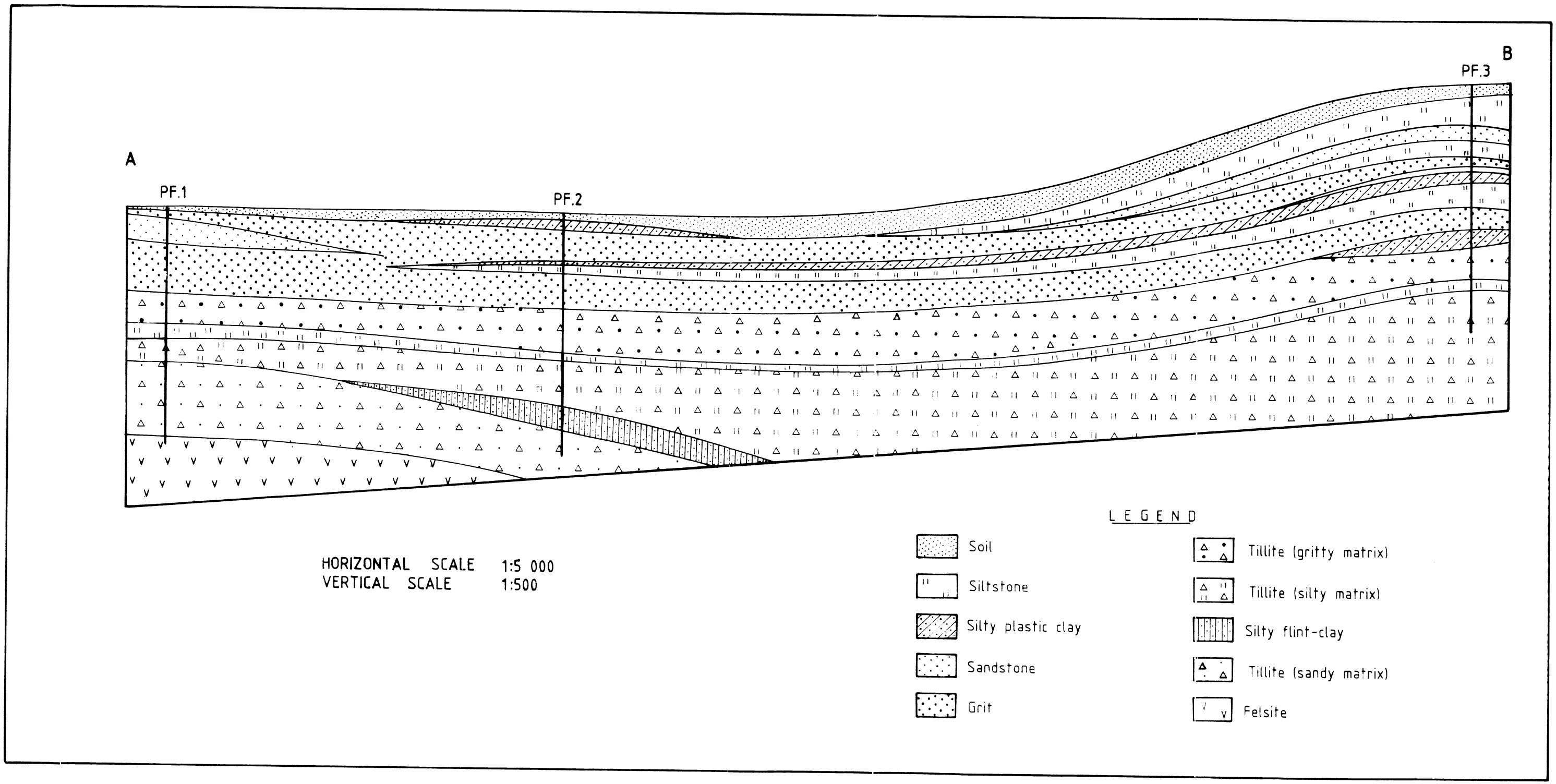

Fig.3.34 W-E section through boreholes on Paardefontein 282 JR

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In view of the generally disappointing drilling results, only one sample (137) was taken to investigate the composition and properties of the Dwyka "flint clay" intersected between 24,6 and 27,2 m in borehole PF 2. It was found to consist mainly of illite and kaolinite, about 45 per cent quartz and subordinate amounts of potassium feldspar. The material has an exceptionally high bulk density (2,55), an apparent porosity of 4,36 per cent, and the PCE was indicated to be 27. Although it can therefore still be classified as a flint refractory clay according to the definition presented earlier, it is doubtful whether material of this nature would ever be utilised in the refractories industry. The major-element chemical composition is as follows (all values in per cent):

SiO_2	64,95
TiO_2	0,59
Al_2O_3	21,68
Fe_2O_3	1,46
FeO	1,23
MnO	0,06
MgO	1,09
CaO	0,11
Na_2O	0,08
K_2O	4,23
P_2O_5	0,07
CO_2	0,84
H_2O^+	3,03
Total	99,42

H_2O^- on air-dried sample:	0,71
Al_2O_3 on a calcined basis:	22,56

The trace-element concentrations (in ppm) are presented below:

V 78, Co 17, Ni 28, Cu 61, Zn 63, Ga 25, Ge 6, Rb 288, Sr 67, Y 33, Zr 287, Nb 21 Mo <5, Sn 15, Sb 25, W <1, Pb 17, Se <5, Th 22, U <1, As <5, S 481.

Seeing that these Dwyka "flint clays" closely resemble true flint clay from the Ecca Group in hand specimen, it is important to point out the characteristic features which may serve

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to distinguish the two types. As it is often difficult to establish with certainty whether a particular clay indeed belongs to the Dwyka Formation, the abovementioned sample which clearly forms part of this stratigraphic unit is used here as an example:

(1) When compared with the bulk density – apparent porosity relationship established by Bennetts (1963) for the Transvaal flint clays, sample 137 plots outside the 95 per cent confidence interval of individual plots, indicating a predominance of minerals with relative densities higher than that of kaolinite.

(2) With a pH of 6,5, sample 137 is clearly anomalous with respect to the relationship between bulk density and pH illustrated in Bredell (1974). True flint clay normally has a pH of well below 6,0.

(3) The TiO_2 content of 0,59 per cent is significantly lower than the concentration range of about 1,0 to 2,0 per cent for this component in refractory clays from the Ecca Group.

(4) The Rb content of 288 ppm is about 130 ppm higher than the maximum value recorded for all Ecca refractory clays analysed during this study.

It can consequently be concluded that the drilling on Paardefontein failed to indicate the presence of economically significant clay deposits and that further prospecting for refractory clay within this particular outlier would most probably also lead to negative results.

3.5.3 Kloppersbos 128 JR

This area is situated on a small outlier of the Ecca Group, about 40 km north-east of Pretoria and 11 km south-east of Hammanskraal. The author's attention was drawn to the site by the presence of a small flint-clay quarry which had been abandoned shortly before the time of investigation towards the end of 1975. It is located near the northern boundary of the outlier on the south-western corner of Boekenhoutkloof 129 JR (see Fig. 3.35). A small amount of flint clay was produced here by Premier Kiln Products (Pty) Ltd. but mining was obviously stopped as a result of an unfavourable overburden/clay ratio and the limited scope for expansion within the company's property on Boekenhoutkloof. It was consequently decided to investigate the possible southerly continuation of this deposit onto

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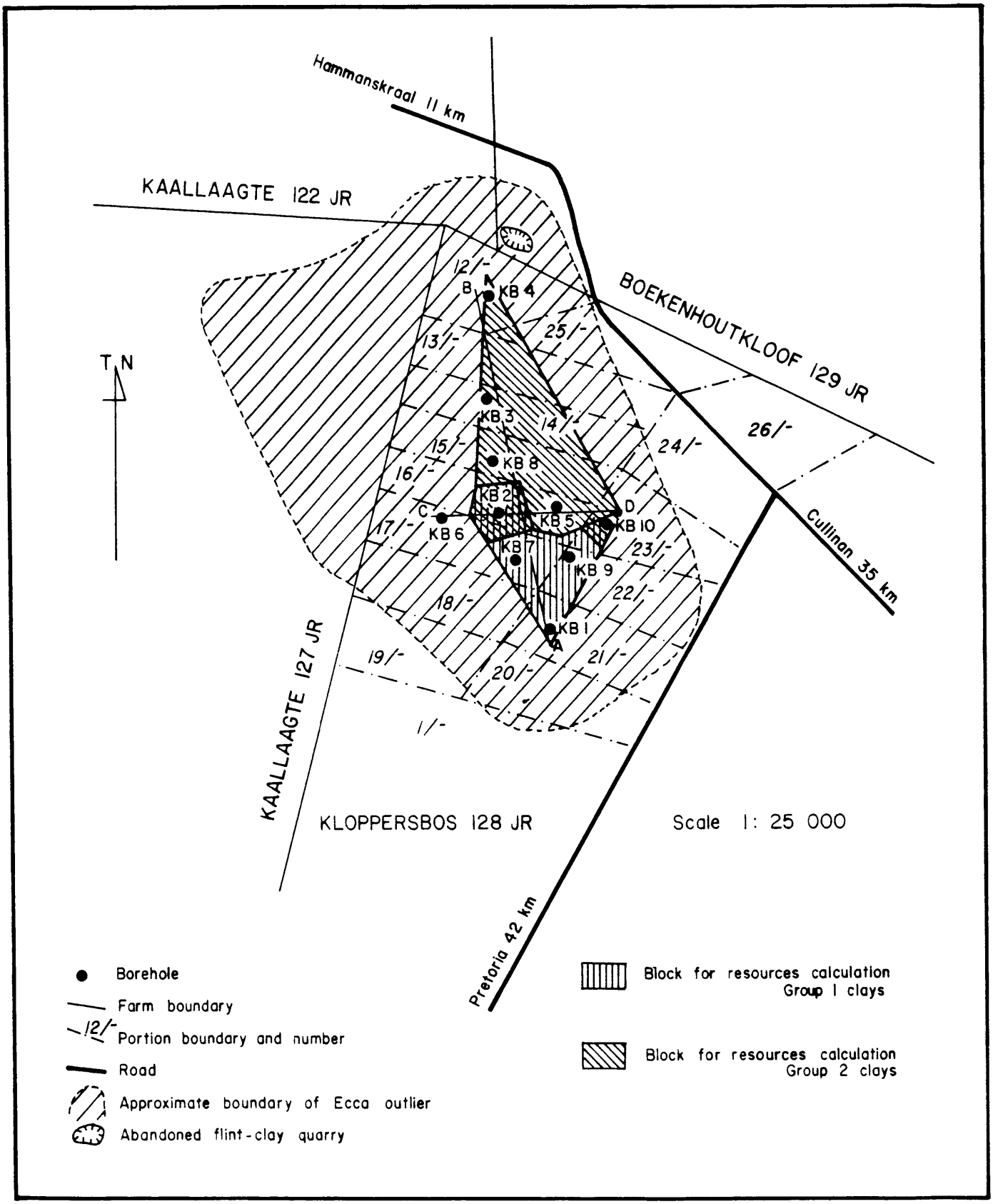

Fig. 3·35 Positions of boreholes drilled for clay on Kloppersbos 128 JR

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the major part of the outlier on Kloppersbors 128 JR. As shown in Fig. 3.35, ten boreholes were drilled on Portions 12, 14, 15, 16, 17, 21, 22 and 23 of this farm (Bredell, 1976b).

Nine of the holes intersected sediments of the Ecca Group, but KB 6 struck an unexpected high in the pre-Karoo basement and penetrated felsite of the Rooiberg Group directly below the alluvium. The deepest part of the outlier seems to be located roughly near its centre around boreholes KB 8 and KB 3; the Ecca Group attains a maximum thickness of about 27 m in this area while the total thickness of the Karoo Sequence is probably in the order of 40 m. The general succession as indicated by the boreholes is as follows (see Fig. 3.36 and Appendix 4):

Sandy soil, lateritic in places.	
Grit. Sandstone with layers and lenses of flint clay, plastic clay and siltstone. Semi-plastic clay. Flint clay. Siltstone. Grit. Carbonaceous shale, carbonaceous clay and dull coal.	ECCA GROUP
Tillite with occasional lenses of siltstone.	DWYKA FORMATION
Felsite.	ROOIBERG GROUP

The very obvious thinning of both the Dwyka Formation and the carbonaceous lower portion of the Ecca Group towards the north and south (Fig. 3.36) suggests that deposition probably commenced in a small isolated basin, giving rise to a swampy environment. The carbonaceous material was subsequently covered by predominantly silt and clay which appear to increase in volume towards the southern, more distal part of the basin. Subsequently, accumulation of arenaceous material prevailed, probably as a result of braided outwash fans prograding across the basin from the north. Limited deposition of clay and silt during these later stages can possibly be attributed to seasonal fluctuations in depositional energy. Poorly exposed cross-bedding in the quarry on Boekenhoutkloof seems to indicate palaeocurrents from the north north-west in a direction between 162 and 176°.

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As shown in Table 3.17, all the boreholes which were drilled into the Ecca Group intersected refractory clay. Of the 17 samples tested, 13 can be classified as flint clay, 3 as semi-flint and one as semi-plastic. Only three of the samples yielded PCE values of less than 34^{-}; all the others can therefore be regarded as representing clays of good refractoriness. Although the refractory properties within a particular layer appear to be generally consistent between boreholes, the siliceous nature and relatively low refractoriness of the second flint-clay layer above the carbonaceous horizon as intersected in borehole KB 8 indicate that lateral variations in quality should be expected. The other less refractory clays seem to be confined to specific stratigraphic levels, viz. the second flint-clay lens from the top in KB 2 and the lenticular layer immediately below the carbonaceous horizon in KB 4. Sites offering the most favourable stripping ratios are located around boreholes KB 1, 5 and 7 in the southern part of the area. Of particular interest is the intersection in KB 1 where a continuous succession of 7,3 m of refractory clay with a PCE of 35^{-} was indicated beneath an overburden of only 3,7 m. Further prospecting to the south of this hole is therefore strongly recommended.

The generally low alumina contents of the clays (Table 3.18) cause the grades to be disappointingly low. Not one of the samples can be classified as Grade I which means that these flint clays are not of export quality. The deficiency in alumina can in most cases be attributed to a high percentage of quartz (Table 3.17); fortunately this is compensated for by low iron contents which evidently account for the relatively high fusion temperatures.

The mineralogy of these clays is remarkably constant, considering the fact that the samples were derived from stratigraphically different layers. Illite is the only minor component of the clay-mineral fraction in all but one sample, while kaolinite forms the only major constituent except in the case of sample 152 which was also found to contain some pyrophyllite. The presence of this mineral is exceptional and as far as could be established, pyrophyllite has not previously been identified in South African refractory clays. An occurrence of pyrophyllite-bearing flint clay in the Permian Illawarra Coal Measures of New South Wales has been described by Loughnan and Ward (1971) and a detailed study indicated this pyrophyllite to be of detrital origin, having most probably being derived from the nearby Gerringong Volcanics. Pyrophyllite is generally considered to form through hydrothermal alteration of acid volcanics (Searle and Grimshaw, 1959), but a diagenetic origin in sediments has also been proposed (Millot, 1970). According to Hemley and Jones (1964) and Reed and Hemley (1966), kaolinite in the presence of quartz has been shown experimentally to convert to pyrophyllite at temperatures of between 300 and 380^{o}C and a pressure of

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TABLE 3.17 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON KLOPPERSBOS 128 JR

			Physical properties				Classification		Mineralogical composition (Kaolinite is the major constituent of all samples)**	
Sample No.	Borehole No.	Depth (m)	PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
138	KB 1	3,70–8,40	35^-	1,95	25,39	N8	Semi-plastic	III	Illite	4
139	KB 1	8,40–11,00	35^-	2,38	8,58	N7	Flint	II	None	10
140	KB 2	4,10–5,10	33	2,34	10,76	N8	Flint	IV	Illite	25
141	KB 2	11,30–12,10	34^+	2,35	10,41	N8	Flint	IV	Illite	15
142	KB 2	13,20–14,70	34^+	2,35	9,58	N7	Flint	III	Illite	20
143	KB 3	12,55–13,70 plus 13,85–14,50	34^+	2,49	4,64	N5–N4	Flint	IV	Illite	20
144	KB 4	4,65–5,80	34^-	2,37	9,60	N7	Flint	IV	Illite	40
145	KB 4	14,00–15,00	33	2,51	3,88	N5	Flint	IV	Illite	18
146	KB 5	1,60–2,20 plus 2,70–3,20	34^-	2,37	9,51	N8	Flint	IV	Illite	30
147	KB 5	4,10–6,00	34	2,37	9,59	N8	Flint	IV	Illite	20
148	KB 5	6,90–11,00	34^+	2,40	8,62	N8	Flint	IV	Illite	28
149	KB 7	3,90–5,30 plus 5,80–6,90	35^-	2,36	10,26	N8–N9	Flint	III	Illite	22
150	KB 8	9,10–10,70	30	2,42	8,23	N8	Flint	IV	Illite	55
151	KB 8	12,70–14,20	34^+	2,39	9,09	N8	Flint	IV	Illite	15
152	KB 9	11,50–13,40	34^-	2,15	20,95	N7–N8	Semi-flint	II	Illite	12
153	KB 10	6,00–8,70	34^-	2,27	13,80	N8	Semi-flint	IV	Illite	23
154	KB 10	8,70–11,50	34^-	2,03	22,14	N8–5YR8/1	Semi-flint	III	Illite	15

*PCE = Pyrometric cone equivalent

**Sample 152 also contains pyrophyllite as major constituent in addition to kaolinite

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TABLE 3.18 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON KLOPPERSBOS 128 JR

Sample No.*	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154
SiO_2	48,30	45,87	52,98	53,64	50,13	51,96	58,58	52,59	55,48	54,03	53,00	48,37	54,65	54,25	44,46	59,09	49,30
TiO_2	3,52	2,40	1,37	1,56	1,43	1,37	1,39	2,56	1,50	1,36	1,34	1,40	1,42	1,39	2,17	1,64	1,18
Al_2O_3	33,73	35,63	31,79	31,56	33,65	30,44	27,51	31,93	29,30	30,74	31,40	35,32	30,76	30,45	37,84	26,72	34,05
Fe_2O_3	0,42	0,57	0,68	0,84	0,06	0,71	0,93	0,26	0,35	0,70	0,82	0,94	0,81	0,50	0,03	1,06	0,82
FeO	<0,15	<0,15	<0,15	<0,15	0,48	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	1,01	<0,15	1,05
MnO	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,03	0,02	0,02	0,03	0,02	0,01	0,01
MgO	0,78	0,10	0,38	0,81	0,83	0,11	0,11	0,71	0,81	0,13	0,22	0,78	0,83	0,86	0,69	0,81	0,81
CaO	0,05	0,19	0,13	0,03	0,03	0,15	0,16	0,07	0,02	0,14	0,14	0,02	0,02	0,02	0,03	0,03	0,05
Na_2O	0,10	0,22	0,19	0,04	0,16	0,18	0,20	0,09	0,04	0,22	0,21	0,04	0,04	0,03	0,04	0,03	0,05
K_2O	0,34	0,31	1,17	1,17	1,28	1,17	0,67	0,20	0,68	1,07	1,08	1,09	0,89	1,03	0,10	0,85	0,47
P_2O_5	0,09	0,19	0,13	0,08	0,07	0,17	0,25	0,10	0,06	0,11	0,08	0,07	0,10	0,07	0,20	0,09	0,09
CO_2	0,38	0,61	0,35	0,36	1,64	1,60	0,31	1,20	0,19	0,25	0,28	0,25	0,25	0,22	0,22	0,44	0,22
H_2O^+	11,30	13,54	10,02	9,84	10,26	10,84	8,72	10,18	10,00	10,98	11,10	10,81	9,44	9,48	12,61	9,16	11,89
Total	99,04	99,64	99,20	99,93	100,03	98,71	98,84	99,90	98,44	99,74	99,70	99,11	99,23	98,32	99,41	99,93	99,97
H_2O^- on air-dried sample	0,71	0,51	0,61	0,45	0,50	0,12	0,09	0,51	0,37	0,35	0,21	0,48	0,57	0,47	0,49	0,53	0,71
Al_2O_3 on a calcined basis	38,24	41,53	35,50	35,15	38,19	34,83	30,28	36,03	32,68	34,64	35,45	39,76	34,09	33,78	43,45	29,56	38,74
pH	6,1	5,0	5,2	5,1	5,3	5,4	5,1	4,6	5,6	5,3	5,4	5,2	5,7	5,0	6,1	5,8	6,4

*See Table 3.17 for sample positions

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1 000 bars. In the case of Kloppersbos, two possible mechanisms to explain the presence of pyrophyllite can therefore be envisaged. The area is underlain and surrounded by felsite of the Rooiberg Group which could through local hydrothermal action have yielded pyrophyllite that was subsequently deposited in the Ecca Group. However, no occurrence of pyrophyllite has been reported from the Rooiberg Group or from other rocks in the possible source area and this, together with the fact that pyrophyllite has only been found in one of the clay samples, make an allochtonous origin rather unlikely. In the author's opinion, a more acceptable explanation for the localised nature of the pyrophyllite would be to assume that it developed *in situ* from detrital kaolinite as a result of elevated temperatures caused by the intrusion of a dolerite dyke. As indicated in the description of borehole KB 9 in Appendix 3, about 6 m of dolerite was intersected only 0,6 m below the pyrophyllite-bearing layer of semi-flint clay. No dolerite was found in any of the other boreholes. The proximity of this dyke together with the pressure exerted by the approximately 1 160 m of overlying strata as estimated by Bennetts and Pieterse (1963), could perhaps have been sufficient to convert part of the kaolinite into pyrophyllite. The high alumina content indicated by the bulk analysis of this clay (Table 3.18) suggests, however, that the proportion of pyrophyllite is probably quite small, and the occurrence is therefore only of academic interest.

The trace-element composition of these clays (Table 3.19) is generally quite similar to that of the clays in the Witwatersrand area, but the more subtle differences are discussed in Chapter 4. From an exploration point of view, it is, however, important to point out at this stage that the inverse relationship between refractoriness and rubidium content as observed in the case of the Witwatersrand clays is definitely not evident in the Kloppersbos samples. In fact, the opposite seems to be true. This can probably be attributed to quartz being the predominant mineralogical variable in these clays. As rubidium is mostly concentrated in the clay-mineral fraction which is largely composed of kaolinite, this element can be expected to vary inversely with the quartz content and consequently directly with the fusion temperature.

The particle size of the flint clays typically varies between 5 and 10 μm and there is a clear tendency towards random orientation (Fig. 3.37). Booklets of kaolinite are very scarce; they were only observed in the semi-flint samples and are of the compact variety as shown in Fig. 3.38. Quartz grains range up to 50 m in diameter and are invariably well-rounded.

Owing to the apparently restricted distribution of the less refractory clays (PCE less than 34^{-}), and their non-plastic nature which renders them unsuitable for applications such as the

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TABLE 3.19 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON KLOPPERSBOS 128 JR

Sample No.*	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154
V	54	51	45	40	38	42	37	163	31	51	48	50	30	22	36	44	125
Co	45	42	36	33	36	39	28	31	17	40	31	32	25	14	23	32	38
Ni	23	17	22	18	5	17	29	62	7	33	21	<5	29	14	13	15	44
Cu	34	32	46	42	178	123	57	69	37	42	42	48	63	44	55	41	60
Zn	41	37	43	48	48	54	38	84	48	51	49	48	53	50	35	48	51
Ga	38	46	38	37	40	36	33	40	32	30	32	38	35	36	51	32	40
Ge	5	5	7	5	<5	5	<5	<5	<5	7	6	7	5	6	18	5	5
Rb	106	104	94	103	108	111	69	42	69	112	110	106	93	108	25	89	54
Sr	43	41	61	64	44	47	115	101	55	51	46	43	145	80	1 091	85	55
Y	87	98	109	111	81	83	103	84	88	91	89	87	93	80	48	91	113
Zr	416	421	389	405	311	417	639	741	535	462	412	410	492	452	573	496	429
Nb	39	42	48	52	45	48	40	86	36	38	36	41	38	52	52	46	54
Mo	12	14	12	14	14	16	5	12	9	9	<5	<5	17	<5	18	17	16
Sn	28	33	25	28	47	39	44	36	30	32	29	33	1	20	21	41	37
Sb	18	22	26	24	43	41	41	38	21	23	19	25	1	11	18	38	32
W	<1	<1	<1	<1	<1	<1	<1	1	1	<1	1	1	1	1	1	1	1
Pb	19	21	15	13	22	25	25	31	15	26	28	31	41	33	64	<5	<5
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Th	59	61	64	67	74	72	60	66	53	62	49	52	52	70	70	64	62
U	5	5	6	6	6	6	4	12	2	5	6	7	4	4	5	7	7
As	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	10	<5	<5	<5	<5
S	46	143	32	36	166	1 560	29	1 506	12	38	44	32	29	26	21	115	28

*See Table 3.17 for sample positions

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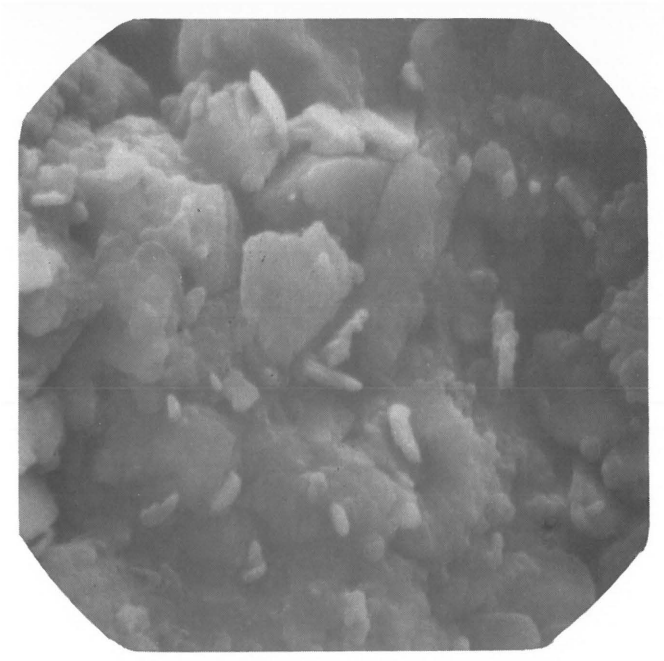

Fig. 3.37 Typical texture of flint clay from Kloppersbos 128 JR. Magnification 3 200X.

Tipiese tekstuur van flintklei op Kloppersbos 128 JR. Vergroting 3 200X.

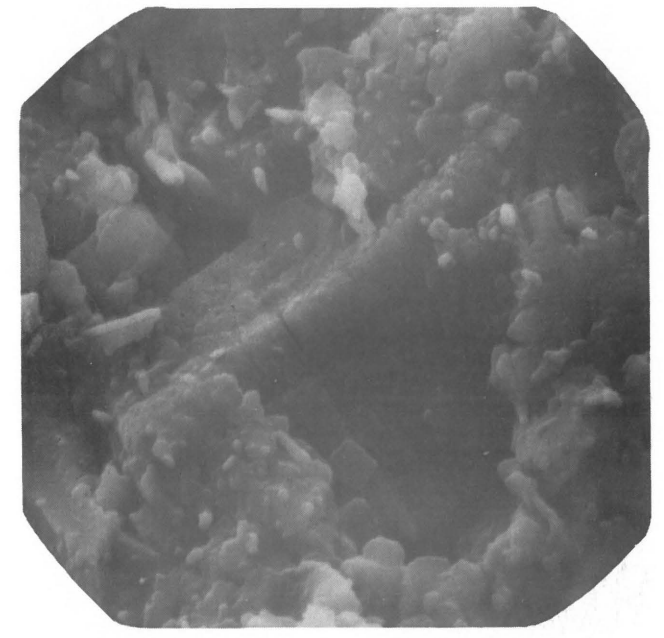

Fig. 3.38 Rare, massive kaolinite booklet in semi-flint clay from Kloppersbos 128 JR. Magnification 2 400X.

Skaars, massiewe kaolinietboekie in semi-flintklei op Kloppersbos 128 JR. Vergroting 2 400X.

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manufacture of building bricks, they can be regarded as having no economic potential. Calculation of resources was therefore restricted to the more refractory types. These were subdivided into two groups according to type and grade:

Group 1: All grade II and III semi-plastic, semi-flint and flint types.
Group 2: All grade IV semi-flint and flint types.

As neither of the two groups can be accurately delineated from the available borehole data, calculations are based on the blocks indicated in Fig. 3.35. Group 1 clays have an average bulk density of 2,20, an average thickness of 2,7 m and they are assumed to occur over an area of approximately 221 200 m^2. Indicated resources are therefore in the order of 1,31 Mt. Clays belonging to Group 2 have an average bulk density of 2,38, an average thickness of 1,9 m and they are assumed to be present over an area of 425 000 m^2. Indicated resources amount to about 1,92 Mt. These resources estimates differ somewhat from those presented in Bredell (1976b) because after re-analysis, some of the marginal samples had to be allocated to a different grade category.

The overburden for the Group 1 clays varies between 3,7 and 13,2 m with an average of 8,2 m. The overburden/clay ratio ranges from 0,8 (borehole KB 1) to 8,8 (the bottom layer in KB 2). Group 2 clays are covered by an overburden of 1,6 to 12,7 m (average 7,5 m) and the overburden/clay ratio varies from 1,5 (borehole KB 5) to 14,1 (the second layer in KB 2). In the vicinity of boreholes KB 2, 3, 8 and 9 the overburden/clay ratio can be expected to exceed 6,0 in respect of all clay layers and exploitation of clay in these areas would therefore not be economically feasible under present-day conditions. Unfortunately, the underlying coal does not appear to have any potential for augmenting the exploitability of clay in this deposit. Individual seams are only 50 to 200 mm thick and are separated by relatively thick partings of carbonaceous shale and clay.

The total indicated resources of 3,23 Mt of clay with a good refractoriness should be regarded as a conservative estimate and the total resources within this outlier are probably much larger. However, the fact should be stressed that the blocks used for resources calculations were to a large extent arbitrarily selected and variations from the thickness and quality indicated by the widely spaced boreholes are therefore to be expected. Furthermore, a substantial proportion of the clay in this outlier is probably covered by excessive overburden. A major disadvantage to the possible future exploitation of the deposit on Kloppersbos is the extensive subdivision of the area (Fig. 3.35). Acquiring the surface and

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mineral rights can therefore be expected to present a problem. The outlier as a whole nevertheless warrants further investigation and the area immediately south of borehole KB 1 appears to be the most promising as the best quality clay seems to extend and thicken in that direction.

3.5.4 Rietfontein 470 JR

The part of this farm which was investigated (Portion 6) is located about 20 km north of Bronkhorstspruit on the south-western spur of the large (Nooitgedacht) outlier of the Ecca Group which forms the subject of the next section. The deposit on Rietfontein is discussed separately because it does not form part of, and the clay differs markedly in physical properties from the predominantly flint-clay deposits further to the north-east. After preliminary field investigations had established a general palaeocurrent direction from the north-east for this outlier as a whole, it was decided to attempt exploration in the most distal south-western part where no refractory-clay exploitation was taking place at the time but which appeared to be a likely site for clay deposition. Portion 6 of Rietfontein was selected for drilling because a small excavation on the southern part of this property revealed the presence of white, plastic kaolinitic clay.

The eight boreholes drilled (Fig. 3.39) all intersected sediments of the Ecca Group and were stopped in the Dwyka Formation; the Waterberg Group which forms the pre-Karoo basement in this area was not penetrated. A summary of the general succession indicated by the boreholes is presented below:

Sandy soil	
Friable, decomposed sandstone with a thin grit layer sporadically developed at its base. Semi-plastic to semi-flint clay. Predominantly plastic clay.	ECCA GROUP
Alternating siltstone, sandstone and tillite with occasional lenses of silty flint clay.	DWYKA FORMATION

The stratigraphic position of the clay horizon (directly on top of the Dwyka Formation) is quite uncommon for refractory clay in the Pretoria – Belfast area and rather corresponds to many of the Witwatersrand deposits. No underlying carbonaceous zone is developed and

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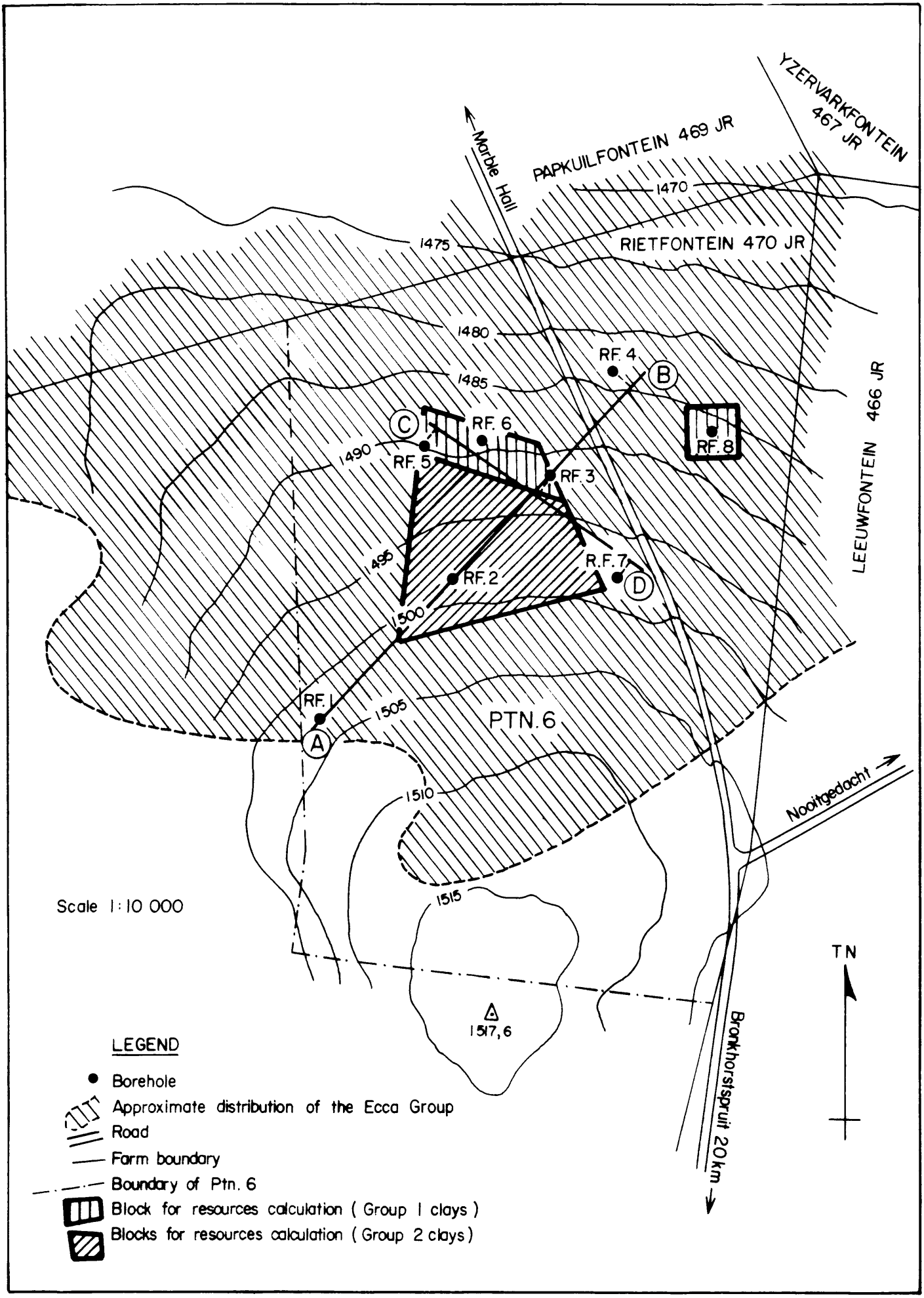

Fig. 3·39 Positions of boreholes drilled for clay on Portion 6 of Rietfontein 470 JR

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the characteristic Ecca grit is also practically absent. It would appear therefore that these clays were deposited as a result of the transgression of predominantly argillaceous material onto this distal perimeter of the basin (or sub-basin) after the deeper part of the basin in the Nooitgedacht – Loopspruit area (see Section 3.5.5) had been filled with a "normal" succession of Ecca sediments. According to the model proposed in Chapter 4, the presence of subordinate lenticular bodies of essentially non-plastic clay within the clay zone probably indicates the development of small isolated swampy areas (mainly during the closing stages of clay deposition) where edge-to-face flocculation of kaolinite particles predominated in a relatively low-pH environment.

As illustrated in Fig. 3.40, the clay zone pinches out in the south-west between boreholes RF 1 and RF 2. It has a slight northerly dip and the thickness gradually increases to a maximum recorded value of 7,6 m in the north-east (borehole RF 4). Seen as a whole, the clay zone seems to have quite a persistent distribution, but sampling and subsequent testing have proved it to lack lateral homogeneity as far as physical and chemical properties are concerned (Tables 3.20 and 3.21). When comparing the sampling intervals in Table 3.20 with the core descriptions in Appendix 4, it will be noted that only a portion of the total clay layer was sampled in some cases; the portions not sampled were obviously too impure (too ferruginous or siliceous) or too thin to justify further investigation.

As in the case of Kloppersbos, the mineralogical composition of these clays is remarkably constant with kaolinite being the major clay-mineral constituent in all cases and illite and quartz the only other minerals which could be detected. The particle size and orientation are almost identical to that of corresponding clay types at Kloppersbos. Sample 155 obviously forms part of the Dwyka Formation and can be readily distinguished from the Ecca clays by a much higher quartz content, lower TiO_2 content, higher Rb content (Table 3.22) and an anomalously high pH in respect to its bulk density. Seven of the samples yielded PCE values of 34$^-$ and higher and three of these can be classified as Grade I refractory clays. The best quality material appears to be concentrated in the area around boreholes RF 3, 5 and 6. Most promising is the intersection of 5,8 m of Grade I semi-flint and plastic clay in RF 3. There is no distinct relationship between Rb content and refractoriness in these clays but the lower-grade material does contain slightly higher concentrations of this element. This can probably be attributed to a variation in illite content as opposed to the Kloppersbos clays where quartz appeared to be the main mineralogical variable.

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Fig. 3.40

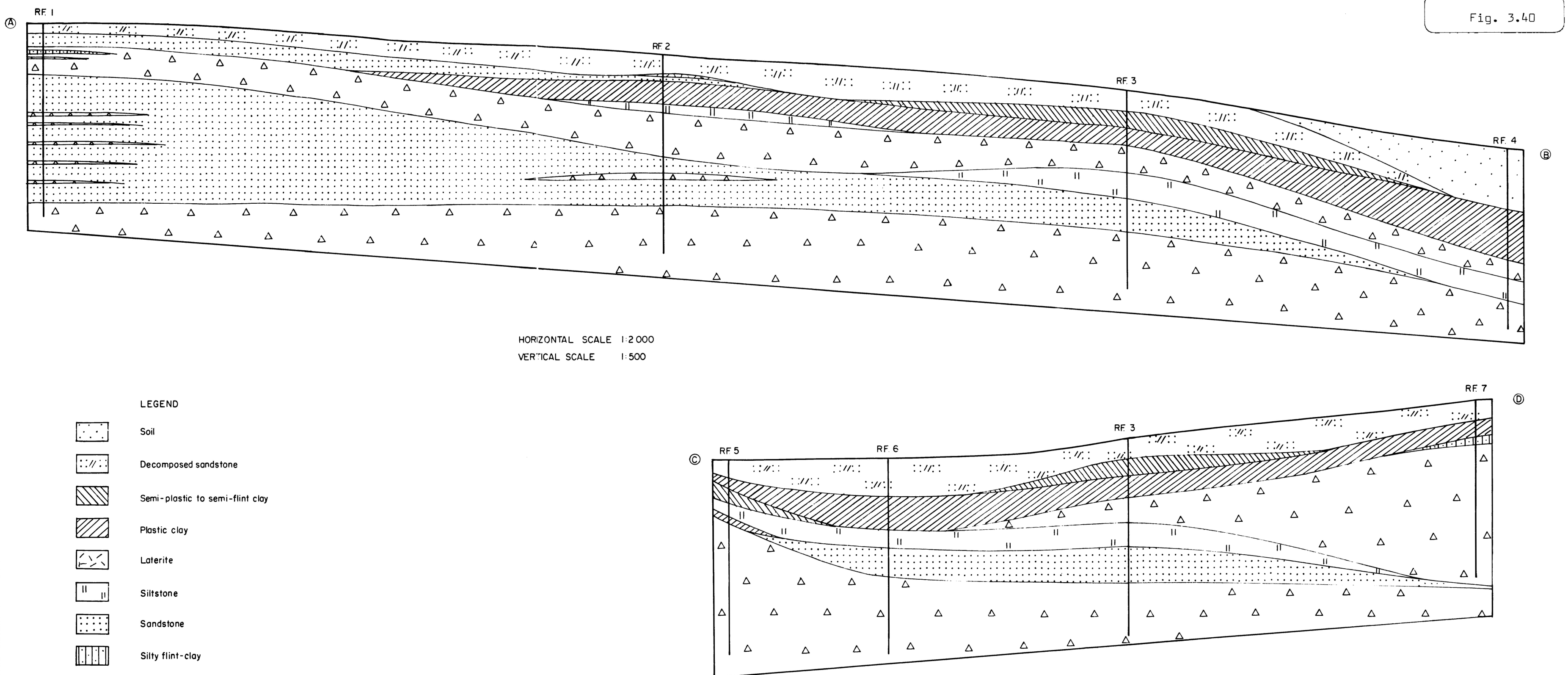

Fig. 3·40 SW-NE and NW-SE sections through boreholes on Portion 6 of Rietfontein 470 JR

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TABLE 3.20 PHYSICAL PROPERTIES, CLASSIFICATION AND QUARTZ CONTENT OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 470 JR

Sample No.	Borehole No.	Depth (m)	Physical properties				Classification		Approximate percentage quartz
			PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	
155	RF1	4,10–4,80	29	2,44	7,37	10YR6/2	Flint	IV	55
156	RF 2	4,00–7,70	34	1,91	26,21	5YR8/1–N8	Semi-plastic	IV	12
157	RF 3	3,00–5,85	35^-	2,14	17,41	N8–5YR8/1	Semi-flint	I	1
158	RF 3	5,85–8,80	34	1,80	30,91	5YR8/1–N8	Plastic	I	5
159	RF 4	9,40–17,00	32	1,79	31,68	5YR8/1–N8	Plastic	IV	8
160	RF 5	3,10–4,50	34^-	1,91	26,60	5YR8/1	Semi-plastic	IV	15
161	RF 5	4,50–6,80	34	2,24	14,65	N8–5YR8/1	Semi-flint	I	3
162	RF 6	5,80–11,00	34	1,75	33,00	5YR8/1–N8	Plastic	II	6
163	RF 7	3,10–5,40	34	1,86	28,95	5YR8/1	Plastic	IV	9
164	RF 8	1,90–4,40	33^+	1,93	25,95	10 R 6/2	Semi-plastic	II	8

*PCE = Pyrometric cone equivalent

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TABLE 3.21 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 470 JR

Sample No.*	155	156	157	158	159	160	161	162	163	164
SiO_2	64,87	58,60	44,02	42,44	46,79	52,95	42,86	45,09	50,97	47,54
TiO_2	0,71	1,43	1,00	1,91	1,53	1,50	0,86	1,95	2,79	2,03
Al_2O_3	24,04	27,00	40,06	40,05	32,60	30,73	39,15	37,32	33,21	35,33
Fe_2O_3	0,22	2,63	0,45	0,10	3,36	0,16	0,93	0,68	0,72	< 0,10
FeO	< 0,10	< 0,15	< 0,15	1,25	< 0,15	1,41	1,25	< 0,10	< 0,10	1,23
MnO	0,02	0,03	0,01	0,02	0,07	0,01	0,02	0,02	0,01	0,01
MgO	0,73	0,84	0,68	0,61	0,50	0,76	0,63	0,67	0,71	0,75
CaO	< 0,01	0,07	0,02	0,01	0,15	0,01	0,01	0,02	0,02	0,01
Na_2O	0,04	0,24	0,06	0,05	0,14	0,05	0,04	0,07	0,05	0,07
K_2O	0,05	1,20	< 0,01	0,05	0,42	0,31	0,03	0,05	0,04	0,11
P_2O_5	0,05	0,07	0,11	0,07	0,19	0,08	0,14	0,07	0,07	0,18
CO_2	0,32	0,28	0,58	0,41	1,45	0,67	0,28	0,42	0,38	0,69
H_2O^+	7,19	6,87	13,51	12,98	12,44	10,37	13,18	12,12	11,27	11,56
Total	98,23	99,27	100,50	98,70	99,64	99,02	99,38	98,48	100,23	99,50
H_2O^- on air-dried sample	0,42	0,68	0,43	0,36	0,42	0,51	0,92	0,48	0,51	0,70
Al_2O_3 on a calcined basis	26,03	29,12	46,59	46,34	37,88	34,59	45,28	42,77	37,58	40,29
pH	6,6	6,4	6,1	6,6	6,7	6,2	5,7	6,6	6,6	6,2

*See Table 3.20 for sample positions

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TABLE 3.22 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 470 JR

Sample No.*	155	156	157	158	159	160	161	162	163	164
V	83	85	87	93	102	106	117	75	113	144
Co	25	26	25	33	24	15	37	15	13	16
Ni	7	33	20	30	21	16	26	17	33	12
Cu	36	100	32	40	43	48	37	38	43	54
Zn	36	63	35	32	34	32	38	27	31	28
Ga	23	37	34	37	36	32	36	33	39	37
Ge	5	6	6	10	5	6	5	9	8	6
Rb	128	34	19	21	31	33	24	24	23	28
Sr	25	86	200	117	79	81	255	92	22	635
Y	39	104	40	47	52	61	59	50	58	72
Zr	398	476	286	548	379	352	280	640	660	556
Nb	29	48	30	41	37	35	35	47	61	42
Mo	<5	6	<5	17	6	15	<5	6	7	<5
Sn	22	10	7	28	10	<1	26	11	8	8
Sb	21	5	1	20	5	<1	30	4	<1	<1
W	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb	15	33	34	22	36	49	57	36	24	65
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Th	25	68	41	68	43	35	44	55	69	64
U	1	<1	<1	7	<1	<1	<1	5	7	13
As	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
S	15	16	51	46	95	67	34	52	44	73

*See Table 3.20 for sample positions

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In the estimation of clay resources, only material represented by samples which indicated a good refractoriness was taken into consideration. The clay intersected in borehole RF 8 (PCE 33^{+}) was, however, included on account of its favourable chemical composition and relatively low quartz content. To facilitate resources calculations, the following grouping was used:

Group 1: All grade I and II semi-flint, semi-plastic and plastic types.
Group 2: All grade IV semi-plastic and plastic types.

Blocks representing the areas supposedly occupied by these two clay groups are indicated on Fig. 3.39. A mining-restriction zone of 100 m parallel to the Bronkhorstspruit – Marble Hall road is assumed to allow for the possibility of blasting being used during quarrying operations.

Group 1 clays have an average bulk density of 1,98, an average thickness of 4,4 m and they are assumed to occupy an area of about 24 600 m^2 around boreholes RF 3, 5 and 6. Indicated resources are therefore in the order of 214 000 t. Additional resources of this group are present around borehole RF 8 to the east of the Marble Hall road. If a bulk density of 1,93, an average thickness of 2,5 m and an area of 10 000 m^2 are assumed, the clay resources at this locality probably amount to about 48 000 t. Total indicated resources of Group 1 clay are therefore approximately 262 000 t. Clays classified as Group 2 have an average bulk density of 1,89, an average thickness of 2,5 m and are present over an assumed area of 90 100 m^2. Indicated resources total about 425 000 t. These estimates differ somewhat from those in Bredell (1976a) because a few of the marginal samples were grouped in a different grade category after re-analysis.

The overburden for the Group 1 clays ranges from 1,9 m (RF 8) to 5,8 m (RF 6) with overburden/clay ratios varying between 0,5 (RF 3) and 2,0 (RF 5). Group 2 clays have an overburden of 3,1 to 4,0 m and the overburden/clay ratio varies from 1,1 (RF 2) to 2,2 (RF 5). As the overburden was indicated to consist largely of soft, decomposed sandstone, its removal should be a relatively inexpensive operation.

In view of the fact that the true limits of the deposit could only be established in one direction namely the south-west, the total indicated resources of 687 000 t of clay with a good refractoriness can be regarded as a conservative estimate. The preliminary exploration carried out by the author suggested, however, that this deposit has a definite economic potential

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and based on the results of this investigation, the owner of the property started exploitation in the vicinity of boreholes RF 3 and 6. He also completed an extensive diamond-drilling project during 1983 in order to establish resources more accurately. Apart from refractory clay, this area also seems to have potential for the production of building sand from the overburden, while the more ferruginous and less refractory clay to the east of the Marble Hall road could possibly be used as a raw material for the manufacture of semi-face and stock bricks. Further sampling and testing would, however, be required before exploitation of these possible by-products.

3.5.5 The Nooitgedacht Outlier

This prominent outlier, some 20 km due north of Bronkhorstspruit (Fig. 3.41), is the largest of the approximately 45 erosional relicts of the Ecca Group in the Pretoria – Belfast area. It covers about 90 km^2 and is referred to as the "Nooitgedacht outlier" after the farm Nooitgedacht 436 JR which is situated near its centre. Although the Nooitgedacht outlier has rendered a large proportion of the total flint-clay production in the country and is at present hosting 2 of the 11 operating flint-clay mines in the Republic, virtually no information has been published on the regional distribution of the clay or the general lithostratigraphy and sedimentological history of the basin. It was therefore considered an obvious and most important target during the reconnaissance exploration programme. The main field investigation was conducted between April and September 1976 and comprised a study of the quarries and available outcrops as well as the drilling of 23 boreholes along a roughly north – south traverse over a distance of some 9 km (Fig. 3.42). Five additional holes were drilled during January 1979.

3.5.5.1 Previous Investigations

The first published record of the Nooitgedacht outlier was in the Annual Report of the Geological Survey of the Transvaal for the year 1905 (Mellor, 1906). The boundaries of the outlier were subsequently transferred without any changes to Sheet 3 (Middelburg), published by the Geological Survey of the Transvaal (Mellor, 1908). Except for a few minor changes, the basic shape of the outlier was retained in Sheet 2528D/2529C (Visser, *et. al.*, 1961) and recently directly reduced for the 1 : 250 000 Sheet 2528 Pretoria (Geological Survey, 1978). No description of this outlier in particular is, however, presented in any of the explanations to the above-mentioned maps.

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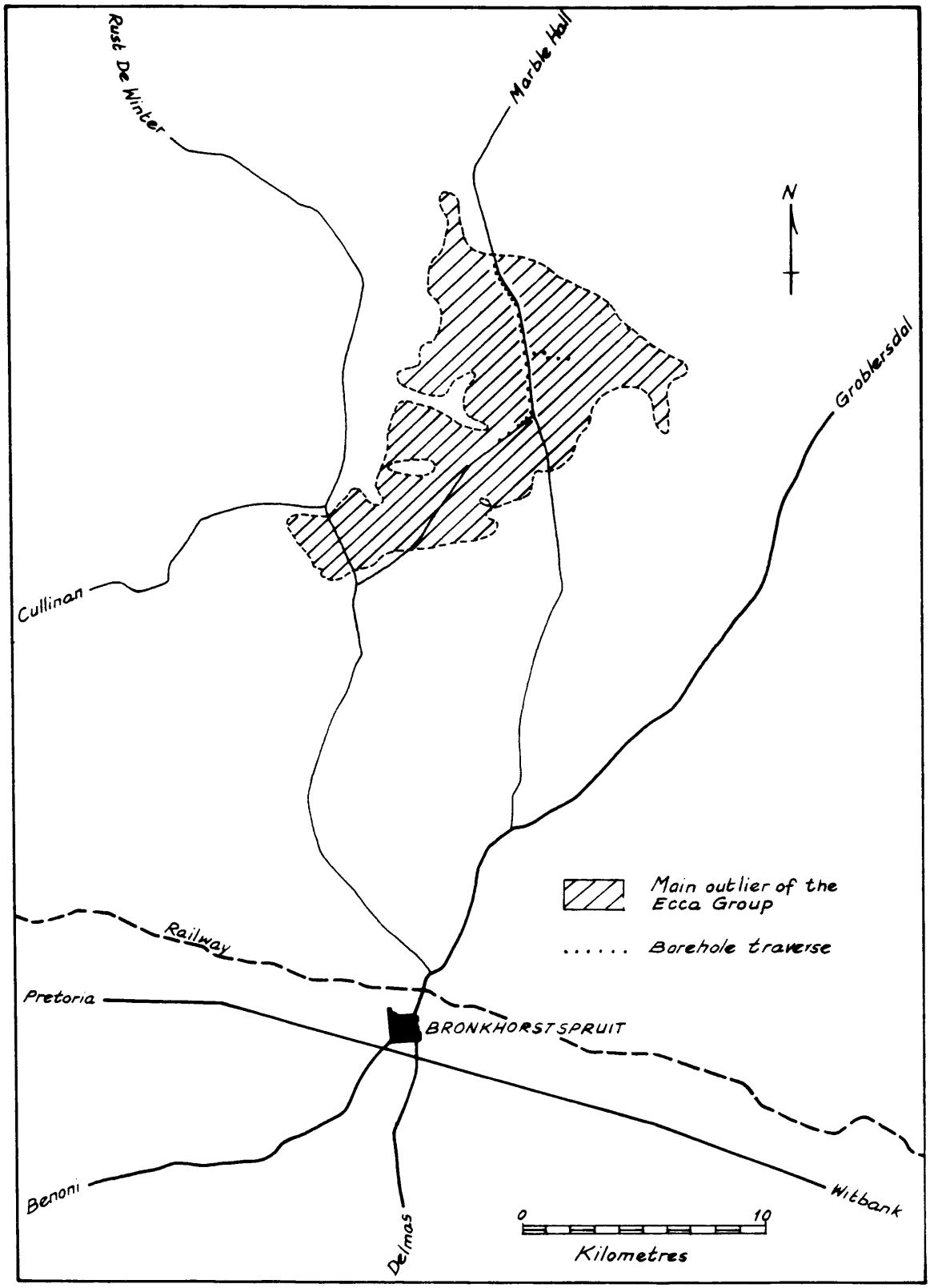

Fig. 3·41 Locality map showing the main Ecca Group outlier North of Bronkhorstspruit.

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Fig. 3.42

28°45'

25°30'

N

ROODEPOORT 439 JR

ROOIPOORT 440 JR

HARTEBEESTSPRUIT 434 JR

LOOPSPRUIT 435 JR

NOOITGEDACHT 436 JR

YZERVARKFONTEIN 467 JR

PAPKUILFONTEIN 469 JR

RIETFONTEIN 470 JR

SCHOONGE ZICHT 465 JR

TAAIFONTEIN 461 JR

BLESBOKFONTEIN 459 JR

VALSCHSPRUIT 458 JR

VLAKFONTEIN 453 JR

F, LS 10, LS 9, E, LS 8, LS 7, LS 6, LS 5, LS 4, D, LS 3, LS 2, LS 1, C, NG 13, NG 12, NG 11, NG 14, NG 15, RP 1, RP 2, RP 3, NG 10, NG 9, NG 8, NG 7, NG 6, NG 5, B, NG 4, NG 3, NG 2, NG 1, A

1 : 50 000

0 1000 2000 3000 m

EXPLANATION

- Boundary of the Ecca Group (only the main outlier is indicated)
- Dwyka Formation
- Wilgerivier Formation (Waterberg Group)
- Nebo Granite (Bushveld Complex)
- Loskop Formation
- Selonsrivier Formation (Rooiberg Group)
- NG 3 — Boreholes drilled by Geol. Survey (this study)
- Boreholes drilled by Geol Survey (Rietfontein)
- Boreholes drilled by private companies
- (A)-(F) — Section line : Fig. 3.43
- Approximate limit of carbonaceous strata

Fig. 3·42 Exploration boreholes and approximate limit of carbonaceous strata in the Ncoitgedacht outlier.

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Bennetts (1965) investigated the quarries which existed at the time as well as the clay exposed in prospecting pits and trenches; he presented analytical and test results of seven clay samples from the area. The most comprehensive account of the geology and clay deposits of the Nooitgedacht area has been published by Bredell (1980) on which this section is largely based. Permission granted by Anglo American Corporation of S.A. Ltd. to use the results of their boreholes drilled on the outlier in interpreted form is gratefully acknowledged.

3.5.5.2 Stratigraphy and Sedimentology

The pre-Karoo basement comprises mainly felsite of the Selonsrivier Formation in the north and sandstone, quartzite and conglomerate of the Wilgerivier Formation in the south (Fig. 3.42). Except for small areas in the extreme north where the Ecca Group rests directly on felsite, these sediments are almost entirely underlain with no apparent unconformity by the Dwyka Formation. The latter consists of tillite with occasional interbedded sandstone, siltstone and siliceous mudstone. These interbeds are identical in appearance to corresponding sediments in the Ecca Group and in places where they occur at the top of the Dwyka Formation, the Dwyka/Ecca contact is very difficult to define. Part of the "tillite" was evidently reworked by meltwater from the retreating glaciers and could perhaps better be described by the non-genetic term "diamictite". Distinction between the two types on a regional basis is virtually impossible and was not attempted for the purpose of this investigation. The tillite/diamictite consists chiefly of subrounded to angular pebbles of white, grey and pink sandstone, shale and felsite in a light grey to pinkish grey silty to sandy matrix. It is suggested that, although probably of Ecca age, the diamictite be included in the Dwyka Formation on the basis of lithological contrast to the normal succession of well-sorted fluvial sediments in the Ecca Group.

Being larger than any of the other remnants of the Ecca Group in the area, the Nooitgedacht outlier lends itself perfectly to a study of the lithostratigraphy of this unit as well as the lateral behaviour of the various clay horizons over a considerable distance. Unfortunately natural exposures are rare, consisting mostly of coarse sandstone and grit, while the clay quarries only allow a study of the upper few metres of the succession. It was therefore decided to deviate from the more conventional practice of refractory-clay exploration as applied at the localities previously described, by drilling a traverse across the more promising northern part of the outlier. The observations discussed below are mostly based on these borehole results.

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The basic lithological types in the Ecca Group include grit, sandstone, siltstone, plastic clay, flint clay, shale and coal. The finer-grained clastics (fine-grained sandstone, siltstone, shale and clay) are commonly carbonaceous, particularly in the north-central part of the outlier (Fig. 3.42). Unconsolidated grit, sand and silt occurring immediately below the soil cover (Appendix 3) are interpreted as residual weathered material derived from the underlying rock types. A cross-section showing the vertical and lateral behaviour of individual beds along the borehole traverse is presented in Fig. 3.43.

The total stratigraphic thickness of the Ecca Group in this area is at least 140 m and a characteristic feature of the succession is a series of upward-fining units which are particularly well developed in the central part of the outlier (see Fig. 3.44). Individual units attain thicknesses of up to 20 m and, where fully developed, range from grit at the base, followed by gritty sandstone, sandstone, siltstone and clay. A total of 16 fully and partially developed upward-fining units can be recognised; the latter resulting predominantly from non-deposition of certain beds and to a lesser extent from syn-sedimentary erosion.

The Ecca Group attains thicknesses in excess of 50 m in the central and north-western parts of the outlier on Nooitgedacht 436 JR, Loopspruit 435 JR and Roodepoort 439 JR; the maximum thickness recorded is 57 m (Fig. 3.45). Over the eastern and southern parts, the thickness is generally less than 20 m. The distribution of thicknesses within the outlier is to some extent a reflection of the topography of the surface on which the Ecca sediments were deposited (Fig. 3.46). The main features revealed by contouring this surface are:

(1) An approximately 5 km long north-south trending valley just to the east of the northernmost tip of the outlier.

(2) A NE–SW trending valley on the eastern part of Nooitgedacht, forming a tributary to the valley mentioned in (1).

(3) A NW–SE trending ridge linking the two inliers of Wilgerivier Formation on Taaifontein 461 JR and Yzervarkfontein 467 JR.

(4) An east-west trending ridge branching from the one mentioned in (3) and situated immediately to the south of it.

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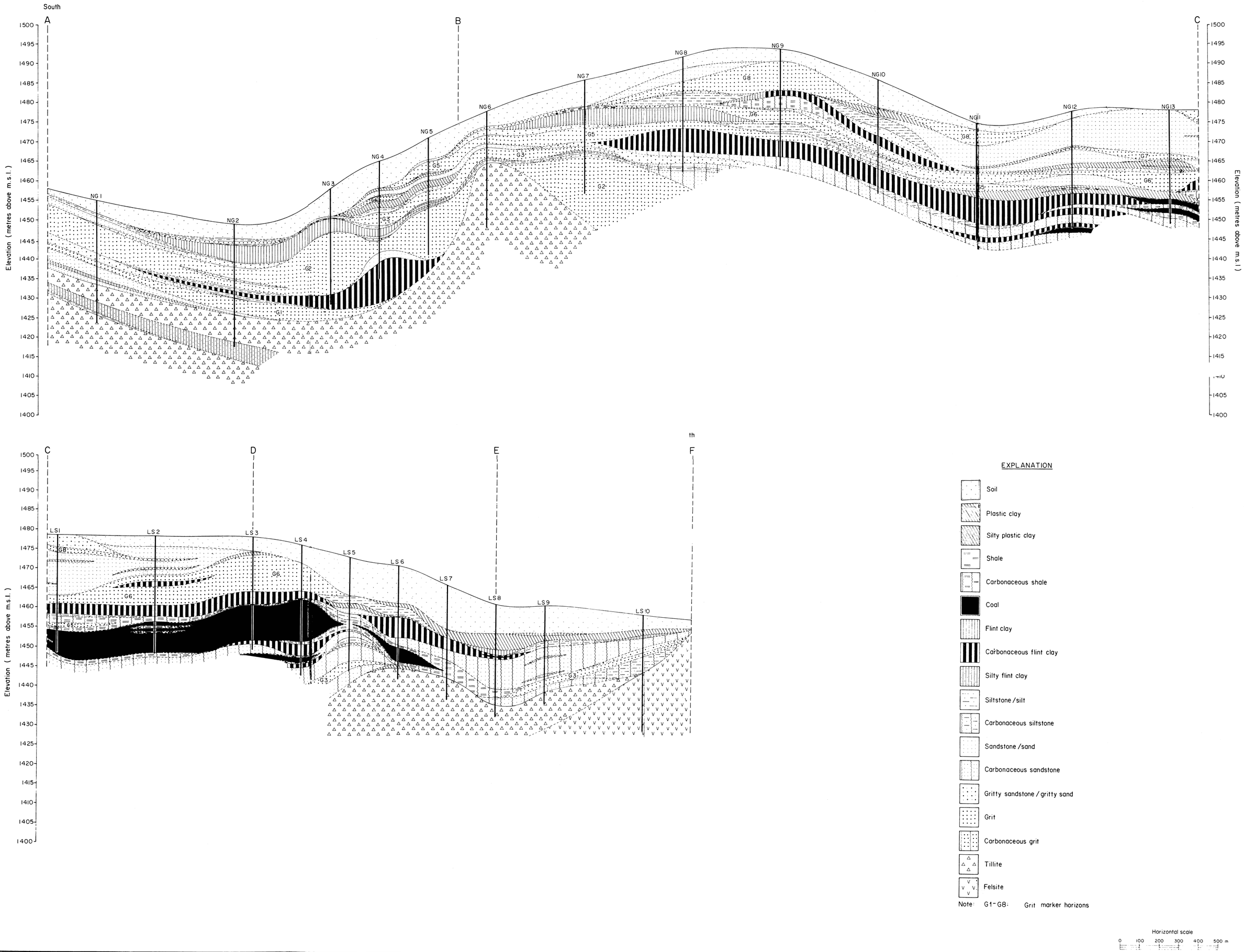

Fig. 3·43 South-North section through boreholes on the Nooitgedacht outlier.

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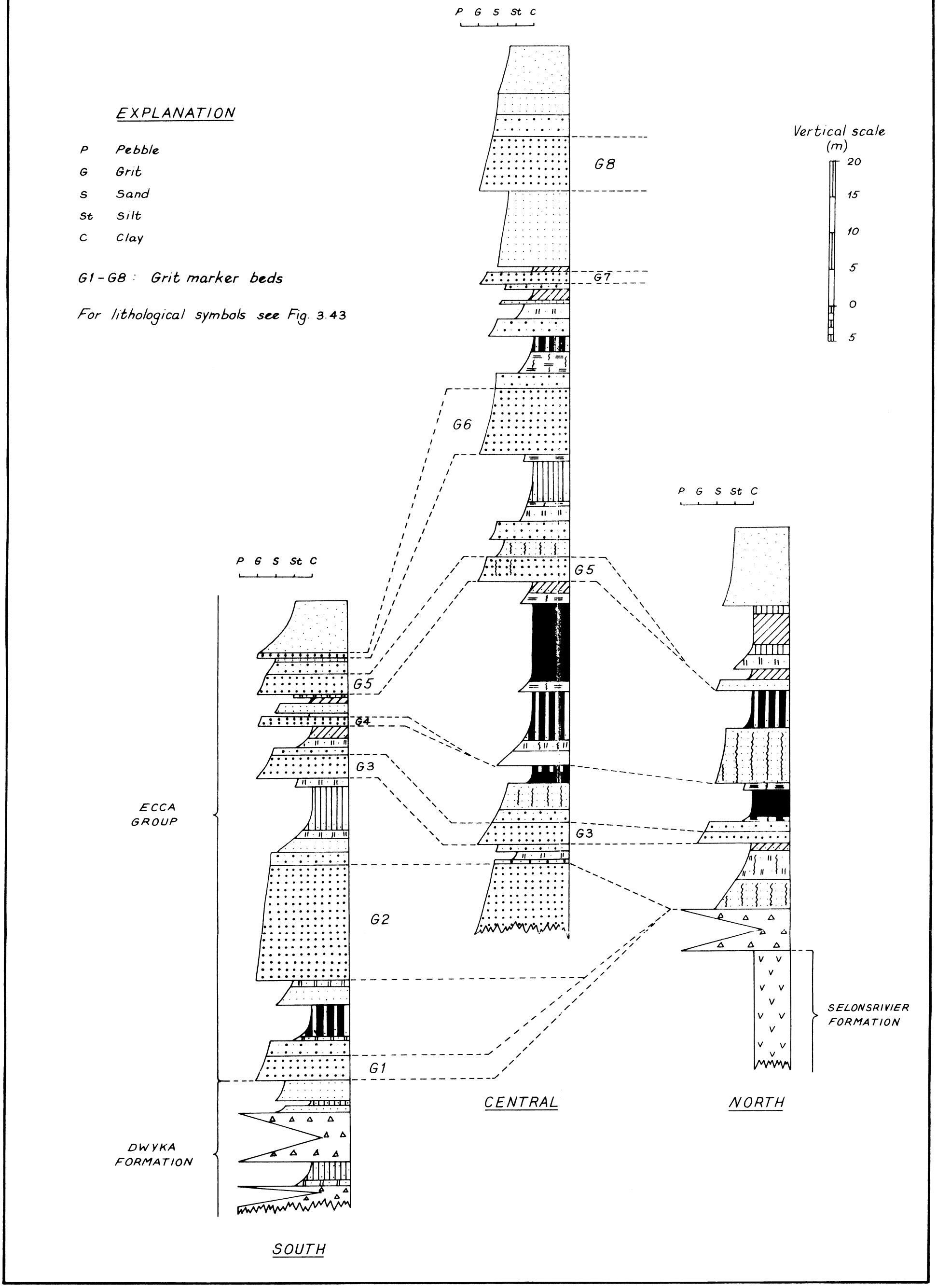

Fig. 3·44 Composite lithological sections from the Southern, Central and Northern parts of the drilling traverse, showing correlation and vertical grain-size variation.

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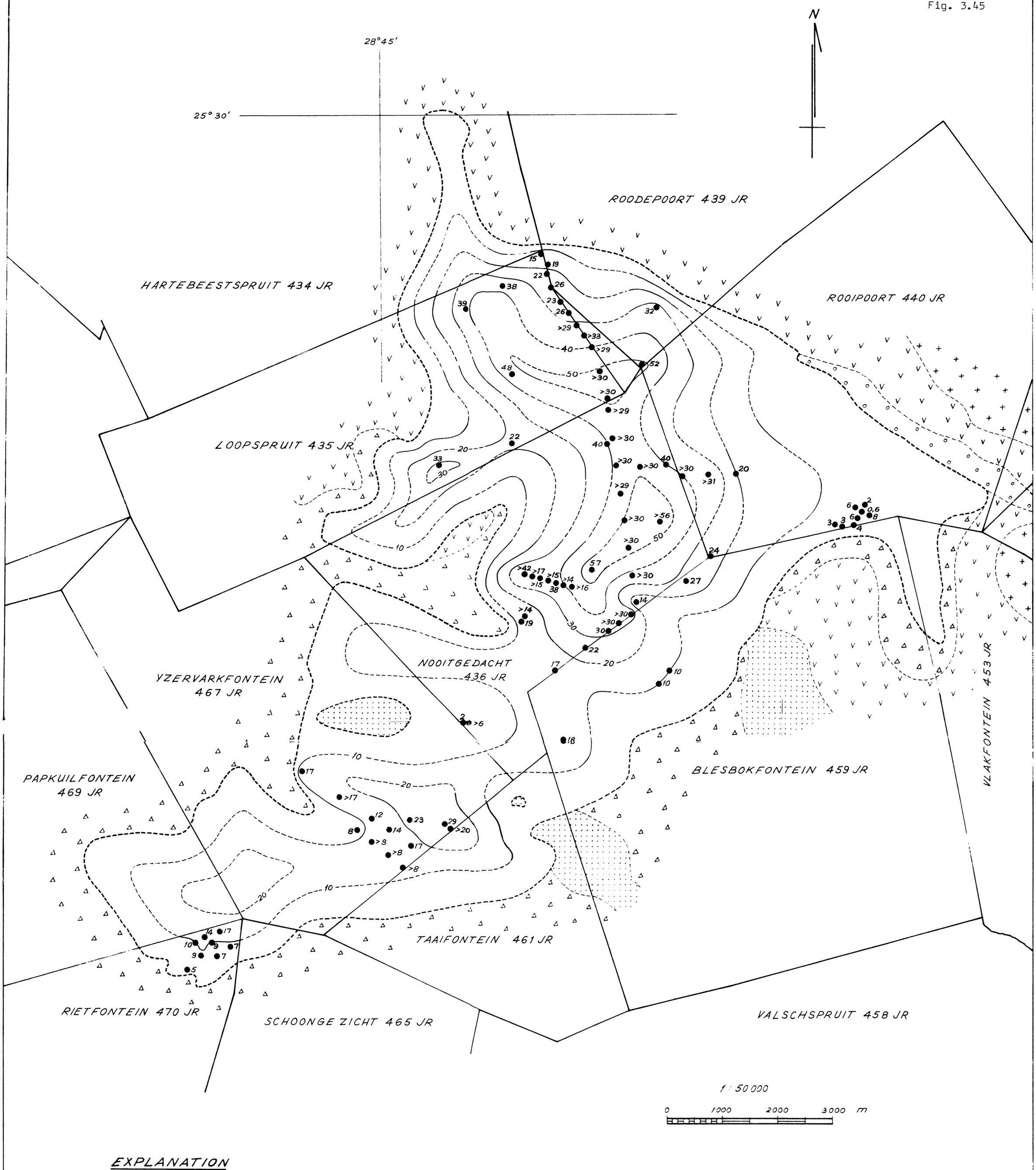
Fig. 3.45



EXPLANATION

- Boundary of the Ecca Group (only the main outlier is indicated)
- Dwyka Formation
- Wilgerivier Formation (Waterberg Group)
- Nebo Granite (Bushveld Complex)
- Loskop Formation
- Selonsrivier Formation (Rooiberg Group)
- ●57 Borehole with thickness of Ecca Group in metres
- --10-- Isopach of Ecca Group (interval 10m)

Fig. 3·45 Isopach map of the Ecca Group in the Nooitgedacht outlier.

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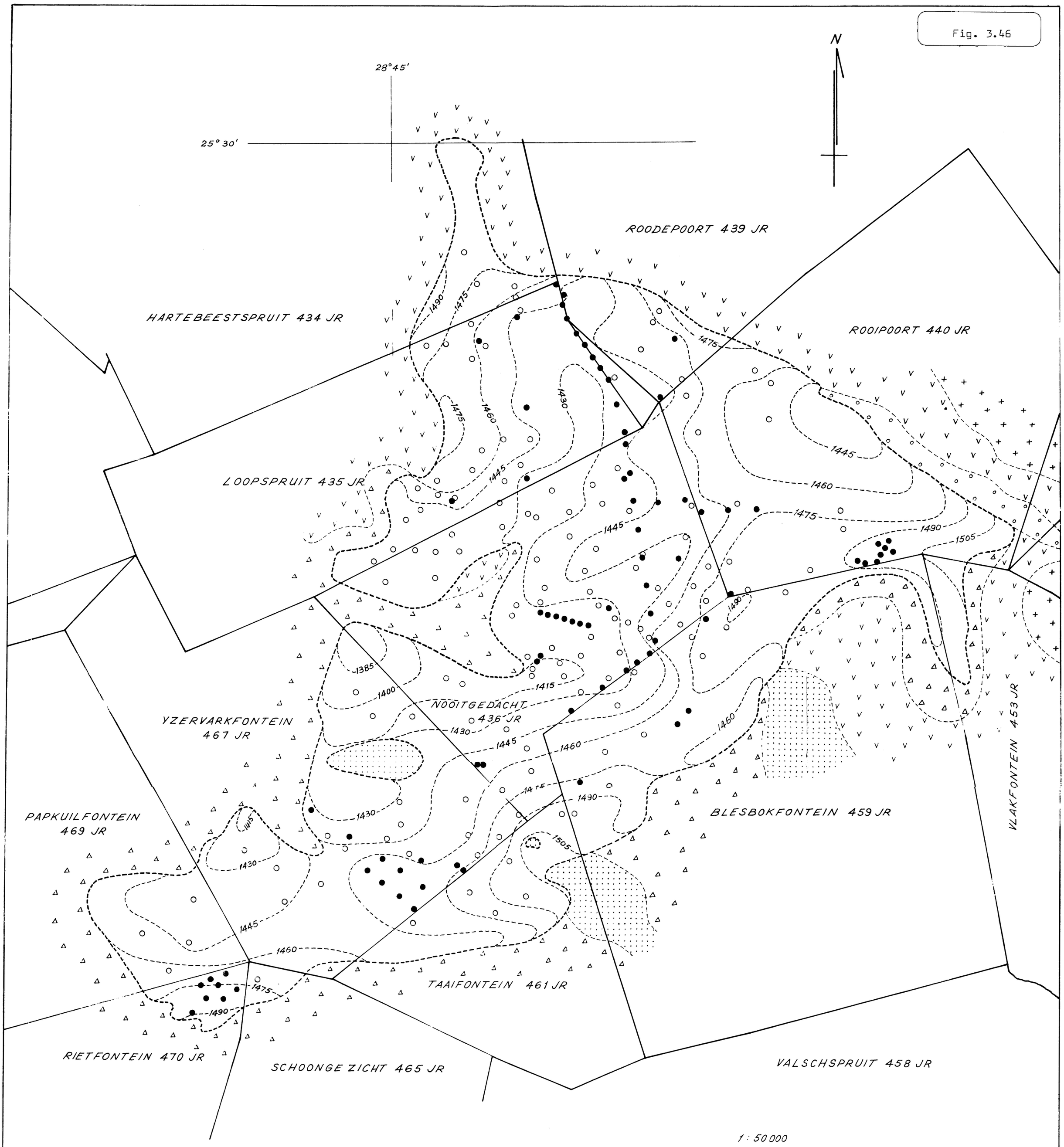
Fig. 3.46



EXPLANATION

Boundary of the Ecca Group (only the main outlier is indicated)

Dwyka Formation

Wilgerivier Formation (Waterberg Group)

Nebo Granite (Bushveld Complex)

Loskop Formation

Selonsrivier Formation (Rooiberg Group)

1460 Elevation contours (metres above sea level) at the base of the Ecca Group

Borehole

Additional data points obtained by combining isopachs and surface contours

Fig. 3·46 Basal topography of the Ecca Group in the Nooitgedacht outlier.

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The thickest parts of the Ecca Group in the northern part of the outlier correspond to the valleys described above, while in the southern part a relatively thick succession of sediments has been preserved in the trough between the two ridges formed by the underlying Wilgerivier Formation. The otherwise relatively weak correspondence between thickness and basal topography can be attributed to the levelling effect of the Dwyka Formation on the pre-Karoo topography as well as the influence of the present surface topography. The pre-Ecca topography also indicates that the present configuration of the Nooitgedacht outlier is not due to it having been an isolated basin, but that it rather constitutes a remnant of substantial post-depositional erosion. Although small isolated troughs and basins most probably existed within the present confines of the outlier, the latter must have originally formed part of a much larger basin which extended particularly towards the west and north-east.

Measurements of palaeocurrent directions on cross-bedding in coarse sandstone and grit were made at 127 localities on the outlier (see Fig. 3.47). The predominant current directions indicated are towards the south and south-west but local variations are evident, especially in the central and north-eastern parts. Comparison of Figs. 3.46 and 3.47 shows that the pre-Ecca topography must have had substantial control on the direction of sediment transport. In the north, for example, the indicated current directions coincide remarkably well with the N–S and NE–SW trending valleys mentioned above. In the north-east the currents were apparently deviated around a high in the palaeo-topography, resulting in a local westerly flow direction. The ridge of Wilgerivier Formation in the south which strikes more or less perpendicular to the predominant current direction, acted as a barrier causing considerable disturbance on its northern side where current directions of between south-east and north-east were measured.

The palaeocurrent directions indicate a provenance located towards the north and north-east of the outlier and the main source rocks were probably granite and granophyre of the Bushveld Complex and felsite of the Rooiberg Group (see Chapter 4). These rocks must, however, have been subjected to considerable erosion since deposition of the Ecca Group because the present-day topography slopes quite steeply away from the Nooitgedacht area in a northerly direction.

Basinal evolution appears to have commenced with the retreat of Dwyka glaciation. After partial reworking of the marginal and bottom tills in the basin to form the diamictite referred to above, meltwater from the retreating glaciers probably formed swampy or lacus-

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Fig. 3.47

28°45'

25°30'

N

HARTEBEESTSPRUIT 434 JR

ROODEPOORT 439 JR

ROOIPOORT 440 JR

LOOPSPRUIT 435 JR

YZERVARKFONTEIN 467 JR

NOOITGEDACHT 6 JR

VLAKFONTEIN 453 JR

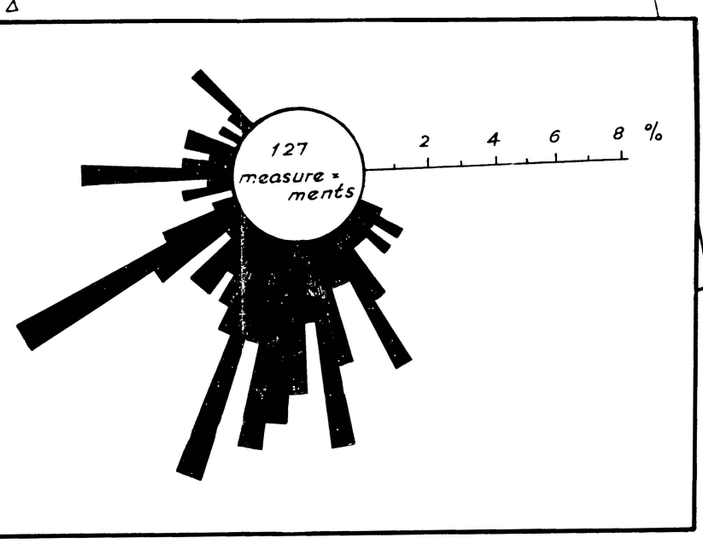
BLESBOKFONTEIN 459 JR

PAPKUILFONTEIN 469 JR

TAAIFONTEIN 461 JR

RIETFONTEIN 470 JR

SCHOONGE ZICHT 465 JR



1 : 50 000

0 1000 2000 3000 m

EXPLANATION

Boundary of the Ecca Group
(only the main outlier is indicated)

Dwyka Formation

Wilgerivier Formation (Waterberg Group)

Nebo Granite (Bushveld Complex)

Loskop Formation

Selonsrivier Formation (Rooiberg Group)

Measurement locality and palaeocurrent direction

Fig. 3·47 Palaeocurrent directions on various parts of the Nooitgedacht outlier. A composite rose diagram is shown as an inset.

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trine conditions in the distal basin, while in proximal areas braided outwash fans developed. Most of the sedimentation in the lacustrine/swamp environment is interpreted as relatively slow accumulation of clay, silt, mud and carbonaceous material. The upward-fining units mentioned earlier are most probably the result of waning floods. As the glaciers retreated, the braided outwash fans most likely prograded across the basin, at first interfingering into the lacustrine sediments and later covering the whole basin with predominantly grit and sand. Referring to the pH model discussed in Bredell (1974), it is not surprising to find flint clay lower down in the succession associated with carbonaceous material, while plastic clays were deposited at a later stage when the stronger influx of fresh water diluted the humic acid concentration in the basin.

3.5.5.3 Refractory Clay

As illustrated in Fig. 4.43, refractory clay was mostly encountered along the southern and central part of the drilling traverse. Further north on Loopspruit, an extensive layer of highly siliceous carbonaceous flint clay was intersected above the coal zone, but no sampling was done as this material is clearly too silty to be classified as refractory clay.

In contrast to the Witwatersrand deposits, the sedimentary clays in this outlier occupy different stratigraphic horizons, with individual clay beds generally forming the top of successive upward-fining cycles. Despite this difference, the regional stratigraphic position of the clay zone as a whole is remarkably similar to that of the Witwatersrand clays, i.e. low down in the Ecca Group and overlying carbonaceous strata.

Analytical and test results of 18 samples of argillaceous material from the borehole cores are presented in Tables 3.23, 3.24 and 3.25. Samples from the Dwyka Formation (165, 166 and 168) are highly siliceous, containing 50 to 60 per cent quartz, and are further characterised by relatively lower TiO_2 contents, higher Rb contents, the presence of K-feldspar, anomalously high pH values in respect to their high bulk densities, and a low refractoriness. With the exception of sample 172 which also proved to have a low fusion temperature (PCE 31^+) as a result of a high (22 per cent) quartz content, all the Ecca clays have a good refractoriness with PCE values ranging between 34 and 36. Eight of these samples can be classified as grade I, but it is interesting to note that sample 200 which has the highest alumina content on a calcined basis, was indicated to have the lowest PCE value (34) of all the grade I samples. From the available results, this apparent contradiction can best be explained in terms of the higher iron content of sample 200, and in particular its distinctly

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TABLE 3.23 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON THE NOOITGEDACHT OUTLIER

			Physical properties				Classification		Mineralogical composition (Kaolinite is the major constituent of all samples)	
Sample No.	Borehole No.	Depth (m)	PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Minor constituents	Approximate percentage quartz
165	NG 1	19,70–20,35	30⁻	2,48	4,84	N7	Flint	IV	Illite	60
166	NG 1	25,80–28,50	27⁻	2,43	8,76	N7	N.r.**	–	Illite, K-feldspar	55
167	NG 2	5,40–9,35	35⁻	2,31	10,75	N9–N8	Semi-flint	II	Illite	8
168	NG 2	30,00–31,50	27	2,37	10,70	N7	Flint	IV	Illite, K-feldspar	50
169	NG 3	7,60–9,45	35	2,07	20,03	N8–5YR8/1	Semi-flint	II	Illite (very little)	2
170	NG 3	9,45–11,30	36	2,23	13,42	N8–N7	Semi-flint	I	None	1
171	NG 4	26,00–30,20	36⁻	2,42	5,73	N5–N3	Flint	I	None	1
172	NG 7	7,50–9,20	31⁺	2,01	22,25	N9–5YR8/1	Semi-flint	IV	Illite	22
173	NG 7	9,20–11,33	34⁺	2,15	17,18	N8	Semi-flint	IV	Illite	11
174	NG 8	14,15–15,00	35⁻	2,18	15,30	5YR8/1–N7	Semi-flint	I	Illite (very little)	3
175	NG 8	18,25–21,00	36⁻	2,43	5,30	N5	Flint	I	Illite (very little)	0
176	NG 10	23,50–27,00	35	2,38	4,65	N3	Flint	I	None	2
177	NG 12	21,00–22,00	36⁻	2,44	3,75	N4–N5	Flint	I	None	1
198	NG 14	13,60–14,40	34	1,98	28,79	5YR8/1	Semi-plastic	IV	Sericite and montmorillonite	12
199	NG 14	17,80–20,25	34⁻	2,45	4,23	N3	Flint	II	Sericite (very little)	10
200	NG 14	25,75–30,00	34	2,45	4,23	N3	Flint	I	Sericite (very little)	2
201	NG 15	8,10–10,00	34	1,93	24,89	N8–5YR8/1	Semi-plastic	II	Sericite (very little)	18
202	NG 15	28,35–29,00	35	2,36	7,30	N3	Flint	I	None	4

*PCE = Pyrometric cone equivalent

**N.r. = Non-refractory

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TABLE 3.24 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON THE NOOITGEDACHT OUTLIER

Sample No.*	165	166	167	168	169	170	171	172	173	174	175	176	177	198	199	200	201	202
SiO_2	73,54	74,71	47,89	80,83	47,87	45,19	43,43	54,61	55,84	44,71	44,00	43,88	42,67	51,99	44,23	40,92	48,21	42,52
TiO_2	0,60	0,44	1,24	0,52	0,92	1,16	1,48	0,78	0,86	1,03	1,21	1,50	1,59	1,54	1,58	1,06	1,03	1,92
Al_2O_3	13,78	11,79	35,64	10,01	35,97	38,27	38,16	30,71	31,03	39,31	37,73	37,65	39,30	31,57	36,33	38,75	35,36	36,90
Fe_2O_3	0,98	1,11	0,21	1,97	0,34	0,32	0,19	0,30	0,33	0,43	0,37	0,43	0,11	1,84	0,45	0,65	1,12	0,24
FeO	1,28	2,85	<0,15	1,20	<0,15	<0,15	<0,15	<0,10	<0,15	<0,15	<0,15	<0,15	<0,15	<0,15	<0,10	1,15	<0,15	<0,15
MnO	0,09	0,09	0,02	0,03	0,02	0,02	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,02	0,02	0,02
MgO	0,81	0,91	0,63	0,93	0,60	0,64	0,72	0,74	0,78	0,64	0,67	0,71	0,60	0,80	0,70	0,73	0,72	0,70
CaO	0,04	0,06	0,02	0,03	0,01	0,02	0,08	0,01	0,01	0,03	0,21	0,35	0,01	0,06	0,14	0,55	0,04	0,08
Na_2O	0,04	0,07	0,04	0,10	0,03	0,05	0,05	0,04	0,01	0,01	0,03	0,07	0,04	0,08	0,08	0,07	0,04	0,04
K_2O	0,42	2,11	0,07	1,70	0,02	0,15	0,25	0,48	0,49	0,29	0,22	0,11	<0,01	0,59	0,09	0,16	0,28	0,46
P_2O_5	0,06	0,05	0,11	0,08	0,06	0,10	0,14	0,09	0,10	0,13	0,40	0,20	0,08	0,25	0,13	0,29	0,35	0,13
CO_2	1,27	2,24	0,40	1,00	0,16	0,48	3,71	0,20	0,17	0,44	1,95	5,46	2,42	0,57	5,63	3,86	0,31	5,55
H_2O^+	4,13	2,43	12,08	1,58	12,09	13,21	11,01	10,68	10,25	12,68	12,27	9,15	12,18	10,99	10,84	12,16	11,90	11,20
Total	97,05	98,86	98,35	99,98	98,08	99,61	99,21	98,65	99,92	99,73	99,07	99,53	99,02	100,29	100,22	100,37	99,39	99,76
H_2O^- on air-dried sample	0,21	0,03	0,46	0,94	0,53	0,25	0,59	0,57	0,42	0,92	0,73	0,75	0,64	0,72	0,72	0,85	0,87	1,14
Al_2O_3 on a calcined basis	14,59	12,37	40,82	10,28	41,10	44,37	44,81	34,52	34,64	45,26	44,05	44,13	46,10	35,68	43,47	46,11	40,31	44,35
pH	6,6	6,5	5,2	6,3	5,8	4,6	4,6	6,0	5,8	5,5	4,6	5,2	4,8	6,0	4,6	4,5	6,2	5,4

*See Table 3.23 for sample positions

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TABLE 3.25 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON THE NOOITGEDACHT OUTLIER

Sample No.*	165	166	167	168	169	170	171	172	173	174	175	176	177	198	199	200	201	202
V	69	61	167	27	155	161	195	63	66	176	199	129	145	170	237	143	112	122
Co	26	25	36	<1	21	24	41	29	32	23	31	38	34	20	47	36	29	43
Ni	20	14	29	23	21	27	49	11	18	20	56	38	17	17	38	36	50	23
Cu	63	47	51	41	35	48	55	37	36	70	72	64	44	86	60	64	74	43
Zn	65	92	38	51	46	39	215	29	39	44	107	175	30	51	288	238	61	61
Ga	23	20	36	20	38	41	42	32	35	40	43	42	41	45	43	42	49	46
Ge	5	6	5	5	<5	<5	<5	5	6	5	<5	5	5	9	<5	<5	9	6
Rb	51	109	34	96	21	23	33	37	50	46	36	28	18	57	28	31	42	24
Sr	48	39	136	36	30	53	98	79	81	182	642	37	60	555	136	103	838	70
Y	65	45	74	39	62	63	45	84	71	132	62	75	39	106	65	71	239	46
Zr	575	434	558	539	806	353	467	398	455	382	411	500	410	573	614	541	548	491
Nb	25	22	41	19	64	32	38	34	39	44	39	42	48	44	49	44	43	47
Mo	6	<5	<5	<5	32	14	9	<5	5	17	9	<5	<5	26	<5	<5	<5	5
Sn	22	7	36	3	10	10	31	36	38	5	5	36	29	6	37	14	<1	35
Sb	34	16	39	<1	8	2	30	34	37	<1	<1	35	22	<1	31	4	<1	22
W	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1
Pb	24	19	35	16	23	41	63	50	35	57	62	52	83	70	79	69	99	58
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Th	24	9	44	10	41	36	52	43	48	56	49	39	39	57	64	51	50	68
U	2	3	4	6	<1	1	6	<1	<1	8	8	5	2	12	12	8	13	5
As	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	8	<5	13	<5	9	11	13	<5
S	164	84	30	85	20	<10	129	116	33	<10	40	120	<10	20	250	240	<10	110

*See Table 3.23 for sample positions

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higher FeO content (1,15 per cent). This not only serves to illustrate the powerful fluxing properties of ferrous iron, but it also emphasises the value of a comprehensive chemical analysis in evaluating refractory clays.

As indicated by their light to dark grey colour and CO_2 contents which range up to 5,63 per cent, almost all the flint and semi-flint clays are slightly carbonaceous. However, this does not seem to affect their refractoriness detrimentally and may even turn out to be advantageous by possibly reducing the amount of fuel required during firing.

The flint clays are characterised by a tightly interlocking, essentially random orientation of kaolinite particles (Fig. 3.48), while the semi-plastic clays on the other hand have a comparatively well-orientated, finer-grained texture with isolated illite flakes of up to about 65 μm across (Fig. 3.49).

With reference to Fig. 3.43 and Table 3.23, the indicated resources of refractory clay along the drilling traverse are summarised below. The width of each layer across the line of boreholes is assumed to be half its indicated length and only clays with PCE values of more than 34$^-$ are taken into account; these are present at three different stratigraphic levels:

(1) Grade I carbonaceous flint clay (PCE 36$^-$), at least 4,2 m thick, struck in boreholes NG 3 and NG 4 near the base of the Ecca Group at the top of the sedimentary unit starting with grit G1. The overburden is excessive (26 – 27 m) and mining of this material would probably not be feasible in the foreseeable future. Calculated at a pessimistic average thickness of 2,0 m, a bulk density of 2,4 and over an area of 300 m x 150 m, the indicated resources amount to about *200 000 t.*

(2) Grade I to II semi-flint clay (PCE 35$^-$ to 36) intersected in boreholes NG 2, NG 3 and NG 4 and partially overlying the flint clay mentioned in (1) above. It forms the top of the sedimentary unit with grit G2 at its base and is between 1,8 and 3,95 m thick with an overburden of 6 – 18 m. Indicated resources over an area of 900 m x 450 m at an average thickness of 2,0 m and a bulk density of 2,2 are about *1,8 Mt.*

At the same stratigraphic level, but separated from the semi-flint clay by a ridge in the pre-Ecca topography, a layer of grade I carbonaceous flint clay (PCE 34 to 36$^-$) was intersected in adjacent boreholes NG 8 – NG 12 as well as in boreholes

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Fig. 3.48 Randomly orientated kaolinite in flint clay from Nooitgedacht 436 JR. Magnification 1 600X.

Wanordelik georiënteerde kaoliniet in flintklei van Nooitgedacht 436 JR. Vergroting 1 600X.

Fig. 3.49 Illite flake in fine-grained semi-plastic clay from Nooitgedacht 436 JR. Magnification 1 200X.

Illietvlokkie in fynkorrelrige semi-plastiese klei van Nooitgedacht 436 JR.

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NG 14 and 15. The thickness varies between 1,0 and 3,5 m below an overburden of 21 – 27 m. Indicated resources at an average thickness of 2,0 m, a bulk density of 2,4 and over an area of 2 200 m x 1 100 m amount to *11,6 Mt.* The excessive overburden would, however, preclude mining of this apparently extensive deposit in the near future.

(3) Grade I to IV semi-flint clay (PCE 34^{+} to 35^{-}), partially overlying the flint clay mentioned in (2) above and occurring at the top of the unit which starts with grit G5 at its base. This clay layer was intersected in boreholes NG 7 and NG 8 and was indicated to be between 0,85 and 1,1 m thick with an overburden of 9 – 14 m. At an average thickness of 1,0 m and a bulk density of 2,15, indicated resources are approximately *500 000 t* over an area of 700 m x 350 m.

A layer of grade II to IV semi-plastic clay (PCE 34) was indicated in boreholes NG 14 and 15 at the same stratigraphic level below an overburden of 8 – 14 m; the thickness varies between 0,8 and 1,9 m. Indicated resources at an average thickness of 1,0 m, and a bulk density of 1,96 are about *200 000 t* over an area of 500 x 250 m.

Total resources of clay with a good refractoriness indicated by this drilling project are therefore approximately *14,3 Mt,* but unfortunately most of this material will not be economically extractable in the near future due to excessive overburden. Adding the 687 000 t of semi-flint and plastic clay found on Rietfontein 470 JR (section 3.5.4), the total resources of refractory clay indicated by Geological Survey drilling in the Nooitgedacht outlier amount to almost 15 Mt. Owing to the lack of borehole data, no reliable estimate of refractory-clay resources for the whole outlier can be made, but indications are that the area has tremendous future potential, especially for high-grade carbonaceous flint clay.

When considering the future mining potential of refractory clay in the Nooitgedacht outlier, due cognisance should also be taken of the other exploitable mineral commodities within this Ecca relict. Substantial thicknesses of unconsolidated grit and sand have been intersected at shallow depth along the central and northern parts of the drilling traverse and these deposits undoubtedly represent a potential source of concrete and building sand (see Appendix 4). The demand for these materials is expected to increase strongly in this area in the near future and if planned properly, their exploitation could bring a vast amount of high-grade carbonaceous flint clay within reach of open-cast extraction. Coal is also

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known to occur in the northern part of the outlier and was partly intersected during the present drilling project. In view of the fact that mining of this coal could expedite refractory-clay exploitation and vice versa, more details on the coal deposit are presented in the next section.

3.5.5.4 Coal

Coal mining in the area started before the turn of the century at the small Nooitgedacht Colliery on Nooitgedacht 436 JR (Visser *et. al.*, 1961). Most of the production was consumed by the local farmers, but at one stage coal was also supplied to the Albert Silver Mine on Roodepoortjie 250 JR. The colliery was worked intermittently by various owners until about 1960 and between 1953 and 1956 the coal was even marketed in Pretoria. According to Visser *et. al.*, (1961), the lowest coal seam in the mine is between 1,8 and 2,1 m thick and can possibly be correlated with the No. 1 Seam of the Witbank coal field. The ash content of this seam was reported to be about 30 per cent and the heating value approximately 21,9 MJ/kg. About 3 m above the lower seam is another of equally low quality and between 0,9 and 7,0 m thick; this is possibly the equivalent of the No.2 Seam in the Witbank coal field. A third, poorly developed seam (0,3 to 0,9 m thick) occurs about 6 m higher up in the succession.

In spite of the obviously isolated nature and limited extent of the coal in this outlier, a considerable number of exploration boreholes have been drilled since 1959. Using the results of this drilling as well as evidence from boreholes drilled for clay, the approximate limit of carbonaceous strata could be established (Fig. 3.42). The available data are unfortunately inadequate to delineate coal as such. Although probably not very accurate due to widely and irregularly spaced data points, the area indicated at least reduces the target for possible future exploration. Comparison with Figs. 3.45 and 3.46 shows that the distribution of carbonaceous material roughly corresponds with the deepest part of the basin where the thickest succession of Ecca sediments has been preserved.

During the present study, coal and carbonaceous material intersected in 8 of the boreholes (NG 12, NG 13, LS 1, LS 2, LS 3, LS 4, LS 6 and LS 8) were submitted to the Fuel Research Institute for analysis. Lithological descriptions appear in Appendix 4 and the analytical results are listed in Table 3.26.

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TABLE 3.26 ANALYSES OF COAL INTERSECTED IN BOREHOLES ON THE NOOITGEDACHT OUTLIER DURING THE PRESENT INVESTIGATION

Borehole No.	Sample No.	Depth interval (m)	Thickness sampled (m)	Ash in raw coal (air-dry basis) (%)	Size of coal washed (mm)	Relative density	Float yield (%)	Analysis of float (air-dry basis)				
								Heating value (MJ/kg)	H_2O (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)
NG 12	223 A	29,4 –30,05	0,65	19,0	Not washed	–	–	24,1*	4,5*	–	20,7*	55,8*
NG 13	755 E	22,5 –23,34	0,84	41,6	-25	1,60	25,6	24,1	4,2	19,7	27,2	48,9
	972 D	23,34–23,86	0,52	44,8	-25	1,60	14,7	28,1	4,3	10,7	34,7	50,3
	121 C	23,86–24,95	1,09	69,4	Not washed	–	–	–	–	–	–	–
	975 B	24,95–25,53	0,58	35,7	-25	1,60	34,8	24,0	3,9	21,4	26,6	48,1
	333 A	25,53–26,16	0,63	49,5	Not washed	–	–	–	–	–	–	–
LS 1	79 D	24,41–26,65	2,24	36,5	-25	1,60	35,4	24,7	4,2	18,7	25,2	51,9
	187 C	26,65–28,5	1,85	48,8	-25	1,60	22,9	24,6	4,5	18,3	24,6	52,6
	644 B	28,5 –29,45	0,95	53,9	-25	1,60	2,7	n.d.	n.d.	n.d.	n.d.	n.d.
	865 A	29,45–30,1	0,65	23,8	-25	1,60	71,8	24,2	5,0	18,2	17,2	59,6
LS 2	119 E	21,86–22,97	1,11	39,3	-25	1,60	24,1	22,6	4,4	24,1	19,8	51,7
	467 D	22,97–23,75	0,78	68,3	-25	1,60	1,7	n.d.	n.d.	n.d.	n.d.	n.d.
	777 C	23,75–24,53	0,78	37,9	-25	1,60	31,8	25,4	4,7	16,1	21,0	58,2
	590 B	24,8 –26,77	1,97	39,6	-25	1,60	36,1	25,1	4,4	17,1	26,1	52,4
	1 017 A	26,77–29,8	3,03	36,4	-25	1,40	3,6	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,4–1,6	35,9	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,60	39,5	22,5	4,6	22,2	22,1	51,1
LS 3	970 D	17,52–20,11	2,59	46,0	-25	1,50	7,9	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,5–1,6	12,1	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,6–1,7	16,3	19,8	4,0	30,9	17,9	47,2
					-25	1,60	20,0	24,3	4,3	19,0	22,0	54,7
					-25	1,70	36,3	22,3	4,2	24,3	20,2	51,3
	661 C	20,11–21,94	1,83	38,6	-25	1,50	24,2	26,8	4,1	12,8	31,0	52,1
					-25	1,5–1,6	15,9	23,2	4,0	21,4	23,0	51,6
					-25	1,6–1,7	12,4	n.d.	3,8	29,5	21,2	45,5

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TABLE 3.26 (Continued)

Borehole No.	Sample No.	Depth interval (m)	Thickness sampled (m)	Ash in raw coal (air-dry basis) (%)	Size of coal washed (mm)	Relative density	Float yield (%)	Analysis of float (air-dry basis)				
								Heating value (MJ/kg)	H_2O (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)
					-25	1,60	40,1	25,4	4,1	16,2	27,8	51,9
					-25	1,70	52,5	n.d.	4,0	19,3	26,3	50,4
	978 B	21,94–24,0	2,06	30,8	-25	1,40	3,6	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,4–1,5	11,7	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,5–1,6	33,0	22,9	4,5	21,2	20,6	53,7
					-25	1,6–1,7	13,2	n.d.	4,3	27,3	19,8	48,6
					-25	1,50	15,3	26,6	4,5	12,9	27,0	55,6
					-25	1,60	48,3	24,1	4,5	18,6	22,6	54,3
					-25	1,70	61,5	n.d.	4,5	20,4	28,0	47,1
	60 A	24,0 –26,48	2,48	35,2	-25	1,40	3,3	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,4–1,5	7,7	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,5–1,6	19,5	23,2	4,2	21,7	20,1	54,0
					-25	1,6–1,7	19,9	n.d.	3,9	29,7	19,8	46,6
					-25	1,50	11,0	27,0	4,5	11,6	25,5	58,4
					-25	1,60	30,5	24,6	4,3	18,1	22,0	55,6
					-25	1,70	50,4	n.d.	4,1	22,7	21,2	52,0
LS 4	236 E	13,93–16,28	2,35	54,5	-25	1,60	13,2	–	3,0*	–	15,5*	27,0*
	105 D	16,28–19,08	2,80	38,2	-25	1,60	33,3	25,5	4,7	15,1	23,4	56,8
	765 C	19,08–21,76	2,68	29,0	-25	1,60	55,4	24,6	4,6	17,6	22,2	55,6
	261 B	21,76–24,58	2,82	36,2	-25	1,40	4,2	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,4–1,6	29,9	n.d.	n.d.	n.d.	n.d.	n.d.
					-25	1,60	34,1	24,3	4,2	19,0	22,5	54,3
	250 A	28,75–30,1	1,35	49,2	Not washed	–	–	–	3,2*	–	14,9*	32,7*
LS 6	583 C	21,11–22,16	1,05	30,9	-25	1,60	45,1	25,2	4,0	17,6	20,7	57,7
	547 B	22,16–23,65	1,49	62,2	-25	1,60	6,4	n.d.	n.d.	n.d.	n.d.	n.d.
	20 S A	23,65–24,73	1,80	28,1	-25	1,60	53,8	24,9	4,0	18,4	22,4	55,2
LS 8	602 A	13,24–13,5	0,26	44,2	Not washed	–	–	–	3,3*	–	15,4*	37,1*

*These values refer to unwashed coal

n.d. – not determined

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The main coal zone intersected or partially penetrated is probably the equivalent of the No. 2 Seam in the Witbank coal field. It is up to 10,65 m thick (borehole LS 4) and its top was struck at depths varying between 13,93 and 24,41 m from surface. The roof consists of carbonaceous shale or clay while the floor comprises carbonaceous shale, sandstone or clay. To the south of borehole NG 13 the "No. 2 Seam" pinches out and is represented at the same stratigraphic level by a layer of carbonaceous flint clay (Fig. 3.45). It also pinches out abruptly to the north of borehole LS 4, and in borehole LS 5 only carbonaceous shale was intersected. In LS 6 it was again struck near the base of the Ecca Group, but it is not developed further north.

The lower seam (probably the No. 1 Seam of the Witbank coal field) was struck only in boreholes NG 12 and LS 4. It was fully intersected in the latter borehole and found to be only 1,35 m thick. A poorly developed (0,26 m thick) lens of coal occurring stratigraphically above the "No. 2 Seam" was intersected in LS 8; this probably represents the No. 3 Seam of the Witbank coal field.

The best quality coal was found in the "No. 1 Seam" in borehole NG 12 at a depth of about 30 m. The ash content is reasonably low (19 per cent) in the raw coal but due to the fact that only the upper 0,62 m of the seam was penetrated, float and sink analyses were not performed. Although this material could therefore possibly be upgraded to a high-grade steam coal by washing in a heavy-medium plant, its distribution is probably very limited in view of the fact that the same seam, where intersected in borehole LS 4, was found to have a much higher ash content (49,2 per cent) in the untreated material.

Despite its substantial thickness, the "No. 2 Seam" consists essentially of bituminous coal with a high ash content. Float and sink tests yielded generally poor results and a float yield in excess of 70 per cent at a relative density of 1,60 was only achieved in the case of the lower 0,65 m of the seam in borehole LS 1. According to the specifications of the Petrick report (1975), only the following parts of the seam can be regarded as *mineable low-grade steam coal:*

(1) The lower 4,54 m in borehole *LS 3* at depths of between 21,94 and 26,48 m.

(2) 2,68 m of the seam in borehole *LS 4* at 19,08 to 21,76 m from surface.

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Coal with an ash content of up to 37 per cent, i.e. just higher than the specified maximum of 35 per cent and exceeding 1,2 m in thickness, was found in the following parts of the "No. 2 Seam":

(1) The upper 2,24 m in borehole *LS 1* at depths of between 24,41 and 26,65 m.

(2) The lower 3,03 m in borehole *LS 2* at 26,77 – 29,8 m from surface.

(3) The lower 2,82 m in borehole *LS 4* between 21,76 and 24,58 m.

The more promising coal appears, therefore, to be fairly continuous between adjacent boreholes LS 1 to LS 4 (a distance of approximately 1 200 m), with better-quality material concentrated around LS 3 and LS 4. If all material containing up to 37 per cent ash is considered, the indicated resources within an area of 1 200 m x 600 m amount to about 2,9 Mt of low-grade steam coal at an average thickness of 2,5 m and a relative density of 1,60. If mined by open-cast methods, some 20 – 27 m of overburden would have to be removed.

An estimate of the total coal resources within the Nooitgedacht outlier is unfortunately not possible at this stage because of inadequate borehole data. Substantial additional resources of low-grade steam coal can, however, be expected to be present both to the east and west of the drilling traverse.

3.5.6 Rietfontein 314 JS

Areas where refractory clay is most often located, i.e. near the edges of the Vryheid Formation, are extensively developed to the south and east of Middelburg in the form of a long, irregular, erosional contact. It is surprising, therefore, that very few exploitable deposits have been found in this region. For the purposes of this study, two sites were largely arbitrarily selected for drilling, based on the observation that palaeocurrents in the area are predominantly indicated to be in a direction just to the west of south. The first of these sites is situated on Rietfontein 314 JS near the south-western margin of a prominent north-westerly striking tongue of Vryheid Formation, about 10 km south-west of Middelburg (see Fig. 3.50). Limited production of flint clay has taken place to the west of the road to Middelburg, while shallow excavations by the farmer have exposed flint clay over a small area to the east of this road. Drilling was aimed at investigating the extent of these occurrences, particularly in view of possible claims for compensation which may arise from the extension of the N4 freeway.

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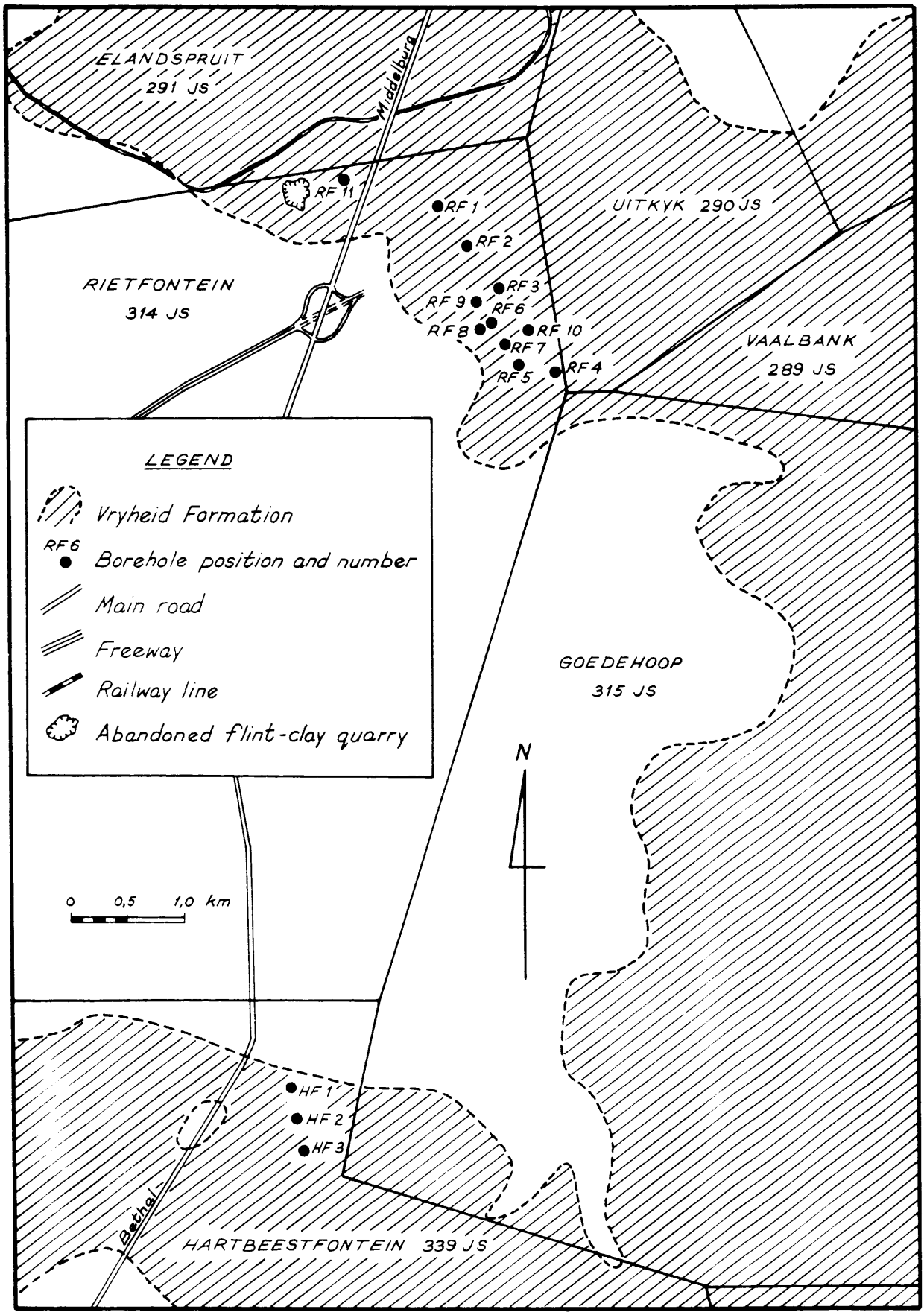

Fig. 3 50 Boreholes for refractory clay on Rietfontein 314 JS and Hartbeestfontein 339 JS

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As indicated by the borehole descriptions in Appendix 4 and the physical properties of clay samples in Table 3.26, the drilling project on Rietfontein yielded rather disappointing results. Refractory clay was only intersected in boreholes RF 3 and RF 6 and although two of the samples can be classified as grade I flint and semi-flint clay respectively, the obviously limited lateral extent and thickness of this material would render economical exploitation impossible.

An exceptional feature revealed by the drilling is the substantial thickness of sericitic Dwyka clay found in boreholes RF 5, 6 and 8. Although probably not of economic importance, this material is noteworthy because of its remarkable macroscopic resemblance to high-grade flint clay. Exploration geologists should take particular care not to misidentify this rock type in the field. As pointed out in section 3.5.2, however, Dwyka "flint clay" can be readily distinguished from its genuine Ecca counterpart on the basis of a number of physical and chemical parameters. In this particular case the Dwyka clay is for example distinctly characterised by a much lower refractoriness (Table 3.27) and contrastingly high K_2O and Rb contents as well as a low concentration of TiO_2 and an anomalously high pH (Tables 3.28 and 3.29). The tightly intergrown nature of the sericite in the Dwyka clay also suggests a distinct genetical difference between the two clays types. Whereas an allochtonous origin is proposed for the kaolinite in the Ecca refractory clays (Chapter 4), the sericite in the Dwyka clay has most likely been formed from the *in situ* alteration of very fine-grained alkali feldspar which had originally been deposited as glacial flour.

The nine northernmost boreholes all intersected bituminous coal of varying quality and thickness at depths ranging from between 9–14 m in the north and 22–25 m in the south. Analyses by the Fuel Research Institute indicated that the only significant intersections are those in boreholes RF 1 and 11 near the northern boundary of the farm. In the latter hole, two coal seams were found, separated by a 0,47 m grit layer (see Appendix 4). The lower seam is 2,42 m thick (11,48–13,90 m) and contains 26,7 per cent ash, 20,9 per cent volatiles and 49,9 per cent fixed carbon on a raw air-dry basis, while the corresponding figures for the overlying 1,05 m thick seam are 27,8, 16,0 and 53,0 per cent respectively. The single 1,60 m thick seam intersected between 16,37 and 17,97 m in RF 1 is of decidedly lower quality, containing 31,2 per cent ash, 21,1 per cent volatiles and 45,1 per cent fixed carbon. The apparent geographic separation of potentially mineable coal from the stratigraphically overlying but isolated occurrence of high-grade flint clay on Rietfontein therefore excludes the possibility of a dual mining operation in this area.

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TABLE 3.27 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 314 JS

			Physical properties				Classification		Mineralogical composition		
Sample No.	Borehole No.	Depth (m)	PCE*	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Major constituents	Minor constitutents	Approximate percentage quartz
182	RF 3	7,50–8,50	33	1,94	26,21	10 YR8/2–5 YR8/1	Semi-plastic	IV	Kaolinite	Sericite	20
183	RF 3	8,50–9,54	35	2,37	8,36	N7	Flint	I	Kaolinite	Sericite	3
184	RF 5	15,25–21,50	11	2,47	10,46	5 YR6/1–5 YR4/1	N.r.**	–	Kaolinite, sericite	Chlorite	20
185	RF 5	21,50–30,48	9^+	2,55	5,16	5 YR6/1–5 YR4/1	N.r.	–	Kaolinite,sericite	Chlorite	22
186	RF 6	4,90–5,75	35	2,28	11,81	N7–N6	Semi-flint	I	Kaolinite	Illite, chlorite	5
187	RF 6	25,10–30,50	16	2,59	3,99	N7	N.r.	–	Sericite	Chlorite	25
188	RF 8	18,60–26,68	16^+	2,60	4,80	N7	N.r.	–	Sericite,kaolinite	Chlorite	30
189	RF 8	26,68–34,78	16^+	2,61	3,71	N7	N.r.	–	Sericite,kaolinite	Chlorite	28

*PCE Pyrometric cone equivalent

**N.r. Non-refractory

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TABLE 3.28 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 314 JS

	Sample No.*							
	182	183	184	185	186	187	188	189
SiO_2	50,57	43,95	57,34	58,51	41,04	59,91	61,08	59,16
TiO_2	1,08	1,36	0,56	0,57	2,03	0,75	0,82	0,78
Al_2O_3	32,18	38,31	19,94	20,05	39,61	21,02	22,12	20,58
Fe_2O_3	2,65	0,45	8,26	6,05	0,42	2,54	1,61	2,33
FeO	<0,15	<0,15	<0,15	2,03	<0,15	1,63	1,78	2,97
MnO	0,05	0,01	0,09	0,10	0,01	0,04	0,02	0,04
MgO	0,85	0,69	2,06	2,45	0,67	1,54	1,25	1,57
CaO	0,04	0,08	0,25	0,33	0,08	0,11	0,25	0,52
Na_2O	0,08	0,08	0,10	0,20	0,08	0,36	0,55	0,63
K_2O	0,68	0,29	5,74	5,77	0,17	3,79	4,27	4,51
P_2O_5	0,10	0,24	0,15	0,15	0,36	0,06	0,08	0,07
CO_2	0,48	1,33	0,41	0,20	2,07	1,02	0,98	2,48
H_2O^+	10,45	12,73	4,21	4,02	12,27	5,25	4,22	3,84
Total	99,21	99,51	99,11	100,42	98,79	98,02	99,05	99,49
H_2O^- on air-dried sample	0,70	1,87	0,57	0,71	0,78	0,27	0,32	0,29
Al_2O_3 on a calcined basis	36,16	44,61	20,91	20,93	46,34	22,46	23,35	21,98
pH	6,1	5,4	6,3	6,6	5,4	6,3	6,2	6,3

*See Table 3.27 for sample positions

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TABLE 3.29 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON RIETFONTEIN 314 JS

	Sample No.*							
	182	183	184	185	186	187	188	189
V	150	156	95	92	111	113	136	120
Co	32	37	34	32	37	30	29	46
Ni	39	30	107	95	25	102	59	84
Cu	61	66	110	133	114	48	99	85
Zn	82	38	172	161	39	97	108	106
Ga	29	43	26	26	46	27	28	27
Ge	< 5	7	< 5	< 5	7	5	< 5	5
Rb	70	47	272	295	38	221	201	247
Sr	125	824	36	31	909	78	103	118
Y	99	49	35	30	126	51	44	40
Zr	313	353	183	177	502	320	264	259
Nb	29	32	15	13	50	16	16	16
Mo	< 5	< 5	< 5	< 5	< 5	< 5	7	< 5
Sn	4	27	1	2	34	< 1	18	12
Sb	2	29	1	20	31	< 1	34	22
W	1	1	1	1	1	< 1	< 1	< 1
Pb	25	56	46	43	51	24	21	46
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	36	44	31	11	63	36	23	20
U	1	12	1	1	22	2	< 1	2
As	< 5	< 5	< 5	< 5	< 5	10	< 5	12
S	<10	<10	40	20	<10	<10	40	100

*See Table 3.27 for sample positions

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3.5.7 Hartbeestfontein 339 JS

The second target in the Middelburg area is situated about 8 km south of the first site and is also located on a north-westerly trending spur of the Vryheid Formation (Fig. 3.50). As noted in Appendix 4, all three boreholes (HF 1–3) struck Dwyka tillite at shallow depth after passing through a thin cover of probably *in situ* weathered sandstone, siltstone and impure plastic clay of the Vryheid Formation. Dwyka "flint clay" intersected in HF 1 and 3 proved to have very similar properties to corresponding material on Rietfontein 314 JS and is consequently of no economic significance (Tables 3.30 to 3.32).

Although a potentially mineable deposit could not be located by the two attempts at exploration in the Middelburg area, the results indicate that conditions for the deposition of high-grade flint clay did prevail locally in these parts of the Vryheid Formation. Extensive, systematic drilling along the margins of this formation would, however, be required to trace possibly viable deposits.

3.5.8 Klipfontein 385 JS

Mining of flint clay in the Belfast area has mostly been confined to very small Ecca outliers to the north and north-west of the town. The present study was therefore largely aimed at investigating the possibility of similar deposits occurring within the main sheet of the Vryheid Formation immediately to the south. The site selected for drilling is shown in Fig. 3.51.

Plastic clay of good refractoriness and with rather similar chemical characteristics to the clay on Rietfontein 470 JR was intersected at mineable depth in two of the three boreholes (Tables 3.30 to 3.32). The presence of plastic clay in this area in relation to the flint-clay deposits further north also corresponds to the distribution of plastic and flint clay as observed in the Nooitgedacht outlier and conforms to the overall regional pattern in the Transvaal of flint clay being largely confined to proximal areas in the north and plastic types located in larger distal basins to the south. The small flint-clay bearing outliers north of Belfast therefore probably represent erosional remnants of the deeper parts of isolated proto-basins, while predominantly plastic clay was subsequently deposited further south under higher pH conditions.

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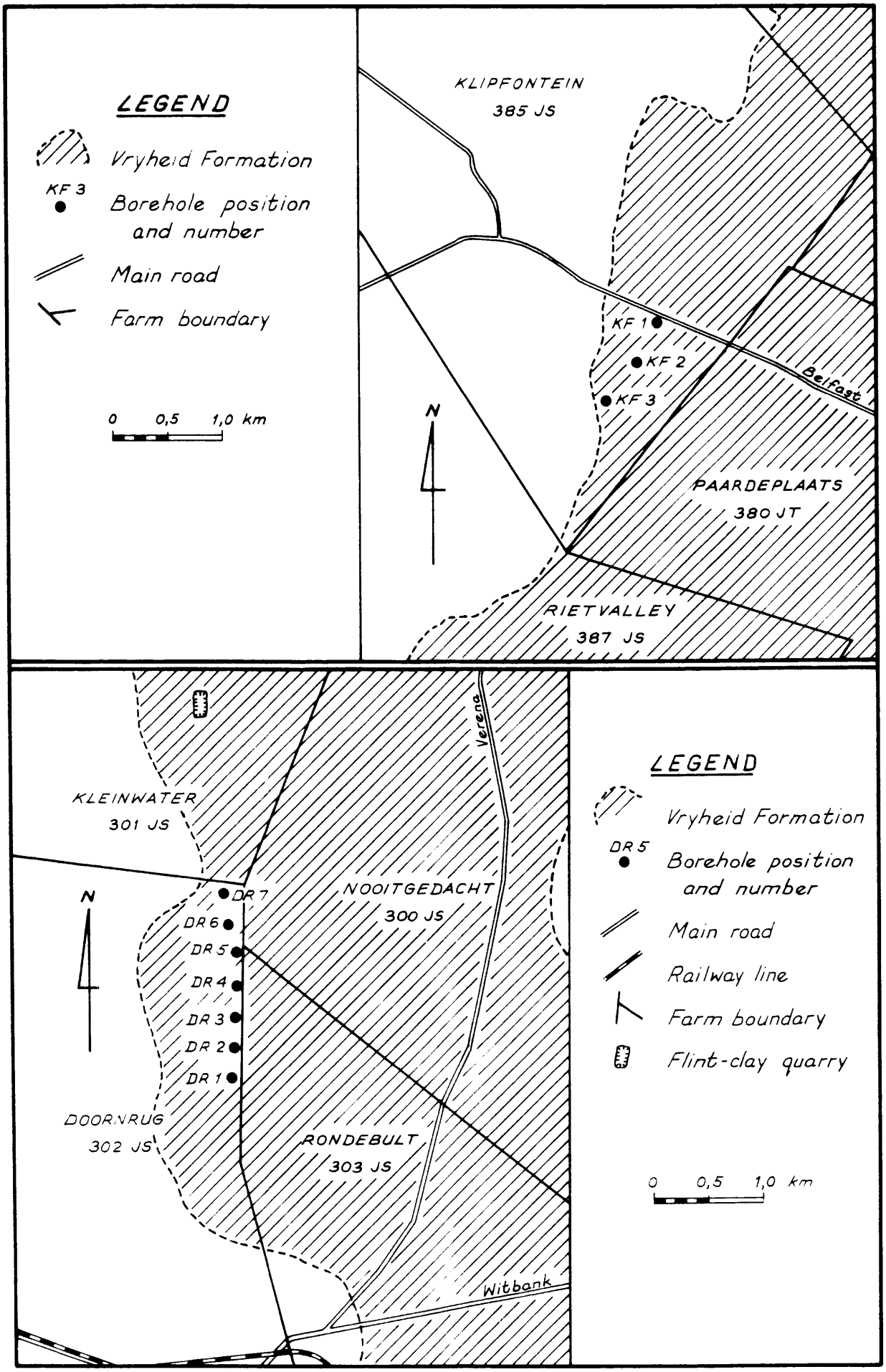

Fig. 3·51 Boreholes for refractory clay on Klipfontein 385 JS and Doornrug 302 JS

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TABLE 3.30 PHYSICAL PROPERTIES, CLASSIFICATION AND MINERALOGICAL COMPOSITION OF CLAY SAMPLES FROM BOREHOLES DRILLED ON HARTBEESTFONTEIN 339 JS, KLIPFONTEIN 385 JS AND DOORNRUG 302 JS

			Physical properties				Classification		Mineralogical composition		
Sample No.*	Borehole No.	Depth (m)	PCE**	Bulk density	Apparent porosity (%)	Munsell symbols	Type	Grade	Major constitutents	Minor constitutents	Approximate percentage quartz
190	HF 1	21,80–24,40	13	2,56	3,00	N7–5R3/4	N.r.***	–	Kaolinite, sericite	Chlorite	28
191	HF 3	21,40–22,10	15	2,48	2,12	N5	N.r.	–	Kaolinite	Sericite, mont-morillonite	50
192	KF 1	9,30–12,48	35	1,85	28,43	10 YR8/2	Plastic	III	Kaolinite	Sericite	11
193	KF 1	18,45–21,60	35	1,76	31,74	5 YR8/1	Plastic	II	Kaolinite	Sericite	5
194	KF 3	1,50–2,80	34	1,64	36,67	10 R8/2	Plastic	III	Kaolinite	Sericite	4
195	DR 1	6,30–7,00	35	1,81	30,28	5 YR8/1	Plastic	IV	Kaolinite	Sericite	15
196	DR 2	7,00–9,15	34	1,76	32,79	5 YR8/1	Plastic	IV	Kaolinite	Sericite	12
197	DR 4	7,60–9,00	31	1,83	29,62	5 YR8/4–N8	Plastic	IV	Kaolinite	Sericite, mont-morillonite	13

*Samples 190–191: Hartbeestfontein 339 JS
192–194: Klipfontein 385 JS
195–197: Doornrug 302 JS

**PCE = Pyrometric cone equivalent

***N.r. = Non-refractory

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TABLE 3.31 MAJOR-ELEMENT COMPOSITION (IN PER CENT) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON HARTBEESTFONTEIN 339 JS, KLIPFONTEIN 385 JS AND DOORNRUG 302 JS

	Sample No.*							
	190	191	192	193	194	195	196	197
SiO_2	54,44	56,01	47,87	44,72	44,99	50,20	51,80	48,62
TiO_2	0,60	0,45	2,14	1,63	2,06	1,17	1,13	1,17
Al_2O_3	18,88	11,34	34,25	37,85	34,77	33,75	29,87	31,55
Fe_2O_3	2,75	3,85	1,50	1,04	3,41	0,65	3,94	5,04
FeO	5,70	9,41	<0,15	<0,15	<0,15	<0,10	<0,15	<0,15
MnO	0,15	0,25	0,01	0,02	0,03	0,05	0,02	0,04
MgO	2,60	2,26	0,76	0,70	0,75	0,75	0,73	0,85
CaO	1,00	1,95	0,02	0,03	0,02	0,03	0,02	0,03
Na_2O	0,23	0,11	0,07	0,06	0,04	0,07	0,07	0,07
K_2O	5,09	2,05	0,11	0,17	0,03	0,70	0,50	0,60
P_2O_5	0,16	0,10	0,10	0,11	0,16	0,16	0,10	0,16
CO_2	4,49	9,30	0,25	0,56	0,35	0,32	0,35	0,28
H_2O^+	3,23	2,48	11,72	12,45	12,36	10,49	10,92	10,99
Total	99,33	99,58	98,81	99,35	98,97	98,35	99,44	99,40
H_2O^- on air-dried sample	0,71	0,30	0,51	0,56	0,63	0,72	0,77	0,62
Al_2O_3 on a calcined basis	20,47	12,86	38,97	43,55	39,89	37,92	33,69	35,58
pH	6,4	6,5	6,7	6,7	6,8	6,6	6,8	6,6

*See Table 3.30 for sample positions

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TABLE 3.32 TRACE-ELEMENT COMPOSITION (IN PPM) OF CLAY SAMPLES FROM BOREHOLES DRILLED ON HARTBEESTFONTEIN 339 JS, KLIPFONTEIN 385 JS AND DOORNRUG 302 JS

	Sample No.*							
	190	191	192	193	194	195	196	197
V	85	88	155	187	227	182	155	207
Co	28	63	17	34	33	38	25	46
Ni	101	133	58	57	55	12	32	55
Cu	58	101	42	47	52	48	87	67
Zn	147	176	43	55	63	41	81	100
Ga	25	23	36	39	46	35	30	34
Ge	< 5	< 5	< 5	8	7	6	< 5	5
Rb	267	100	24	28	18	58	49	61
Sr	68	156	93	144	109	267	60	289
Y	35	41	40	179	49	101	81	93
Zr	200	225	461	459	541	326	351	316
Nb	15	18	27	35	38	30	28	32
Mo	< 5	7	18	< 5	10	< 5	5	< 5
Sn	< 1	< 1	7	25	31	26	4	19
Sb	< 1	< 1	4	22	29	30	4	23
W	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	26	25	39	32	75	54	25	42
Se	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Th	23	18	21	48	36	46	30	49
U	< 1	3	< 1	2	2	6	1	6
As	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
S	10	250	<10	<10	60	<10	<10	<10

*See Table 3.30 for sample positions

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Although the presence of flint clay in the main sheet of Vryheid sediments to the west and south-west of Belfast cannot be excluded on the available evidence, the area certainly does not appear to be a promising exploration target for this commodity. If a demand for plastic refractory clay should arise in this area in the future, further investigation of the occurrence located on Klipfontein might be justified, particularly to the north of KF 1.

3.5.9 Doornrug 302 JS

As indicated in Table 2.1, flint clay has been mined at several localities within the extensive tongue of Vryheid Formation to the west of Witbank. Most of these deposits are situated along the western margin of this erosional feature and are known to occur as far south as 26° latitude. From an exploration point of view, the whole area therefore appears to be most promising and during the present study two sites were selected for drilling in order to fill in some of the many gaps which still exist on this target. The site on Doornrug is located about 2 km south of the Kleinwater flint-clay quarry (Fig. 3.51) and was chosen to test the apparent continuity of deposits along the western margin. Following the analogy of regional clay distribution in the Nooitgedacht outlier and in the Belfast area (Klipfontein), a second site (Hartbeestspruit 281 JS) was selected in the more proximal north-eastern part of the Vryheid Formation (see section 3.5.10).

Drilling on Doornrug proved to be very disappointing and only plastic refractory clay, more siliceous than that found on Klipfontein, was intersected in three of the seven boreholes (Appendix 4 and Tables 3.29 to 3.31). The complete absence of flint-clay can probably be attributed to the fact that the elevation of the pre-Vryheid floor at this locality is at least 50 m higher than at the deposit on Kleinwater 301 JS and the one to the south on Hartebeestlaagte 325 JS. The succession on Doornrug is consequently younger and the plastic clay was most likely deposited from a much larger volume of water than the flint-clay to the north and south which had probably formed in isolated depressions during the very early stages of deposition of Vryheid sediments in the area.

The only material found in the boreholes which could possibly be of economic significance is the very persistent layer of unconsolidated sand that occurs on surface over a distance of at least 1,5 km and with an average thickness of about 6 m. This deposit would certainly be worthwhile considering if a local supply of building sand is required in the area.

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3.5.10 Hartbeestspruit 281 JS

The second drilling site in the Witbank area is situated about 17 km north-west of this town near the north-eastern extremity of the spur of Vryheid Formation (Fig. 3.52). No clay was intersected and although not conclusive, the succession of carbonaceous sandstone and siltstone (Appendix 4) suggests that refractory clay which might have been deposited in this area was probably subsequently removed by erosion.

Although the present study failed to reveal the presence of new flint-clay deposits in the Witbank area, the potential of this region is still far from fully assessed and further exploration is strongly recommended. The most important aspect brought to light by the drilling is the need for a better knowledge of the configuration of the pre-Vryheid floor. Such an investigation was unfortunately not possible during the present study because of a lack of sufficient boreholes, but if it could be attempted in the future, the selection of exploration targets for flint clay would be greatly facilitated.

3.5.11 Bankfontein 375 JS

Very few occurrences of refractory clay have been located in the extensive sheet of Ecca rocks between Middelburg and Belfast (Table 2.1) and the area can be regarded as largely unexplored. An exceptionally irregular outlier about 20 km north-east of Middelburg was selected for reconnaissance exploration during the present investigation (Fig. 3.52), but neither on surface, nor in any of the three boreholes drilled on Bankfontein, could a trace of refractory clay be found. The presence of siltstone at the stratigraphic level normally occupied by refractory clay (Appendix 4) may be indicative of the absence of a clay source in the provenance, but it is more likely to be the result of a local unfavourable depositional environment. The extent of such conditions is, however, completely unknown and the discouraging results obtained in this isolated study should certainly not be regarded as representative of the whole area between Middelburg and Belfast.

3.5.12 Identified Resources in the Pretoria – Belfast Region

As in the case of the Witwatersrand, the general lack of intensive exploration, even in producing areas, renders the calculation of total refractory-clay resources highly conjectural. Bennetts (1965) estimated the "probable ore reserves" of flint-clay to be in the order of

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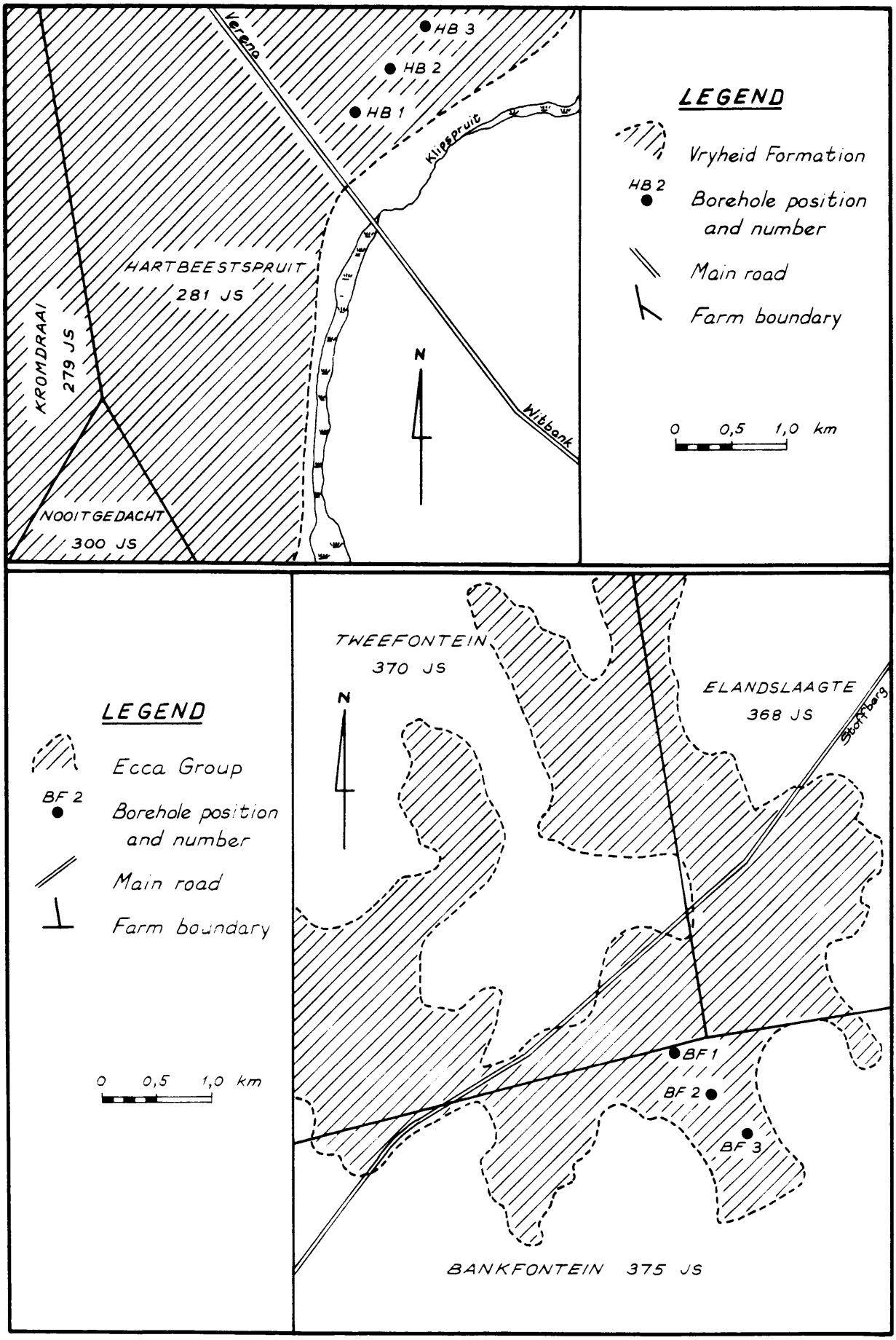

Fig. 3·52 Boreholes for refractory clay on Hartbeestspruit 281 JS and Bankfontein 375 JS

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1 to 2 Mt and added that these "reserves" may exceed 50 Mt when underground mining is resorted to. Based on information received from industry, Heckroodt (1967) reported "proved reserves of high-quality flint-clay" amounting to about 3,5 Mt and additional "estimated reserves" of about 4 Mt. Because of the terminology used, these figures are difficult to interpret and both investigators also admitted that their estimates are probably not very reliable.

Although also based on inadequate data, the author would like to propose the following summary of identified resources in respect of clays with PCE values in excess of 34⁻:

(1) **Grade I flint-clay**
Demonstrated resources of 15,2 Mt of which only about 3,4 Mt represent measured reserves under present conditions.
Inferred resources: 1,0 Mt.

(2) **Grade I semi-flint and Grade II and III flint-clay**
Demonstrated resources: 4,6 Mt.
Inferred resources: 1,0 Mt.

(3) **Grade I to III plastic clay**
Demonstrated resources: 1,2 Mt.
Inferred resources: 0,5 Mt.

Although these resources probably constitute only a small fraction of the total potential in the Pretoria – Belfast region, the discovery of new deposits is a costly and time-consuming process and identified deposits should therefore not only be utilised to the utmost but also be protected against sterilisation as far as practically possible.

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4. GENESIS

The genesis of clays and clay minerals is a wide and complex subject and it is beyond the scope of this thesis to review all genetical aspects relating to refractory clays. Most of the basic concepts regarding clay-mineral formation (particularly kaolinisation) have been extensively dealt with in the literature and broad concensus has also been reached that refractory clays can be classified as sedimentary kaolin. There is, however, still considerable dispute as to whether the kaolinite in the refractory clay was formed before deposition or after deposition, and if pre-depositional, whether the kaolinite was transported as discrete tiny flakes (i.e. detrital and truely allochtonous), or as a colloidal gel from which kaolinite subsequently crystallised (i.e. diagenetic and essentially autochtonous). The source of the clay is another matter which has led to considerable speculation and for which no satisfactory answers have been found as far as the South African deposits are concerned. During the present investigation, the emphasis was consequently mainly placed on these controversial issues and in this chapter an attempt will be made to cast more light on two genetical aspects, *viz.* the depositional environment and possible parent rocks.

The following facts established during exploration are most relevant during a discussion of the genesis of South African refractory-clay deposits:

(1) The zonal distribution of clay types with flint clay occurring predominantly in the north and mostly plastic types further south in the Witwatersrand area.

(2) Local trends showing a tendency for flint clay to occur in proximal areas and plastic clay in more distal parts with respect to the provenance.

(3) The generally small size of flint-clay deposits as compared to the more extensive deposits of plastic clay.

(4) Plastic clays normally overlie the flint types stratigraphically.

(5) Flint and plastic clays are confined to separate beds which are often mutually intercalated and defined by sharp contacts between the types.

(6) The deposits occur stratigraphically above coal seams or carbonaceous shale and are often overlain by grit.

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(7) The generally less refractory plastic clays are located at a higher elevation than the bulk of the high-quality flint types.

(8) Plastic clays generally contain more non-kaolinite minerals than flint clay.

(9) The difference in texture between flint and plastic clays, i.e. essentially random orientation in flint and well-orientated particles in the plastic types.

(10) The scarcity of kaolinite booklets in all the clay types.

(11) The absence of small angular rock and mineral fragments.

(12) Palaeocurrent directions are generally from the north, but local variations indicate that deposits in the various regions could have been derived from different principal source rocks.

(13) The great variety of pre-Karoo rocks in the possible provenance areas which could have served as a source of kaolinite.

4.1 FOSSIL pH AS A GUIDE TO THE DEPOSITIONAL ENVIRONMENT

Any attempt at finding an adequate explanation for the genesis of refractory clay should not only account for the exceptional purity of these sediments, but also for the observed relationships and differences between the various types, i.e. flint, semi-flint and plastic. The author is convinced that the answers to most of these questions primarily entail a better understanding of the nature of the environment at the time of deposition. Unfortunately, there are not many parameters which can still be measured quantitatively in these clays today that would reflect their palaeodepositional conditions during Permian times. Although providing valuable clues, conventional sedimentological observations and field relationships are only of limited value in this regard. It has, however, been reported by several authors that the pH of an aqueous extract from a sedimentary rock reflects the original acidity of the water at the time of deposition. The following quotation from Millot (1970, p. 331–332) is most relevant in explaining this concept of "fossil pH":

> *An echo of the original pH may be recorded in sedimentary rocks, which are fossil sediments. I say 'echo' because the disappearance of organic matter and many successive evolutions could have modified the initial value. Without guaranteeing the initial state and in the absence of totally deforming diagenesis,*

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> *which must be rather frequent, one can say: The internal environment of a rock possesses some of the characters of the original sediment, characters that are fixed, preserved, fossilized, approximately intact, or at least of the same order of magnitude as in the original.*

It has also been shown that the pH of suspensions from argillaceous rocks characterises the type of clay mineral they contain (Millot, 1970) and that the pH of the original suspension determined the flocculation and orientation of the clay particles at the time of deposition (Schofield and Samson, 1954). Both these properties, i.e. mineralogical composition and particle orientation, have a direct bearing on purity and type differences which, as already mentioned, are the main features of refractory clays that need to be explained in terms of their origin. An attempt was consequently made to establish a correlation between fossil pH and other properties and observations in order to find a basis for a genetical model.

Considering the mineralogical composition of the clays first, it is most significant that according to Bennetts (1965), Bredell (1974) and the results presented in Chapter 3 of this thesis, all South African refractory clays have been found to be acidic. Seeing that Millot (1970) reported that kaolinitic argillites have been statistically shown to yield pH values of less than 7, while sediments composed predominantly of 2 : 1 type micaceous minerals are alkaline, the observed acidic nature of the local clays is not surprising. More important, however, is the possibility that their acidic nature is not the result but the cause of their essentially kaolinitic composition. If the great variety of pre-Ecca rocks surrounding these clay deposits is considered (mafic and acid igneous rocks as well as sedimentary formations), it can readily be accepted that the weathered profiles from which the Ecca sediments were derived must have consisted of quite an assortment of clay and non-clay minerals which had been produced under locally different conditions of decomposition. During transport of this weathered residuum, the clay-mineral fraction could have been separated from the coarser clastic material by a process of differential settling under the influence of gravity. The various clay minerals would, however, remain in suspension and would eventually settle out together under prolonged quiet conditions, unless they could be separated through some process of differential flocculation. This in turn can probably only be achieved by differences in electrolyte concentration in the suspending medium, a process which has been proved experimentally by Schofield and Samson (1954). A situation can therefore be visualised where almost pure kaolinite is deposited from a clay-mineral suspension upon entering an acidic environment as could have been caused by a concentration of organic acids in small swampy basins during the early stages of Ecca sedimentation. As

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these conditions were subsequently gradually replaced by a fluvial and lacustrine environment, the pH of the water increased, reducing the efficiency of the differential flocculation process and allowing more and more other clay minerals to be deposited together with kaolinite. Bennetts (1965) also suggested that increasing amounts of fine-grained clastic material such as quartz and feldspar were introduced at this stage as a result of higher stream velocities and eventually led to shale deposition. The proposed differences in acidity of the environments in which pure and less pure clay were deposited are substantiated by the correlation between fossil pH and mineralogical composition as illustrated in Chapter 5. This strongly suggests therefore, that a pH-controlled differentiation process played a much more important role in the purity of these clays than either the nature of the source material or post-depositional alteration.

In order to explain the differences in physical properties between the various types of refractory clays, the two ways of kaolinite flocculation as described by Schofield and Samson (1954) should be considered. They found that under more acidic conditions, flocculation of kaolinite will occur through electrostatic attraction between positively charged edges and negatively charged cleavage faces of adjacent crystals. This edge-to-face flocculation which is reported to take place rapidly and which results in the formation of a three-dimensional network, would account for the "random, interlocking, rigid structure of the kaolinite grains and is also responsible for the low plasticity of the flint clays" (Bennetts, 1965). It also explains the non-fissile character, absence of bedding and conchoidal fracture exhibited by these clays. Their dense nature after compaction can easily be imagined, especially in view of the observed fact that material which flocculates in this edge-to-face manner is much more viscous than that which flocculates in a face-to-face manner. This latter type of flocculation takes place in a saline environment due to the screening effect of positive charges on plate edges by the introduced anions, which leads to a decrease in the repelling forces between adjacent negatively charged crystal faces, and therefore a tendency for the cystals to stick together with their flat surfaces in contact. This type of flocculation occurs less rapidly and leads to a high degree of preferred orientation of particles after deposition. The larger deposits of more plastic, less dense refractory clay on the East and West Rand are interpreted as having been deposited in this fashion. These clays are softer due to the weaker attraction between particles, often exhibit some degree of bedding and have a typical blocky fracture. The textural differences between flint and plastic types are confirmed by the scanning electron micrographs in Chapter 3 and have also been reported by *inter alia* Keller (1978) and Patterson and Hosterman (1962). Strong supportive evidence for the

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proposed mechanism that gave rise to these textural differences is also provided by the close correlation that was found to exist between fossil pH and both bulk density and preferred orientation (see Chapter 5).

Local depositional conditions pertaining within a wide range of deposits in different regions have already been discussed in terms of the above-mentioned theory (Chapter 3) and all observations regarding the relative stratigraphic setting of the various clay types as well as compositional differences within individual deposits appear to be in general accordance with such a concept. In a more regional context, it is also significant that the proposal conforms to the overall distribution pattern mentioned in Chapter 2, i.e. a flint-clay province in the north and a plastic-clay province to the south. Assuming a general transport direction from north to south for the Ecca sediments in the study area, the flint clays can therefore be interpreted as being the product of early edge-to-face flocculated kaolinite in small acid swamps close to the provenance, while the plastic clays represent less selective face-to-face flocculation in larger brackish basins during subsequent transgression of Ecca sedimentation further to the south. This zonal distribution of refractory-clay types on a regional scale is remarkably similar to that reported by Keller (1968) for deposits in Missouri, U.S.A. The main differences are that in the latter area the plastic-clay province is located to the north and that the zone of flint clay to the south is further followed in this direction by a belt of diaspore-bearing flint clay ("burley clay") and then by virtually pure diaspore. As will be discussed below, however, Keller (1981) explains this zoning of the Missouri clays in terms of a refractory-clay genesis which differs rather drastically from that proposed by the author.

4.2 SOME ALTERNATIVE INTERPRETATIONS OF REFRACTORY-CLAY GENESIS

Although the ideas on the depositional environment and the mechanism of deposition put forward in this thesis are in close agreement with the views of most previous investigators on South African deposits (particularly Bennetts, 1965 and to a lesser extent Warde, 1949 and Bosazza, 1946), it is important to take note of other distinctly different theories which have been postulated on the formation of refractory clays. In the following paragraphs, the more important of these alternative interpretations are critically reviewed, especially in terms of their possible validity in the South African situation and in comparison with the author's proposals:

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(1) **The "seat-clay" concept.** One of the oldest and most popular theories explaining the refractory character of these clays is the idea that they originally constituted the soil in which coal-forming vegetation grew and that the elimination of fluxes was effected by the leaching and absorptive action of plant roots. A summary of this theory and its many variations is presented by Ries (1927). Observations which led to the formulation of these concepts are the occurrence of coal seams directly on top of many of the refractory clays in the United States and United Kingdom, and the frequent presence of fossil roots in such inferred "seat-clays" or "under-clays". There seems to be much evidence against these ideas and it is doubtful whether plant-root leaching was the major mechanism in the formation of any refractory-clay deposit:

- South African deposits typically occur above coal seams or carbonaceous shale and are often overlain by massive grit beds.

- No fossil roots have been reported from South African refractory clays.

- There is no evidence indicating the upper parts of clay beds to be more pure than their lower parts and the lower contact of a refractory-clay bed is just as sharp and well-defined as its upper contact.

- The theory presents no explanation for the observed differences in physical properties between clay types, e.g. plasticity and particle orientation, as well as their zonal distribution on a regional scale.

It has to be admitted, however, that the extraction of potash and other compounds by coal-measure vegetation as suggested by Keeling (1954) cannot be excluded as a contributing factor in establishing the refractoriness of clays from certain areas.

(2) **A glacial origin.** The close association between refractory clays and the often immediately underlying Dwyka tillite has led some earlier investigators to believe that the clay represents kaolinised glacial flour (Bosazza, 1943 and Plumstead, 1969). As already pointed out in the discussion on the West Rand clays, this possibility is considered unlikely:

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- The absence of small angular rock and mineral fragments.

- The scarcity of kaolinite booklets which, according to Keller (1978), typify residual or *in situ* kaolinisation of aluminium silicates.

- The inferred parent material must have contained a fair amount of very fine-grained quartz, a mineral which usually remains stable under normal conditions of weathering. The transformation of a quartz-rich glacial flour into a virtually pure kaolinite is therefore difficult to conceive.

- *In situ* kaolinisation offers no explanation for the difference in particle orientation between the various clay types.

- In the case of *in situ* weathering, the leaching potential of argillaceous sediments underlain by dolomite would be expected to be better than in a situation where the removal of dissolved constituents is inhibited by a less porous floor of igneous rock. In South Africa, however, deposits overlying igneous rocks are generally of better quality than those on dolomite.

(3) **Resilicification of bauxite minerals in a parent laterite.** This hypothesis for the origin of bauxitic flint clay in Ayrshire has been proposed by Wilson (1922) and Curtis and Spears (1971). Although the conversion of gibbsite to kaolinite through the introduction of dissolved silica has been indicated to be theoretically possible (Schellmann, 1975), and definite signs of the formation of such secondary kaolinite have also been observed in the Natal bauxites (Bredell, Barnardo and Horn, 1980), it is doubtful whether this process could give rise to South African deposits of refractory clay:

- The frequent association of refractory clay with coal and carbonaceous shale is incompatible with the highly oxidising conditions of a lateritic environment.

- A highly irregular lower surface which is characteristic of most bauxite deposits, is not developed in beds of refractory clay.

- If the inferred parent bauxite is considered to be sedimentary (i.e. not formed *in situ*), both above-mentioned objections could be accounted for, but the typical pisolitic texture of such deposits is not present in refractory clay.

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- No remnants of a possible parent bauxite have been observed in the vicinity of refractory-clay deposits in South Africa. It is difficult to conceive that resilicification could have been so complete that not even the more stable monohydrates of alumina (diaspore or boehmite) have been preserved in places.

The presence of bauxite minerals in some flint clays (e.g. in Missouri), should therefore rather be attributed to post-depositional desilicification of kaolinite under favourable conditions of leaching, and not as the result of incomplete kaolinisation of an original bauxite.

(4) **An early diagenetic origin : Crystallisation from a colloidal gel.** This concept which has been developed by Keller (1981), offers perhaps the most feasible alternative to the genetic model favoured by the author. It is mainly based on observations at the Missouri deposits which are regarded by Keller as "a prototype for flint-clay genesis", but he admits that not all deposits of flint clay were necessarily formed in precisely this way. The proposal can be briefly summarised as follows:

Colloidal to fine-grained clay sediments representing weathered residuum from sedimentary rocks accumulated in plant-fringed swamps on a karstic surface of Ordovician dolomite and sandstone. During deposition and early consolidation of this clay sediment, it was "digested or diagenized" by inorganic and organic processes and reagents to produce a colloidal gel-like phase of kaolinitic composition from which kaolinite crystallised, forming the mutually interlocking micro-texture of flint clay. The formation of different clay types (plastic, semi-plastic, semi-flint, flint and diaspore-bearing flint) is partly attributed to compaction and differences in the composition of the parent material, but is primarily considered to be the result of relative intensities of leaching. The latter is assumed to have been determined by the topographic setting of the various deposits, thereby explaining their zonal distribution. Considering the generally northward-dipping topography, the plastic clays in the north are lowest in elevation and were leached with least intensity, while in the highest areas to the south, more severe leaching resulted in the development of variable amounts of diaspore. Because of the absence of a concentration of silica and alkalies in the lowermost parts of the deposits, leaching is assumed to have been predominantly upwards with the dissolved ions being flushed off by surface drainage.

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Although this theory seems to provide a satisfactory explanation for the genesis of the Missouri clays and other similar deposits, its application to the South African situation is questionable:

- The topographic setting of the Transvaal clays contradicts the process of relative leaching intensity envisaged by Keller. Not only are the more impure plastic clays located at a higher elevation (Witwatersrand area) than the bulk of the most refractory flint clays (Pretoria – Belfast area), but they are also predominantly situated on dolomite which would have provided a better leaching potential than the igneous floor rocks in the north.

- In contrast to Missouri where plastic and flint clay have been reported to occur in gradational lateral association within a single deposit (Keller, 1978), these clay types, where present in the same deposit in the Transvaal, are always confined to separate beds which are often mutually intercalated and defined by sharp contacts between the types. This latter association can definitely not be explained in terms of differential leaching and is more likely to be the result of successive changes in pH during the deposition of the individual beds.

- It is difficult to conceive how during the upward-leaching process envisaged by Keller, all the dissolved impurities could have been flushed away by surface drainage and it is reasonable to assume that concentrations of silica and/or iron must have accumulated locally on top of the deposits. No such remnants in the form of silcrete or ferri-silcrete have been found to overlie the Transvaal clays and nothing of the kind is described from the Missouri area.

- The theory offers no adequate explanation for the distinct difference in particle orientation between flint and plastic refractory clays. Although the micro-texture of flint clay could admittedly be interpreted as being the result of crystallisation from a colloidal gel, the well-orientated discrete flakes of kaolinite in plastic clays could hardly be attributed to such a process. The close correlation between fossil pH and particle orientation which has been established for the Transvaal clays can also not be accounted for in terms of this hypothesis. Detrital deposition of the kaolinite as proposed by the author therefore seems to be more feasible, a view which is also expressed by Loughnan and Ward (1971) in respect of the flint-clay deposits in New South Wales.

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In conclusion one can say that perhaps not one of the many divergent genetical models should be completely disregarded. There must be some merit in each of these proposals because after all, they have been formulated to account for particular observations at various localities. In the author's opinion it would therefore be unwise to dogmatically propose a universal genetical concept for refractory clays. Referring to clay genesis, Millot (1970) most appropriately remarked as follows:

> *Often the strongest oppositions can be seen as simply mirroring differences in situation, all of equal credibility.*

4.3 POSSIBLE PARENT ROCKS

The variety of pre-Ecca rocks in the possible provenance areas and the fact that most of these lithologies could yield kaolinite upon weathering, have led to a great deal of speculation as to which of these older rocks acted as the main source for the refractory clays. Bosazza (1943) first proposed Witwatersrand shale as a likely source, but he subsequently suggested that the "old granite" was probably the predominant parent rock for the Witwatersrand clays (Bosazza, 1946). The evidence provided for this latter proposal is, however, not very convincing, *viz.* "The presence of muscovite, microcline and plagioclase feldspar as well as the nature of the quartz grains ...". Warde (1949) considers two principal sources, dolomitic limestone and feldspathic igneous rocks, but also suggests possible contributions from feldspathic and argillaceous sedimentary rocks as well as ash derived from the decay of coal-forming plants. He obviously favours dolomite as the most likely parent rock in spite of the fact that, according to his own calculations, the formation of one volume unit of refractory clay would require the decomposition of 33 volume units of dolomite. Granites of the Bushveld Complex are proposed by Bennetts (1965) as source rocks for the flint-clay deposits in the Pretoria – Belfast area. He bases this conclusion on the heavy-mineral suites detected in these clays (leucoxene, zircon, rutile, tourmaline, garnet and monazite), as well as the coarse-grained, angular nature of the quartz in grit beds with which the clay deposits are frequently associated. It is clear therefore that no specific effort has as yet been made to try and solve the question of parent rocks.

Considering the palaeocurrent directions in the vicinity of refractory-clay deposits in the various regions (Fig. 4.1), it seems reasonable to assume that at least the Witwatersrand clays and those in the Pretoria – Belfast area could have been derived from different principal sources. In an attempt to cast more light on this subject, the author first of all tried to

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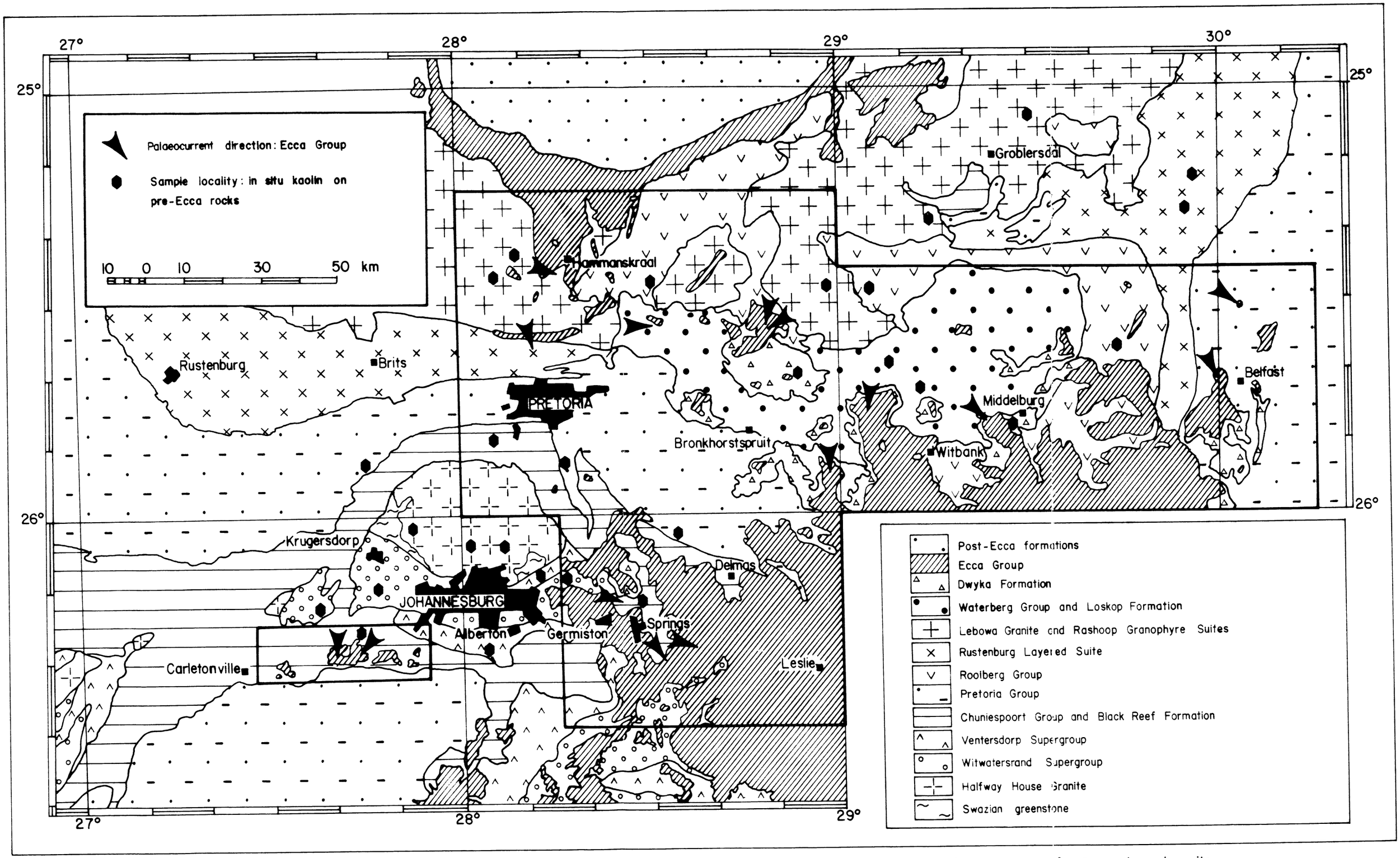

Fig. 4·1 Simplified geological map of the study area and surroundings, showing palaeocurrent directions in the Ecca Group near refractory-clay deposits as well as sample sites of in situ kaolin on pre-Ecca rocks.

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establish whether there are any characteristic differences in the minor-element composition of clays from these regions which would support the assumption of more than one predominant parent rock. Computer manipulation of the available data showed, however, that the relative concentrations of only two elements (Rb and Sr) are vaguely distinctive on a regional basis, and in view of the known mineralogical variations in the samples, the significance of this trend was considered doubtful.

As an experiment, trace-element analyses were then repeated on a few carefully selected samples which proved to consist only of kaolinite upon XRD examination. Rb and Sr again turned out to be the only distinctive elements, but a clear separation in terms of their relative concentrations could now be obtained for clays from the West Rand, the East Rand and the Pretoria – Belfast area, as well as for kaolinite from material resembling flint clay in the Dwyka Formation (see Fig. 4.2). The next logical step was therefore to compare these results with the Rb and Sr contents of kaolinite which has been derived by *in situ* weathering from the most likely parent rocks.

Although guided to some extent by the palaeocurrent directions in the Ecca Group, the sample localities of residual kaolin on pre-Ecca rocks were largely determined by the availability of suitable exposures of weathered profiles (Fig. 4.1). Sampling itself was a tedious process and in many cases subsequent washing and screening had to be done in order to obtain a few grams of essentially pure kaolinite; several samples had to be rejected eventually after checking with XRD.

The Rb and Sr concentrations compared in Fig. 4.2 reveal some highly significant correlations and based on these results, the following conclusions can be drawn:

(1) The West Rand clays appear to have been largely derived from the Swazian Halfway House Granite, with a possible contribution from weathered shale of the Witwatersrand Supergroup.

(2) Refractory clays on the East Rand are indicated to have received kaolinite from two main sources, *viz.* Halfway House Granite and granite of the Bushveld Complex.

(3) Flint as well as plastic refractory clays in the Pretoria – Belfast area obviously obtained most of their kaolinite from Bushveld granite, but contributions from Rooiberg felsite, shales of the Pretoria Group and arkosic sediments of the Waterberg Group cannot be excluded.

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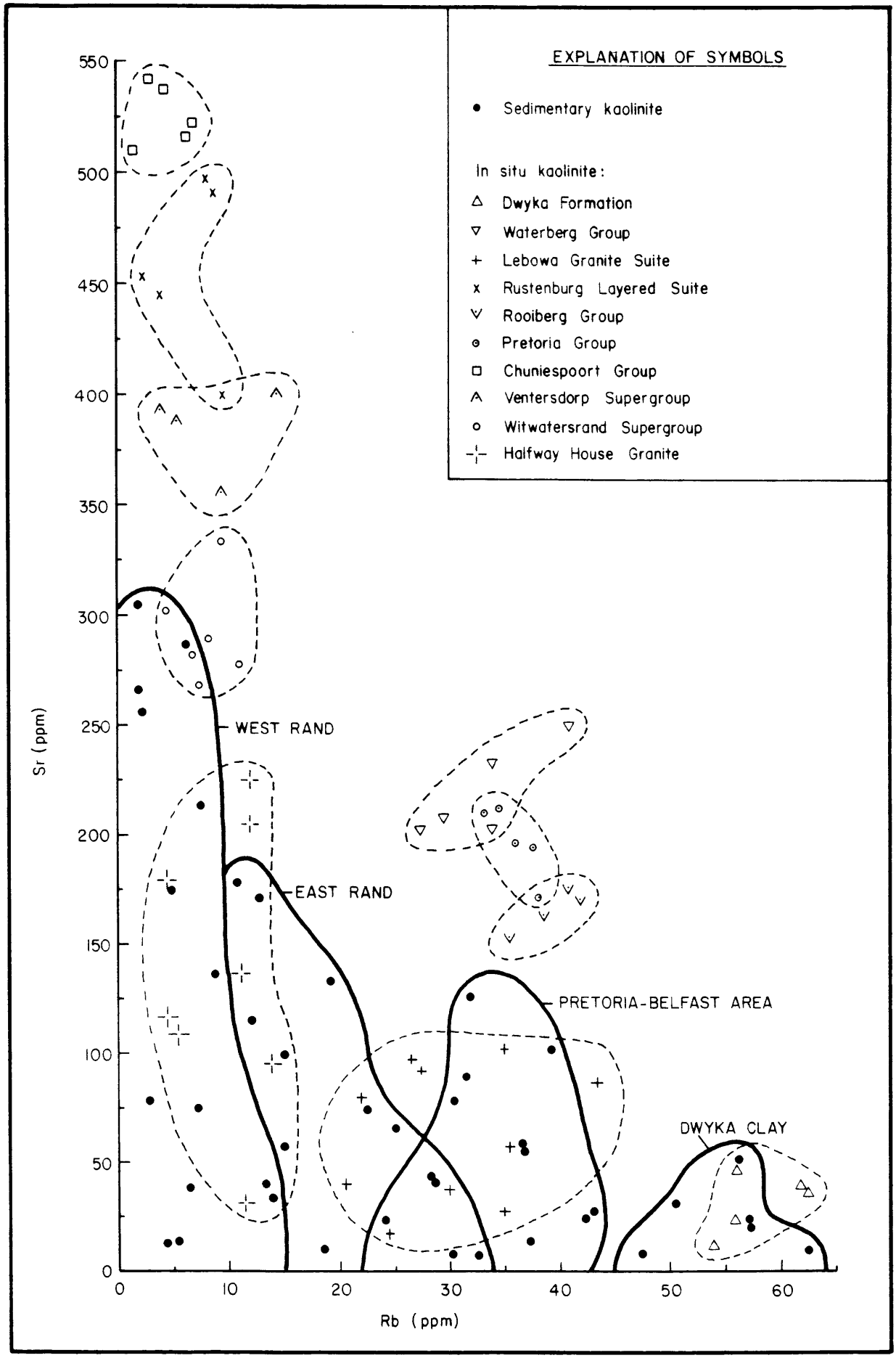

Fig. 4·2 The Rb and Sr content of kaolinite in sedimentary clays from different areas in the Ecca Group and Dwyka Formation as compared to in situ kaolinite derived from various pre-Karoo rocks.

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(4) Kaolinite from "pseudo flint clay" in the Dwyka Formation was probably derived from clay profiles developed on pre-existing Dwyka tillite.

(5) The relatively high Sr contents of kaolinite derived from dolomite, basic igneous rocks of the Bushveld Complex and andesite of the Ventersdorp Supergroup seem to rule out these rocks as major sources for the refractory clays.

In evaluating these conclusions, one has to bear in mind, however, that they are based on a limited set of samples which is by no means claimed to be representative of either all the refractory-clay deposits or the full spectrum of parent-rock lithologies. It is also not implied that a similar exercise would yield satisfactory results in respect of all transported clays because intense post-depositional alteration can most certainly be expected to destroy the trace-element signature inherited from the parent rocks. The author would therefore like this investigation to be seen as an experiment which indicated a possible technique for establishing the origin of transported clays and it is sincerely hoped that this will stimulate more detailed research along these lines.

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5. PROPERTY INTERRELATIONSHIPS

As mentioned previously, one of the most difficult tasks of the exploration geologist is to make a realistic prediction of the quality of a refractory clay from the results of the various analyses, tests and measurements carried out in the laboratory. The main reason for this is that natural clays are complex systems which vary widely in chemical and mineralogical composition as well as texture. Although well-established aids such as phase diagrams are of great value in determining theoretical trends, natural raw materials can rarely be regarded as simple mixtures of components and their behaviour under firing is therefore largely unpredictable. It is remarkable that one often hears the comment from a geologist that a particular clay is of bad quality because "the alumina is too low" or the "quartz is too high". Are such judgements valid, and if so, how low is "low" and how high is "high"? What are then the limitations of assessing refractory-clay quality from laboratory results and which are the most meaningful parameters to be used in such an assessment? In order to answer some of these questions, an attempt is made in this chapter to illustrate some of the more important physico-chemical interrelationships which have been established on a set of 200 samples tested and analysed during this study. As mentioned in Chapter 3, all these samples received identical treatment, and although the relationships could of course have been statistically improved by addition of data from the literature and other sources, mutual differences in analytical and test procedures would have decreased the value of the results. In view of the relatively small number of samples, it should therefore be emphasised that the various trends presented here are only intended to be used as a guide in the initial evaluation of refractory clays. It was furthermore not practically feasible to present all possible relationships graphically, and for this reason a correlation matrix of the more important variables is included in Appendix 5.

5.1 BULK DENSITY – APPARENT POROSITY

The linear relationship between bulk density and apparent porosity of Transvaal flint clays has already been established by Bennetts and Pieterse (1963) in respect of 34 samples with bulk densities ranging from about 2,08 to 2,43. During the present study a linear relationship with essentially the same characteristics has now been proved to exist for refractory clays with a much wider range of bulk densities (1,46 to 2,51), i.e. also including the plastic and semi-plastic types (see Fig. 5.1). The calculated regression line has the equation $Y = 99,71 - 38,351X$ which corresponds even closer to the theoretical line ($Y = 100 - 38,388X$) than the equation calculated by Bennetts and Pieterse ($Y = 101,71 - 39,151X$). As shown on Fig. 5.1, the correlation coefficient (r) is 0,987. The linearity of the regression

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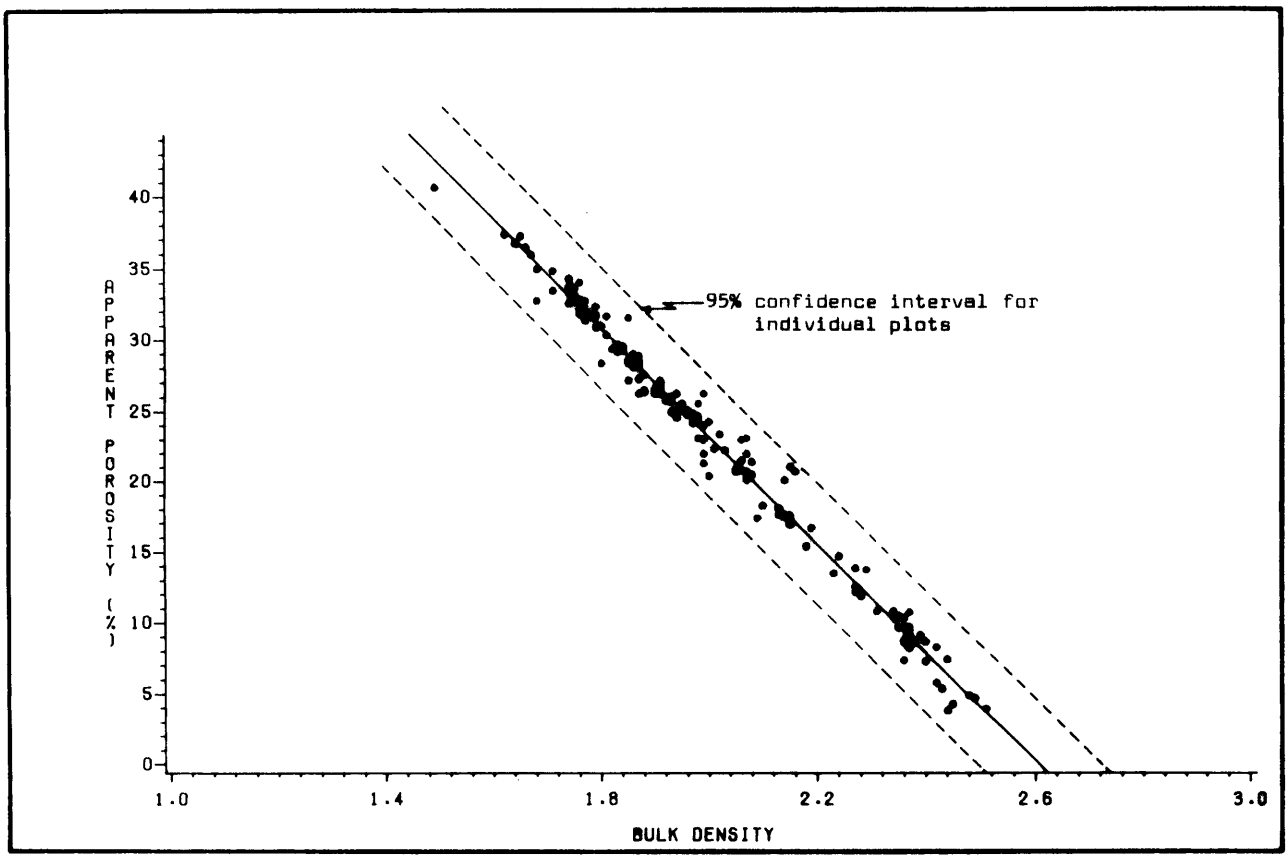

Fig. 5.1 Linear relationship between bulk density and apparent porosity (r = -0,987).

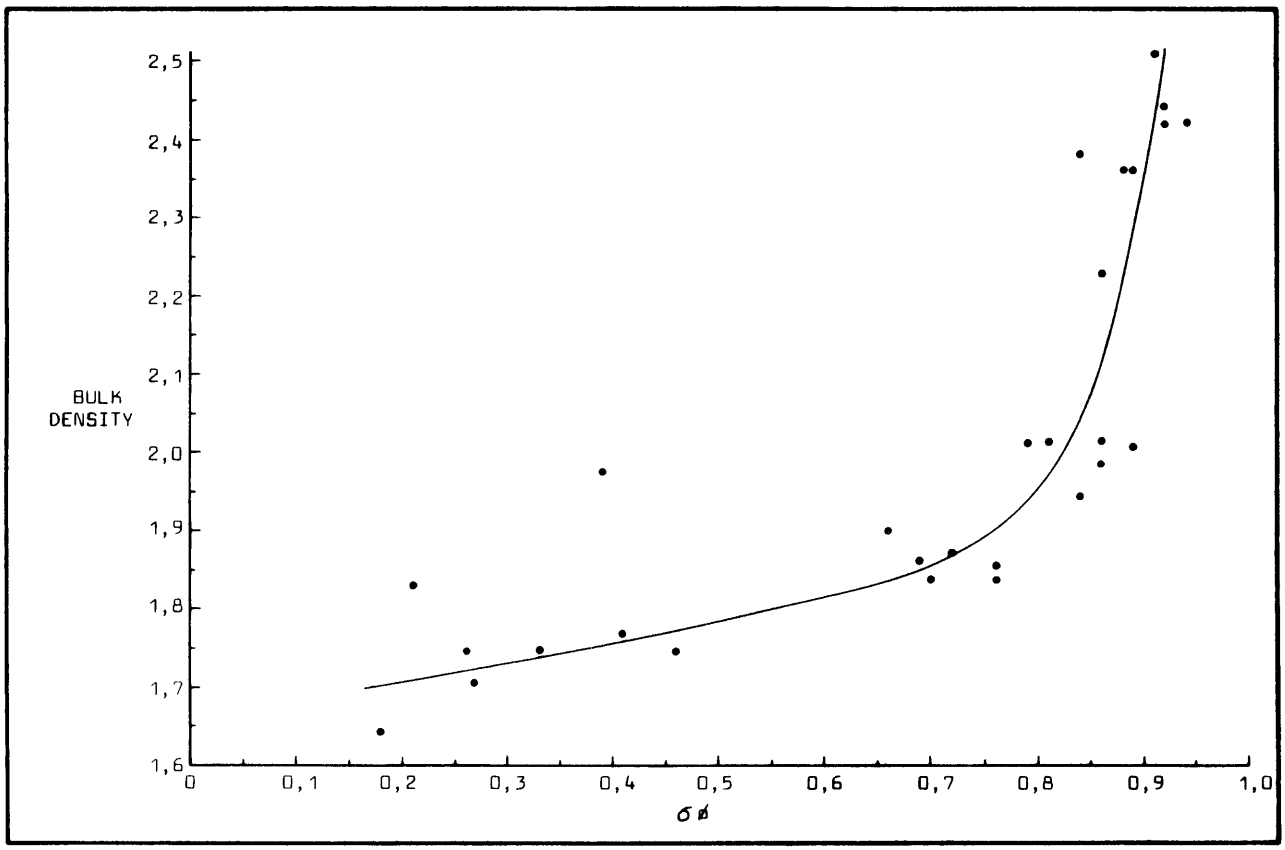

Fig. 5,2 Negative correlation between the degree of grain-size sorting (expressed as the standard deviation) and bulk density (r = 0,786).

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line and its near coincidence with the theoretical relationship shows that there are virtually no closed pores present in these clays. Bennetts and Pieterse proposed that this relationship between bulk density and apparent porosity may be used as an inexpensive means for preliminary identification of flint clay, a concept which can now be extended to include the full spectrum of refractory clays. This method should, however, be used with great caution as it is quite possible that non-refractory clays may be encountered which also have no closed pores and consist of minerals with a mean relative density close to 2,60, thereby plotting within the 95 per cent confidence region shown on Fig. 5.1. Some of the non-refractory pseudo flint clays in the Dwyka Formation do in fact have such properties. It has also not been proved conclusively that all refractory clays lack a significant degree of pore cementation which if present, would lead to misidentification according to this method. The relationship between the bulk density and apparent porosity of a suspected refractory-clay sample should therefore be regarded as nothing more than a useful check, and no sample should be rejected or positively identifiied without further confirmation by other techniques.

5.2 BULK DENSITY – PARTICLE SIZE AND ORIENTATION

Particle-size and particle-orientation data in respect of 30 refractory-clay samples are listed in Table 5.1. Comparing these measurements with corresponding bulk-density values, some interesting trends emerge. As is to be expected, a negative correlation between bulk density and the degree of grain-size sorting is evident (Fig. 5.2), indicating how packing density is increased by smaller grains filling the interstitial positions between larger ones. A weaker negative correlation is obtained between the degree of preferred orientation (relative to the macro-bedding of the clay) and bulk density (Fig. 5.3). This supports the observed textural differences between flint and plastic types and the poor correlation can be attributed to the fact that bulk density is more strongly controlled by grain-size sorting. As illustrated in Fig. 5.4, no meaningful correlation is apparent between the average particle size and bulk density. This suggests that the generally more plastic nature of the less dense clays is not a result of smaller grain size, but rather an effect of particle orientation.

5.3 pH – BULK DENSITY

The relationship between pH and bulk density proposed by Bredell (1974) on a limited set of samples has been further substantiated during the present study (see Fig. 5.5). A fossil pH value of 6,0 quite distinctly subdivides the clays into two groups; a semi-flint/flint group with a bulk density of more than 2,15 and a semi-plastic/plastic group of lower bulk density.

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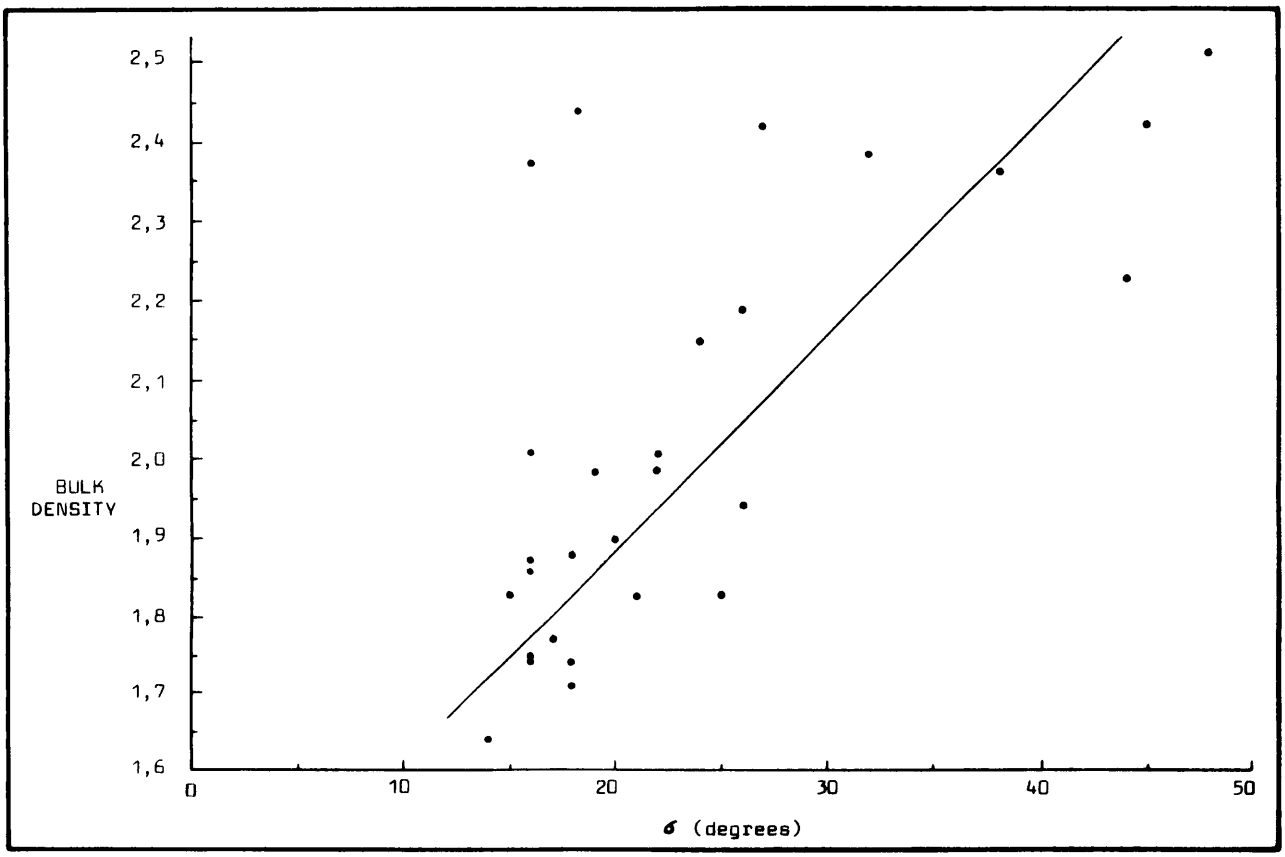

Fig. 5.3 Weak negative correlation between the degree of preferred orientation (expressed as standard deviation) and bulk density (r = 0,683).

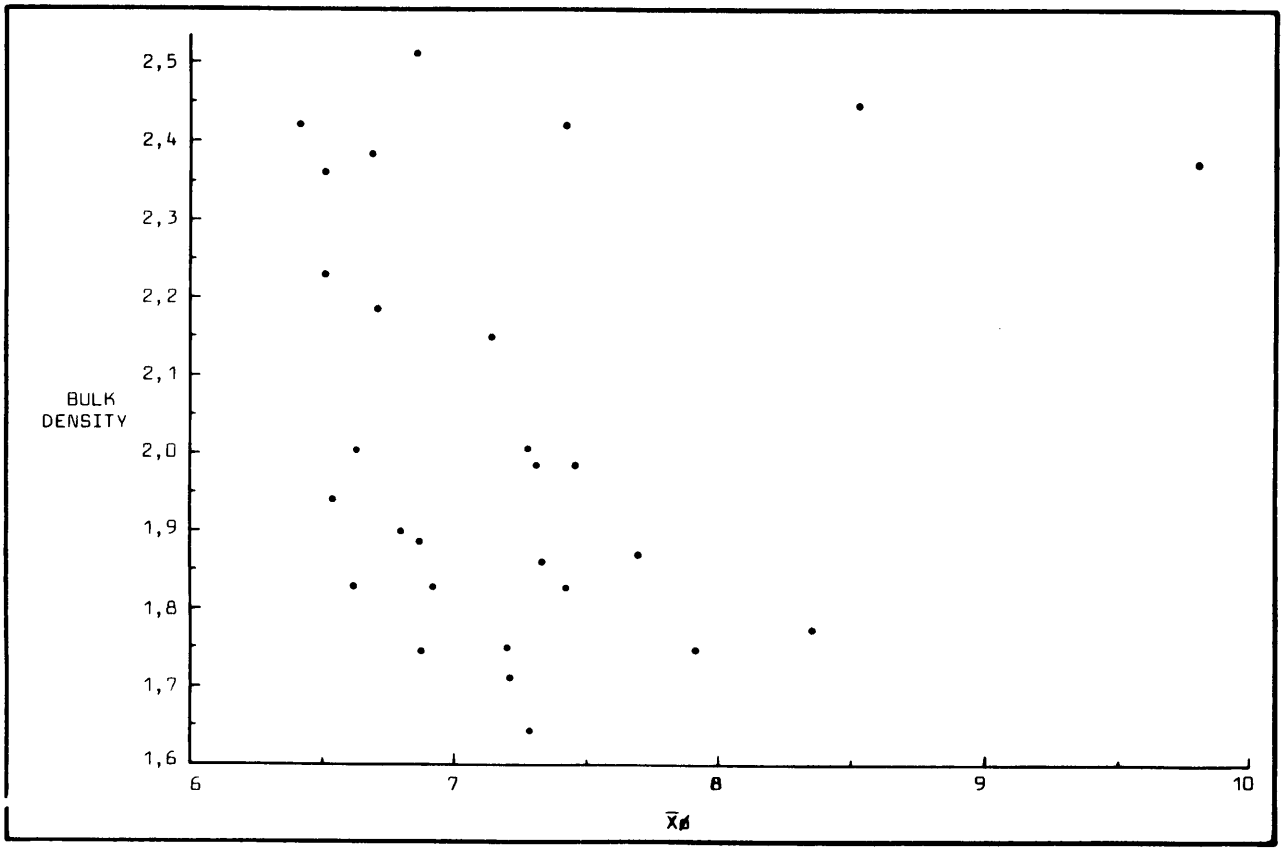

Fig. 5.4 Random relationship between average particle size and bulk density (r = 0,102).

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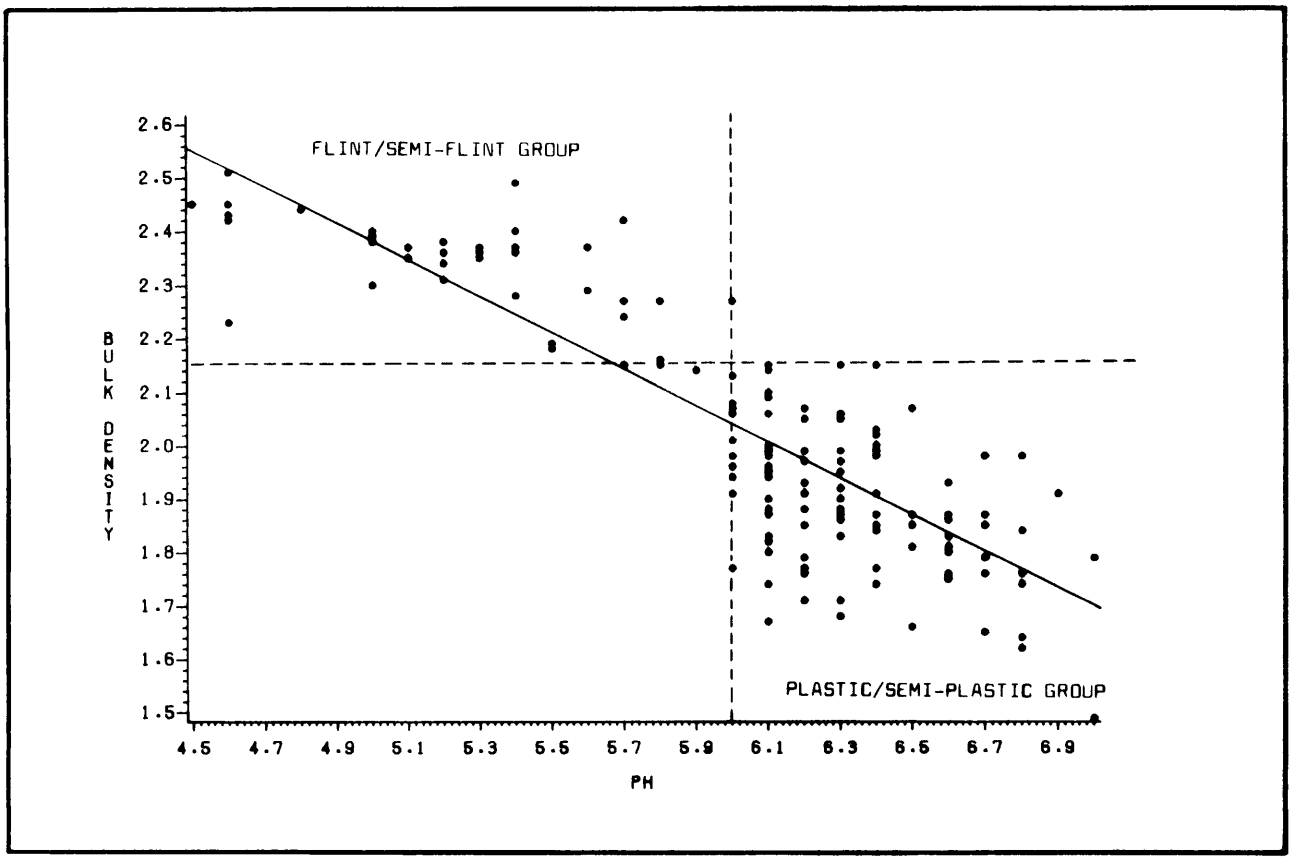

Fig. 5.5 Relationship between fossil pH and bulk density (r = -0,607).

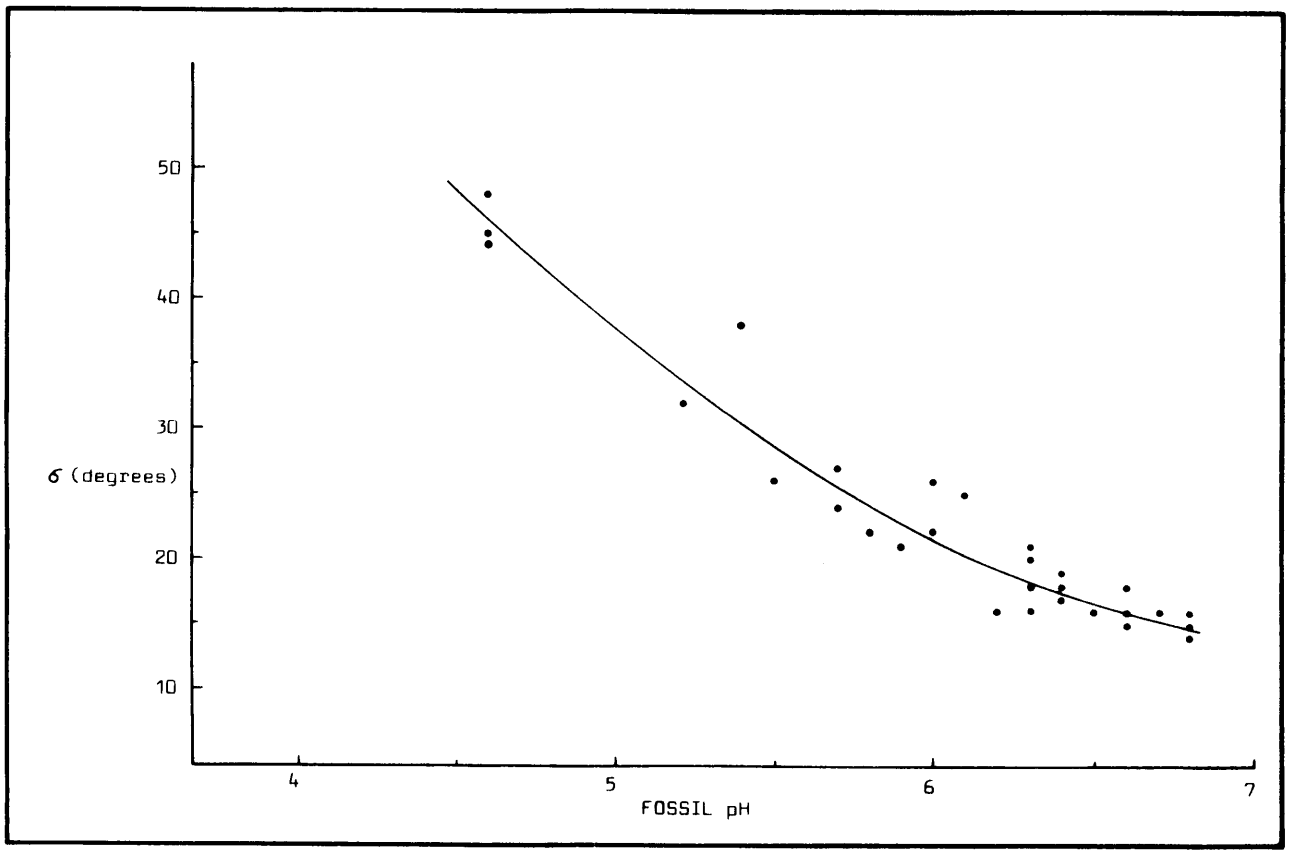

Fig. 5.6 Positive correlation between fossil pH and the degree of preferred orientation (expressed as standard deviation) (r = -0,954).

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TABLE 5.1 PARTICLE-SIZE AND PARTICLE-ORIENTATION DATA FOR 30 SAMPLES OF REFRACTORY CLAY

Sample No.	Particle size		Orientation
	Phi arithmetic mean ($\bar{X}\phi$)	Phi arithmetic standard deviation ($\sigma\phi$)	Standard deviation (σ-degrees)
19	7,20	0,33	16
24	6,88	0,46	18
26	7,70	0,69	16
30	6,80	0,66	20
31	7,92	0,26	16
40	7,33	0,76	16
41	6,87	0,72	18
44	7,28	0,89	16
52	8,59	0,20	15
60	7,46	0,86	19
74	6,54	0,84	26
93	6,62	0,76	25
100	6,92	0,70	21
115	8,35	0,41	17
120	7,21	0,27	18
122	7,23	0,26	21
131	6,71	0,86	26
132	7,14	0,79	24
145	6,86	0,91	48
150	7,42	0,94	27
155	8,53	0,87	18
168	9,81	0,88	16
169	6,63	0,81	22
170	6,51	0,86	44
171	6,42	0,92	45
176	6,69	0,84	32
194	7,28	0,18	14
197	7,42	0,21	15
198	7,31	0,39	22
202	6,51	0,89	38

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This division at 2,15 is conveniently close to the bulk-density value of 2.00 which actually separates flint and plastic types according to the classification used, and therefore allows preliminary identification of the major clay type by means of fossil-pH determinations. Caution should, however, be exercised when dealing with suspected pseudo flint clays from the Dwyka Formation as these rocks have been proved to have anomalously high pH values compared to their bulk densities.

5.4 pH – PARTICLE SIZE AND ORIENTATION

The control of pH on the orientation of particles during flocculation as postulated in the genetical model is confirmed by the positive correlation between fossil pH and the degree of preferred orientation (Fig. 5.6). Although poorly defined, the trends in Figs. 5.7 and 5.8 suggest that the acidity of the environment at the time of deposition also controlled the size and sorting of particles to some extent. It would appear that predominantly larger but poorly sorted grains were flocculated under more acidic conditions, while a higher pH led to deposition of smaller and better sorted particles. This relationship between pH and grain-size sorting is also in accordance with the previously mentioned correlations between pH and bulk density and between bulk density and grain-size sorting.

5.5 pH – MINERALOGICAL COMPOSITION

In order to test the assumption that pH controlled the selective flocculation of kaolinite from a mixed clay-mineral suspension (Chapter 4), the kaolinite and illite contents of 32 samples were calculated according to the method proposed by Spears (1978). The results are listed in Table 5.2 and a comparison between fossil pH and mineralogical composition is graphically displayed in Figs. 5.9 to 5.11. From Fig. 5.9 it is evident that pH has virtually no control over the deposition of quartz and this most probably explains the rather weak correlation between fossil pH and both kaolinite and illite. The trends in Figs. 5.10 and 5.11 are, however, in accordance with the genetical model and the observations reported by Millot (1970).

5.6 pH – REFRACTORINESS

Because pH has been indicated to determine particle size and kaolinite content to some extent, it can also be expected to have a bearing on fusion temperature. As illustrated in

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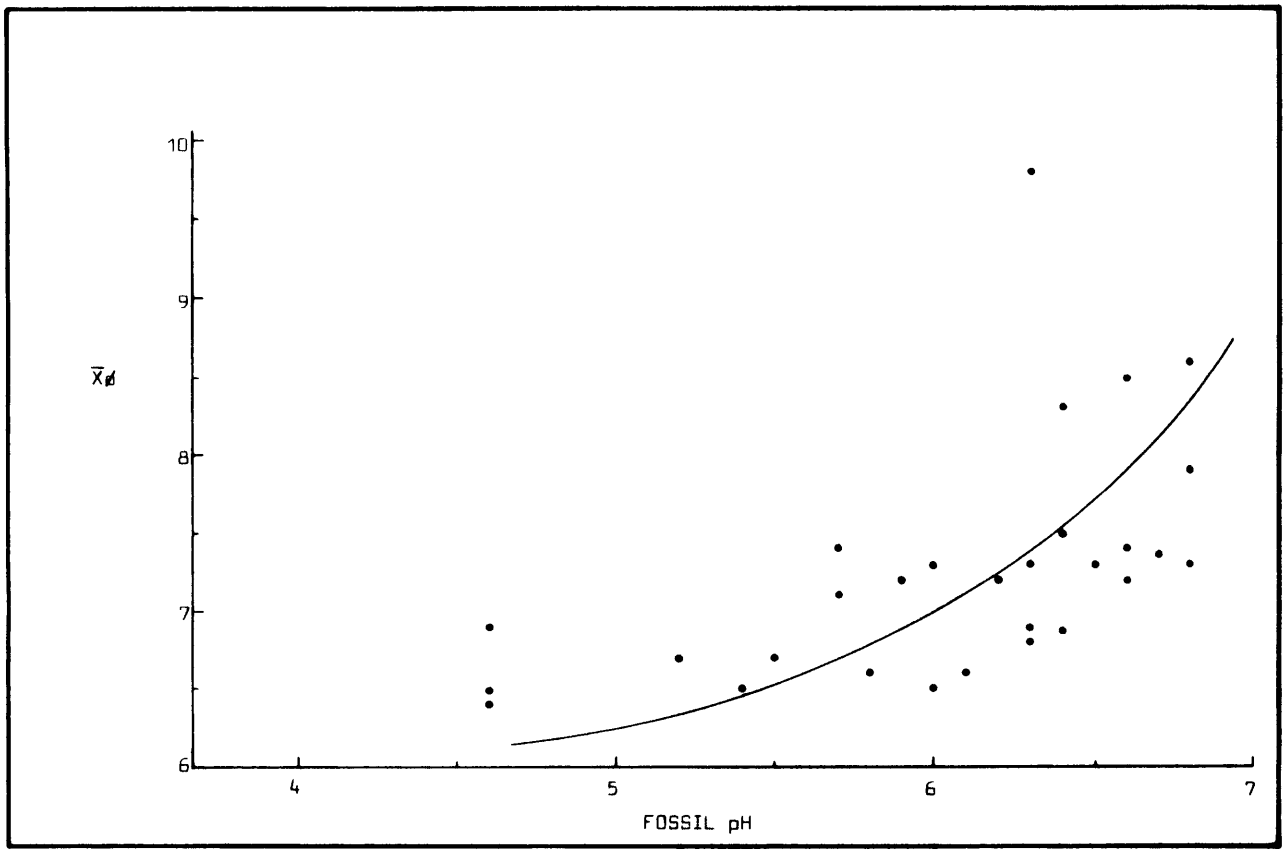

Fig. 5.7 Weak negative correlation between fossil pH and average particle size (r = 0,537).

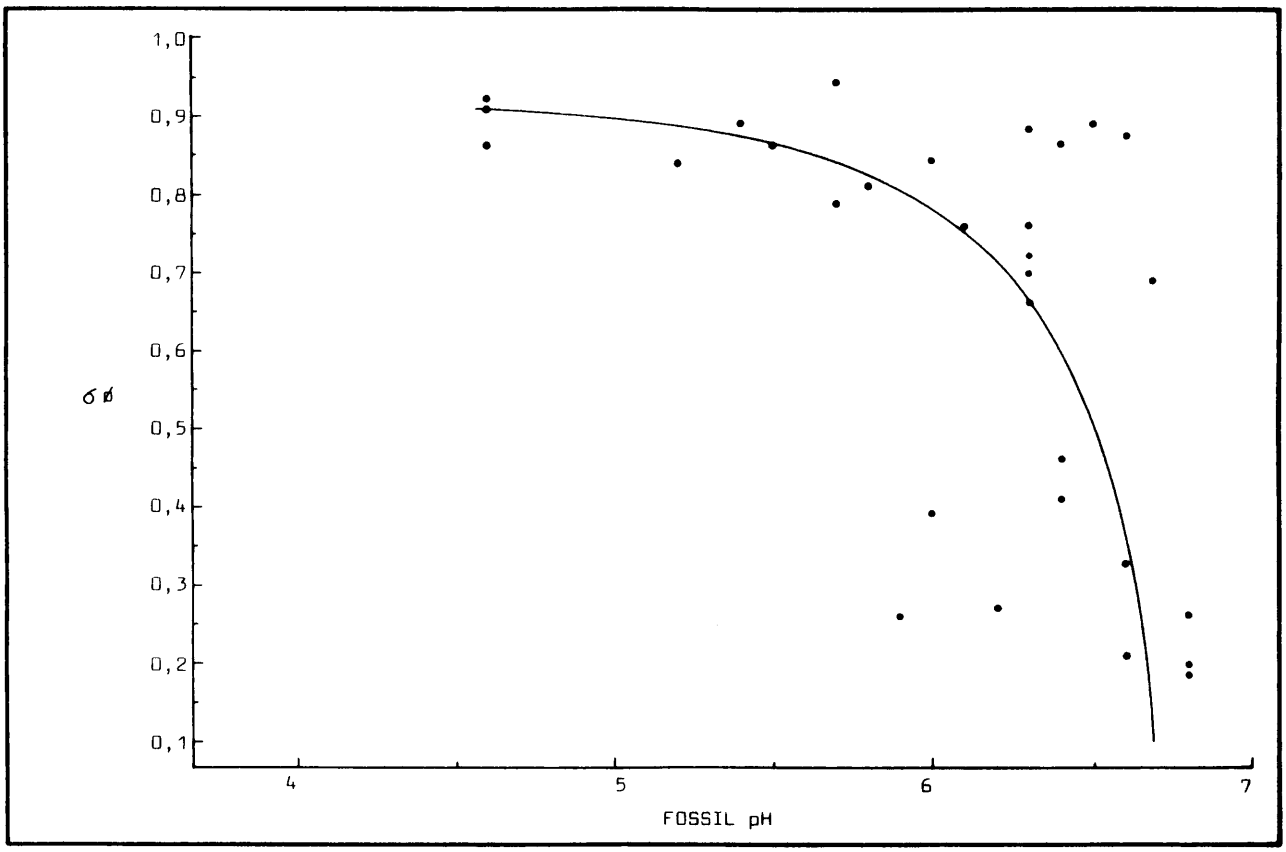

Fig. 5.8 Weak positive correlation between fossil pH and the degree of grain-size sorting (expressed as standard deviation) (r = -0,562).

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TABLE 5.2 CALCULATED KAOLINITE AND ILLITE CONTENTS OF 32 SAMPLES OF REFRACTORY CLAY

Sample No.	Kaolinite (%)	Illite (%)
26	65,6	10,3
32	79,7	7,4
74	88,8	6,2
76	71,5	8,6
93	85,1	7,8
99	88,4	7,6
100	81,9	4,8
103	89,5	6,9
104	76,3	3,1
110	84,2	4,7
114	50,7	7,4
115	68,3	9,5
117	73,1	7,0
138	82,9	4,2
140	71,2	2,4
141	77,6	5,2
142	75,9	4,8
143	74,2	4,6
145	86,8	2,1
146	62,6	5,5
147	75,2	4,3
149	76,4	2,3
151	76,0	2,0
153	65,2	7,1
157	81,0	6,9
159	77,2	9,8
164	83,1	3,6
167	89,2	2,0
172	69,1	4,2
173	81,2	2,9
174	92,1	3,9
175	95,0	1,5

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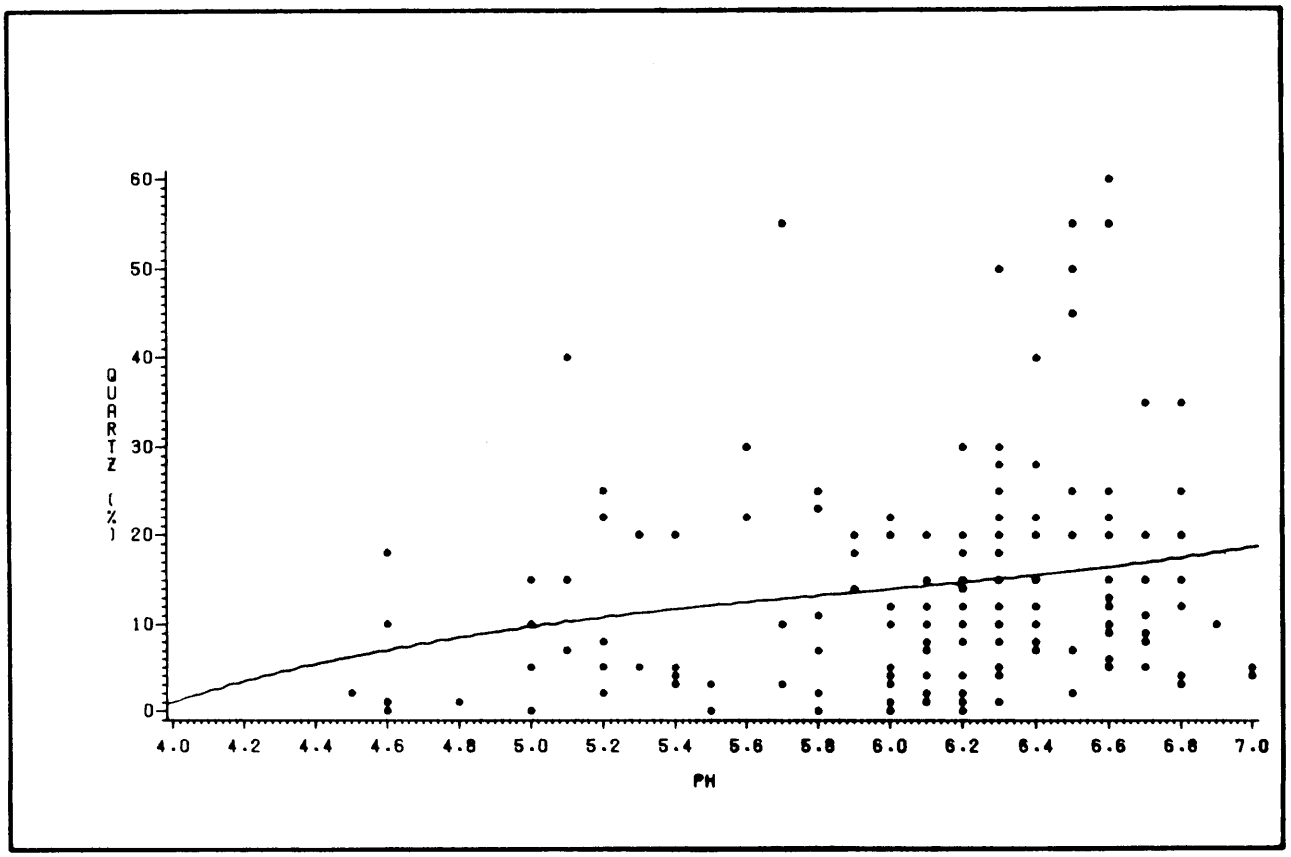

Fig. 5.9 Weak positive correlation between fossil pH and quartz content (r = 0,145).

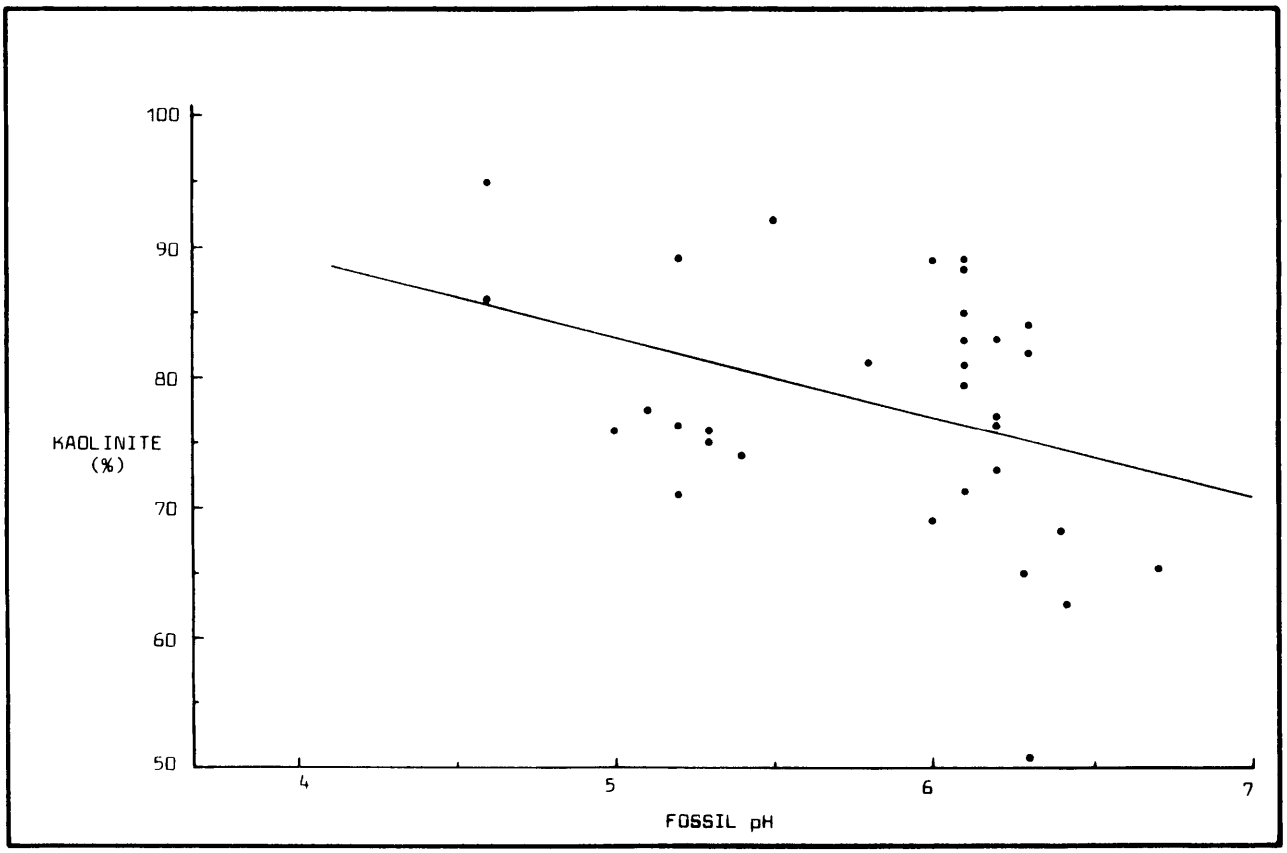

Fig. 5.10 Weak negative correlation between fossil pH and kaolinite content (r = -0,371).

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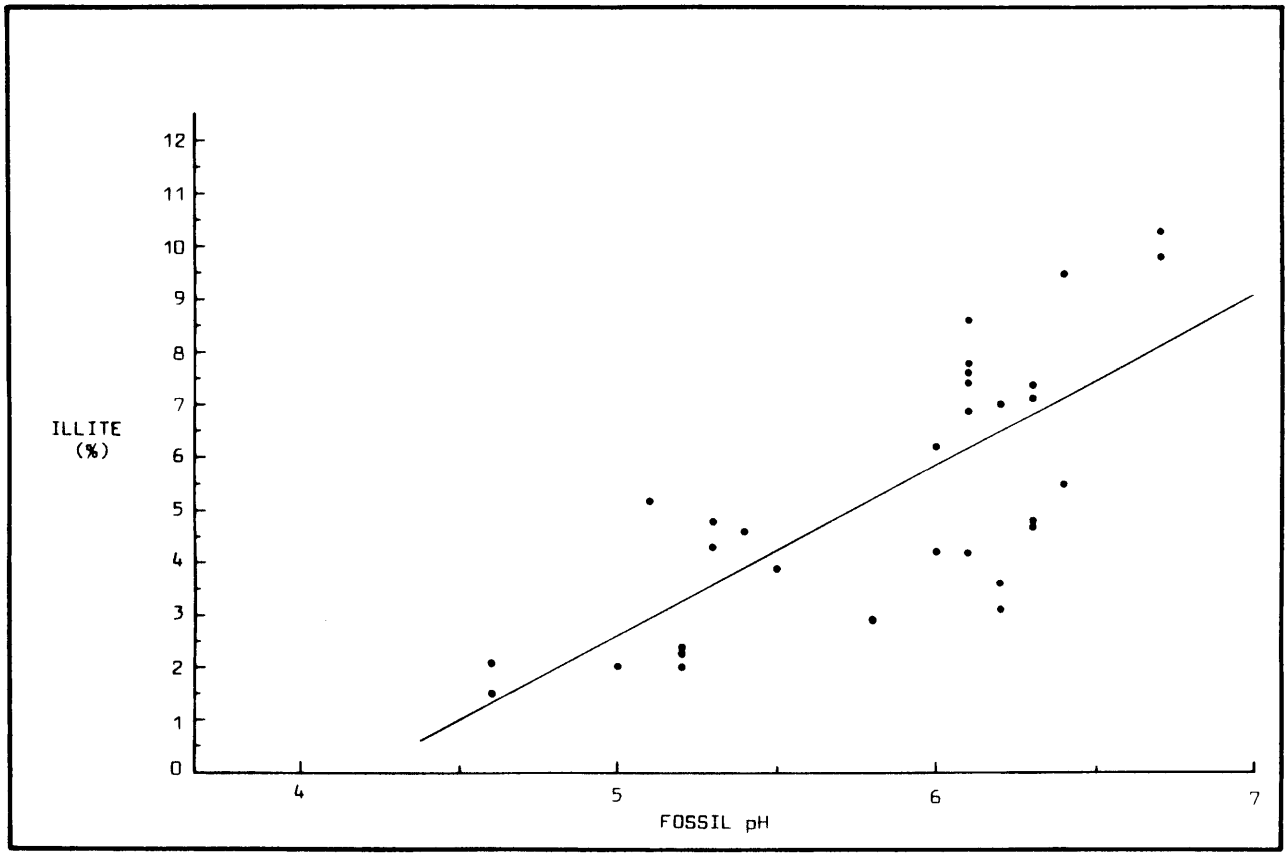

Fig. 5.11 Positive correlation between fossil pH and illite content (r = 0,754).

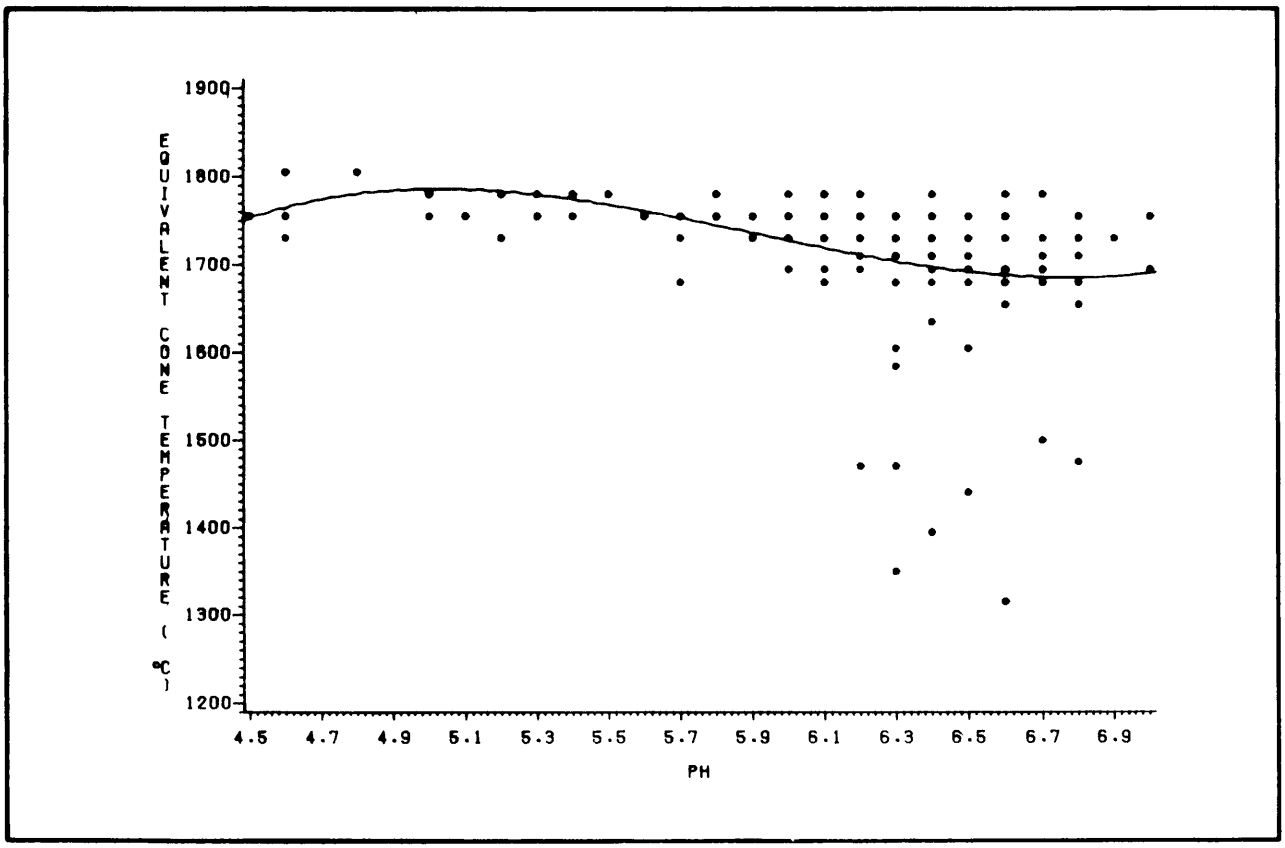

Fig. 5.12 Weak negative correlation between fossil pH and fusion temperature (r = -0,362).

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Fig. 5.12, however, an essentially random relationship exists between fossil pH and refractoriness. This can probably be accounted for by varying amounts of fluxes which are only very weakly controlled by acidity as indicated by the correlation coefficients in Appendix 5.

5.7 MINERALOGICAL COMPOSITION – REFRACTORINESS

According to Searle and Grimshaw (1959) pure kaolinite has a fusion temperature of between 1 745 and 1 790°C. Most other clay minerals contain iron, alkalies or alkaline earths as essential constituents and consequently have a much lower refractoriness (1 000 – 1 500°C according to Grim, 1962). With the exception of free alumina in the form of gibbsite or diaspore, there are in fact no non-kaolinite minerals commonly present in refractory clays which would not tend to reduce their refractoriness. No evidence has, however, been found for the presence of bauxite minerals in the Transvaal clays and without considering textural differences, it can therefore be expected that their fusion temperatures would be directly proportional to the kaolinite content and inversely proportional to the amount of non-kaolinite minerals.

The weak negative correlation displayed in Fig. 5.13 indicates that the quartz content of a clay cannot be used as a reliable estimate of refractoriness. Clays containing as much as 40 per cent quartz may for example still have a fusion temperature of 1 755°C (Seger cone 34). The reason for this is that very small quartz grains probably act as a flux, while larger grains could increase the refractoriness, especially in the case of impure clays. Determination of the quartz content is nevertheless important because of its effect on other physical properties such as plasticity and shrinkage. A much better correlation is obtained between kaolinite content and fusion temperature (Fig. 5.14) but here again, other factors such as grain size and the presence of fluxes of varying strength probably prevent a more closely defined trend. The same applies to the weak negative correlation between illite content and refractoriness as illustrated in Fig. 5.15.

5.8 CHEMICAL COMPOSITION – REFRACTORINESS

Of all laboratory results, chemical analyses are most frequently used to try and predict refractoriness. Many attempts have been made to find a definite relationship between chemical composition and fusion temperature and it has been shown that rough estimates of refrac-

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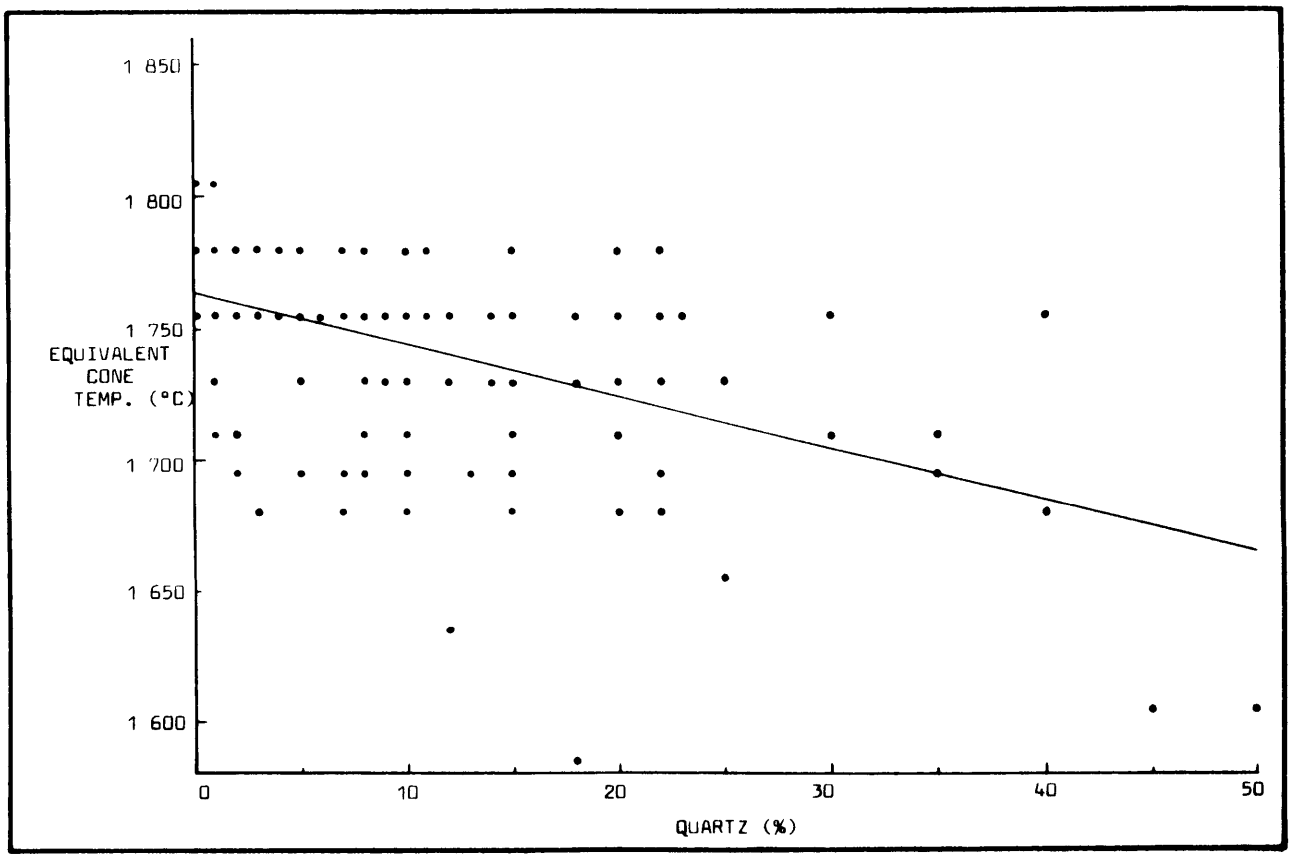

Fig. 5.13 Weak negative correlation between quartz content and fusion temperature (r = -0,455)

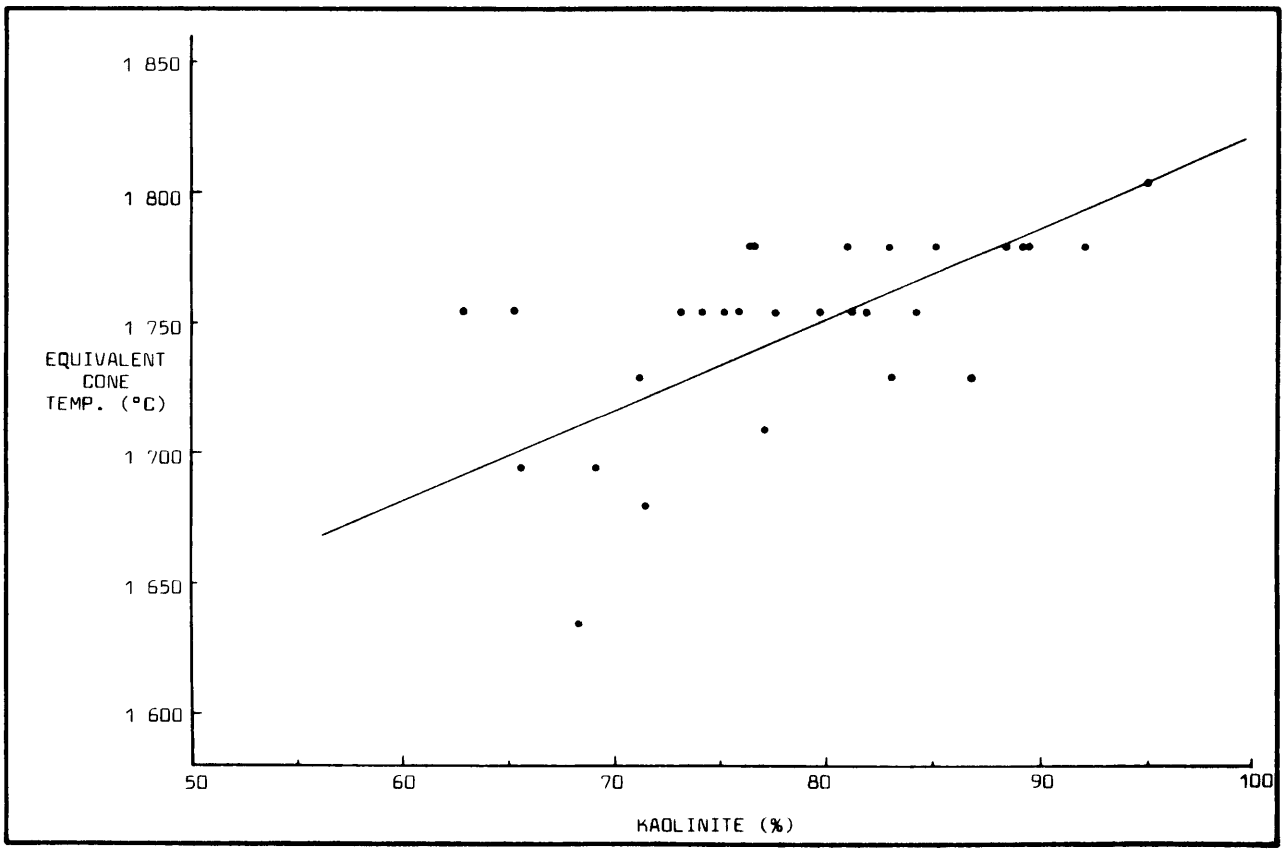

Fig. 5.14 Positive correlation between kaolinite content and fusion temperature (r = 0,731).

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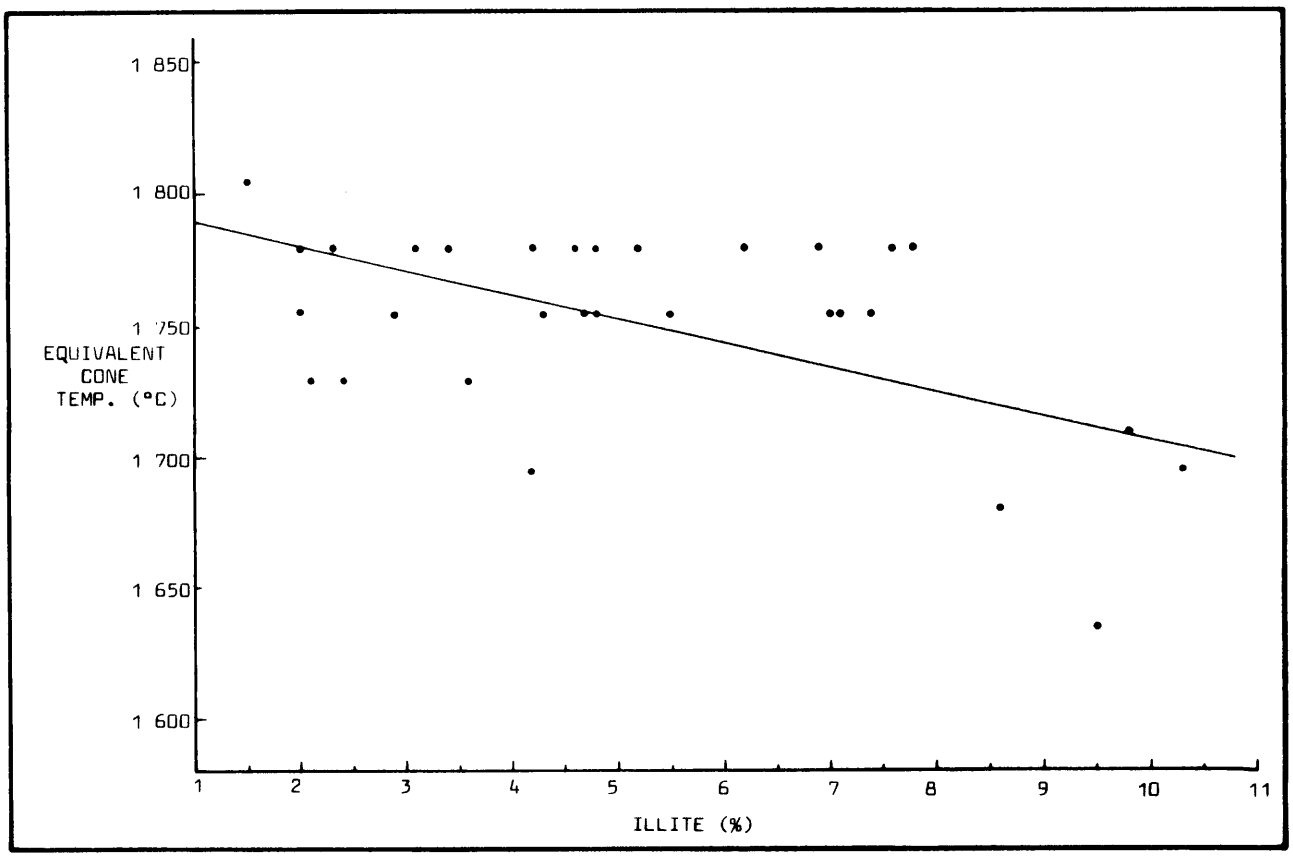

Fig. 5.15 Weak negative correlation between illite content and fusion temperature (r = -0,447).

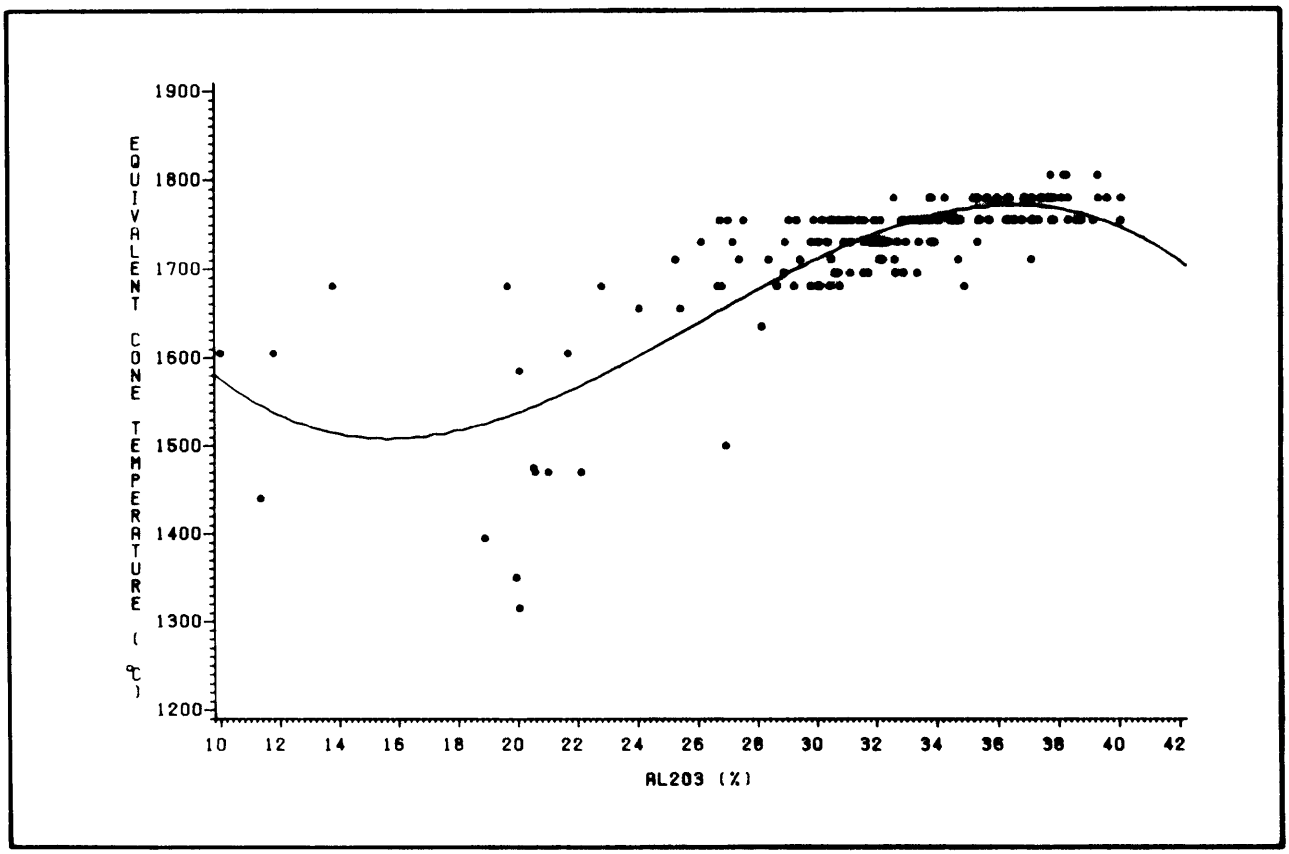

Fig. 5.16 Positive correlation between alumina content and fusion temperature (r = 0,745).

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toriness can be obtained from the molecular concentrations of the fluxes as applied for example in the Ludwig Chart (Searle and Grimshaw, 1959). Seeing that refractoriness can be measured directly in terms of pyrometric cone equivalent, the use of such formulae is of doubtful practical value, especially since the effects of texture and the distribution of the different components cannot be properly accounted for in the calculations. The general tendency is therefore to rather use the "raw" chemical data as complementary to PCE determinations for detecting mutual differences between clays and to get some idea as to which of the components could be detrimental to refractoriness. As an aid to such an assessment, the results of the present study are related graphically in Figs. 5.16 to 5.31. These graphs are largely self-explanatory and only some of the more interesting aspects will therefore be discussed.

Perhaps the most significant feature revealed by the comparisons is the limitation of using individual components as a measure of refractoriness. Constituents which are for example commonly used in isolation as estimates of fusion temperature are alumina on a calcined basis, H_2O^+ or iron content. A mere glance at Figs. 5.25, 5.24, 5.19 and 5.20 shows the inadequacy of such a procedure. On the other hand, the graphs do indicate certain wide limits within which estimates of refractoriness could be made with a fair amount of confidence.

Although some of the trends are poorly defined, all of them with the exception of TiO_2 are in accordance with theoretical considerations (i.e. either positive or negative). Experiments conducted on mixtures of kaolin and TiO_2 have indicated the latter to act as a strong flux (Ries, 1927). The positive correlation between TiO_2 and fusion temperature displayed in Fig. 5.17 would therefore appear to be anomalous and needs some explanation. Probably the most likely reason is the fact that in natural clays which have been formed through a process of weathering, there is normally a concomitant enrichment in both alumina and TiO_2 as a result of the immobility of these elements. This positive correlation between Al_2O_3 and TiO_2 is also evident in the case of the Transvaal refractory clays (Appendix 5) and the fluxing influence of TiO_2 therefore seems to be more than compensated for by the accompanying higher alumina content. Such inter-component relationships again emphasises the complexities involved in trying to compare the behaviour of natural raw materials with that of artificial mixtures.

In view of their low concentrations, trace elements do not seem to have a direct bearing on refractoriness. Some may, however, be of indirect use as an indication of the presence of other major components. As pointed out in Chapter 3, rubidium is the best example of

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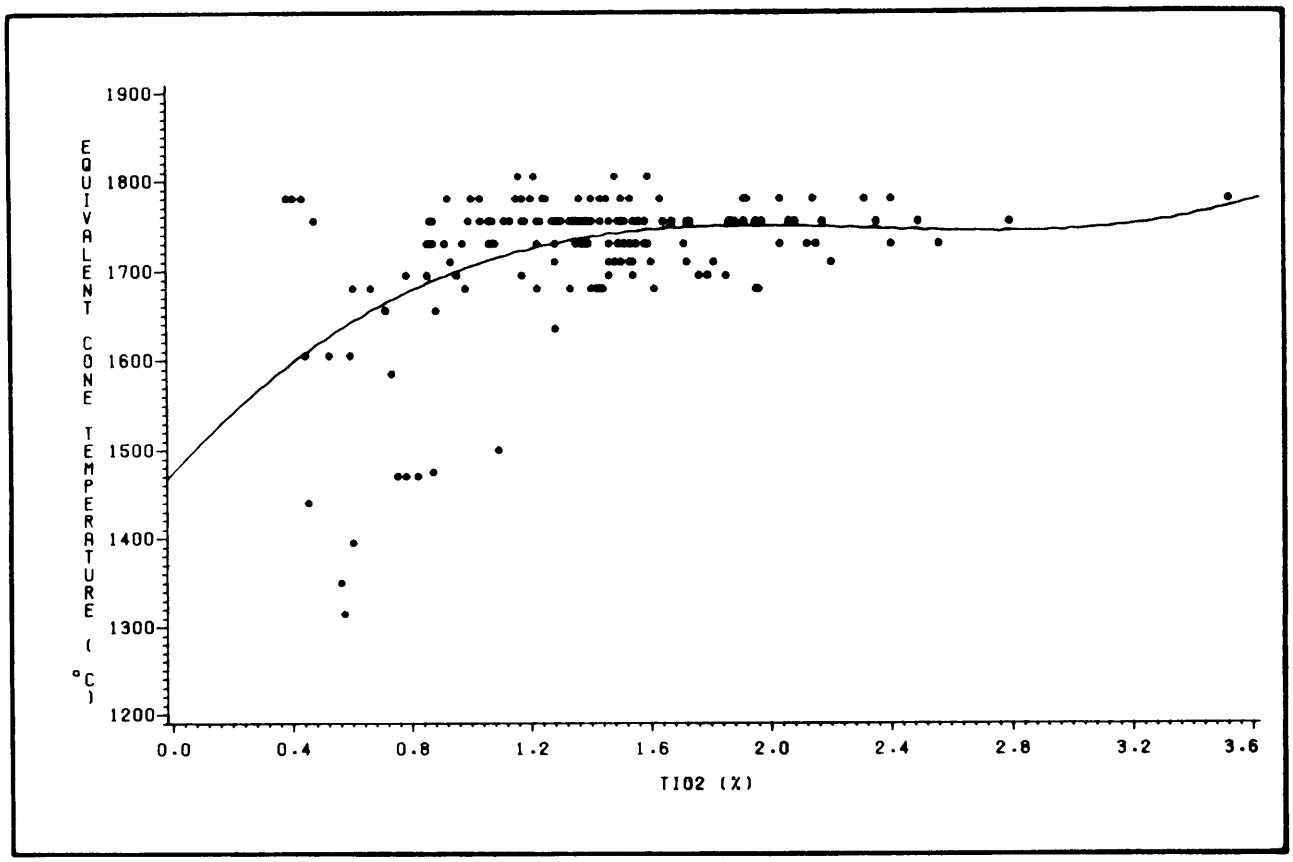

Fig. 5.17 Weak positive correlation between TiO_2 and fusion temperature (r = 0,463).

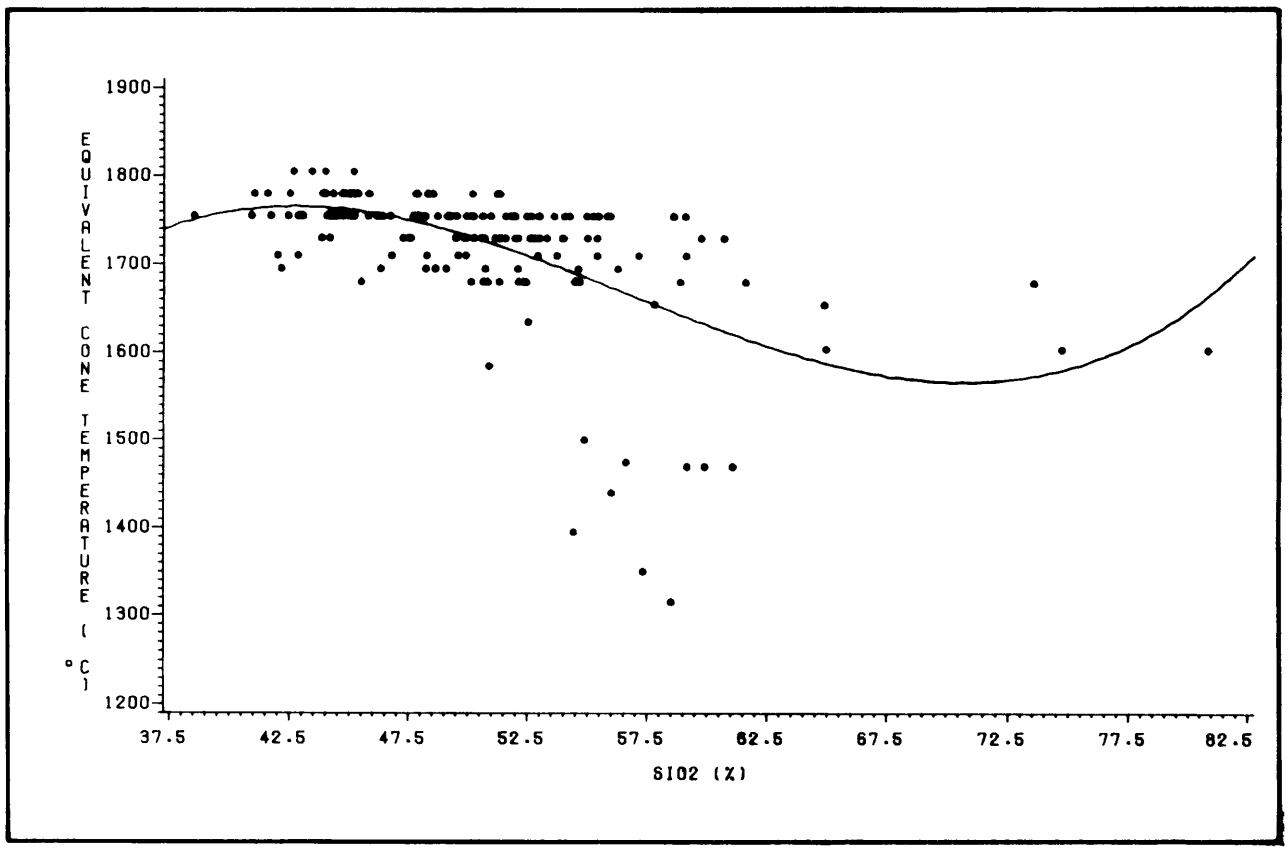

Fig. 5.18 Weak negative correlation between SiO_2 and fusion temperature (r = -0,467).

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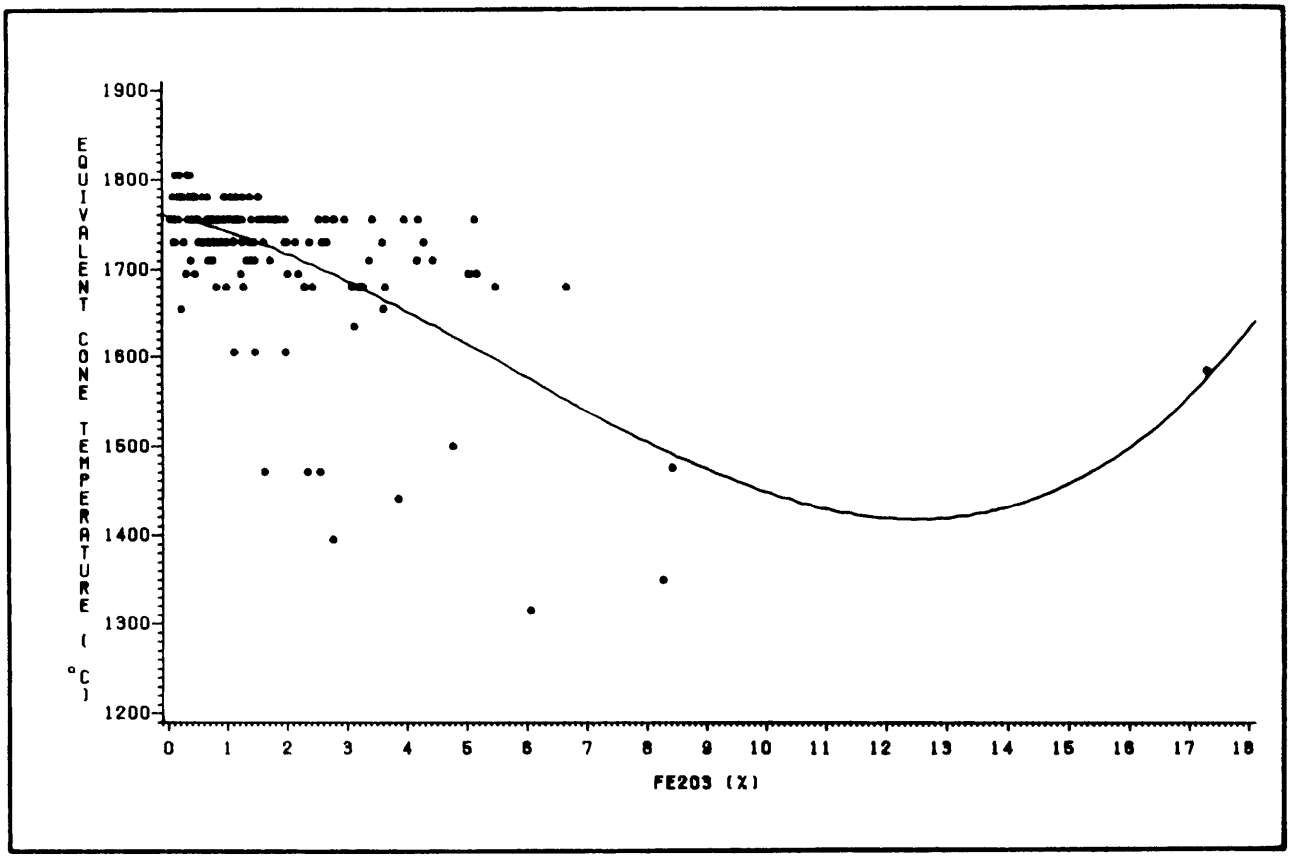

Fig. 5.19 Weak negative correlation between Fe_2O_3 and fusion temperature (r = -0,548).

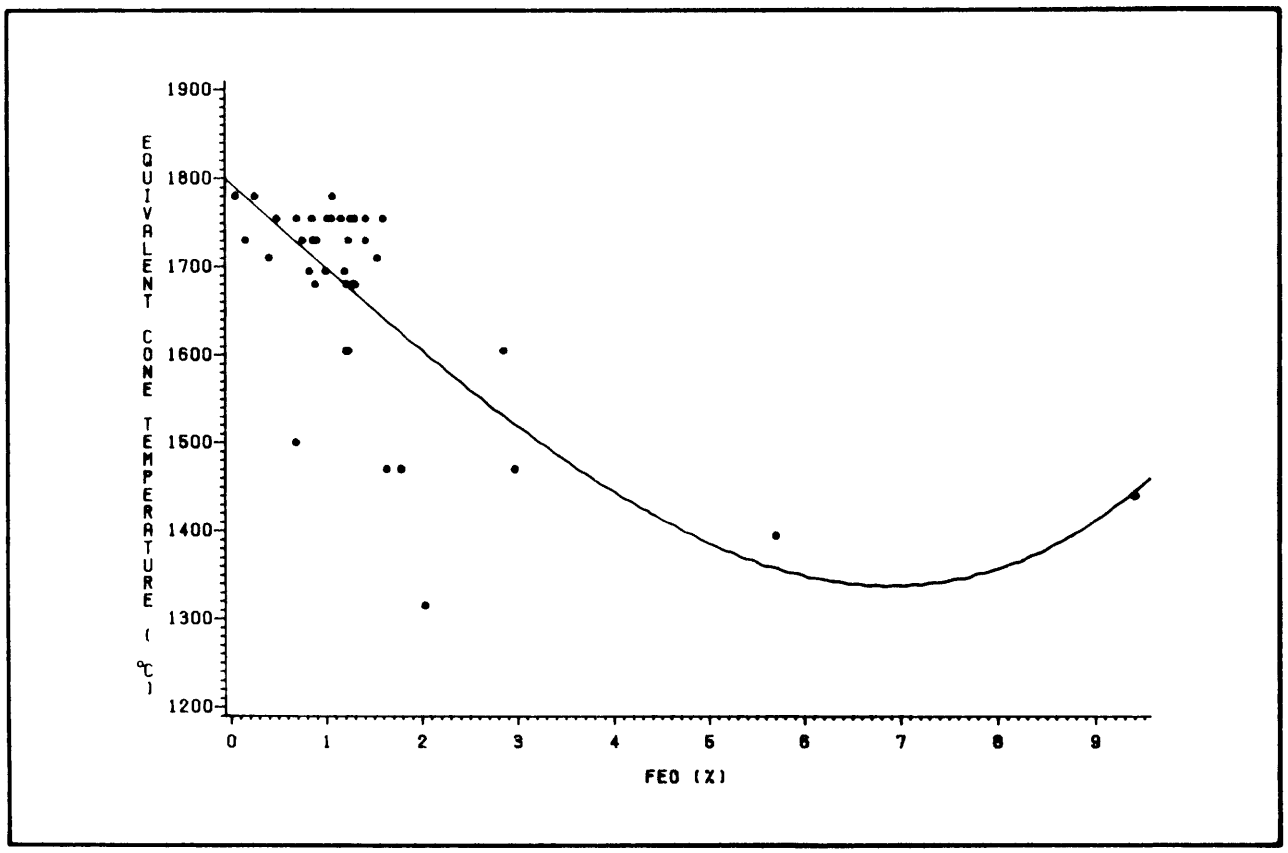

Fig. 5.20 Weak negative correlation between FeO and fusion temperature (r = -0,667).

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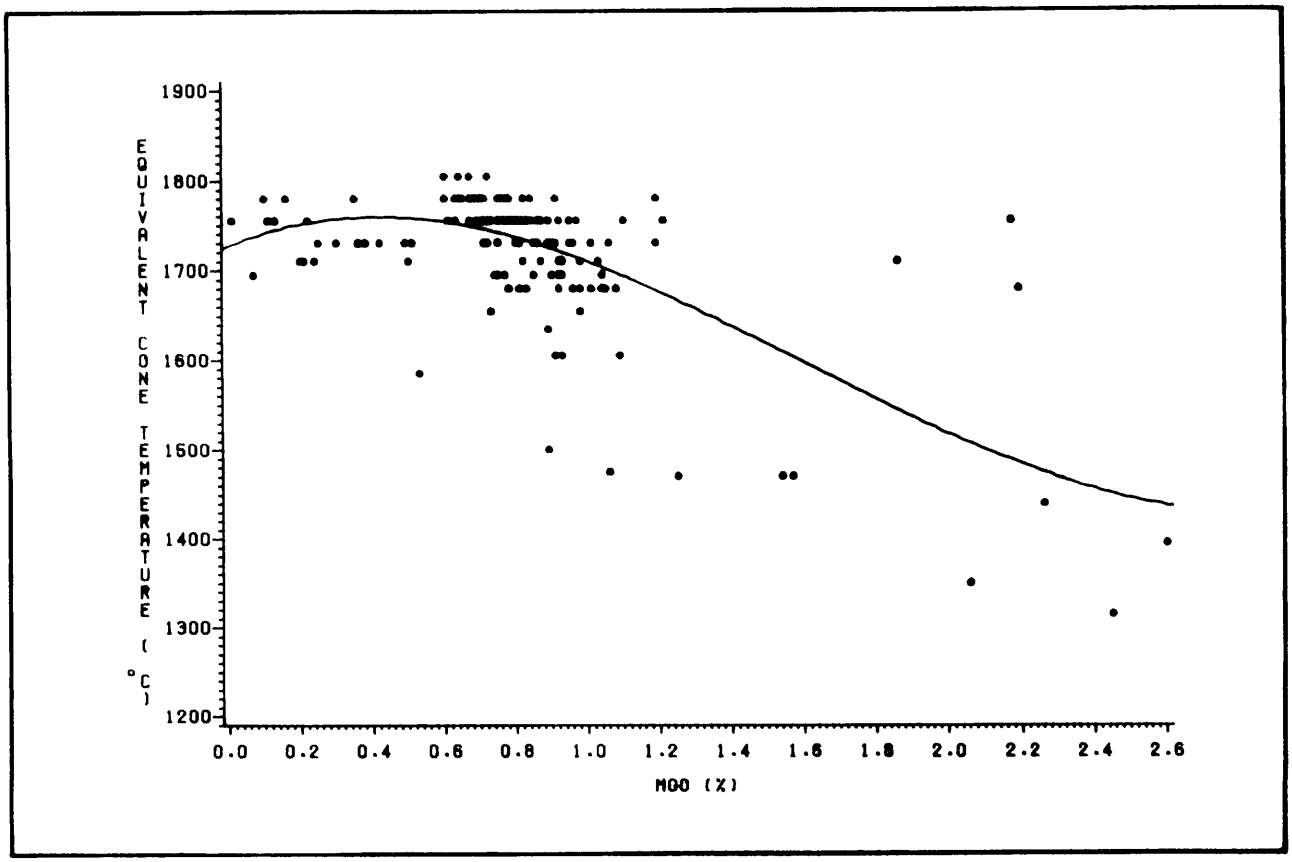

Fig. 5.21 Weak negative correlation between MgO and fusion temperature (r = -0,677).

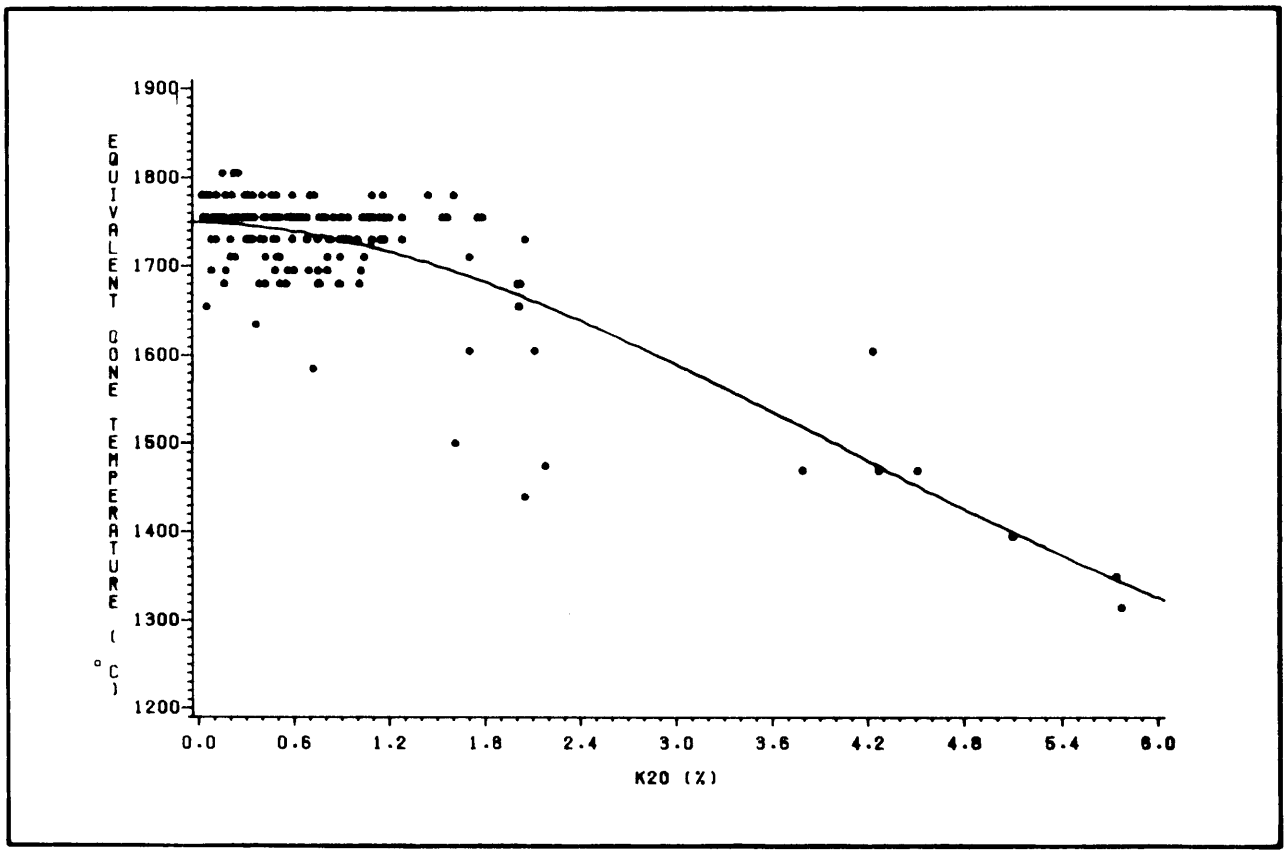

Fig. 5.22 Negative correlation between K_2O and fusion temperature (r = -0,815).

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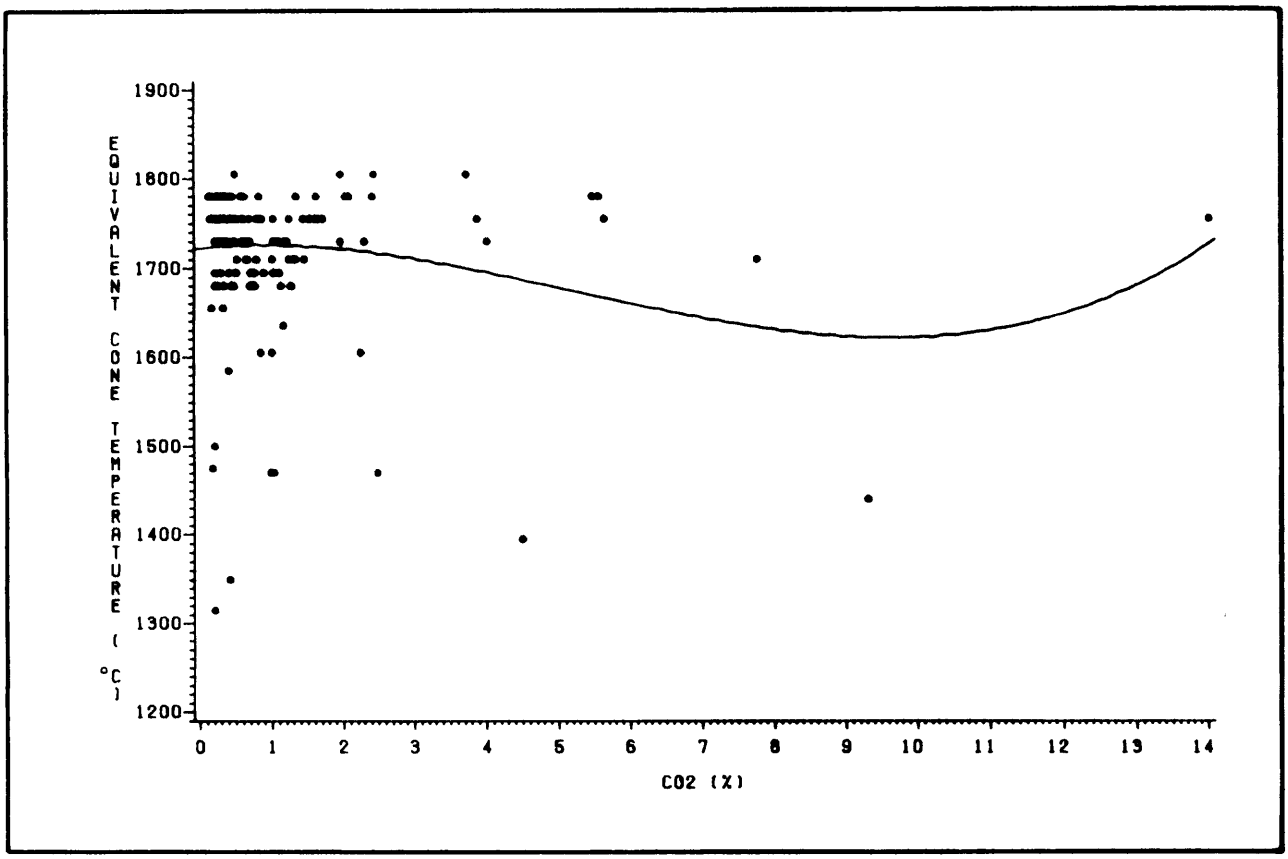

Fig. 5.23 Random relationship between CO_2 content and fusion temperature (r = -0,110).

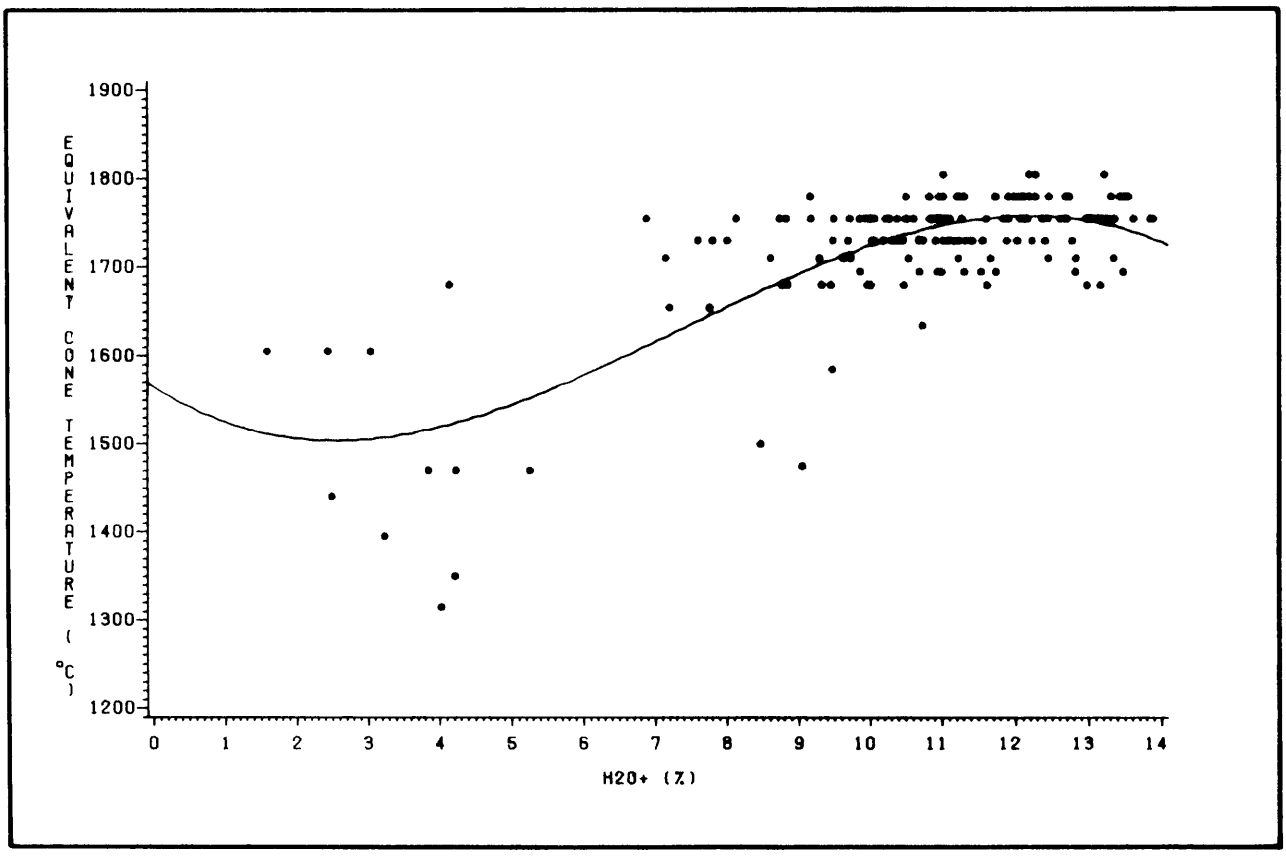

Fig. 5.24 Positive relationship between H_2O^+ and fusion temperature (r = 0,699).

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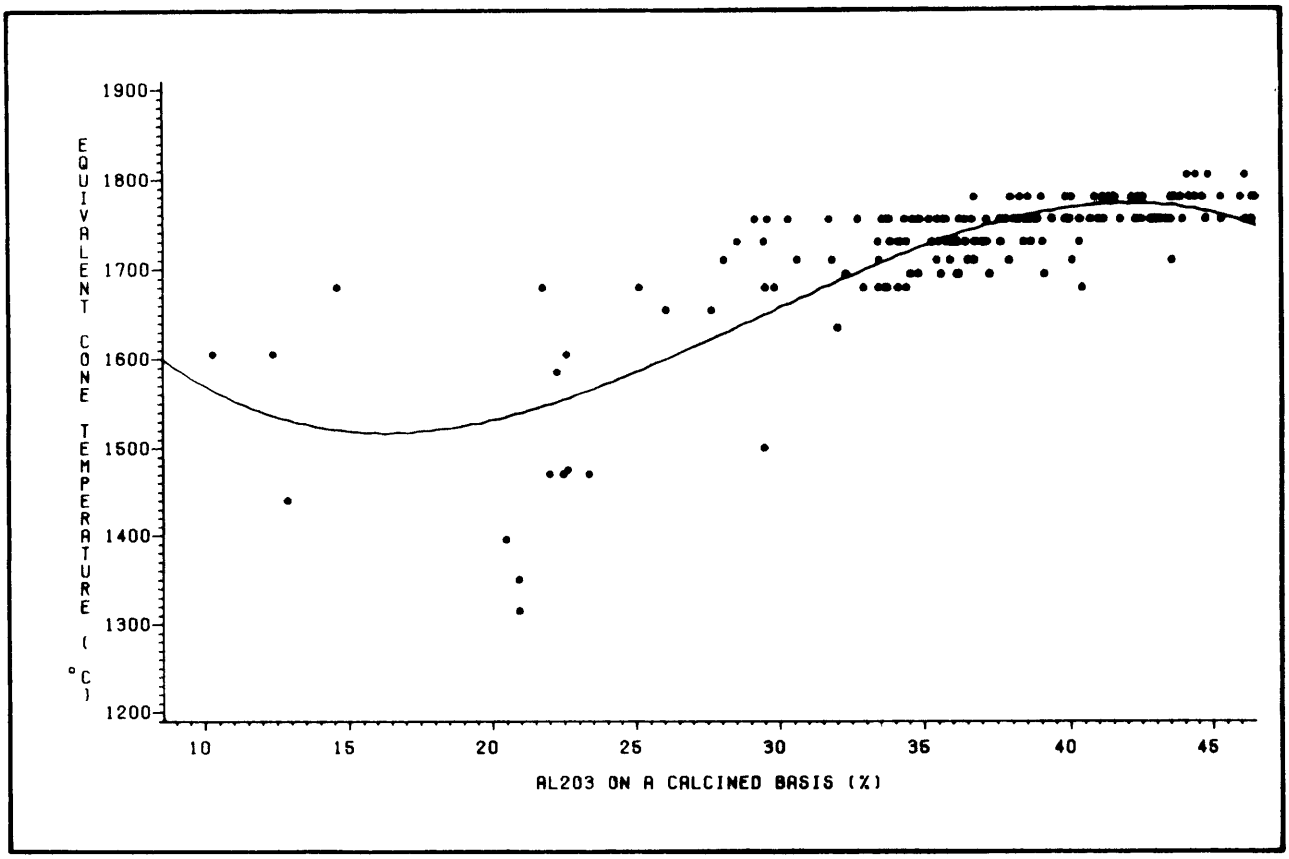

Fig. 5.25 Positive correlation between alumina content on a calcined basis and fusion temperature (r = 0,743).

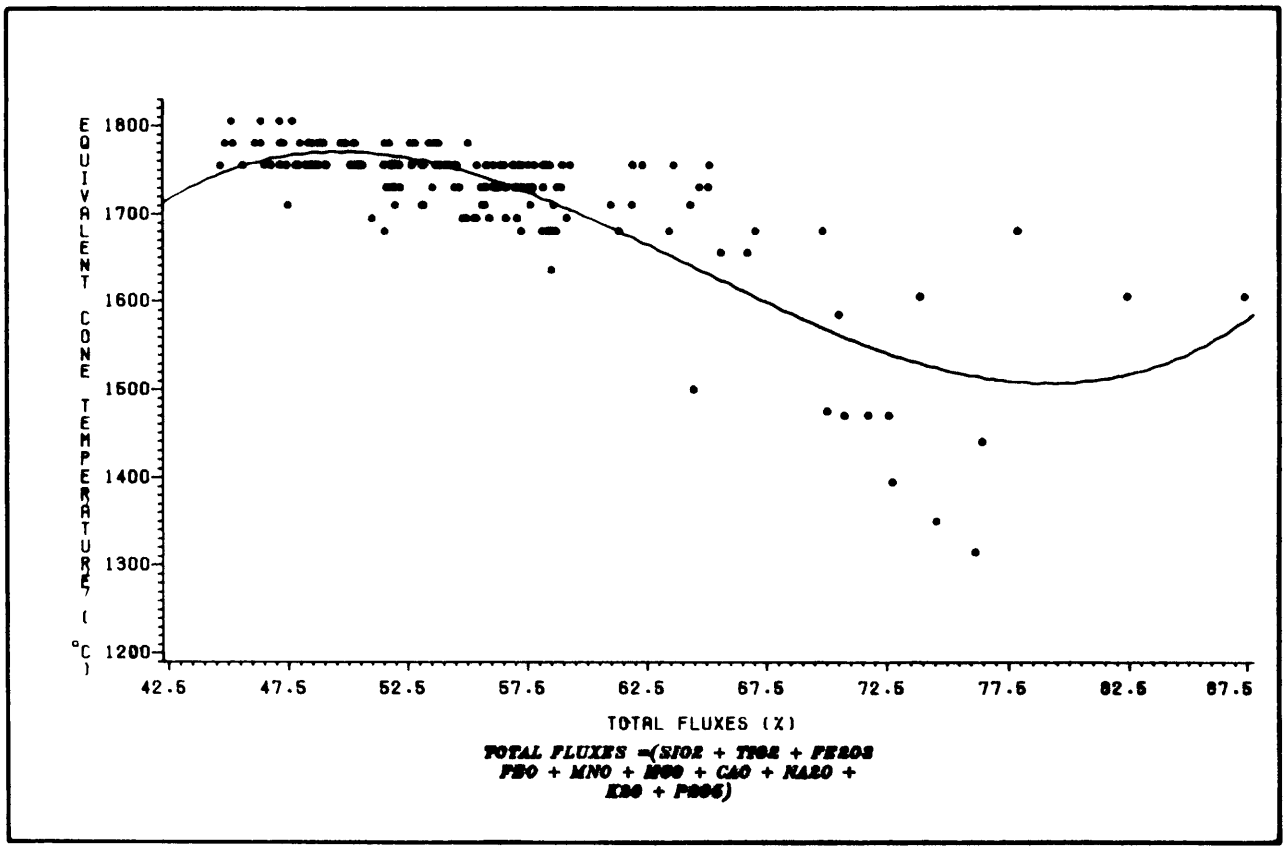

Fig. 5.26 Negative correlation between total flux content and fusion temperature (r = -0,745).

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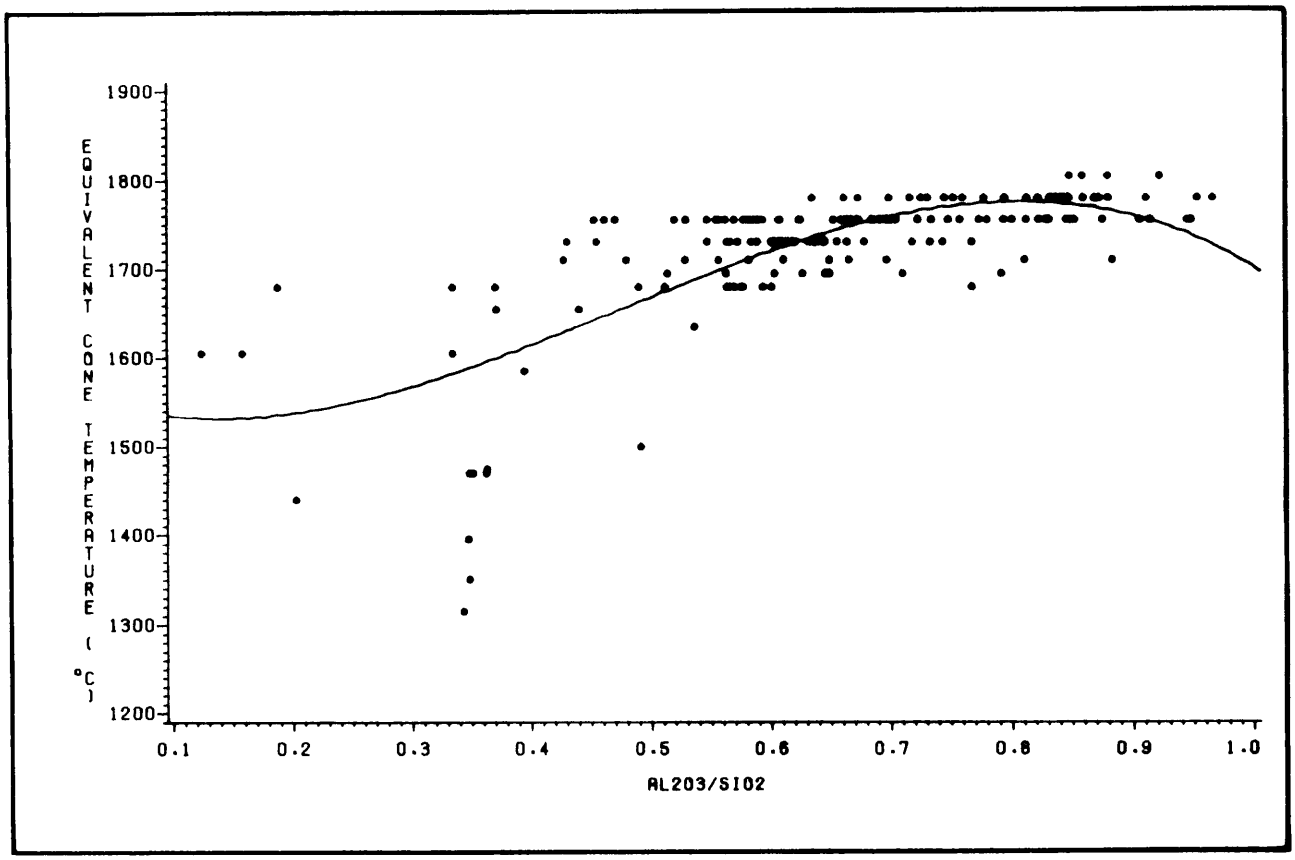

Fig. 5.27 Weak positive correlation between Al_2O_3/SiO_2 and fusion temperature (r = 0,660).

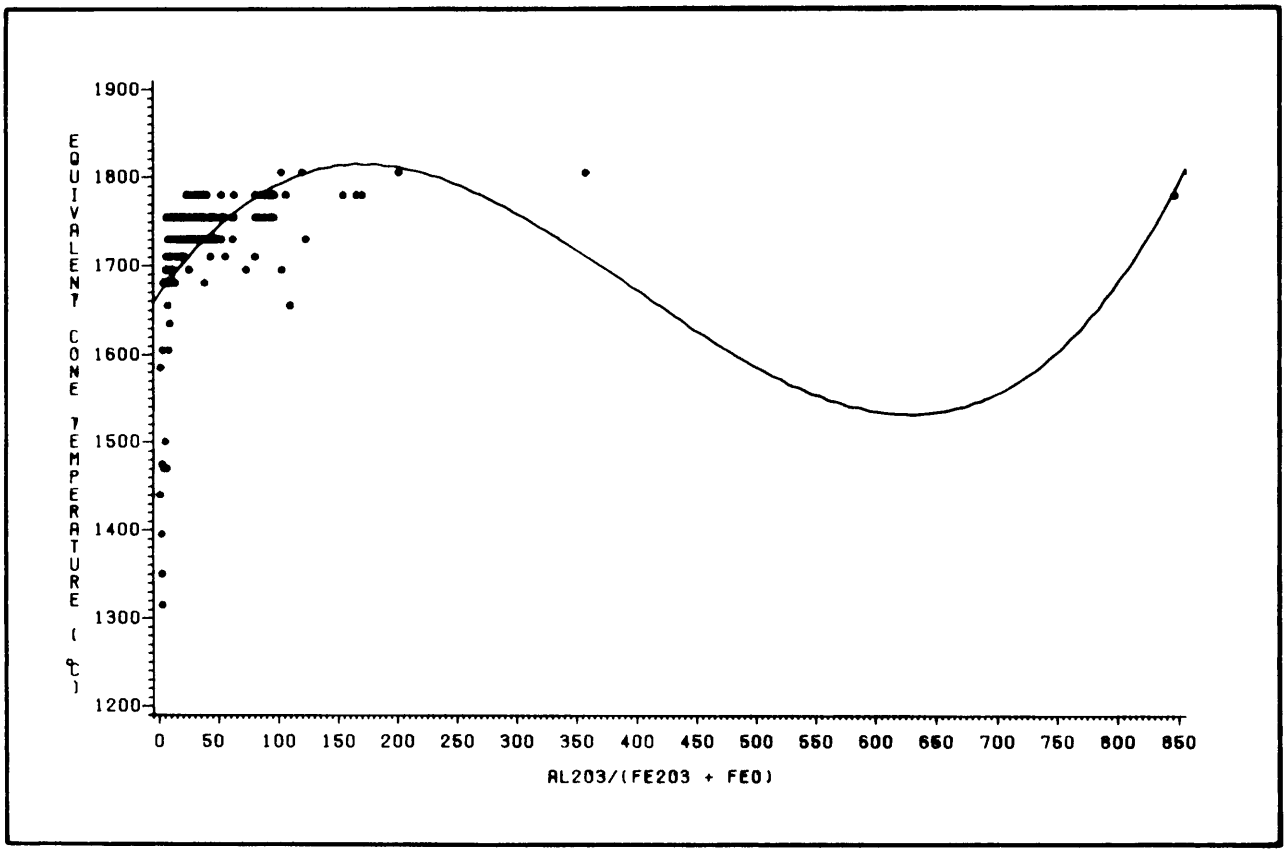

Fig. 5.28 Weak positive correlation between $Al_2O_3/(Fe_2O_3+FeO)$ and fusion temperature (r = 0,421).

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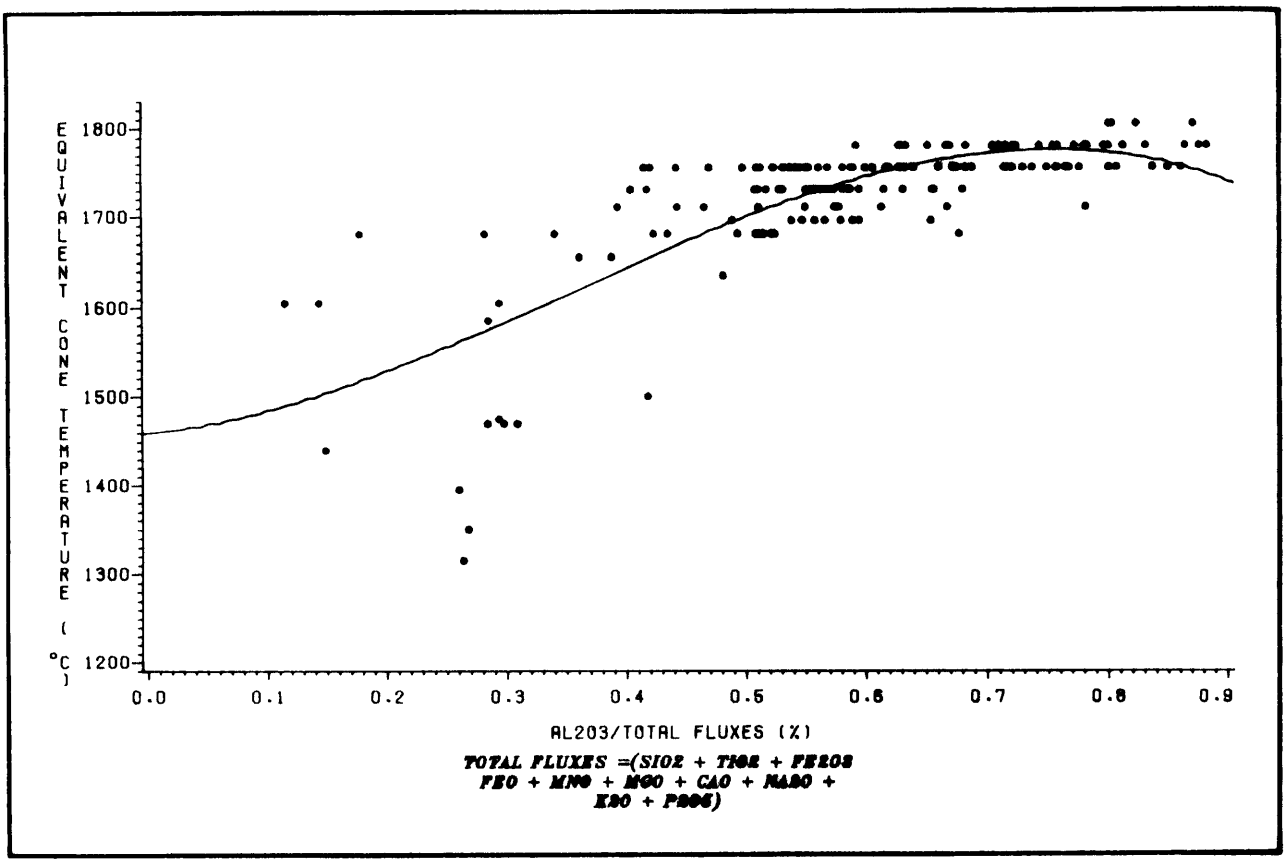

Fig. 5.29 Positive correlation between Al_2O_3/total fluxes and fusion temperature (r = 0,718).

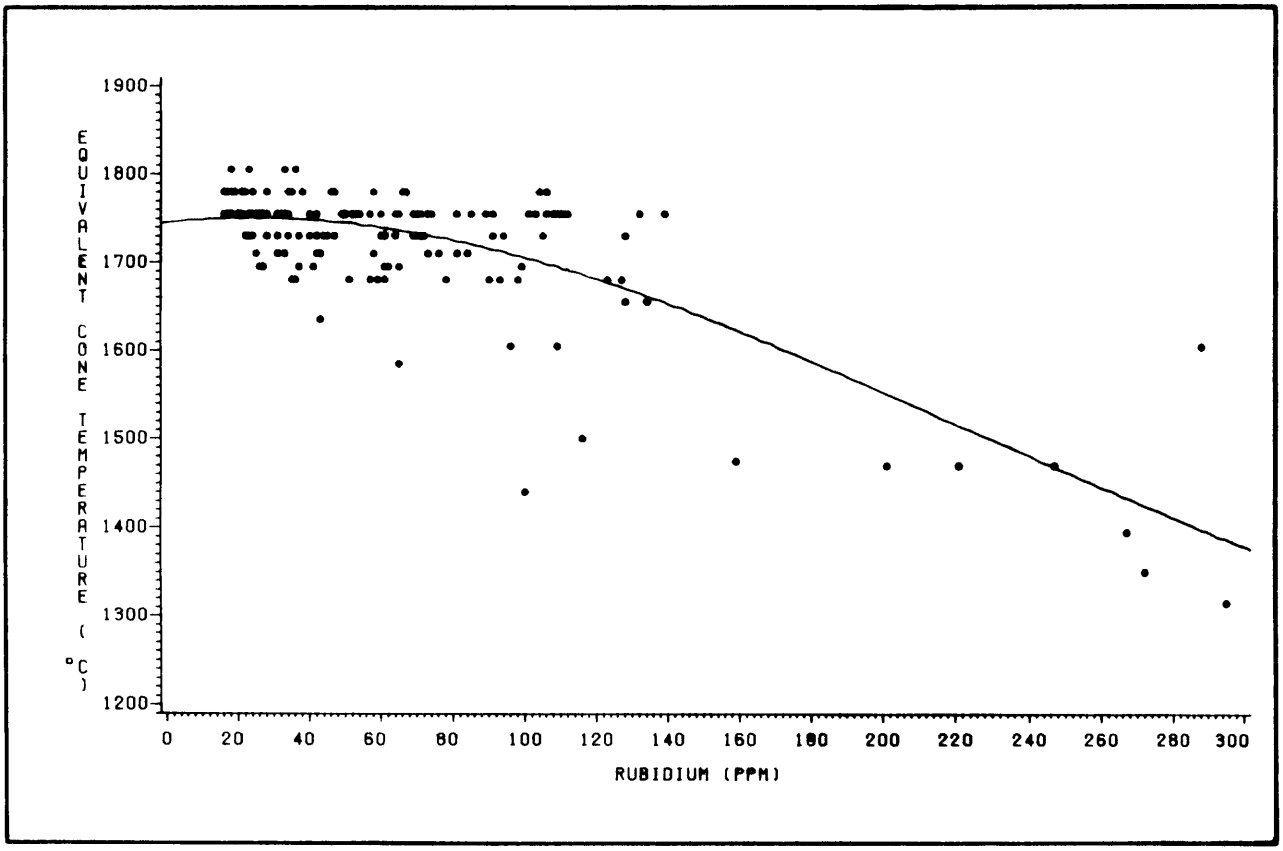

Fig. 5.30 Negative correlation between rubidium content and fusion temperature (r = -0,726).

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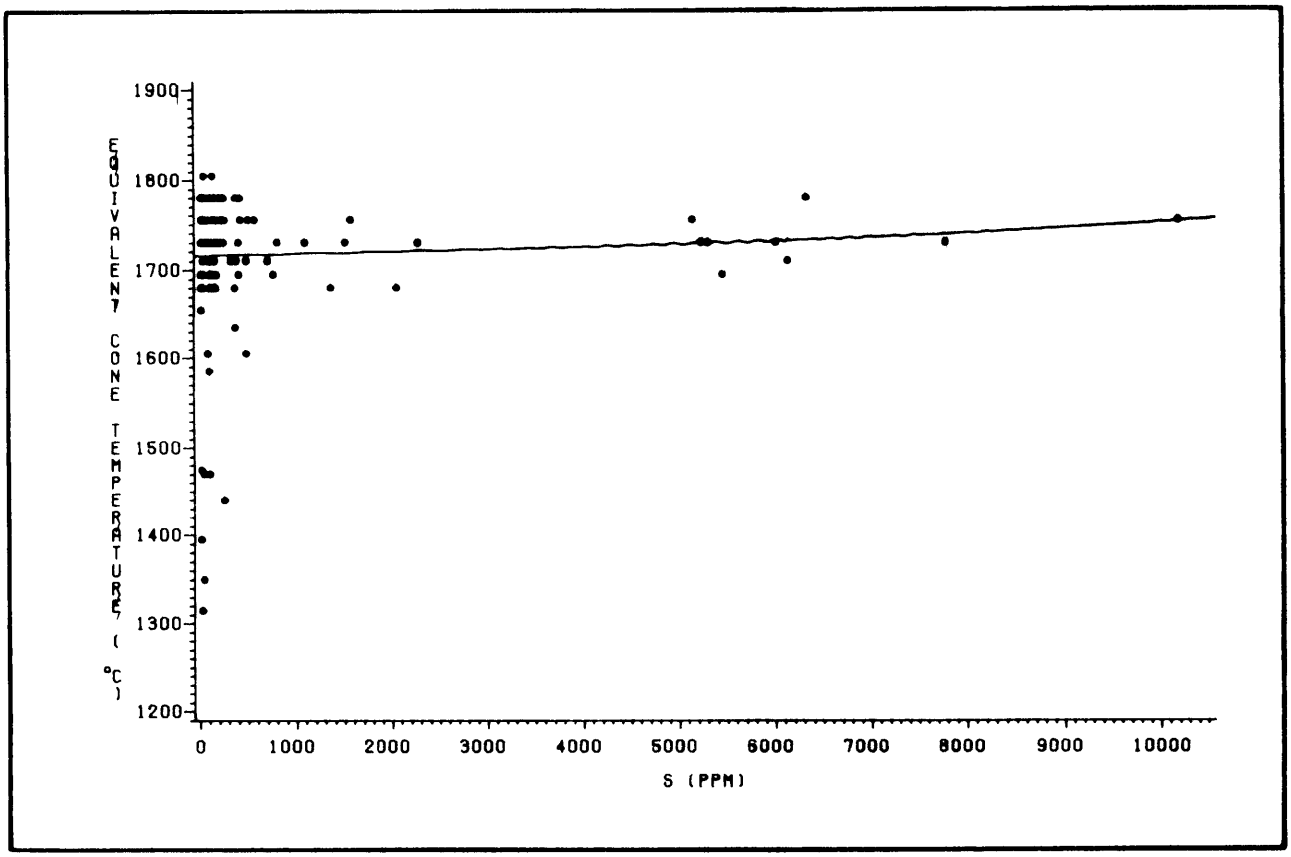

Fig. 5.31 Random relationship between sulphur content and fusion temperature (r = 0,073).

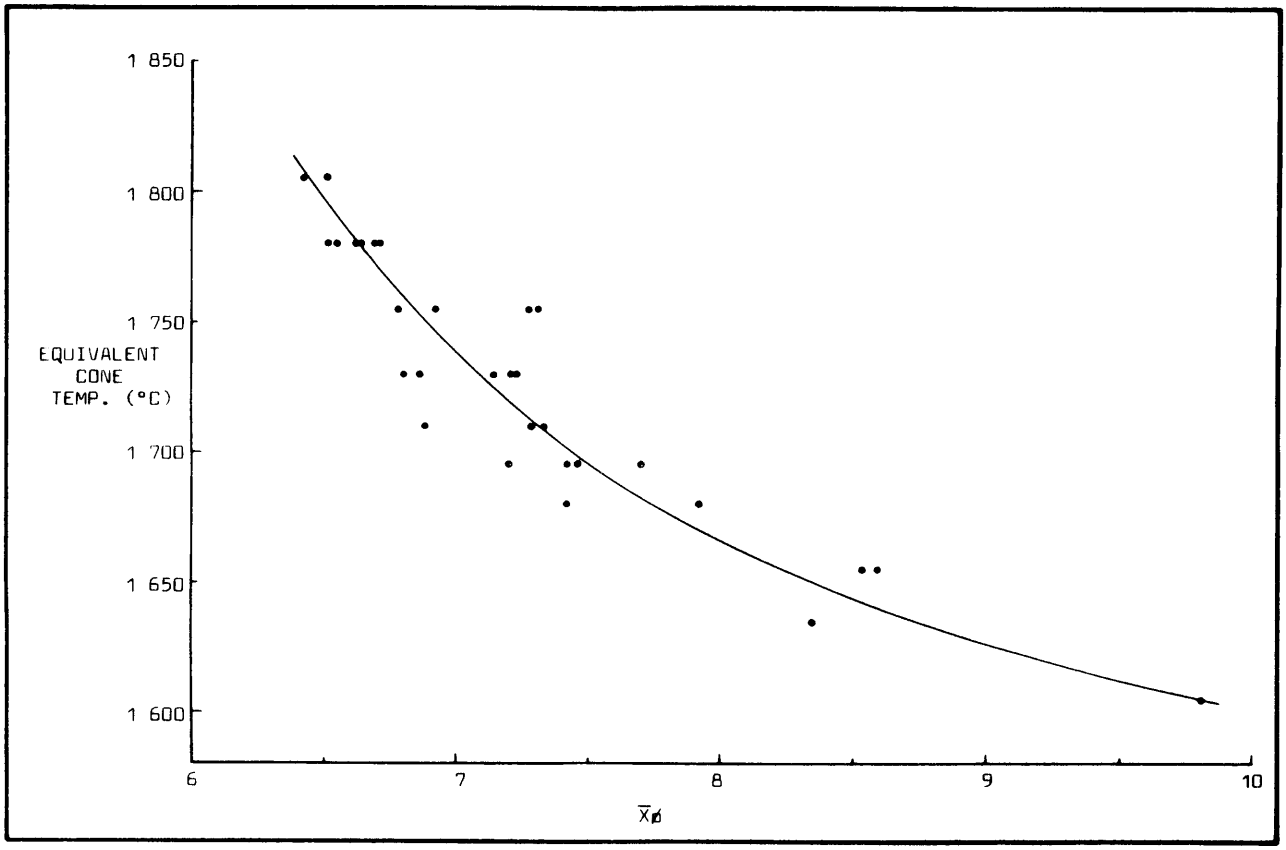

Fig. 5.32 Positive correlation between average particle size and fusion temperature (r = -0,906).

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such a indicator element. Being generally inversely proportional to the kaolinite content, a negative correlation between Rb and fusion temperature is evident (Fig. 5.30).

5.9 PARTICLE SIZE AND ORIENTATION – REFRACTORINESS

The effect of texture on fusion temperature is frequently mentioned in ceramic literature, but it has never really been quantified. In order to investigate some of the trends involved as far as the local refractory clays are concerned, the textural data listed in Table 5.1 are compared with equivalent cone temperature in Figs. 5.32 to 5.34. The most significant result is the fact that, in accordance with theoretical considerations, a rather strong positive correlation between average particle size and refractoriness is revealed (Fig. 5.32). Particle orientation also seems to have a bearing on refractoriness (Fig. 5.33) as clays with a higher degree of preferred orientation would offer better grain-to-grain contacts and thus reduce the fusion temperature. The weak negative correlation between grain-size sorting and refractoriness is more difficult to explain and a positive relationship would actually be expected. The real influence of sorting is probably obscured by the fact that clays with a higher fusion temperature normally have a higher kaolinite content which in turn implies a lower pH and consequently poorer sorting as already indicated.

In view of the good correlation between grain size and refractoriness, it is to be expected that a combination of this parameter with chemical composition would improve the correlation of the latter with fusion temperature. The results of such an exercise are illustrated in Figs. 5.35 and 5.36. In the case of alumina, the correlation coefficient (r) is 0,822 when compared with equivalent cone temperature without taking grain size into account. Inclusion of particle size increases r to 0,915. The correlation between K_2O and refractoriness for this particular set of samples is rather poor (r = -0,469), but again a combination with grain size shows some improvement (r = -0,537).

The routine measurement of textural features would probably never be practically feasible in the case of refractory clays, but the results of this study do indicate the importance of this aspect and occasional particle-size determinations could be quite valuable to establish the cause of apparent anomalies which are sometimes encountered between chemical analyses and PCE values.

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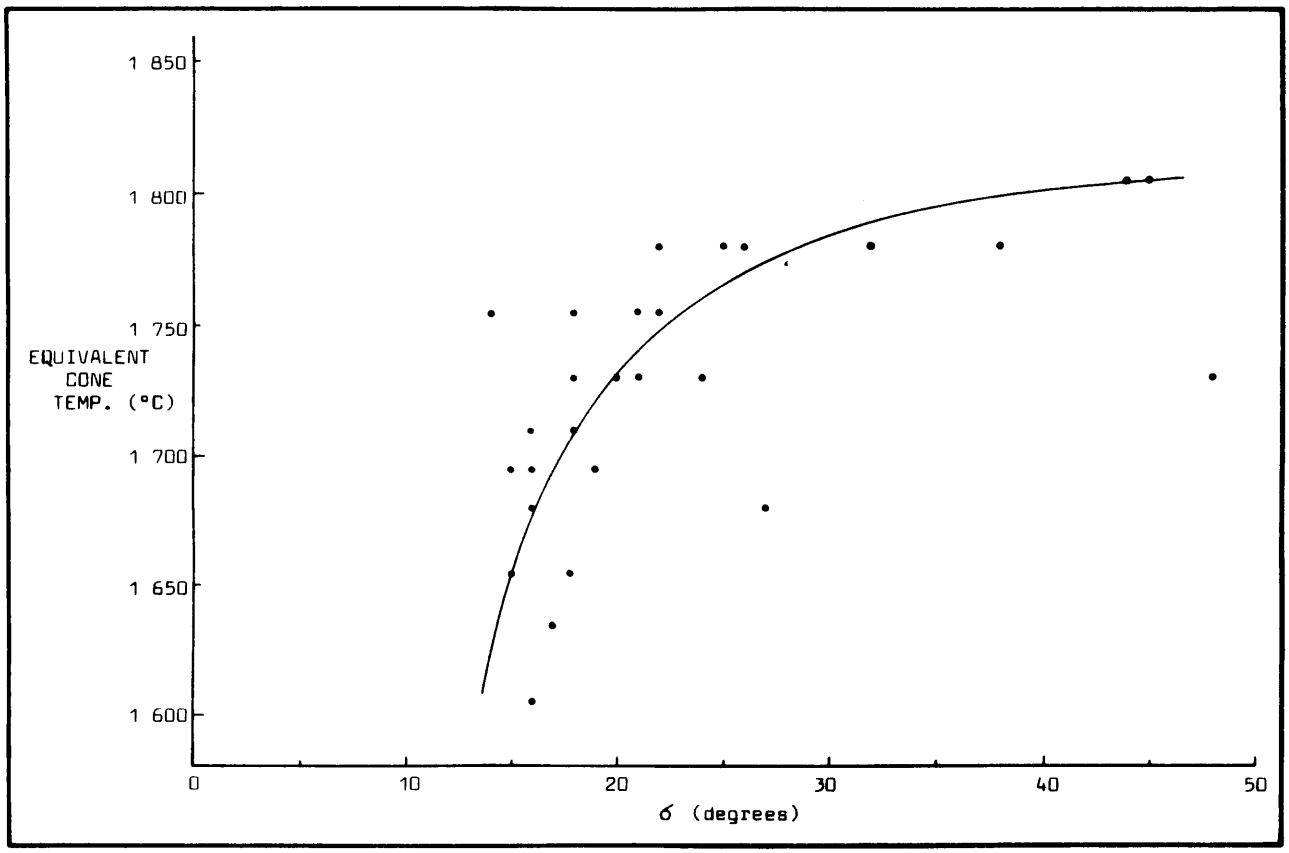

Fig. 5.33 Negative correlation between the degree of preferred orientation (expressed as standard deviation) and fusion temperature (r = 0,590).

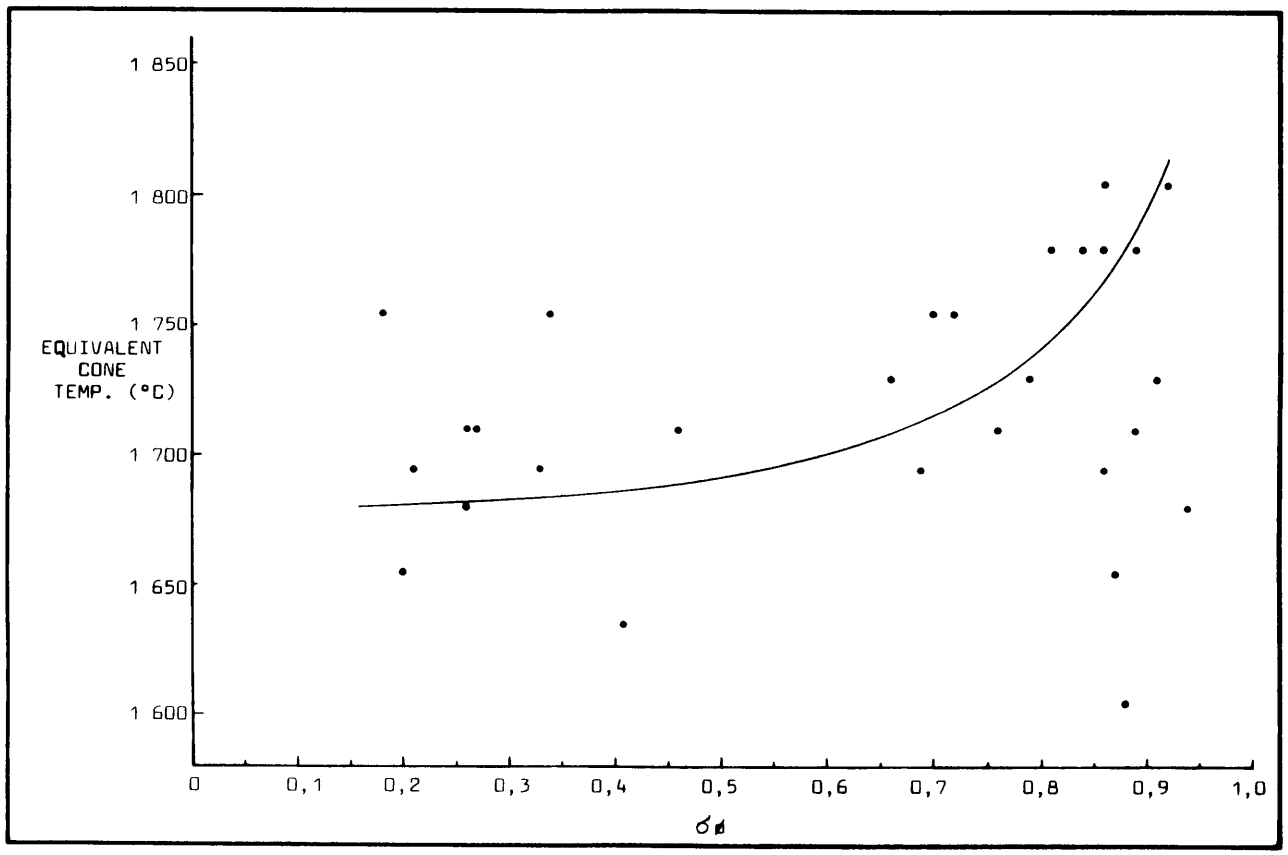

Fig. 5.34 Weak negative correlation between grain-size sorting (expressed as standard deviation) and fusion temperature (r = 0,271).

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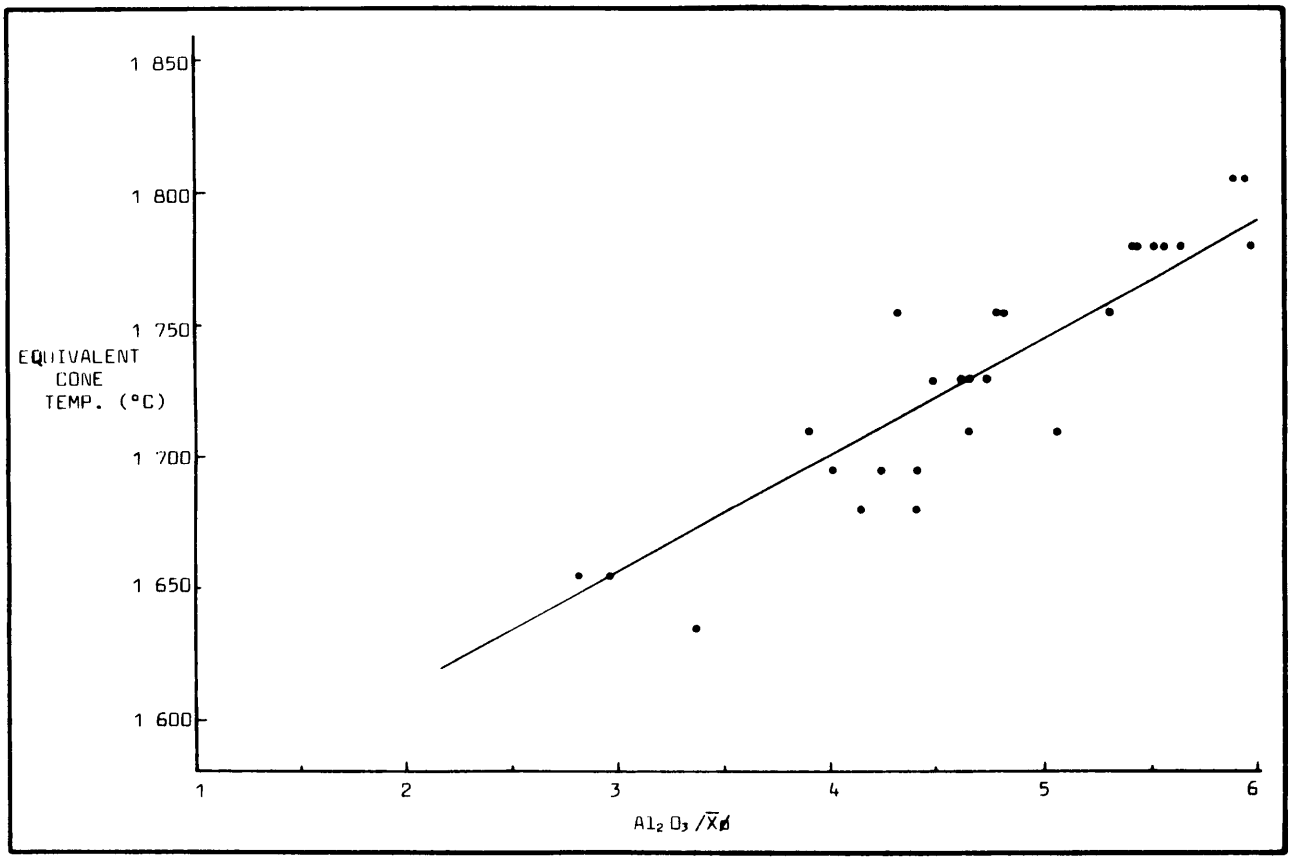

Fig. 5.35 Positive correlation of a combination of Al_2O_3 and average particle size with fusion temperature (r = 0,915).

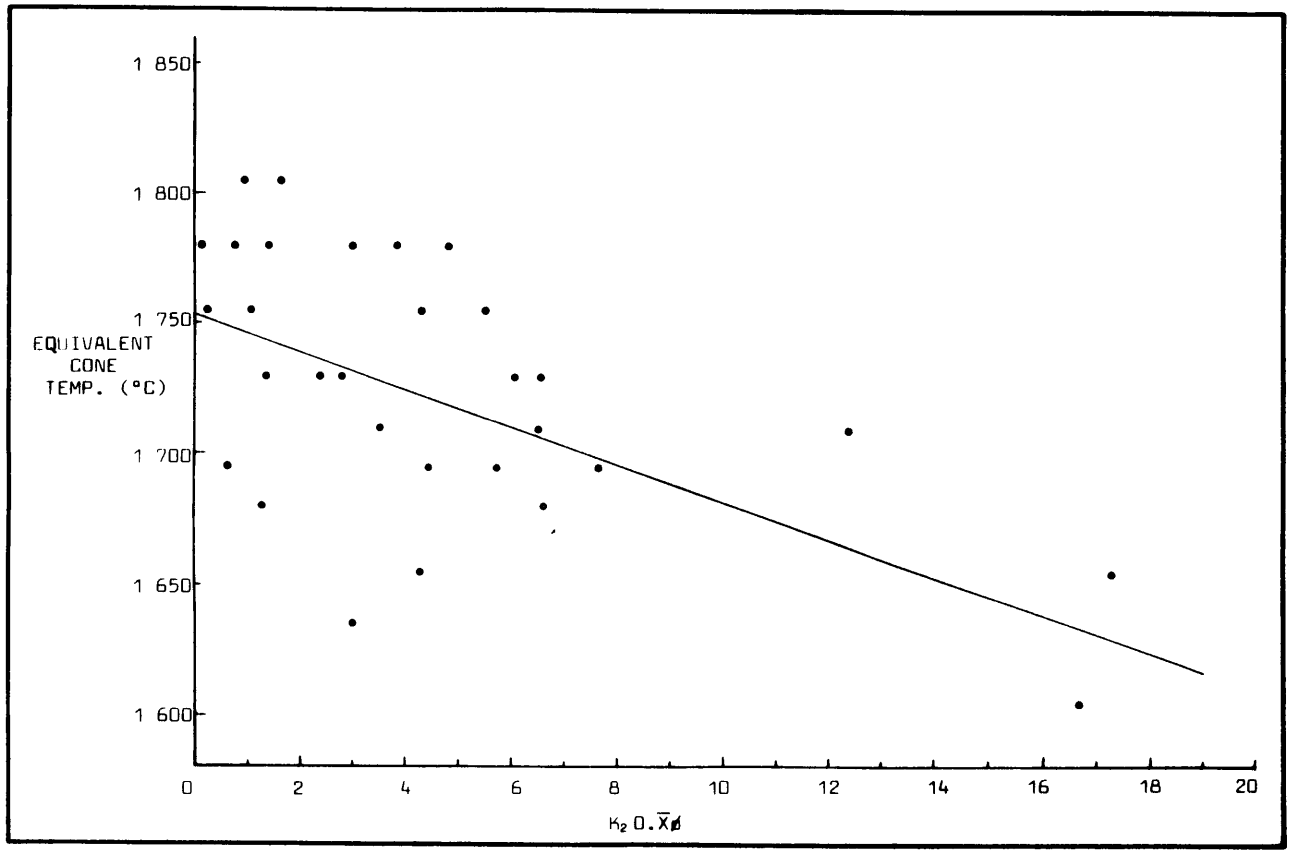

Fig. 5.36 Weak negative correlation of a combination of K_2O and average particle size with fusion temperature (r = -0,537).

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5.10 COLOUR – CHEMICAL COMPOSITION

The colour of a clay is certainly one of the most frequently recorded features and the question can therefore rightfully be asked whether such observations can in fact be meaningfully interpreted in terms of clay quality. It is generally accepted that the colour of a clay is somehow related to its composition and texture, but can such a relationship be quantified? Because of their fine-grained nature, refractory clays lend themselves perfectly to a comparison of colour and composition and an experiment was consequently conducted on 48 homogeneously coloured specimens. Colours were recorded by comparison with the "Rock-color Chart" of the Geological Society of America (1963) after drying the test specimens in the sun for about 4 hours. Chemical analyses were subsequently performed according to the techniques described in Chapter 3. Half of the samples selected had a very low iron content and their colours which ranged from white (N9) to grayish black (N2) can therefore be interpreted as being almost entirely due to differences in carbon content. The results displayed in Fig. 5.37 indicate quite a good correlation which allows a rough estimate to be made of the amount of carbon in a clay of this nature. The other set of samples had hues ranging from red (R) to yellowish-red (YR) which, according to their chemical compositions, were largely due to varying amounts of iron. Fig. 5.38 shows how the chroma or degree of colour saturation (the last digit in the colour symbol) may be used as a rough approximation of iron content. It should be emphasised, however, that these relationships would not be applicable to multicoloured clays or clays where the colour is not uniformly distributed.

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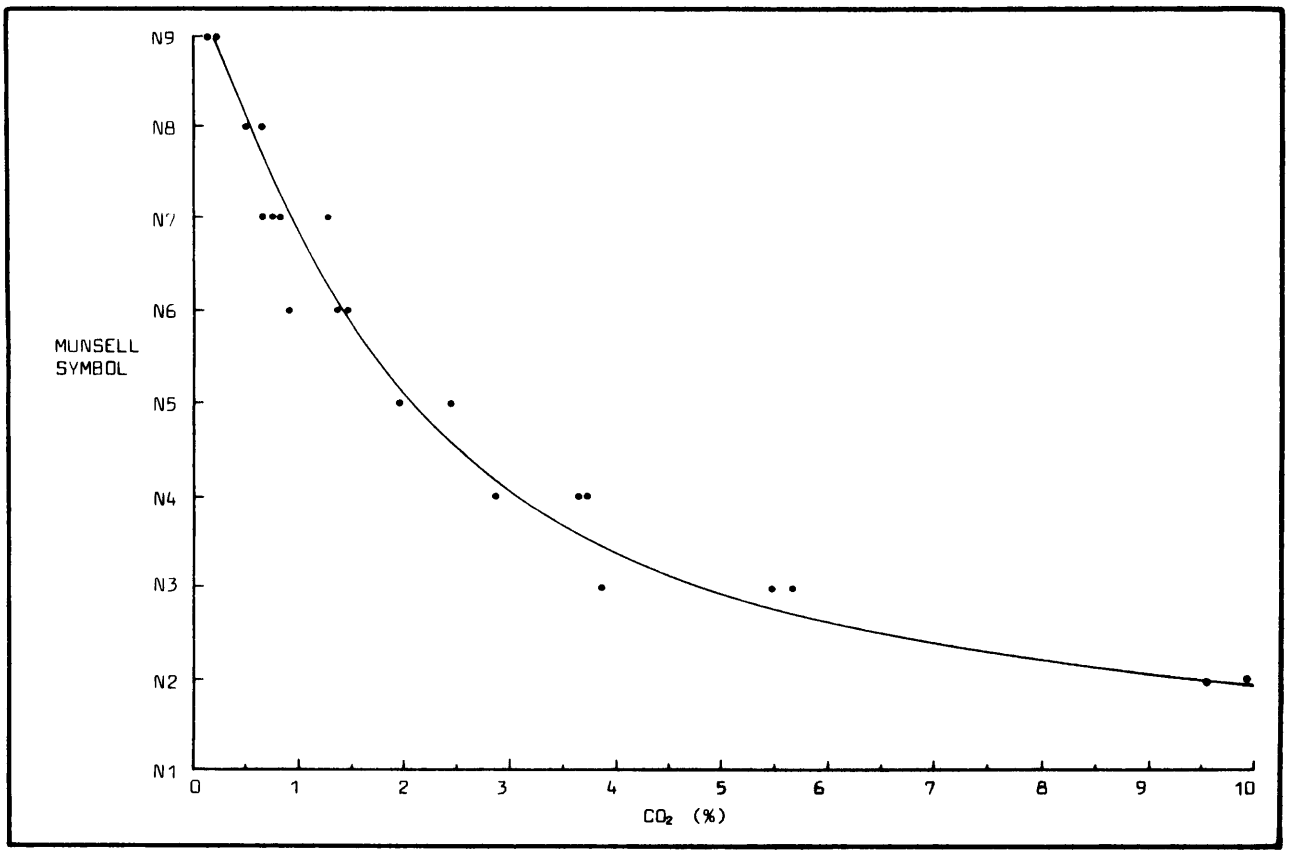

Fig. 5.37 Relationship between carbon content (expressed as CO_2) and the greyness value of selected specimens of refractory clay (r = -0,874).

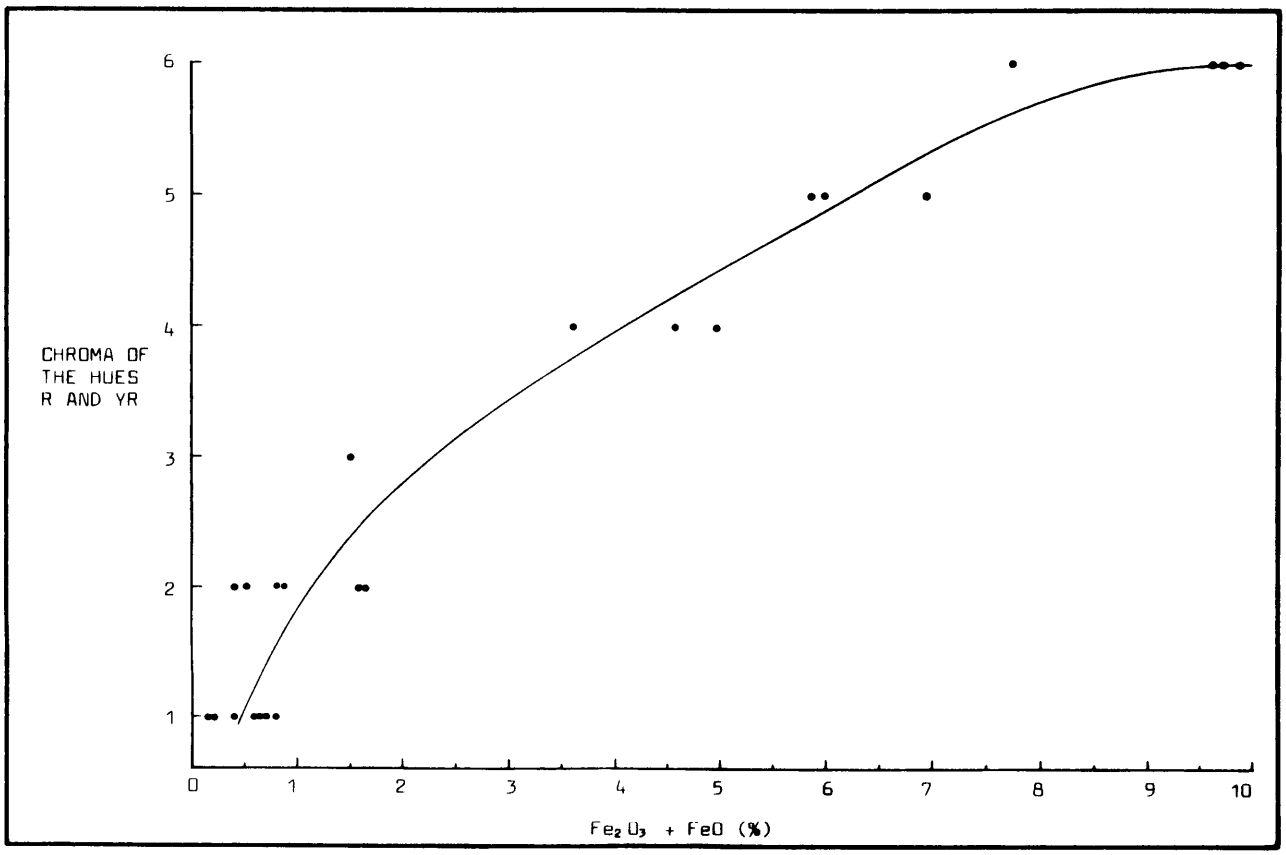

Fig. 5.38 The degree of colour saturation (chroma) of reddish and yellowish-red refractory and non-refractory clays as an approximation of the iron content (r = 0,966).

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6. REFRACTORY CLAYS AS A POSSIBLE SOURCE OF ALUMINA

Since aluminium is the third most abundant element in the earth's crust, it is somewhat surprising that commercial production of this metal has up to now almost exclusively been derived from its hydrated oxides, either gibbsite or boehmite. The Bayer process for alumina extraction and the Hall – Héroult smelting process were both specifically designed for bauxite as raw material and these two processes are still dominating the aluminium industry after almost a century since their development. Most of the major bauxite deposits are, however, located in remote tropical areas in less industrialised countries and it can be regarded as a scarce commodity compared to aluminium silicates which form a major constituent in most rocks and their weathering products.

For various reasons, some actually economical and others purely political, interest in finding a suitable substitute for bauxite has revived from time to time in industrialised countries over the last 40 years. The first serious attempt in this regard was during World War II when the bauxite supply from South America to the USA became jeopardised (Grim, 1962). This led to the launching of a large research effort and the eventual conclusion that high-alumina clay fulfills more of the requirements of an alternative for bauxite than any of the other aluminous rocks. Several pilot plants were put in operation, but with the end of the war and the restoring of bauxite supplies, the incentive was temporarily lost. However, other aspects such as environmental considerations have since prompted the search for alternative raw materials and extraction processes (Peacy and Davenport, 1974). Numerous processes have been developed in different countries and demonstrated to be technologically feasible on a laboratory scale. Few of these have, however, reached the pilot-plant stage and up to now neither a process nor a substitute raw material has been proved to be economically competitive with the conventional bauxite – Bayer route on a commercial basis. The only alumina production from a non-bauxitic source on an industrial scale has been in the Soviet Union where nepheline syenite is used as raw material (Baer, 1959).

In view of its total dependence on imported alumina for the local aluminium-producing industry established at Richards Bay in 1971, South Africa has more incentive than most other countries to become at least partly self sufficient in alumina. This is particularly true in the light of a second smelter which was purchased by ALUSAF in 1981 and which is expected to double the present aluminium production of 84 000 t per year (Groenewald, 1982). Over the last 20 years, the Geological Survey and the Council for Mineral Technology (Mintek) have carried out several investigations to assess the possibility of producing alumina from

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locally available resources. Refractory clay has featured strongly in most of these assessments and no discussion on this commodity would be complete without considering its potential as an ore of alumina.

The author has been closely involved in these studies since 1974 and Table 6.1, which is an updated version of the table presented in Bredell (1975b), provides a comparative summary of the various non-bauxitic raw materials in South Africa which could be considered as sources of alumina. The data were obtained from numerous published and unpublished sources of which the following are the most important: Brabers (1974), Coetzee and Hanekom (1963), Coetzee (1965), Coetzee (1964), De Villiers (1973), Frick (1976), Nel (1974), Retief (1965), Smit (1962), Visser and Schoch (1973). Only the most important geological and mineralogical considerations are dealt with, but it becomes quite clear that even if measured against these basic requirements, the majority of raw materials does not qualify for further investigation. The two most promising materials appear to be coal ash (fly ash) and plastic refractory clay, but in view of the fact that the most advanced non-bauxitic processes have been tested on kaolinitic clay, the latter appears to be the best proposition.

Of the many patented processes to which refractory clay would be amenable, carbo-chlorination and acid-leaching seem to have been the most successful. The most promising of these are in turn the TAC (or Toth) process developed by the Toth Aluminium Corporation in the United States, and the H-plus process of Pechiney Ugine Kuhlmann of France. The TAC process involves chlorination of calcined clay (mixed with coke) to form aluminium trichloride (Peacy and Davenport, 1974) which could either be smelted directly or converted to alumina for use in a conventional Hall – Héroult smelter. In the H-plus process, clay is leached with concentrated H_2SO_4 and HCl, and alumina is recovered as the end product (Cohen and Mersier, 1976). As a joint venture between ALCAN and Pechiney, an H-plus pilot plant with a capacity of 20 Mt alumina per year was erected near Marseilles during 1976 (Anon., 1974). The raw-material specifications of both these processes are not very stringent and could be met by even low-grade refractory clay. For the H-plus process, the chemical requirements of a kaolinitic clay is for example as follows (D.J. Erasmus, IDC – pers. comm.):

$$Al_2O_3 > 25 \text{ per cent}$$
$$Fe_2O_3 < 8 \text{ per cent}$$
$$56\,(MgO/40 + Na_2O/62 + CaO/56) < 0{,}1\,Al_2O_3$$

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TABLE 6·1 A GEOLOGICAL AND MINERALOGICAL COMPARISON BETWEEN THE DIFFERENT LOCALLY AVAILABLE NON-BAUXITIC POTENTIAL ORES OF ALUMINIUM.

PROPERTIES	RAW MATERIAL													
	1. ANDALUSITE	2. ANORTHOSITE	3. ALUMINUM PHOSPHATES	4. ALUNITE	5. COAL ASH	6. DIASPORE BEARING SHALES	7. FLINT CLAY	8. IJOLITE	9. KAOLIN	10. PHLOGOPITE	11. PLASTIC REFRACTORY CLAY	12. PYROPHYLLITIC SHALE	13. SERICITE	14. STAUROLITE	15. SYENITE (PHALABORWA)
1. MAIN Al_2O_3-BEARING MINERAL(S).	Andalusite	Plagioclase	Aluminium phosphate (Various minerals.)	Alunite	Mullite	Diaspore	Kaolinite	Nepheline	Kaolinite	Phlogopite	Kaolinite	Pyrophyllite	Muscovite	Staurolite	Orthoclase, albite, plagioclase
2. PERCENTAGE OF MAIN Al_2O_3-BEARING MINERAL(S) IN THE RAW MATERIAL.	± 20% by weight in andalusite bands. Average recovery ± 7%	79–95%, with the maximum in the critical zone of the Bushveld Complex.	Not known.	Not known.	± 40%, which contains about 80% of the alumina. The remaining 20% is associated with a glassy component	Maximum 40%, usually less than 5%.	± 90–99%	58,3% (Average of 6 core samples)	± 80–99%	Not known	80–99%	± 50–95%	Not known	10–12% (recovered in tests from the shale host rock).	a. Fenites: 67–96%; Av. 83% b. Syenite plugs: i. Porphyritic: 56–79%; Av. 68% ii. Hypidiomorphic: 59–94%; Av. 82% iii. Granular: 59–89%; Av. 74% iv. Gneissic: 57–85%; Av. 76%
3. CHEMICAL COMPOSITION OF MAIN Al_2O_3-BEARING MINERAL(S).	Al_2SiO_5	Varying between Ab ($NaAlSi_3O_8$) and An ($CaAl_2Si_2O_8$) Plagioclase composition varies between An_{44}–An_{86}	Various minerals of varying composition	$KAl_3(OH)_6(SO_4)_2$	Varies between limits $\geq Al_2O_3$ $\leq SiO_2$ and $\geq Al_2O_3$ SiO_2	$AlO(OH)$	$Al_2Si_2O_5(OH)_4$	$(Na,K)(AlSi)_2O_4$	$Al_2Si_2O_5(OH)_4$	$KMg_3AlSi_3O_{10}(OH)_2$	$Al_2Si_2O_5(OH)_4$	$Al_2Si_4O_{10}(OH)_2$	$KAl_3Si_3O_{10}(OH)_2$	$FeAl_4Si_2O_{10}(OH)_2$	Varying proportions of $KAlSi_3O_8$, $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$.
4. THEORETICAL Al_2O_3 CONTENT OF THE MAIN Al_2O_3-BEARING MINERAL(S).	63,2%	Between 19,4% (albite) and 36,6% (anorthite)	Varying from mineral to mineral.	37,0%	62,0–71,8%	85%	39,5%	35,9% in the artificial compound $NaAlSiO_4$	39,5%	12,2%	39,5%	28,3%	38,4%	55,9%	Orthoclase: 18,4% Plagioclase: 19,4–36,6%
5. PERCENTAGE Al_2O_3 IN RAW MATERIAL (OR CONCENTRATE).	Av. 52% in concentrate (W Tvl.) Av. 60% in concentrate (E. Tvl.)	25–34% in raw material.	0,6–21,1% (Av. 10,5%) in raw material.	Not known.	25 – 35 %	In samples with an average diaspore content of 10,9%, the whole-rock Al_2O_3 content was found to be ± 30%.	Raw material: 30,5–40,1% (Av 38,1%) Calcined: 33,8–46,1% (Av 44,1%)	14–27% (Av 19%) (Ijolite samples)	20–38% (Raw material)	± 12%	Raw material: 26–39% (Av 34%) Calcined: 30–46% (Av 38%)	As these shales usually contain some diaspore, no figures on the pyrophyllitic parts as such are available	23–30% (in raw material).	39–48% (in concentrate)	a. Fenites: 13–19%; Av. 16% b. Syenite plugs: i. Porphyritic: 10–15%; Av. 13% ii. Hypidiomorphic: 11–18%; Av. 15% iii. Granular: 11–17%; Av. 14% iv. Gneissic: 11–16%; Av. 13%
6. LOCALITY (-IES).	Marico area (W Tvl.) North of Burgersfort (E.Tvl.)	Bushveld Complex (Transvaal)	Saldanha and Langebaan. (Cape Province.)	Vioolsdrif (NW Cape Province.)	Sasolburg, Secunda Various power stations.	Between Sishen and Postmasburg (N. Cape Province)	Pretoria – Belfast area	Spitskop Alkaline Complex (Grobiersdal district, Tvl.)	Numerous localities in the Cape Province, Natal and Transvaal.	Phalaborwa Complex (NE. Transvaal)	East and West Witwatersrand (Transvaal.)	Between Sishen and Postmasburg. (N. Cape Province)	Ventersdorp district. (Transvaal)	North of Burgersfort. (E.Tvl.)	Phalaborwa Complex (NE. Transvaal)
7. MODE OF OCCURENCE.	a. In upper Timeball Hill shale along a strike length of ±70 km. (W. Tvl.) b. In Magaliesberg, lower and upper Timeball Hill shale along a strike length of ± 200 km (E. Tvl.)	As layers in the critical-, main and upper zones of the B.C. Mottled anorthosite of the main zone attains thickness of 100m – well exposed in places. The anorthosite unit in the critical zone is ± 300m thick.	Replacement deposits in joints and cracks in quartz–pophyry hills.	Accompanied by gypsum in veins up to 7,6 cm wide in weathered shale of the Kuibis Formation. Strike length more than 100 m. The veins probably do not penetrate to great depth	A waste–product from gasifier and boiler plants.	Diaspore–bearing shales occur as inclusions in the basal terruginous zone of the Gamagara Formation. The Gamagara shale occurs locally in irregular basin–like structures on top of the Blinkklip–,or Silica–breccia The basins occur along a zone about 50 km long and 10km wide.	In small isolated pockets of the Ecca Group as layers and lenses 2–3 m thick with an overburden (soil and grit) 1–15m thick.	As dykes and sills intrusive into pyroxenite. Core drilling revealed no sign of a solid ijolite body. The dykes and sills were found to be between 0,1 and 4,0m thick and comprised between 15 and 50% of the core recovered	Residual deposits derived from the weathering of predominantly granite or shale	In streaks and schlieren throughout the pyroxinite body of the Complex. Maximum concentration and best development of books is in the northern pegmatoid body.	As layers 2–5 m thick at the base of the Ecca Group on the East Rand and as thick deposits (20–40 m thick) in outliers of the Ecca Group on the West Rand.	Pyrophyllite forms the matrix of the Gamagara shales which are locally diaspore–bearing. These shales occur in irregular basin–like structures on top of the Blinkklip– or Silica–breccia. The basins occur along a zone about 50km long and 10km wide.	Interbedded with lavas and subordinate sediments of the Dominion Group.	a. In association with andalusite in lower and upper Timeball Hill shale. b. In slates at the base of the Timeball Hill Formation.	The fenites occur along the western rim of the central complex, while the syenites occur as small conical hills scattered around the central complex.
8. SIZE OF AN INDIVIDUAL DEPOSIT.	More or less continuous along strike.	Not known – probably very large.	Maximum 1 million t (inferred)	Not known – probably small.	Not applicable.	Maximum tonnage per basin is 2 million t of shale (not necessarily diaspore–bearing).	Less than 1 million t.	Not applicable.	200 000 t to about 15 million t	Not known.	Expected to be more than 100 million t (West Rand)	Maximum 2 million t	Not known	More or less continuous along strike.	Typical average size of a syenite hill is about 200 x 200m, which will have a tonnage of about 3,2 million t to a depth of 30m. The fenite is mostly soil–covered and the exact extent is not known.
9. CRYSTAL SIZE (IF APPLICABLE).	a. W Tvl. usually less than 2 mm (Av 1mm.) b. E. Tvl.: 4–8 mm	Not applicable	Not applicable	Not applicable	6 – 7 µm	From 0,1 x 0,2 mm to 2,0 x 7,0 mm. About 70% range between 0,1 x 0,2 mm and 0,2 x 0,4 mm	Not applicable.	Varies from fine– to coarse–grained, with the fine–grained variety being the most abundant.	Not applicable	Very–fine to large books more than 20 cm in diameter.	Not applicable.	Forms the fine–grained matrix in which the diaspore crystal are embedded.	Not applicable.	About 1–2 mm if together with andalusite, with a lmax. size of 2–3 cm if occuring by itself.	Not applicable.
10. POSSIBLE BY–PRODUCTS (IF ANY).	Staurolite as a waste–product.	Cement from the dicalcium silicate which is produced as a by–product during alumina extraction.	Phosphate. The ore contains 3,3–25,4% P_2O_5 (Av. 15,2%)	Gypsum (?)	None	None	None	Possibly potash. K_2O content is, however, not very high (2–5%).	None	Potash. Theoretical K_2O content is 11,3 %	None	None	Potash (7–10% K_2O in raw material).	Staurolite is a waste–product of andalusite mining in the E.Tvl.	Potash, K_2O content as follows a. Fenites: 7–14%; Av. 11% b. Syenite plugs: i. Porphyritic: 8–12%; Av. 10% ii. Hypidiomorphic: 9–15%; Av. 12% iii. Granular: 8–12%; Av. 10% iv. Gneissic: 5–12%; Av. 10%
11. OTHER USES FOR THE RAW MATERIAL.	Used in the refractories and ceramic industries.	None.	Fertiliser	In medicine.	In concrete, mortar, road surfacing. Filler in clay products, fertilizer, etc.	As a refractory.	Refractory raw material (super–duty refractory).	None.	Ceramics, paper, paint, rubber, insecticides, plastics, cosmetics, etc.	As an electrical insulator. (No phlogopite is produced in R.S.A. at present.)	a. Refractory raw material. b. Pipes and tiles. c. Face and stock bricks (if blended with shale)	Could be used for the same purposes as talc.	None	None	None
12. IDENTIFIED RESOURCES OF RAW MATERIAL (OR CONCENTRATES).	72 Mt andulasite as identified resources.	No estimate – probably very large.	Measured reserves: 413 500 t of aluminium phosphate. Inferred resources: More than 1 million t.	No estimate – probably small.	Total reserves not known, but are more than adequate as ± 10 Mt of coal ash is produced per year.	No estimate for the actual diaspore–bearing shales. Most probably small and scattered.	21 Mt as identified resources.	Calculated over an area of 6,8 km^2 to a depth of 30m, assuming a value of 20% for the ijolite content, and a nepheline content of 58,3% for the ijolite, the reserves of nepheline could be in the order of 61,9 million t.	± 46 Mt as identified resources.	No estimate.	Inferred resources on the West Rand more than 200 million t.	No estimate – total reserves probably much more than the ± 5,6 million t reported from four investigated localities.	± 1,2 million t (calculated to a depth of 15m.)	No estimate – most probably large.	Probably in excess of 50 million tons.
13. REMARKS.	a. Total reserves possibly adequate, but distributed over a long strike length. b. The waste–product staurolite is also considered as a possible source of alumina. c. Up–grading through ore–dressing techniques is required.	a. Adequate reserves. b. Hard to mine and crush. c. Ferromagnesian minerals and/or magnetite is present. d. No by–products. (Production of cement from dicalcium silicate is not economically feasible as the local cement industry has an adequate capacity to meet the demand.	The known reserves are inadequate.	The known reserves are inadequate.	a. Being a waste product, it will be cheap. b. Readily available in sufficient quantities. c. Reserves are not likely to be exhausted, since the annual production of ± 3 Mt of alumina (in the ashes) is about 10 times the present requirement.	a. High alumina content; not bound to silica. b. Irregular basins, usually not exposed at the surface, as well as the irregular distribution of diaspore within the shales would render prospecting and mining extremely expensive. c. Up–grading through ore–dressing would be required.	a. Known reserves for open–cast mining are inadequate. b. Deposits are small and isolated. c. Selective mining will have to be done to avoid siliceous and carbonaceous parts. d. Flint clay is in big demand as a refractory material. e. No by products.	a. Relatively low Al_2O_3 and K_2O contents. b. Ijolite and pyroxenite are in close association and seperation could raise mining costs to a high level. c. Solid ijolite most probably exists in depth, but this would require under–ground mining.	a. Adequate reserves. b. Soft, easy to mine. c. No by–products.	a. Low Al_2O_3 content. b. Potash as a possible by–product.	a. Large reserves, considerable thickness, overburden seldom exceeds 5m. b. Ample reserves are available for the refractories and ceramic industries. c. No by–products.	a. Reserves are probably adequate. b. Alumina content low in comparison with the diaspore. Pyrophyllite, however, constitutes the bulk of the shale. c. Pyrophyllite contains alumina in silicate form, while diaspore is hydrated alumina. If both minerals are to be utilized in alumina production, two different extraction processes will probably have to be used. This might not be economically feasible due to the low alumina content of the silicate mineral.	a. Relatively high Al_2O_3 and K_2O contents. b. Known reserves are inadequate.	Staurolite is only being produced as a waste–product at one recently opened andalusite mine in the E.Tvl. No significant amount of staurolite has been dumped at this locality, mainly because the staurolite parts are being avoided as far as possible. Running an alumina producing plant on the presently produced staurolite alone will definitely not be an economic proposition. Up–grading through ore–dressing would also be required.	a. Reserves are adequate. b. Potash as by–product. c. Selective mining of any of the four different syenites will not be economically feasible. Either the fenites or the syenite plugs (as a whole) will ha The sy easier

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Of the refractory clays, flint clay would certainly be the most suitable material, but in view of obviously limited resources and its strategic importance in the refractories industry, it can be disregarded as a potential source of alumina in South Africa. The plastic refractory clays on the West Rand appear to be the most attractive proposition in this respect. Although containing about 5 per cent less alumina on average than the flint clays, large resources of this material have been indicated, adequate amounts of similar clay are available for the refractories and building-brick industries, the deposits are confined to a relatively small area with a well-developed infrastructure, and mining costs can be expected to be low. Assuming that about half of the inferred resources of 200 Mt of clay would be mineable at an average alumina content of 30 per cent of which 80 per cent could be recovered by either an acid-leaching or carbo-chlorination process, the West Rand deposits seem capable of meeting local alumina requirements for a period of about 80 years at an estimated annual demand of 300 000 t.

The discovery of appreciable resources of low-grade bauxite in Natal since 1976 (Bredell, Barnardo and Horn, 1980; Bredell, 1983) has largely, but not totally, eliminated the incentive for further research on non-bauxitic materials. There still seems to be general concensus amongst leaders in the aluminium industry that "... the best substitute for bauxite is lower-grade bauxite ..." (Balkay, 1975), and there is no doubt that the Natal bauxites would receive top priority when contemplating local production of alumina. Recent beneficiation tests conducted by Mintek on bulk samples of this material have also yielded very promising results (Levin, 1983). A serious disadvantage of these deposits is, however, that the resources are distributed over more than 20 individual plateaux, an aspect which will certainly complicate exploitation. It is therefore not impossible that economic considerations could eventually tip the scales in favour of a non-bauxitic alternative such as refractory clay.

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7. SUMMARY AND CONCLUSIONS

Refractory clay is *defined* for the purposes of this study as any clay with a fusion temperature of at least 1 605°C (Seger cone 27) and which is suitable or potentially suitable for use in the manufacturing of ceramic refractory products. It is recommended that formal usage of the popular term "fireclay" be avoided as it is prone to ambiguous interpretation if not properly defined in its context. For practical reasons, the *classification* system for refractory clays as proposed by Bennetts (1965) has been adopted. It is based on two most important quality-determining parameters, *viz.* bulk density which defines clay type (plastic, semi-plastic, semi-flint and flint), and alumina content on a calcined basis which reflects the purity and refractoriness of the clay and allows a grading from I to IV.

Refractory-clay products comprise more than half of all refractories produced in South Africa and most high-temperature industries have become vitally dependent on this commodity. Over the last decade, the export trade in high-grade calcined flint clay has become a significant earner of foreign exchange. An assessment of refractory-clay *production* and *sales* for the period 1961 – 80 reveals the cyclic nature of this industry, indicating its intimate dependence on the national economy. Assuming this trend to continue, an average total annual production of about 500 000 t of refractory clay can be expected over the next 20 years. An alarming aspect is the fact that flint and non-flint types are being produced at roughly the same rate, in spite of the much more limited known reserves of the former. As a result of increasing local demand, exports of flint clay have, however, rapidly declined since 1971 and it is particularly encouraging that the export of raw flint clay has become insignificant since 1972. It is not considered in the national interest to resume export of this unprocessed material at low unit cost. Of the total expected local sales of about 7,5 Mt for the period 1981 – 2000, some 4 Mt are estimated to be flint and 3,5 Mt non-flint refractory clay. Judged only on sales value, the contribution of refractory clay to the South African mineral industry is rather insignificant, amounting to only about 0,06 per cent of the total mineral sales. In spite of this, refractory clay can be regarded as one of the most strategic industrial minerals if measured in terms of its direct and indirect impact on so many other industries.

The present investigation was triggered in the early seventies by realisation of the fact that potentially valuable but undiscovered deposits of refractory clay were being sterilised by rapid urban expansion, particularly on the Witwatersrand. Being a comparatively low-priced commodity which can only be exploited economically by open-cast methods within reason-

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able distance from the major consumer industries, refractory clay is particularly vulnerable to being rendered permanently unmineable by any surface development. The basic *aims* of this study are therefore to locate sufficient resources of refractory clay in areas where these deposits can be reserved, and secondly to delineate potential resources on a regional scale which could, as far as practically possible, be protected from sterilisation. In order to assist in future exploration, genetic and depositional models are formulated and interrelationships between the physical and chemical properties of the clays are illustrated as an aid in evaluating the raw material from laboratory measurements.

All deposits of refractory clay in South Africa are confined to the basal part of the *Ecca Group* in the Transvaal. On a regional scale, the 26° line of latitude roughly subdivides the known deposits into *two provinces* according to type. In the north, flint clays predominate in the form of small deposits which are largely confined to Ecca outliers, while to the south more extensive deposits of essentially plastic clay are located along the margins of the main sheet of Ecca sediments (East Rand) as well as in exceptionally thick outliers situated on dolomite (West Rand). Although the investigation was mainly concentrated on the East and West Rand and the Pretoria – Belfast area, an *inventory* of all known refractory-clay deposits and occurrences in the Transvaal is included. This comprises an alphabetical list of 90 farms and contains information on the type and grade of the clay in each case as well as the mining and extent of individual deposits.

The fundamental problem in refractory-clay *exploration* is the fact that natural outcrops of the material are virtually non-existent and sub-outcrops do not reveal themselves by a characteristic surface expression of any kind. Techniques such as geochemistry and geophysics have no or very limited application in the search for refractory clays and exploratory drilling has to be guided almost exclusively by geological interpretation. This in turn is complicated by the vast or poorly established distribution of the host formation (Ecca Group) in the Transvaal. No fixed set of procedures can be applied to locate new deposits of refractory clay; each area requires a different approach to identify target sites. The following basic steps are, however, proposed as a guide: Establish the extent of the host formation, determine the stratigraphic position of the clay, eliminate areas of excessive overburden and areas sterilised by surface development, reconnaissance drilling, follow-up drilling, and quality and resources assessment.

Diamond-drilling is by far the best technique for the subsurface sampling of refractory clay and was used throughout the exploration programme. For the purposes of core description,

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the different clay types can be readily distinguished with some experience. *Plastic* clays are soft, commonly laminated and become completely plastic when saturated with water. Semi-plastic clay is slightly harder and only becomes plastic after prolonged soaking in water. *Semi-flint* clay is considerably harder and completely non-plastic with a predominantly conchoidal fracture, while *flint* clay is still harder and characterised by a conchoidal fracture on even the smallest pieces.

All determinations of *bulk density, apparent porosity* and *pyrometric cone equivalent* were performed by the National Building Research Institute of the C S I R. The small type of Seger cone was used in respect of all samples. *Chemical analyses* were carried out by the Geological Survey Laboratory and most of the elements were determined by means of X-ray fluorescence. A pH-meter with glass electrode was used to measure the *fossil pH* of pulverised samples in suspension. The approximate quartz content was calculated from X-ray diffraction peaks, but the rest of the *mineralogical* constituents were only established qualitatively (N B R I). Quantitative determinations for kaolinite and illite were performed on some of the samples by applying the technique developed by Pearson (1978). Measurements of *grain size* and *particle orientation* were done directly on scanning electron micrographs.

The part of the *East Rand* selected for exploration is situated between 28° 15' and 29° 00' E, and between 26° 00' and 26° 30'S. The Karoo Sequence covers about 3 100 km² or 75 per cent of this area. After establishing that the refractory clays always occur at or near the base of the Vryheid Formation, it was concluded that only areas where this formation is less than about 30 m thick needed to be considered for exploration. By constructing an isopach map from the logs of some 1 500 boreholes, these areas where refractory clay may be expected to occur at mineable depth could be delineated. A generalised pre-Karoo geological map was also constructed, but although there is a strong tendency for known refractory-clay deposits to be underlain by dolomite, it is concluded that the pre-Karoo geology cannot be used as a reliable guide for exploration. Ten reconnaissance boreholes were drilled and promising intersections were obtained on three farms (Modderfontein 76 IR, Daggafontein 125 IR and Rietfontein 276 IR). Subsequent follow-up drilling on *Modderfontein* partly delineated a deposit containing 11,6 Mt of indicated clay resources of which 1,2 Mt are semi-flint, semi-plastic and plastic clay of good refractoriness (PCE 34^- to 35). The bulk of the deposit (8,8 Mt) comprises semi-plastic and plastic clay of low refractoriness (PCE 28 to 33^+), while the remainder consists of non-refractory feruginous plastic clay. On *Daggafontein,* thirteen follow-up boreholes indicated the presence of 4,1 Mt of semi-flint, semi-plastic and plastic

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clay of good refractoriness (PCE 34⁻ to 35) and 8,1 Mt of lower-quality refractory clay (PCE 30 to 33⁺). The deposit is considered a most attractive proposition for future exploitation as it is favourably situated with respect to infrastructure and the quality of the clay compares well with material mined elsewhere on the East Rand. At the third site on *Rietfontein* near Endicott, drilling established indicated refractory-clay resources amounting to 6,5 Mt of which about 3,0 Mt constitute semi-flint, semi-plastic and plastic clay with PCE values ranging between 34 and 35. On the *East Rand as w hole,* indicated resources of good-quality refractory clay amount to 21,8 Mt of which 10,5 Mt are located within the boundaries of presently active mining areas. In addition to this, 22,4 Mt of clay with a low refractoriness have been indicated and it is estimated that approximately 26,6 Mt of refractory clay have already been sterilised by urban development in this region.

The investigation on the *West Rand* was confined to the tract of dolomite between Bank Station and Lawley. Three main groups of Ecca outliers (south of *Bank Station,* at *Westonaria* and at *Lawley*) and numerous smaller outliers have been delineated in this area by using the combined results of the extensive drilling programme and gravity surveys carried out by the Geological Survey for sinkhole investigations. Ten reconnaissance boreholes were drilled, eight of which intersected refractory clay. The thickness of the clay layer varies between 15 and 40 m, with an average of about 25 m. The average overburden/clay ratio indicated by the boreholes is 0,27. The abnormal thickness of these deposits may be attributed to a gradual subsidence of the basins during deposition, causing swampy conditions necessary for clay accumulation to exist for prolonged periods. All except two of the 35 samples tested for refractoriness proved to be refractory clays with Seger-cone values ranging between 29⁻ and 35. Most of the samples are either plastic or semi-plastic types, but about one third can be classified as semi-flint. The area to the south of Westonaria appears to be the most promising for further prospecting; in one of the holes drilled here, a 36,5 m thick clay layer was intersected which gave PCE values of between 34⁻ and 35. *Total inferred resources* of clay similar to that found in the reconnaissance boreholes could be in excess of 200 Mt. Assuming these boreholes represent a fair reflection of the quality distribution within the West Rand outliers, about 70 per cent of the total resources can be expected to consist of clay with a good refractoriness, while clay with a low refractoriness and non-refractory clay constitute approximately 27 and 3 per cent respectively. At present the West Rand clays are being used only for the manufacture of structural clay products, but it is expected that exploitation of these vast resources for the refractories industry would commence in the near future. It is strongly recommended that these unique deposits be safeguarded from sterilisation as far as possible.

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All production of flint clay and a large proportion of semi-flint clay production in South Africa have come from small outliers and tongues of the Ecca Group in the *area between Pretoria and Belfast.* This can be regarded as the most important refractory-clay producing region in the country. Apart from the distribution of the host formation, no exploration guide can be suggested and the choice of drilling targets for the present investigation was made after eliminating areas which had already been explored and by selecting the most promising of the remaining sites during a field survey.

Drilling on *Paardefontein* 282 JR failed to indicate the presence of economically significant clay and further prospecting within this outlier is not recommended because of the high-energy conditions which prevailed during deposition of Ecca sediments in the area. From *pseudo flint clay* in the Dwyka Formation at this locality, the following criteria are proposed for distinguishing such material from true Ecca flint clay: (1) The bulk density and apparent porosity do not correspond with the linear relationship between these properties which has been established for the Ecca clays. (2) The pH is anomalously high with respect to bulk density. (3) The TiO_2 content is significantly lower than the concentration range of 1,0 to 2,0 per cent in Ecca clays. (4) The Rb content is in the order of 100 ppm higher than the maximum value for refractory clay in the Ecca Group.

On *Kloppersbos* 128 JR, about 11 km south-east of Hammanskraal, ten boreholes indicated the presence of 3,23 Mt of clay with a good refractoriness. About 1,31 Mt are grade II and III semi-plastic, semi-flint and flint clay, while the remainder consists of grade IV semi-flint and flint types. Pyrophyllite which was identified in one of the samples is considered to have developed through *in situ* alteration of kaolinite as a result of elevated temperatures caused by the intrusion of a nearby dolerite dyke. Exploitation of this deposit would be hampered by subdivision of the surface rights but further drilling to the south is recommended as the best quality clay appears to extend and thicken in that direction.

About 20 km north of Bronkhorstspruit on *Rietfontein* 470 JR, a predominantly plastic refractory-clay deposit was partly delineated by eight boreholes. Indicated resources amount to 697 000 t of clay with a PCE in excess of 34. Grade I and II semi-flint, semi-plastic and plastic clay constitute about 262 000 t and the remaining 425 000 t are grade IV semi-plastic and plastic types. The deposit has definite economic potential and exploitation has already commenced.

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The *Nooitgedacht outlier,* which is the largest of the approximately 45 erosional relicts of the Ecca Group in the Pretoria – Belfast area, was investigated by 28 boreholes drilled along a roughly north – south traverse over a distance of some 9 km. The total stratigraphic thickness of the Ecca Group in this area is at least 140 m and a characteristic feature of the succession is a series of upward-fining units which are interpreted as the result of waning floods during the retreat of Dwyka glaciation. Measurement of palaeocurrent directions and a study of the pre-Ecca topography reveal the substantial control of the latter on the direction of sediment transport. In contrast to the Witwatersrand deposits, the clays in this outlier occupy different stratigraphic horizons, generally forming the tops of successive upward-fining cycles. Total resources of clay with a good refractoriness indicated by the drilling project are approximately 14,3 Mt of which the bulk (11,8 Mt) consists of grade I carbonaceous flint clay. Unfortunately, most of this material will not be economically extractable in the near future due to excessive overburden. The mining potential of the refractory clay should, however, be assessed in conjunction with other exploitable commodities in this outlier. Substantial thicknesses of unconsolidated grit and sand have been intersected at shallow depth and represent a potential source of concrete and building sand. In addition, a high-ash bituminous coal zone of up to 10,65 m thick is stratigraphically underlying the refractory clay.

In the *Middelburg area,* drilling was carried out on *Rietfontein* 314 JS and *Hartbeestfontein* 339 JS. On Rietfontein, only limited amounts of grade I flint and semi-flint clay were indicated, underlain by a substantial thickness of non-refractory, sericitic Dwyka pseudo flint clay. No refractory clay was found on Hartbeestfontein.

Plastic clay of good refractoriness, similar to that on Rietfontein 470 JR was intersected at mineable depth in two boreholes on *Klipfontein* 385 JS near *Belfast.* Further drilling is recommended. It is concluded that the small flint-clay bearing outliers north of Belfast represent remnants of isolated proto-basins, while mostly plastic clay was subsequently deposited further south in larger more distal basins under higher pH conditions.

Although drilling at two sites (*Doornrug* 302 JS and *Hartbeestspruit* 281 JS) to the *west of Witbank* yielded negative results, the potential of this area is still far from fully assessed and further exploration is strongly recommended. A better knowledge of the configuration of the pre-Vryheid floor is, however, essential for a logical selection of targets.

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The extensive sheet of Ecca sediments *between Middelburg and Belfast* has been largely unexplored. The absence of refractory clay in boreholes drilled on *Bankfontein* 375 JS can be ascribed to local unfavourable depositional conditions and is not necessarily representative of this whole region.

Total identified resources of refractory clay with a PCE of more than 34⁻ in the Pretoria - Belfast area are estimated at 23,5 Mt of which only about 3,4 Mt represent measured reserves of grade I flint clay under present conditions. The discovery of new deposits is a costly and time-consuming process and all identified deposits should therefore be utilised to the utmost and protected from sterilisation as far as possible.

It has been reported by various authors that the pH of an aqueous extract from a sedimentary rock reflects the original acidity of the environment at the time of deposition. It has also been proved that the pH of a clay-mineral suspension determines which clay-mineral species will flocculate, as well as the arrangement of clay particles in the floccules. By measuring the fossil pH of the clays and applying these principles, a model for *refractory-clay deposition* is formulated. It is proposed that almost pure kaolinite was deposited from a mixed clay-mineral suspension upon entering an acidic environment as could have been caused by a concentration of organic acids in swampy basins during the early stages of Ecca deposition. In the smaller proximal basins and at a low pH, kaolinite particles flocculated in an edge-to-face manner, giving rise to small flint-clay deposits. Under higher pH conditions in larger, more distal brackish basins, flocculation was essentially face-to-face, forming more extensive deposits of plastic clay. Gradual replacement of these conditions by a fluvial and lacustrine environment reduced the efficiency of differential flocculation and eventually led to the deposition of shale. It is suggested that this pH-controlled differentiation process played a much more important role in the purity and type differences of refractory clays than either the nature of the source material or post-depositional alteration.

Palaeocurrent directions in the vicinity of refractory-clay deposits indicate that at least the Witwatersrand clays and those in the Pretoria – Belfast area could have been derived from different principal *parent rocks*. An assessment of the trace-element composition of refractory clays which consist only of kaolinite showed that clays from different regions are characterised by differences in their Rb and Sr contents. By comparing these results with the Rb and Sr concentrations in kaolinite which has been derived from the *in situ* weathering of the most likely parent rocks, the following can be concluded: The West Rand clays received most of their kaolinite from Halfway House Granite with a possible contribution from

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Witwatersrand shale. Clays on the East Rand were derived from both Halfway House Granite and granite of the Bushveld Complex. Bushveld granite served as the main source for both flint and plastic clays in the Pretoria – Belfast area, but contributions from Rooiberg felsite, shales of the Pretoria Group and Waterberg arkose cannot be excluded. These conclusions are tentative and more detailed research is recommended.

A study of the *interrelationships* between the various chemical and physical properties of refractory clays illustrates the limitation of such measurements in assessing the quality of a clay. Some useful trends are, however, revealed. The linear relationship between bulk density and apparent porosity which has been proved by Bennetts and Pieterse (1963) in the case of flint and semi-flint clay, is shown to be valid for the entire range of refractory clays, and can therefore be used as an initial identification method. The correlation between fossil pH and bulk density as well as mineralogical composition provides a rapid way of estimating clay type and purity during reconnaissance exploration. Chemical composition, and particularly individual components, can be very misleading in trying to predict the refractoriness of a clay. Of the trace elements, only the Rb content, which reflects the amount of non-kaolinite clay minerals, may be used as an indicator of refractoriness within a specific area. A positive correlation between average grain size and refractoriness is indicated. Colour symbols may be used as a rough estimate of the carbon or iron content of a clay.

Refractory clay, particularly the large deposits on the West Rand, is indicated to be one of the most promising locally available *non-bauxitic raw materials* for the production of *alumina.* These clays should be amenable for treatment by either of the two most successful non-bauxitic processes developed so far, i.e. the carbo-chlorination process of the Toth Aluminium Corporation and the H-plus process developed by Pechiney Ugine Kuhlmann. The West Rand clay deposits should be capable of meeting local alumina requirements for about 80 years. However, the discovery of appreciable resources of low-grade bauxite in Natal has largely eliminated the need for further research on aluminium-silicate substitutes.

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APPENDIX 1

CALIBRATION CURVES FOR MAJOR ELEMENTS DETERMINED BY X-RAY FLUORESCENCE

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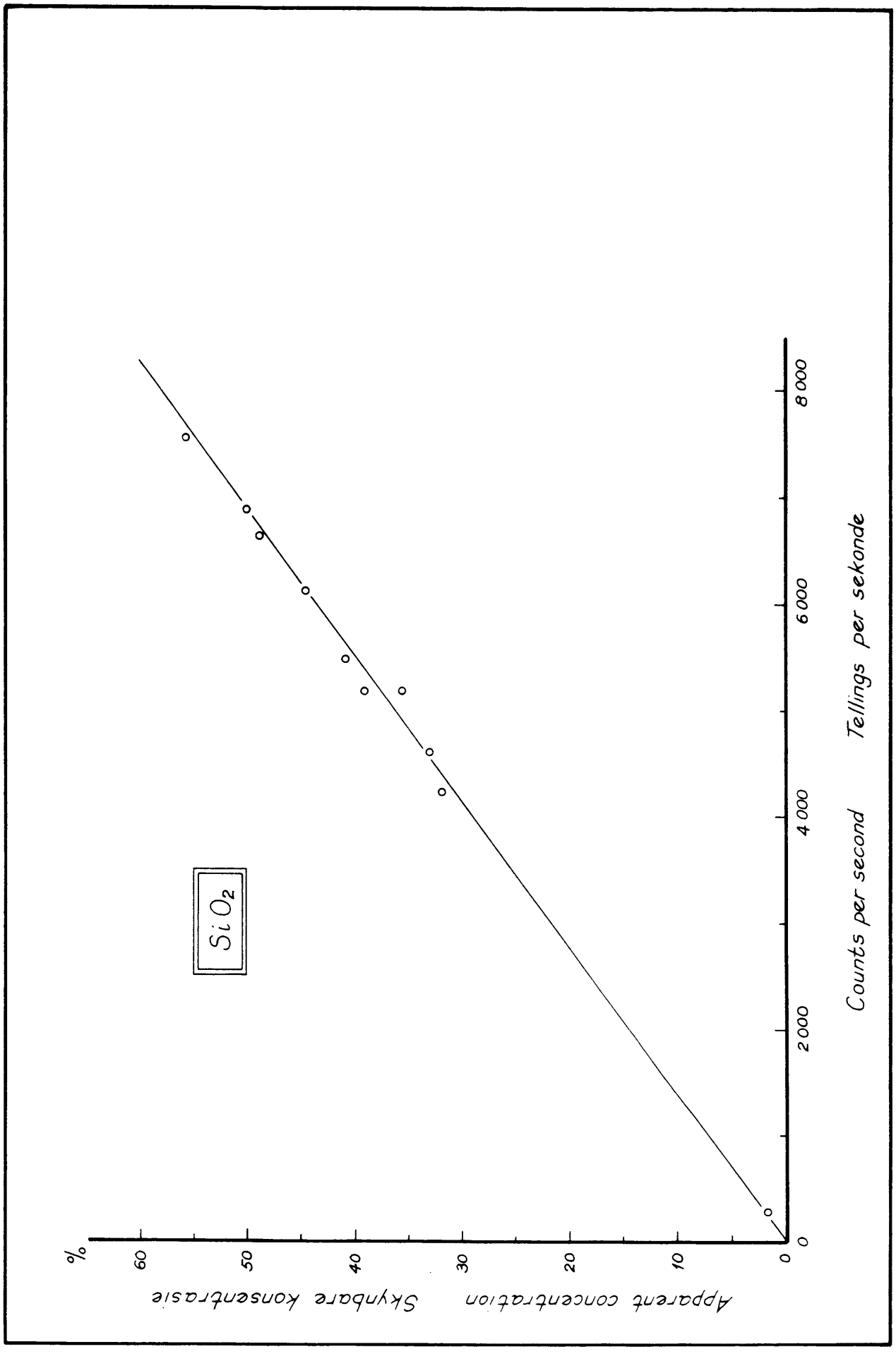

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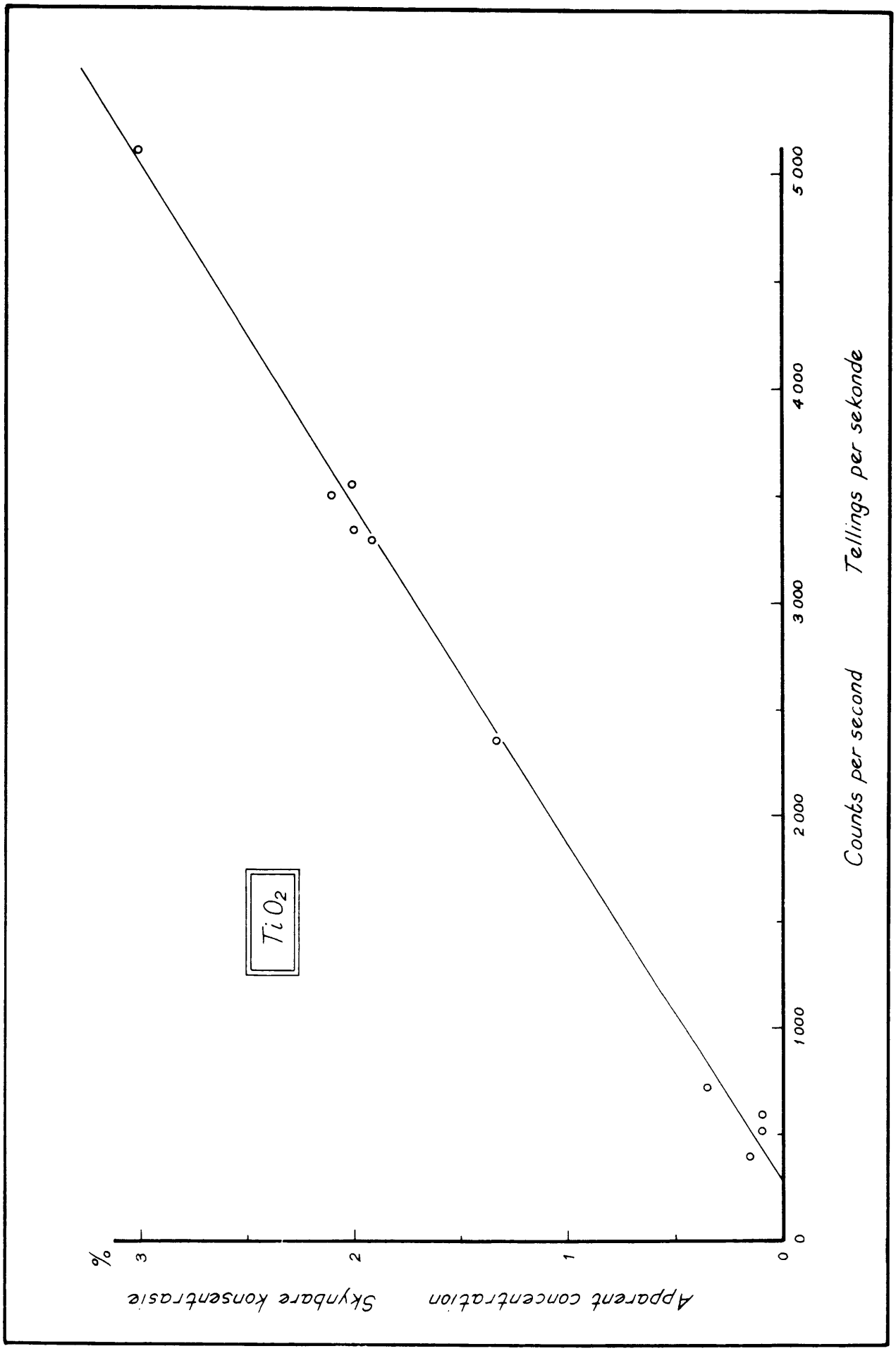

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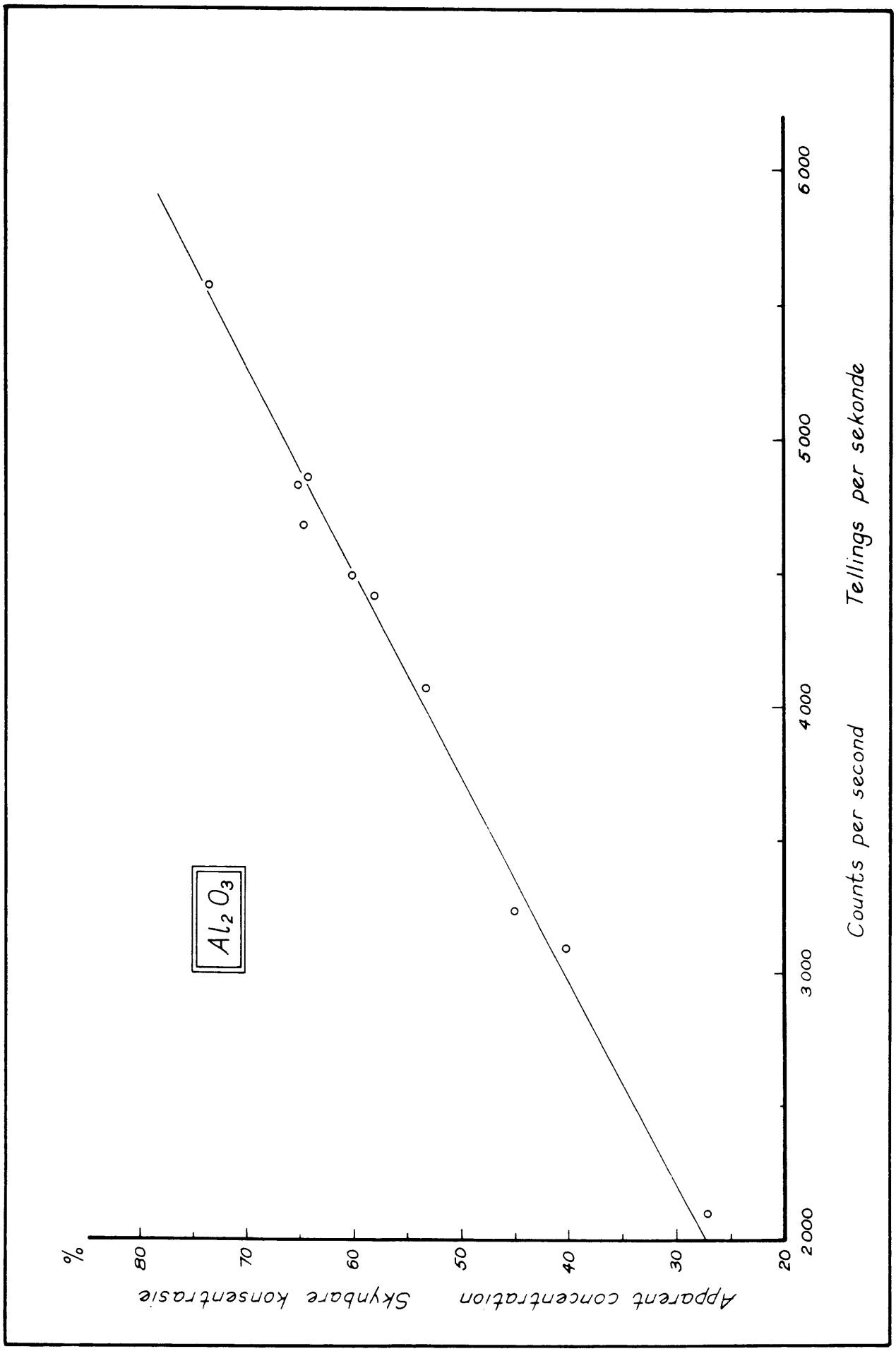

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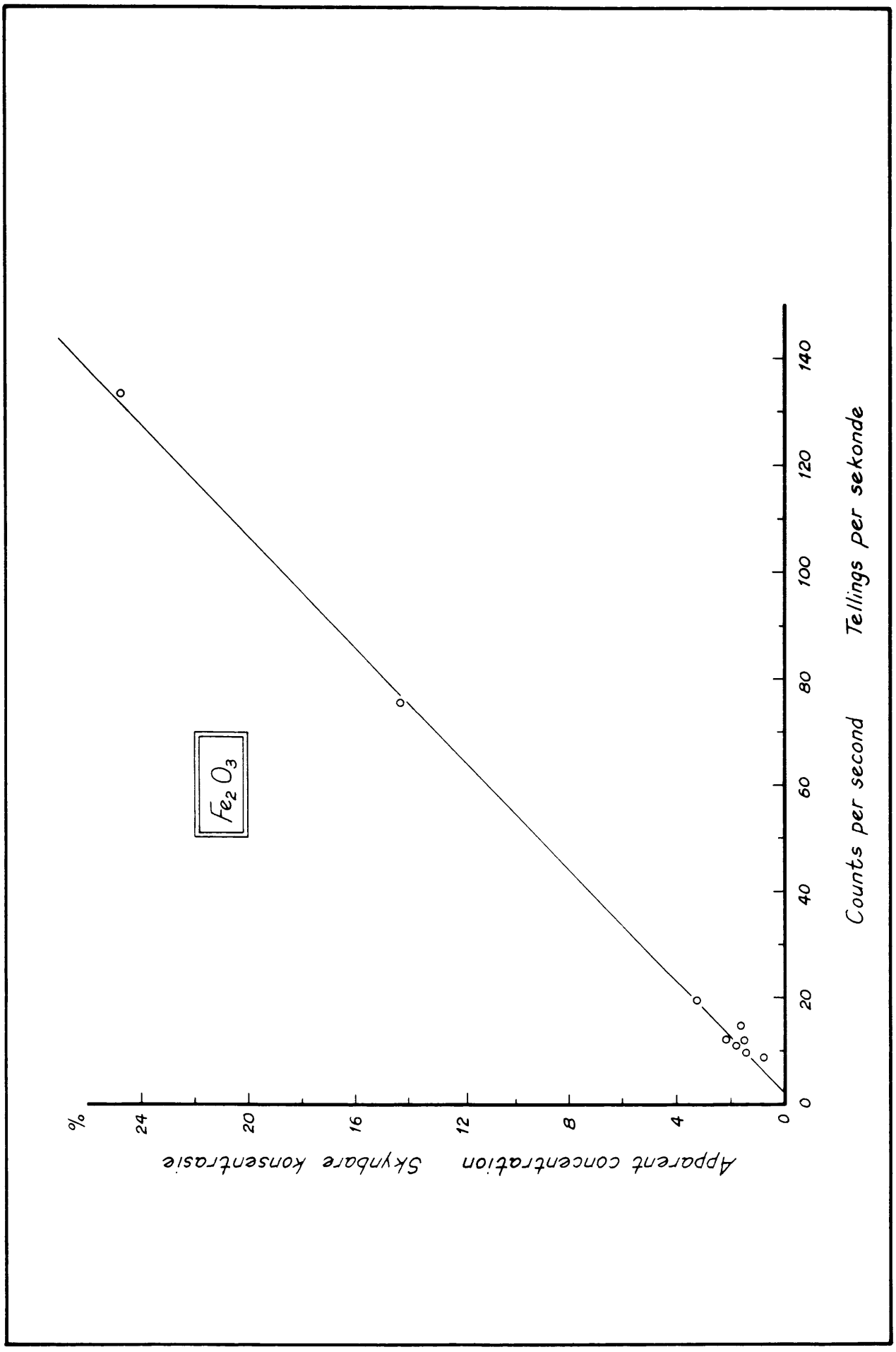

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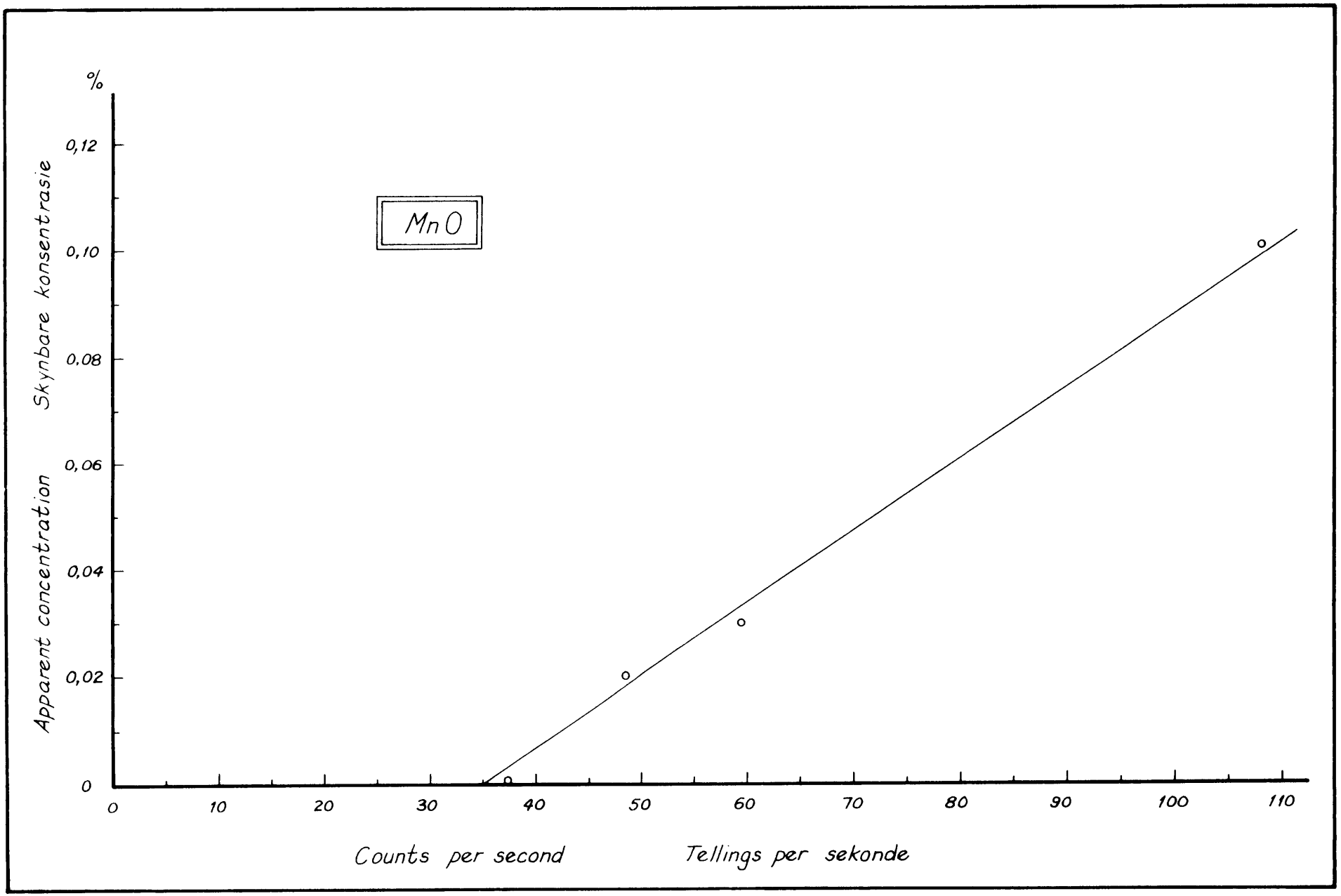

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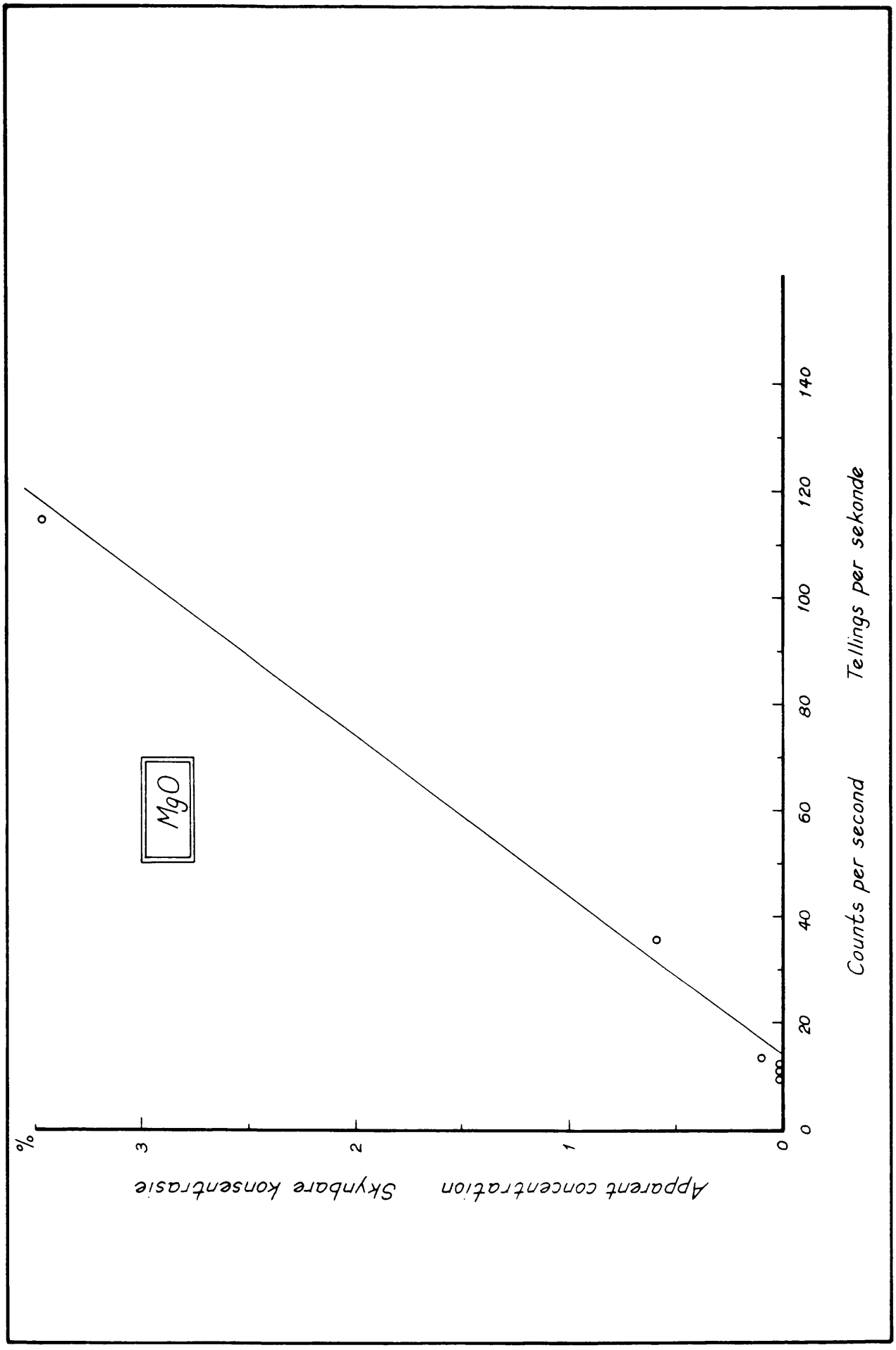

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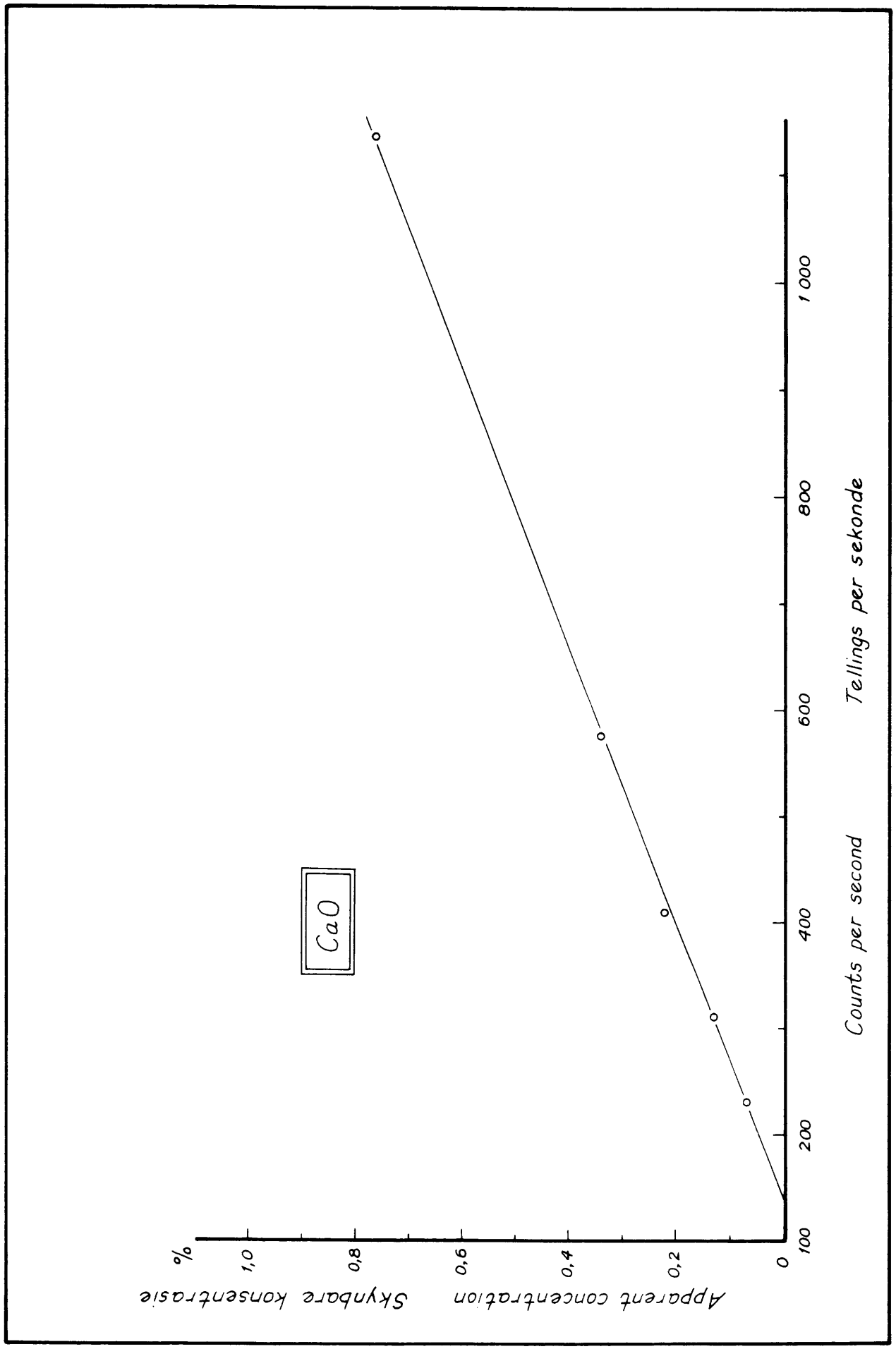

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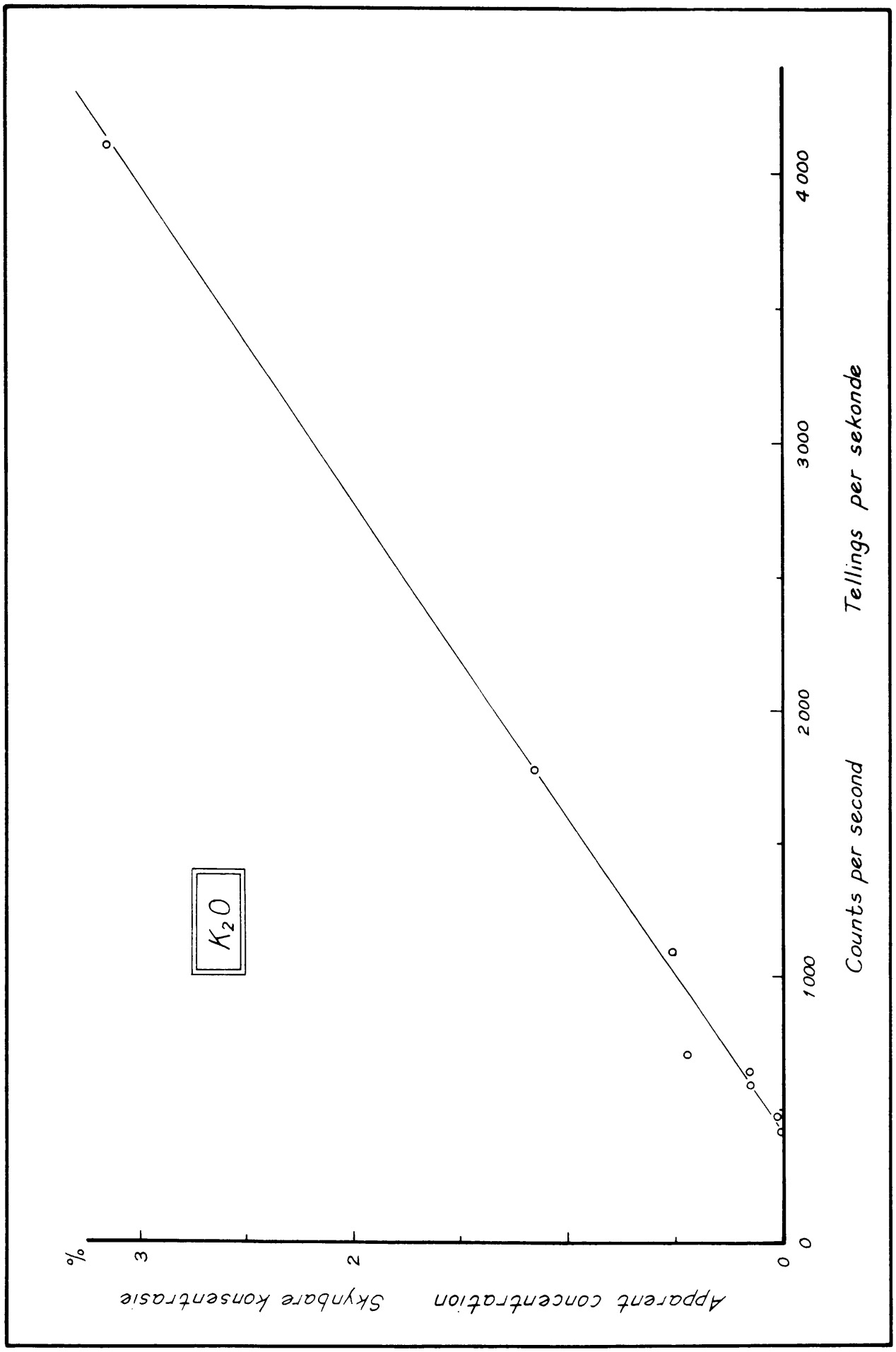

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APPENDIX 2

DESCRIPTION OF CORES FROM RECONNAISSANCE AND FOLLOW-UP BOREHOLES DRILLED ON THE EAST RAND

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Borehole ER 1 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–10,00	10,00	Soil, lateritic; reddish brown and grey.
10,00–10,20	0,20	Sandstone, coarse-grained; reddish-brown.
10,20–14,60	4,40	Shale; greyish-orange to dark yellowish-orange.
14,60–15,10	0,50	Sandstone, coarse-grained; greyish-orange.
15,10–18,60	3,50	Sandstone, soft, weathered, micaceous; yellowish-grey.
18,60–19,90	1,30	*Clay*, plastic; very light grey.
19,90–20,60	0,70	*Clay*, plastic; greyish-yellow.
20,60–20,80	0,20	*Clay*, plastic; light brownish-grey.
20,80–21,60	0,80	*Clay*, plastic; very light grey.
21,60–22,40	0,80	*Clay*, plastic; light brownish-grey.
22,40–22,80	0,40	*Clay*, plastic; pale red.
22,80–25,20	2,40	*Clay*, plastic, carbonaceous; light grey to medium light grey.
25,20–28,20	3,00	*Clay*, plastic, carbonaceous; dark grey.
28,20–29,30	1,10	Shale, carbonaceous; medium light grey to medium grey.
29,30–29,50	0,20	Shale, sandy; light brownish-grey.

Borehole ER 1/1 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–8,50	8,50	Soil, lateritic; reddish-brown.
8,50–22,00	13,50	Tillite, sandy matrix with clay, chert and quartzite inclusions; light grey.
22,00–22,80	0,80	Quartzite (Witwatersrand Supergroup).

Borehole ER 1/2 Locality: Modderfontein 76 IR, Portion 1

0–9,05	9,05	Soil, lateritic; reddish-brown.
9,05–21,70	12,65	Tillite, sandy matrix with clay, chert and quartzite inclusions; light grey.
21,70–22,70	1,00	Quartzite (Witwatersrand Supergroup).

Borehole ER 1/3 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–4,50	4,50	Soil, lateritic; pale brown.
4,50–5,65	1,15	*Clay*, plastic, extremely iron-stained; reddish-brown.
5,65–9,45	3,80	Tillite, sandy matrix with clay, chert and quartzite inclusions; light grey.
9,45–9,65	0,20	Quartzite (Witwatersrand Supergroup).

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Borehole ER 1/4 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–2,00	2,00	Soil, lateritic; reddish-brown.
2,00–10,30	8,30	Shale, weathered, micaceous; moderate reddish-brown to dark yellowish-orange.
10,30–11,70	1,40	*Clay*, plastic, slightly micaceous; greyish-orange to very pale orange.
11,70–12,30	0,60	Siltstone, weathered, micaceous; yellowish-grey.
12,30–12,85	0,55	Shale, micaceous; greyish-orange.
12,85–12,95	0,10	*Clay*, semi-plastic; very light grey.
12,95–13,50	0,55	Shale, micaceous; greyish-orange.
13,50–13,55	0,05	Grit, friable; very light grey.
13,55–13,60	0,05	*Clay*, semi-plastic; very light grey.
13,60–14,70	1,10	Grit, porous; very light grey.

Borehole ER 1/5 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–2,00	2,00	Soil, lateritic; reddish-brown.
2,00–13,00	11,00	Shale, weathered, micaceous; moderate reddish-brown to dark yellowish-orange.
13,00–13,10	0,10	Conglomerate, pebbles of chert and quartzite.
13,10–16,00	2,90	*Clay*, plastic; pale yellowish-orange to light grey to pale yellowish-brown to greyish-orange.
16,00–16,80	0,80	Sitlstone, weathered, micaceous; pale red to dark yellowish-orange.
16,80–17,40	0,60	*Clay*, plastic; very light grey to greyish orange-pink.
17,40–18,10	0,70	Siltstone, very light grey.
18,10–24,20	6,10	Sandstone, weathered; light grey.
24,20–25,00	0,80	Grit, weathered; light grey.

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Borehole ER 1/6 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–6,00	6,00	Soil, lateritic; reddish-brown.
6,00–6,80	0,80	*Clay*, plastic, slightly silty; very pale orange.
6,80–8,30	1,50	Siltstone; yellowish-grey.
8,30–8,40	0,10	Sandstone; weathered, micaceous; yellowish-brown.
8,40–9,10	0,70	*Clay*, plastic, micaceous, silty; very pale orange to dark yellowish-orange.
9,10–15,10	6,00	*Clay*, plastic; multicoloured pinkish-grey to greyish orange-pink to very pale orange to light brown.
15,10–15,80	0,70	*Clay*, semi-flint; light grey to pinkish-grey.
15,80–16,10	0,30	*Clay*, plastic, carbonaceous; light brown to brownish-black.
16,10–16,25	0,15	*Clay*, semi-flint; light grey to pinkish-grey.
16,25–18,10	1,85	*Clay*, semi-plastic; multicoloured pinkish-grey to greyish orange-pink to very pale orange to light brown.
18,10–18,90	0,80	*Clay*, semi-flint; light grey.
18,90–20,60	1,70	*Clay*, plastic, carbonaceous; brownish-black; with inter-bedded ferruginous shale.
20,60–21,55	0,95	Sandstone, ferruginous; reddish-brown.

Borehole ER 1/7 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–8,20	8,20	Soil, lateritic; reddish-brown.
8,20–8,57	0,37	Shale, weathered, micaceous; moderate reddish-brown to dark yellowsh-orange.
8,57–9,57	1,00	Sandstone, weathered; dark yellowish-orange.
9,57–11,10	1,53	Shale, weathered, micaceous; moderate reddish-brown to dark yellowish-orange.
11,10–14,30	3,20	*Clay*, plastic; greyish-orange.
14,30–14,50	0,20	Grit, light grey.
14,50–15,60	1,10	*Clay*, plastic; greyish-orange.
15,60–16,00	0,40	Siltstone, micaceous; greyish-orange.
16,00–18,70	2,70	Sandstone, micaceous; multicoloured, predominantly light brownish-grey.
18,70–19,40	0,70	Grit, weathered; light brownish-grey.

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Borehole ER 1/8 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–2,00	2,00	Soil, lateritic; reddish-brown.
2,00–10,40	8,40	Shale, weathered, micaceous; moderate reddish-brown to dark yellowish-orange.
10,40–13,40	3,00	*Clay*, plastic; greyish-orange.
13,40–14,60	1,20	Grit; very light grey.
14,60–15,50	0,90	Siltstone, micaceous; greyish-orange.
15,50–16,60	1,10	*Clay*, plastic; white.
16,60–17,20	0,60	Grit, weathered; light brownish-grey.

Borehole ER 1/9 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–2,00	2,00	Soil, lateritic; reddish-brown.
2,00–10,40	8,40	Shale, weathered, micaceous; moderate reddish-brown to dark yellowish-orange.
10,40–12,70	2,30	*Clay*, plastic; yellowish-grey.
12,70–14,00	1,30	Sandstone, weathered; greyish-orange.
14,00–16,60	2,60	Siltstone, weathered, micaceous; very pale orange.
16,60–16,80	0,20	*Clay*, plastic; very light grey.
16,80–19,50	2,70	Siltstone, weathered, micaceous; very light grey to pale orange.
19,50–20,00	0,50	Sandstone, weathered; very pale orange to very light grey.

Borehole ER 1/10 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–2,00	2,00	Soil, lateritic; reddish-brown.
2,00–9,40	7,40	Shale, weathered, micaceous; moderate reddish-brown to dark yellowish-orange.
9,40–9,50	0,10	Grit; light brownish-grey.
9,50–12,20	2,70	*Clay*, plastic, micaceous in places; multicoloured, predominantly greyish-orange.
12,20–13,30	1,10	Grit; light brownish-grey.
13,30–13,40	0,10	Siltstone, weathered, dark yellowish-orange.
13,40–14,50	1,00	*Clay*, plastic; light grey.
14,40–15,10	0,70	Grit; light brownish-grey.
15,10–20,00	4,90	*Clay*, plastic; light grey to greyish-orange.

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Borehole ER 1/11 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–9,00	9,00	Soil and decomposed shale.
9,00–9,50	0,50	Grit, slightly weathered; light brownish-grey.
9,50–10,20	0,70	*Clay*, plastic; very light grey.
10,20–11,45	1,25	Grit, weathered; light brownish-grey.
11,45–12,30	0,85	*Clay*, plastic; greyish-pink.
12,30–14,50	2,20	Tillite, silty to sandy matrix with pebbles up to 7 cm diameter; very pale orange.

Borehole ER 1/12 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–10,00	10,00	Soil and decomposed shale.
10,00–15,00	5,00	*Clay*, plastic; yellowish-grey.
15,00–15,50	0,50	Grit, weathered; light brownish-grey.
15,50–17,50	2,00	*Clay*, plastic; very light grey.
17,50–18,20	0,70	Siltstone; very pale orange.
18,20–19,20	1,00	*Clay*, semi-plastic; greyish-orange.
19,20–20,80	1,60	*Clay*, plastic; very pale orange to moderate orange-pink.
20,80–22,00	1,20	Siltstone; light grey.

Borehole ER 1/13 Locality: Modderfontein 76 IR, Portion 1

Depth (m)	Thickness (m)	Description
0–8,00	8,00	Soil and decomposed shale.
8,00–8,20	0,20	*Clay*, plastic; pinkish-grey.
8,20–15,27	7,07	Sandstone, decomposed; greyish-orange.
15,27–16,40	1,13	*Clay*, plastic; very light grey.
16,40–23,07	6,67	Grit, weathered; light brownish-grey.

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Borehole ER 2 Locality: Rietfontein 128 IR, Portion 81

Depth (m)	Thickness (m)	Description
0–2,30	2,30	Soil, lateritic; reddish-brown.
2,30–3,30	1,00	Grit, weathered; reddish-brown.
3,30–4,10	0,80	Sandstone, weathered; greyish-orange.
4,10–9,80	5,70	Shale, sandy, micaceous; greyish-orange. Occasional inclusions of flinty clay.
9,80–10,40	0,60	*Clay*, plastic; very light grey.
10,40–11,20	0,80	*Clay*, plastic; pale pink.
11,20–12,00	0,80	*Clay*, plastic; very light grey.
12,00–12,10	0,10	*Clay*, plastic; medium light grey.
12,10–12,20	0,10	*Clay*, plastic; very light grey.
12,20–12,50	0,30	*Clay*, plastic; light brownish-grey.
12,50–13,60	1,10	*Clay*, sandy; very light grey.
13,60–14,00	0,40	Chert (Malmani Subgroup).

Borehole ER 3 Locality: Daggafontein 125 IR, Portion 113

Depth (m)	Thickness (m)	Description
0–3,50	3,50	Soil, lateritic; reddish-brown.
3,50–5,30	1,80	*Clay*, plastic; very light grey to pale orange.
5,30–5,80	0,50	*Clay*, semi-flint; very light grey to light grey.
5,80–7,10	1,30	*Clay*, plastic; light grey to very light grey.
7,10–11,80	4,70	Tillite with chert, quartzite and shale inclusions; very light grey.

Borehole ER 3/1 Locality: Daggafontein 125 IR, Portion 113

Depth (m)	Thickness (m)	Description
0–2,50	2,50	Soil, gritty; reddish-brown.
2,50–4,20	1,70	Shale, weathered; moderate reddish-brown to greyish-pink to dark yellowish-orange.
4,20–6,30	2,10	Shale, micaceous; very light grey to yellowish-grey.
6,30–6,70	0,40	*Clay*, semi-flint, silty; very light grey.
6,70–8,60	1,90	*Clay*, semi-flint, sandy; very light grey.
8,60–9,70	1,10	Sandstone; yellowish-grey.

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Borehole ER 3/2 Locality: Daggafontein 125 IR, Portion 113

Depth (m)	Thickness (m)	Description
0–3,90	3,90	Soil, lateritic; reddish-brown.
3,90–7,30	3,40	Shale, micaceous; greyish-orange.
7,30–7,60	0,30	Clay, plastic, slightly micaceous; very light grey.
7,60–8,00	0,40	Sandstone, micaceous; very light grey.
8,00–9,40	1,40	Shale, micaceous; yellowish-grey to greyish-yellow.
9,40–9,90	0,50	*Clay*, semi-plastic; very light grey.
9,90–10,20	0,30	*Clay*, sandy; very light grey.
10,20–10,60	0,40	*Clay*, semi-plastic; very light grey to light grey.
10,60–12,30	1,70	Siltstone, micaceous; very light grey.
12,30–13,60	1,30	Sandstone, fine to medium-grained; greyish-orange.
13,60–14,40	0,80	Sandstone, coarse-grained; greyish-orange.

Borehole ER 3/3 Locality: Daggafontein 125 IR, Portion 113

Depth (m)	Thickness (m)	Description
0–5,80	5,80	Soil, lateritic; reddish-brown.
5,80–6,00	0,20	Soil; yellowish-brown.
6,00–6,30	0,30	*Clay*, plastic; pinkish-grey.
6,30–6,60	0,30	*Clay*, semi-plastic; greyish-yellow.
6,60–7,00	0,40	*Clay*, plastic; very light grey.
7,00–9,10	2,10	*Clay*, semi-plastic; very light grey with iron-staining in places.
9,10–11,10	2,00	Sandstone, fine to medium-grained; very light grey.
11,10–12,00	0,90	Tillite, silty matrix with chert and quartzite pebbles; very light grey.

Borehole ER 3/4 Locality: Daggafontein 125 IR, Portion 113

Depth (m)	Thickness (m)	Description
0–4,60	4,60	Soil; reddish-brown.
4,60–7,00	2,40	Mudstone; very light grey.
7,00–8,30	1,30	*Clay*, plastic; white to yellowish-grey.
8,30–9,70	1,40	*Clay*, plastic, pale pink.
9,70–9,80	0,10	*Clay*, plastic; blackish-red.
9,80–10,20	0,40	*Clay*, plastic; pale pink.
10,20–10,30	0,10	*Clay*, plastic; blackish-red.
10,30–10,60	0,30	*Clay*, plastic; pale red.
10,60–12,60	2,00	Sandstone; very light grey.

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Borehole ER 3/5 Locality: Daggafontein 125 IR, Portion 113

Depth (m)	Thickness (m)	Description
0–5,20	5,20	Soil, lateritic; reddish-brown.
5,20–7,40	2,20	*Clay*, semi-flint; multicoloured.
7,40–8,40	1,00	Tillite, silty matrix with occasional chert pebbles up to 7 cm diameter; very light grey.

Borehole ER 3/6 Locality: Daggafontein 125 IR, Portion 113

Depth (4)	Thickness (m)	Description
0–6,50	6,50	Soil, lateritic; reddish-brown.
6,50–11,20	4,70	Shale, weathered, micaceous; light brown to dark yellowish-orange.
11,20–11,80	0,60	*Clay*, plastic; white to pinkish-grey.
11,80–12,90	1,10	*Clay*, semi-flint; yellowish-grey to dusky yellow.
12,90–13,20	0,30	*Clay*, plastic; white to pinkish-grey.
13,20–13,30	0,10	*Clay*, plastic; yellowish-grey.
13,30–13,50	0,20	*Clay*, plastic; white to pinkish-grey.
13,50–14,00	0,50	*Clay*, semi-plastic; pinkish-grey to very light grey with dark brown bands.
14,00–14,10	0,10	*Clay*, plastic; moderate yellowish-brown.
14,10–16,20	2,10	*Clay*, plastic, banded; very light grey to light brownish-grey.
16,20–17,40	1,20	*Clay*, plastic, occasional banding; very light grey to light brownish-grey.
17,40–17,50	0,10	*Clay*, plastic; light grey.
17,50–19,30	1,80	*Clay*, plastic; light brownish-grey to pinkish-grey.
19,30–19,80	0,50	*Clay*, plastic, slightly carbonaceous; brownish-grey.
19,80–21,00	1,20	*Clay*, plastic, carbonaceous; brownish-grey to brownish-black.
21,00–21,60	0,60	*Clay*, plastic; light grey.
21,60–21,90	0,30	*Clay*, plastic, carbonaceous; dark greyish-black.
21,90–23,00	1,10	Tillite, silty matrix with angular inclusions of carbonacous clay; dark grey.

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Borehole ER 3/7 Locality: Daggafontein 125 IR, Portion 112

Depth (m)	Thickness (m)	Description
0–0,60	0,60	Soil; moderate brown.
0,60–1,50	0,90	Soil; moderate reddish-brown.
1,50–3,00	1,50	Grit; decomposed; moderate yellowish-brown.
3,00–3,80	0,80	Grit, weathered; pale reddish-brown.
3,80–4,80	1,00	*Clay*, lateritic; moderate reddish-brown to greyish-orange.
4,80–5,70	0,90	Grit, weathered; pale reddish-brown.
5,70–5,85	0,15	*Clay*, lateritic; moderate reddish-brown to greyish-orange.
5,85–6,10	0,25	Sandstone, weathered; greyish-orange.
6,10–6,37	0,27	*Clay*, lateritic; moderate reddish-brown.
6,37–7,65	1,28	Shale, weathered, micaceous; very pale orange.
7,65–9,50	1,85	Grit, weathered; very pale orange.
9,50–9,95	0,45	*Clay*, semi-flint; white to very pale orange.
9,95–10,20	0,25	Siltstone, micaceous; very light grey.
10,20–10,75	0,55	Grit, weathered; pale yellowish-brown.
10,75–10,80	0,05	Conglomerate, quartzite and chert pebbles.
10,80–11,15	0,35	*Clay*, plastic; white to greyish-orange.
11,15–12,20	1,05	*Clay*, plastic; multicoloured, predominantly greyish-orange.
12,20–12,50	0,30	*Clay*, semi-flint; very light grey.
12,50–13,30	0,80	*Clay*, plastic; very light grey.
13,30–14,20	0,90	*Clay*, plastic; very light grey with red laminae.
14,20–20,40	6,20	Tillite, sandy matrix with chert and quartzite pebbles; very pale orange.
20,40–21,30	0,90	Siltstone; very light grey.
21,30–22,20	0,90	Tillite, silty matrix; very light grey.
22,20–23,10	0,90	Siltstone, clayey; very light grey.
23,10–24,80	1,70	Tillite, silty matrix with chert pebbles; very light grey to pale orange.
24,80–25,15	0,35	Shale; reddish-brown.
25,15–26,00	0,85	Wad and chert fragments.

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Borehole ER 3/8 Locality: Daggafontein 125 IR, Portion 112

Depth (m)	Thickness (m)	Description
0–0,60	0,60	Soil; moderate brown.
0,60–2,30	1,70	Soil; moderate reddish-brown.
2,30–3,00	0,70	Grit, decomposed; moderate yellowish-brown.
3,00–3,50	0,50	Grit, weathered; pale reddish-brown.
3,50–4,15	0,65	*Clay*, lateritic; moderate reddish-brown.
4,15–4,30	0,15	Sandstone, weathered; very light grey.
4,30–4,35	0,05	*Clay*, lateritic; moderate reddish-brown.
4,35–4,75	0,40	Sandstone; very light grey.
4,75–6,30	1,55	Grit; pale reddish-brown to light grey.
6,30–6,50	0,20	*Clay*, plastic; white to very pale orange.
6,50–6,90	0,40	Siltstone; very light grey.
6,90–8,60	1,70	Sandstone; very light grey to pale yellowish-orange.
8,60–10,30	1,70	Grit; pale reddish-brown to light grey.
10,30–11,00	0,70	*Clay*, plastic; white.
11,00–11,70	0,70	*Clay*, plastic; very pale orange, greyish orange-pink.
11,70–11,80	0,10	*Clay*, plastic; white.
11,80–12,25	0,45	*Clay*, plastic; very light grey.
12,25–12,65	0,40	*Clay*, plastic; very pale orange.
12,65–13,50	0,85	*Clay*, plastic; very light grey.
13,50–14,00	0,50	*Clay*, plastic, silty; very light grey.
14,00–12,10	7,10	Tillite, gritty to sandy matrix; very light grey.
21,10–21,65	0,55	Shale, clayey; multicoloured, predominantly very light grey.
21,65–21,85	0,20	Siltstone; very light grey.
21,85–23,95	2,10	Tillite, silty matrix with chert pebbles; very light grey.
23,95–24,40	0,45	Dolomite, weathered, chert and wad.
24,40–26,60	2,20	*Clay*, very plastic; grey with white laminae.
26,60–27,00	0,40	Wad.
27,00–27,20	0,20	*Clay*, very plastic; grey.
27,20–27,70	0,50	*Clay*, very plastic; dark yellowish-orange.
27,70–27,95	0,25	Wad, clayey.
27,95–31,90	3,95	Dolomite, leached and chert.
31,90–33,35	1,45	*Clay*, very plastic; red.
33,35–37,90	4,55	Wad mixed with very plastic red clay.
37,90–38,50	0,60	Dolomite, fresh.

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Borehole ER 3/9 Locality: Daggafontein 125 IR, Portion 112

Depth (m)	Thickness (m)	Description
0–0,60	0,60	Soil; moderate brown.
0,60–3,00	2,40	Soil; moderate reddish-brown.
3,00–3,85	0,85	Grit, decomposed; moderate reddish-brown.
3,85–6,00	2,15	Sandstone, weathered, micaceous, clayey; greyish-orange.
6,00–6,80	0,80	*Clay*, semi-plastic, slightly carbonaceous; very light grey. Contains imprints of fossil flora.
6,80–7,70	0,90	*Clay*, semi-plastic; light grey.
7,70–8,70	1,00	*Clay*, semi-flint; very pale orange to light grey.
8,70–9,50	0,80	*Clay*, semi-flint; greyish orange-pink to light grey.
9,50–10,80	1,30	*Clay*, semi-flint, silty; light grey.
10,80–11,50	0,70	*Clay*, plastic; light grey.
11,50–16,10	4,60	Tillite, sandy matrix; very light grey.
16,10–17,00	0,90	Shale; white to very light grey.
17,00–18,20	1,20	Siltstone; very light grey.
18,20–18,45	0,25	Tillite, sandy matrix; very light grey.
18,45–18,95	0,50	Shale; reddish-brown to pale orange.
18,95–19,55	0,60	*Clay*, very plastic; red.
19,55–24,60	5,05	Wad, leached dolomite and red clay.
24,60–25,20	0,60	Dolomite and chert, fresh.

Borehole ER 3/10 Locality: Daggafontein 125 IR, Portion 101

Depth (m)	Thickness (m)	Description
0–9,00	9,00	Soil and decomposed shale; reddish-brown.
9,00–9,90	0,90	Siltstone, micaceous; Greyish-orange to light brown.
9,90-12,00	2,10	*Clay*, plastic, silty, micaceous; very light grey.
12,00–16,00	4,00	Siltstone, micaceous; greyish-orange.
16,00–17,00	1,00	*Clay*, semi-plastic; light brown to light brownish-grey.
17,00–17,90	0,90	*Clay*, semi-plastic, slightly carbonaecous; pale brown.
17,90–20,00	2,10	*Clay*, plastic, very carbonaceous; brownish-black.
20,00–21,00	1,00	Shale, carbonaceous; black.

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Borehole ER 3/11 Locality: Daggafontein 125 IR, Portion 101

Depth (m)	Thickness (m)	Description
0–10,50	10,50	Soil and decomposed shale; reddish-brown.
10,50–12,40	1,90	Siltstone, clayey, micaceous; dark yellowish-orange.
12,40–15,00	2,60	Siltstone, micaceous; greyish-orange.
15,00–16,20	1,20	*Clay*, plastic, silty, micaceous; light grey.
16,20–20,80	4,60	Siltstone, micaceous; pale yellowish-brown.
20,80–22,90	2,10	*Clay*, plastic; light brown to light brownish-grey.
22,90–24,00	1,10	*Clay*, plastic, slightly carbonaceous; pale yellowish-brown.
24,00–25,50	1,50	*Clay*, plastic, carbonaceous; brownish black.
25,50–25,80	0,30	Shale, carbonaceous; black.

Borehole ER 3/12 Locality: Daggafontein 125 IR, Portion 101

Depth (m)	Thickness (m)	Description
0–6,00	6,00	Soil and decomposed shale (?). (No. core).
6,00–12,30	6,30	*Clay*, plastic, silty, micaceous; light grey.
12,30–12,50	0,20	*Clay*, semi-plastic, slightly silty; light olive-grey.
12,50–12,90	0,40	*Clay*, plastic, silty, micaceous; light grey.
12,90–20,60	7,70	Siltstone, micaceous; greyish-orange.
20,60–23,00	2,40	*Clay*, plastic; light brown to light brownish-grey.
23,00–24,40	1,40	*Clay*, plastic, carbonaceous; black.

Borehole ER 3/13 Locality: Daggafontein 125 IR, Portion 101

Depth (m)	Thickness (m)	Description
0–6,00	6,00	Soil, lateritic; reddish-brown.
6,00–8,00	2,00	Shale, weathered, micaceous; dark yellowish-orange.
8,00–15,90	7,90	Shale, clayey, micaceous; very pale orange.
15,90–16,30	0,40	*Clay*, plastic; greyish-red.
16,30–16,60	0,30	*Clay*, semi-flint, yellowish-grey.
16,60–17,40	0,80	*Clay*, plastic; pale brown to pale red.
17,40–18,80	1,40	*Clay*, plastic, carbonaceous; pale brown.

Borehole ER 4 Locality: Daggafontein 125 IR, Portion 30

Depth (m)	Thickness (m)	Description
0–4,20	4,20	Soil, lateritic; reddish-brown.
4,20–13,60	9,40	Dolomite, leached, and chert.
13,60–16,00	2,40	Wad.
16,00–16,80	0,80	Dolomite and chert, fresh.

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Borehole ER 5 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–2,30	2,30	Laterite; yellowish-red.
2,30–2,50	0,20	Sandstone, decomposed; greyish-orange.
2,50–3,90	1,40	Shale, sandy, micaceous; dark yellowish-orange.
3,90–4,50	0,60	Shale, micaceous; yellowish-grey.
4,50–4,80	0,30	Shale, micaceous; moderate yellowish-brown.
4,80–5,80	1,00	Shale, micaceous; dark yellowish-orange.
5,80–6,10	0,30	Sandstone, weathered; greyish-orange.
6,10–6,40	0,30	Shale, micaceous; moderate yellowish-brown to light bluish-grey.
6,40–6,80	0,40	Sandstone; greyish-orange with pale yellowish-brown shale bands containing imprints of fossil flora.
6,80–7,60	0,80	Shale, sandy, micaceous; greyish-orange to very pale orange to light brown.
7,60–7,80	0,20	*Clay*, plastic; greyish-pink to greyish orange-pink.
7,80–7,90	0,10	*Clay*, semi-flint; light bluish-grey to yellowish-grey.
7,90–8,10	0,20	*Clay*, semi-flint; bluish-white.
8,10–8,90	0,80	*Clay*, plastic, banded; dark yellowish-orange, light grey and brownish-grey.
8,90–9,20	0,30	*Clay*, semi-flint; light grey to very light grey.
9,20–9,30	0,10	*Clay*, plastic; light brownish-grey.
9,30–9,55	0,25	*Clay*, semi-flint; very light grey.
9,55–10,30	0,75	*Clay*, plastic; light brownish-grey to dusky yellow.
10,30–10,55	0,25	*Clay*, plastic; light olive-grey.
10,55–10,75	0,20	*Clay*, semi-flint; light grey.
10,75–10,85	0,10	*Clay*, plastic; light brownish-grey.
10,85–11,20	0,35	*Clay*, semi-flint, pinkish-grey to dusky yellow.
11,20–11,70	0,50	*Clay*, plastic; greyish-red to pale red to greyish orange-pink.
11,70–12,40	0,70	*Clay*, plastic; greyish-pink.
12,40–12,45	0,05	*Clay*, plastic; yellowish-grey.
12,45–12,60	0,15	*Clay*, plastic; pale red to greyish-red.
12,60–13,20	0,60	*Clay*, plastic; light brownish-grey.
13,20–14,40	1,20	*Clay*, semi-plastic; white.
14,40–14,90	0,50	*Clay*, plastic; multicoloured, predominantly pinkish-grey to light brownish-grey.
14,90–15,05	0,15	*Clay*, plastic, carbonaceous; brownish-black.
15,05–15,10	0,05	Shale, carbonaceous; brownish-black.
15,10–15,40	0,30	Coal, dull.

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Borehole ER 5/1 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–1,00	1,00	Soil, clayey; medium grey.
1,00–10,60	9,60	Shale, weathered, clayey; multicoloured.
10,60–10,70	0,10	*Clay*, plastic; very pale orange to greyish orange-pink.
10,70–11,00	0,30	Shale, weathered, clayey; multicoloured.
11,00–12,00	1,00	*Clay*, semi-flint; pinkish-grey to white.
12,00–14,00	2,00	*Clay*, semi-flint; pinkish-grey.
14,00–16,30	2,30	Tillite; medium dark grey.

Borehole ER 5/2 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–5,40	5,40	Soil, gritty; brownish-grey.
5,40–11,30	5,90	Shale, weathered, clayey; multicoloured, predominantly greyish-orange.
11,30–12,80	1,50	*Clay*, semi-flint; light grey to very light grey.
12,80–14,40	1,60	*Clay*, plastic, carbonaceous; brownish-black.
14,40–15,70	1,30	Tillite, dark grey. Upper part contains white flint-clay fragments.

Borehole ER 5/3 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–6,00	6,00	Soil, sandy; brownish-grey.
6,00–11,00	5,00	Shale, weathered; moderate yellowish-brown.

Borehole ER 5/4 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–4,62	4,62	Soil, sandy; brownish-grey.
4,62–9,50	4,88	Shale, weathered, clayey; greyish-orange.
9,50–16,29	6,79	Dolerite, weathered.
16,29–19,69	3,40	Shale, weathered, micaceous; moderate yellowish-brown.
19,69–20,40	0,71	Shale, carbonaceous, micaceous; brownish-black.
20,40–20,60	0,20	Sandstone, light grey.
20,60–22,40	1,80	Shale, clayey, micaceous; pale yellowish-brown to light grey.
22,40–23,40	1,00	Shale, carbonaceous; black.
23,40–24,95	1,55	*Clay*, flint, very carbonaceous; black.
24,95–27,37	2,42	Shale, carbonaceous with thin (5–10 cm) dull coal bands.
27,37–28,55	1,18	*Clay*, flint, very carbonaceous; black.
28,55–30,25	1,70	Shale, carbonaceous with thin (5–10 cm) dull coal bands.

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Borehole ER 5/5 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–4,60	4,60	Soil, sandy; brownish-grey.
4,60–10,00	5,40	Shale, weathered, clayey; light olive-grey.
10,00–10,50	0,50	Dolerite, weathered.

Borehole ER 5/6 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–2,10	2,10	Soil, sandy; brownish-grey.
2,10–7,00	4,90	Shale, weathered, clayey; moderate yellowish-brown.
7,00–11,40	4,40	*Clay*, semi-flint; yellowish-grey to pale brown.
11,40–15,20	3,80	Tillite; very light grey.
15,20–16,00	0,80	Siltstone; light grey.

Borehole ER 5/7 Locality: Rietfontein 276 IR. Portion 3

Depth (m)	Thickness (m)	Description
0–1,80	1,80	Soil, sandy; brownish-grey.
1,80–12,00	10,20	Shale, weathered; moderate yellowish-brown.
12,00–16,30	4,30	Tillite; light grey.

Borehole ER 5/8 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–0,70	0,70	Soil, sandy; brownish-grey.
0,70–10,30	9,60	Shale, weathered, clayey; light olive-grey.
10,30–14,30	4,00	*Clay*, plastic; pinkish-grey. Lower 0,20 m carbonaceous.
14,30–14,60	0,30	Siltstone, weathered; pale yellowish-brown.
14,60–16,50	1,90	*Clay*, plastic, carbonaceous; dark grey.
16,50–18,00	1,50	*Clay*, semi-flint; pale yellowish-brown.
18,00–21,80	3,80	Shale, carbonaceous with thin (5–10 cm) dull coal bands.

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Borehole ER 5/9 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–2,00	2,00	Soil, sandy; brownish-grey.
2,00–7,70	5,70	Shale, weathered; moderate yellowish-brown.
7,70–8,50	0,80	*Clay*, plastic, micaceous, silty; very pale orange.
8,50–11,80	3,30	*Clay*, plastic, carbonaceous; dark grey.
11,80–15,80	4,00	Shale, carbonaceous with thin (5–10 cm) dull coal bands.
15,80–17,00	1,20	*Clay*, flint, carbonaceous; dark grey.
17,00–17,40	0,40	Coal, dull.

Borehole ER 5/10 Locality: Rietfontein 276 IR, Portion 3

Depth (m)	Thickness (m)	Description
0–2,40	2,40	Soil, clayey; brownish-grey.
2,40–7,00	4,60	Shale, weathered; yellowish-grey.
7,00–7,90	0,90	Dolerite.

Borehole ER 6 Locality: Bloemendal 283 IR, Remaining Portion

Depth (m)	Thickness (m)	Description
0–1,60	1,60	Soil, clayey; greyish to brownish-black.
1,60–2,20	0,60	*Clay*, plastic, gritty; olive-grey.
2,20–4,30	2,10	Shale, weathered, slightly sandy; dusky yellow to yellowish-grey.
4,30–4,70	0,40	Mudstone, weathered; yellowish-grey to light olive-grey.
4,70–4,90	0,20	*Clay*, plastic, gritty; greyish-olive.
4,90–5,00	0,10	Sandstone, weathered; yellowish-grey to light olive-grey.
5,00–6,10	1,10	Dolerite, weathered; light olive-grey.
6,10–6,70	0,60	Shale, weathered; moderate yellowish-brown.

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Borehole ER 7 Locality: Moabsvelden 248 IR, Portion 2

Depth (m)	Thickness (m)	Description
0–3,00	3,00	Soil, lateritic, sandy; yellowish-brown.
3,00–4,00	1,00	Soil, gritty; yellowish-brown.
4,00–6,00	2,00	*Clay*, plastic, sandy; reddish-brown to yellow.
6,00–7,10	1,10	Sandstone, weathered, micaceous; very pale orange.
7,10–8,50	1,40	Sandstone, weathered, micaceous; alternating pinkish-grey and light olive-grey layers.
8,50–9,50	1,00	Sandstone, weathered, micaceous; very light grey.
9,50–10,10	0,60	Shale, micaceous; dusky yellow.
10,10–10,80	0,70	Shale, sandy, micaceous; pale yellowish-brown.
10,80–11,50	0,70	Sandstone, fine-grained, micaceous; light brownish-grey.
11,50–11,90	0,40	Shale, greyish yellow-green.
11,90–12,35	0,45	*Clay*, plastic; greyish yellow-green to dusky yellow.
12,35–12,65	0,30	Shale, hard, micaceous; light brown.
12,65–12,75	0,10	Shale, sandy, micaceous; greyish yellow-green.
12,75–13,80	1,05	Shale, sandy micaceous; pale red.
13,80–14,40	0,60	*Clay*, semi-flint; dusky yellow.
14,40–14,60	0,20	*Clay*, plastic; dusky yellow.
14,60–15,50	0,90	*Clay*, semi-flint; dusky yellow.
15,50–16,10	0,60	Sandstone, coarse to fine-grained with thin shale layers; yellowish-grey.
16,10–27,00	10,90	Sandstone, coarse, hard; very light grey.
27,00–27,70	0,70	Shale, soft, carbonaceous; medium dark grey.
27,70–27,90	0,20	*Clay*, plastic, carbonaceous; black.
27,90–31,76	3,86	Coal, weathered.
31,76–32,46	0,70	Shale, carbonaceous.
32,46–34,22	1,76	Coal, dull, weathered.
34,22–35,53	1,31	Coal, dull with a slight lustre.
35,53–37,23	1,70	Coal, mixed, mainly dull.
37,23–37,50	0,27	Coal, dull, inferior.
37,50–38,30	0,80	Tillite, sandy matrix; medium grey to medium dark grey; pebbles of chert, quartzite and shale up to 3 cm diameter.

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Borehole ER 8 Locality: Rietkuil 249 IR, Portion 12

Depth (m)	Thickness (m)	Description
0–2,40	2,40	Soil, lateritic; dark yellowish-orange.
2,40–3,80	1,40	*Clay*, plastic, sandy; light grey to yellowish-grey.
3,80–5,20	1,30	*Clay*, plastic, sandy, micaceous; light grey to dark yellowish-orange.
5,20–5,90	0,70	Shale, micaceous; yellowish-grey.
5,90–6,80	0,90	Mudstone, micaceous; light grey.
6,80–7,20	0,40	Mudstone, carbonaceous; light grey to medium light grey.
7,20–7,70	0,50	*Clay*, plastic, carbonaceous, slightly sandy; dark grey to greyish-black.
7,70–7,90	0,20	Shale, carbonaceous, micaceous; medium dark grey.
7,90–8,80	0,90	Sandstone, weathered, micaceous; yellowish-orange to yellowish-grey.
8,80–9,70	0,90	Sandstone, weathered, very micaceous; light grey.
9,70–9,80	0,10	Grit, weathered; light grey.
9,80–15,20	5,40	Dolerite, decomposed.
15,20–16,60	1,40	Dolerite, fresh.

Borehole ER 9 Locality: Strehla 261 IR, Portion 10

Depth (m)	Thickness (m)	Description
0–1,30	1,30	Soil, sandy, lateritic; pale yellowish-brown.
1,30–3,60	2,30	Sandstone, micaceous; very light grey.
3,60–4,90	1,30	Sandstone, micaceous; light grey with black laminations.
4,90–7,30	2,40	Sandstone, very micaceous; light olive-grey.
7,30–7,35	0,05	*Clay*, plastic; greyish-yellow.
7,35–8,00	0,65	Sandstone, very micaceous; light olive-grey to olive-grey.
8,00–8,30	0,30	Shale, carbonaceous; dark grey.
8,30–8,50	0,20	Sandstone, carbonaceous, micaceous; medium dark grey.
8,50–9,50	1,00	Shale, carbonaceous, micaceous; medium grey.
9,50–9,70	0,20	Shale, carbonaceous, micaceous; black.
9,70–11,30	1,60	Shale, carbonaceous, micaceous; medium dark grey with thin dark yellowish-orange bands.
11,30–12,20	0,90	Sandstone, coarse-grained; light grey with black carbonaceous laminations.
12,20–12,60	0,40	Shale, carbonaceous, micaceous; dark grey.
12,60–13,10	0,50	Sandstone, coarse-grained; very light grey.
13,10–15,50	2,40	Sandstone, medium-grained; very light grey.
15,50–15,80	0,30	Sandstone, fine-grained, cross-bedded; medium light grey.
15,80–16,50	0,70	Diabase with feldspar phenocrysts up to 1 cm long.

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Borehole ER 10 Locality: Heuvelfontein 215 IR, Portion 16

Depth (m)	Thickness (m)	Description
0–3,80	3,80	Soil (?). (No core).
3,80–4,00	0,20	Grit, weathered; greyish orange-pink.
4,00–4,30	0,30	Grit, fresh; greyish orange-pink.
4,30–5,50	1,20	Shale, weathered, sandy; pale red with irregular bodies of white clay.
5,50–6,20	0,70	Sandstone, kaolinitic, slightly micaceous; white.
6,20–8,30	2,10	Sandstone, cross-bedded; very light grey.
8,30–10,50	2,20	Shale, clayey; greyish-yellow to dusky yellow to light grey.
10,50–11,00	0,50	Shale, carbonaceous; medium dark grey.
11,00–12,50	1,50	Sandstone, carbonaceous, micaceous cross-bedded; medium light grey.
12,50–13,50	1,00	Shale, carbonaceous, micaceous; medium dark grey.
13,50–13,60	0,10	Sandstone, carbonaceous, micaceous; light grey.
13,60–14,40	0,80	Shale, carbonaceous, micaceous; medium dark grey.
14,40–15,00	0,60	Coal, dull.
15,00–15,60	0,60	Shale, carbonaceous; medium dark grey with sandstone inclusions up to 3 cm diameter.
15,60–16,10	0,50	Tillite, sandy matrix; medium dark grey.
16,10–16,40	0,30	Shale, carbonaceous; dark grey.
16,40–17,80	1,40	Tillite, sandy matrix; medium light grey.

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APPENDIX 3

DESCRIPTION OF CORES FROM RECONNAISSANCE BOREHOLES DRILLED ON THE WEST RAND

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Borehole WR 1 (Locality: Panvlakte 291 IQ)

Depth (m)	Thickness (m)	Description
0–5,0	5,0	Soil, reddish-brown with chert and quartzite pebbles at the base.
5,00–5,7	0,7	*Clay*, plastic; very pale orange.
5,7 –8,25	2,55	*Clay*, plastic; very light grey.
8,25–10,4	2,15	*Clay*, plastic; pinkish-grey.
10,4 –15,8	5,4	*Clay*, semi-plastic; very light grey to pinkish-grey.
15,8 –16,3	0,5	*Clay*, semi-plastic, sandy; light grey.
16,3 –16,95	0,65	Sandstone, light grey.
16,95–17,0	0,05	Conglomerate: chert, quartzite and clay pebbles up to 10 mm diameter.
17,0 –17,1	0,1	*Clay*, semi-plastic; very light grey.
17,1 –17,8	0,7	*Clay*, plastic; iron-stained and carbonaceous.
17,8 –20,85	3,05	*Clay*, semi-flint; very light grey to pinkish-grey; minor iron staining.
20,85–21,15	0,3	*Clay*, sandy; light grey.
21,15–23,65	2,5	*Clay*, plastic; very light grey to pinkish-grey.
23,65–31,4	7,75	*Clay*, semi-plastic; light brownish-grey to pinkish-grey.
31,4 –32,2	0,8	*Clay*, plastic, carbonaceous; pale brown.
32,2 –41,06	8,86	*Clay*, plastic, slightly sandy; light brownish-grey.
41,06–41,5	0,44	*Clay*, plastic; stained yellow by iron oxide.
41,5 –41,74	0,24	Sandstone

Borehole WR 2 (Locality: Panvlakte 291 IQ)

Depth (m)	Thickness (m)	Description
0–5,0	5,0	Soil, reddish-brown with occasional chert and quartzite boulders.
5,0 –7,2	2,2	*Clay*, plastic, iron-stained, sandy; pale reddish-brown.
7,2 –8,5	1,3	*Clay*, semi-plastic, iron-stained, slightly sandy; very pale orange.
8,5 –11,2	2,7	*Clay*, semi-plastic, slightly iron-stained; very pale orange to moderate orange-pink.
11,2 –16,0	4,8	*Clay*, semi-plastic, iron-stained; very light grey to very pale orange.
16,0 –19,9	3,9	*Clay*, semi-plastic, iron-stained; light brown to very pale orange.
19,9 –20,5	0,6	*Clay*, semi-plastic; moderate brown.
20,5 –45,6	25,1	*Clay*, plastic, iron-stained; very light grey. Occasional chert pebbles from 43 m downwards.

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Borehole WR 3 (Locality: Panvlakte 291 IQ)

Depth (m)	Thickness (m)	Description
0–2,5	2,5	Soil, reddish-brown with occasional quartzite pebbles.
2,5 –3,8	1,3	*Clay*, plastic; very pale orange.
3,8 –4,4	0,6	*Clay*, semi-plastic, slightly sandy; very light grey to yellowish-grey.
4,4 –6,6	2,2	*Clay*, semi-plastic; very light grey to greyish-orange to moderate reddish-orange.
6,6 –7,7	1,1	*Clay*, plastic, slightly sandy; very light grey.
7,7 –10,9	3,2	*Clay*, semi-flint; very pale orange to greyish-orange.
10,9 –11,4	0,5	Angular fragments of hard clay in a pale reddish-brown clayey matrix.
11,4 –11,6	0,2	Shale, pale reddish-brown.
11,6 –12,2	0,6	*Clay*, semi-flint; greyish-orange with thin reddish-brown laminae.
12,2 –13,6	1,4	*Clay*, plastic, fissile; light grey.
13,6 –14,8	1,2	*Clay*, plastic, iron-stained, sandy; very light grey.
14,8 –24,0	9,2	*Clay*, semi-flint; multicoloured.
24,0 –27,0	3,0	Dolomite, weathered.

Borehole WR 4 (Locality: Panvlakte 291 IQ)

Depth (m)	Thickness (m)	Description
0–0,5	0,5	Soil, sandy; brown.
0,5 –3,2	2,7	Soil, reddish-brown.
3,2 –3,4	0,2	Chert and quartzite pebbles, some well-rounded.
3,4 –4,4	1,0	*Clay*, plastic, micaceous; multicoloured (predominantly reddish-brown).
4,4 –10,1	5,7	*Clay*, plastic, micaceous, iron-stained, multicoloured.
10,1 –10,5	0,4	Conglomerate: predominantly quartzite pebbles up to 50 mm diameter.
10,5 –11,5	1,0	*Clay*, semi-plastic, iron-stained; very light grey to pinkish-grey.
11,5 –12,0	0,5	*Clay*, semi-plastic, iron-stained; very light grey.
12,0 –16,5	4,5	*Clay*, plastic, slightly iron-stained and carbonaceous; pinkish-grey to greyish orange-pink.
16,5 –16,7	0,2	The same as 12,0–16,5 but more carbonaceous.
16,7 –18,6	1,9	*Clay*, plastic, pale red to greyish orange-pink changing gradually to very light grey lower down.
18,6 –19,1	0,5	*Clay*, plastic, micaceous; very light grey.
19,1 –19,5	0,4	*Clay*, plastic, iron-stained, carbonaceous; greyish-yellow.
19,5 –20,3	0,8	*Clay*, plastic, iron-stained; very light grey.
20,3 –28,0	7,7	Leached dolomite and wad.

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Borehole WR 5 (Locality: Waterpan 292 IQ)

Depth (m)	Thickness (m)	Description
0–6,4	6,4	Soil, reddish-brown.
6,4 –9,55	3,15	*Clay*, plastic, iron-stained; multicoloured, predominantly reddish-brown.
9,55–12,85	3,3	*Clay*, plastic, micaceous; multicoloured, predominantly greyish-orange.
12,85–33,0	20,15	*Clay*, plastic, micaceous; light grey to yellowish-grey.
33,0 –33,05	0,05	Dolomite, leached.

Borehole WR 6 (Locality: Driefontein 355 IQ)

Depth (m)	Thickness (m)	Description
0–12,5	12,5	Soil, clayey; reddish-brown to yellowish-brown.
12,5 –16,4	3,9	*Clay*, plastic, iron-stained, micaceous; multicoloured.
16,4 –18,5	2,1	*Clay*, plastic, slightly iron-stained; very light grey.
18,5 –21,5	3,0	*Clay*, plastic, iron-stained; very pale orange.
21,5 –24,4	2,9	*Clay*, plastic, slightly iron-stained; light brownish-grey to light grey.
24,4 –27,0	2,6	*Clay*, plastic; pinkish-grey to light brownish-grey to very pale orange.
27,0 –27,9	0,9	*Clay*, plastic, carbonaceous; greyish-red to blackish-red.
27,9 –30,0	2,1	*Clay*, plastic, carbonaceous; black.

Borehole WR 7 (Locality: Oog van Wonderfontein 110 IQ)

Drilling was stopped at 18,6 m; only soil and unconsolidated sand were intersected.

Borehole WR 8 (Locality: Driefontein 355 IQ)

Drilling was stopped at 17,4 m; only soil and unconsolidated sand were intersected.

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Borehole WR 9 (Locality: Driefontein 355 IQ)

Depth (m)	Thickness (m)	Description
0–6,38	6,38	Soil, reddish-brown.
6,38–7,5	1,12	Chert and quartzite boulders.
7,5 –8,25	0,75	*Clay*, plastic, iron-stained; white to pinkish-grey.
8,25–13,35	5,1	*Clay*, plastic, slightly sandy; very pale orange to greyish-orange.
13,35–19,5	6,15	*Clay*, semi-flint, slightly iron-stained; very pale orange to light grey.
19,5 –22,0	2,5	*Clay*, semi-flint; very light grey to light brownish-grey.
22,0 –23,9	1,9	*Clay*, semi-flint, slightly sandy; very light grey to light brownish-grey.
23,9 –24,4	0,5	*Clay*, semi-flint; very light grey to light brownish-grey.
24,4 –25,7	1,3	*Clay*, semi-flint, slightly sandy; very light grey to light brownish-grey.
25,7 –26,5	0,8	*Clay*, semi-flint; very light grey to light brownish-grey.
26,5 –30,8	4,3	*Clay*, semi-plastic,iron-stained; very pale orange to pinkish-grey.
30,8 –33,4	2,6	*Clay*, semi-flint, pale yellowish-brown to light brownish-grey.
33,4 –34,5	1,1	*Clay*, plastic, carbonaceous; medium-grey to medium dark-grey.
34,5 –40,2	5,7	*Clay*, plastic, carbonaceous, black.

Borehole WR 10 (Locality: Syferfontein 293 IQ)

Depth (m)	Thickness (m)	Description
0–4,4	4,4	No core recovered (probably soil).
4,4 –10,4	6,0	*Clay*, plastic, iron-stained; very light grey.
10,4 –11,0	0,6	*Clay*, plastic, iron-stained; moderate reddish brown.
11,0 –11,5	0,5	*Clay*, plastic; dark yellowish orange to light grey.
11,5 –20,0	8,5	*Clay*, plastic; very light grey to moderate reddish brown to yellowish-orange.
20,0 –20,1	0,1	Grit; grains 2–6 mm diameter.

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APPENDIX 4

DESCRIPTION OF CORES FROM BOREHOLES DRILLED FOR REFRACTORY CLAY IN THE PRETORIA – BELFAST AREA

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Borehole PF 1 (Locality: Paardefontein 282 JR)

Depth (m)	Thickness (m)	Description
0–0,6	0,6	Soil, light brown.
0,6 –1,5	0,9	Grit, friable; greyish orange-pink.
1,5 –4,5	3,0	Sandstone, friable; greyish orange-pink.
4,5 –11,05	6,55	Grit very light grey.
11,05–14,6	3,55	Tillite, gritty matrix; very light grey.
14,6 –16,6	2,0	Siltstone; very light grey.
16,6 –19,4	2,8	Tillite, silty matrix; brownish-grey.
19,4 –28,85	9,45	Tillite, sandy matrix; very pale orange.
28,85–30,3	1,45	Felsite, dark reddish-brown.

Borehole PF 2 (Locality: Paardefontein 282 JR)

Depth (m)	Thickness (m)	Description
0–1,5	1,5	Soil, pale brown.
1,5 –2,3	0,8	*Clay,* gritty; dark grey.
2,3 –4,4	2,1	Grit, friable; greyish orange-pink.
4,4 –6,55	2,15	Grit, very light grey.
6,55–7,1	0,55	*Clay,* plastic, silty; light grey.
7,1 –7,9	0,8	Siltstone, lower 10 cm laminated; light olive-grey to dark grey.
7,9 –12,2	4,3	Grit, very light grey.
12,2 –18,0	5,8	Tillite, gritty matrix; very light grey.
18,0 –18,5	0,5	Siltstone, very light grey to dark grey.
18,5 –24,6	6,1	Tillite, silty matrix; very light grey.
24,6 –27,2	2,6	*Clay,* flint, silty; light grey.
27,2 –31,1	3,9	Tillite, large felsite pebbles in a sandy matrix; light brownish-grey.

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Borehole PF 3 (Locality: Paardefontein 282 JR)

Depth (m)	Thickness (m)	Description
0–1,5	1,5	Soil, light brown.
1,5 –5,2	3,7	Siltstone, decomposed; very pale orange.
5,2 –6,95	1,75	Sandstone, fine-grained; very pale orange.
6,95–7,3	0,35	*Clay*, plastic, silty; very pale orange.
7,3 –9,1	1,8	Siltstone, decomposed; very pale orange.
9,1 –10,1	1,0	Grit, very light grey.
10,1 –10,9	0,8	Siltstone, clayey; very pale orange.
10,9 –12,1	1,2	*Clay*, silty; light grey.
12,1 –14,6	2,5	Siltstone, very pale orange.
14,6 –14,7	0,1	*Clay*, plastic; very pale orange.
14,7 –14,9	0,2	Grit, iron-stained.
14,9 –15,3	0,4	Siltstone, very pale orange.
15,3 –18,25	2,95	Grit, iron-stained.
18,25–20,0	1,75	*Clay*, silty; light grey.
20,0 –24,4	4,4	Tillite, gritty matrix; very light grey.
24,4 –24,6	0,2	Siltstone, very pale orange.
24,6 –25,9	1,3	Siltstone, dark grey.
25,9 –31,0	5,1	Tillite, silty matrix; pale brown.

Borehole PF 4 (Locality: Paardefontein 282 JR)

Depth (m)	Thickness (m)	Description
0–1,0	1,0	Soil, sandy; light brown.
1,0 –1,7	0,7	Grit, friable; light brown.
1,7 –2,7	1,0	Sandstone, friable; greyish orange-pink.
2,7 –6,25	3,55	Grit, friable; light brown to greyish orange-pink.
6,25–7,3	1,05	Grit, very light grey.
7,3 –8,1	0,8	Grit, friable; light brown.
8,1 –9,3	1,2	Grit, very light grey.
9,3 –9,8	0,5	*Clay*, plastic, silty; very light grey.
9,8 –11,3	1,5	Siltstone, clayey; very light grey.
11,3 –13,5	2,2	Grit, very light grey; iron-stained in places.
13,5 –15,25	1,75	Tillite, sandy matrix; light grey.
15,25–15,4	0,15	*Clay*, flint; very light grey.
15,4 –20,3	4,9	Siltstone, yellowish-grey.
20,3 –24,2	3,9	Tillite, silty matrix; very light grey.

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Borehole KB 1 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–0,7	0,7	Soil, lateritic; pale brown.
0,7 –2,6	1,9	Sandstone, decomposed; light brown.
2,6 –3,4	0,8	Siltstone, decomposed; light brown.
3,4 –3,7	0,3	*Clay*, flint; yellowish-grey.
3,7 –8,4	4,7	*Clay*, plastic; very light grey.
8,4 –11,0	2,6	*Clay*, flint; light grey.
11,0 –12,45	1,45	Grit, very light grey; Fe-stained.
12,45–14,7	2,25	Tillite, sandy matrix; greyish-orange.
14,7 –24,25	9,55	Felsite, weathered; greyish orange-pink.

Borehole KB 2 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–0,8	0,8	Soil, sandy; light brown.
0,8 –2,1	1,3	Grit, friable; light brown.
2,1 –2,4	0,3	Siltstone, decomposed; light brown.
2,4 –2,8	0,4	*Clay*, flint; pinkish-grey.
2,8 –3,2	0,4	Siltstone, clayey; multicoloured.
3,2 –3,55	0,35	*Clay*, plastic; white.
3,55–4,1	0,55	*Clay*, plastic, silty; very light grey.
4,1 –5,1	1,0	*Clay*, flint; very light grey.
5,1 –5,4	0,3	Siltstone, light brownish-grey.
5,4 –5,55	0,15	*Clay*, flint; very light grey.
5,55–5,6	0,05	*Clay*, plastic; white.
5,6 –10,3	4,7	Sandstone, yellowish-grey.
10,3 –10,5	0,2	*Clay*, flint; very light grey.
10,5 –11,3	0,8	Sandstone, yellowish-grey.
11,3 –12,1	0,8	*Clay*, flint; very light grey.
12,1 –13,2	1,1	Sandstone; light brown.
13,2 –14,7	1,5	*Clay*, flint; light grey.
14,7 –15,8	1,1	*Clay*, flint; Fe-stained.
15,8 –17,3	1,5	Grit, pinkish-grey.
17,3 –26,0	8,7	Alternating dull coal, carbonaceous shale and carbonaceous flint clay.
26,0 –31,5	5,5	Tillite, sandy matrix; light grey.

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Borehole KB 3 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Soil, sandy; moderate yellowish-brown.
3,0 –3,6	0,6	*Clay*, flint; very light grey.
3,6 –4,5	0,9	Sandstone, very light grey.
4,5 –4,7	0,2	*Clay*, flint; very light grey.
4,7 –5,7	1,0	Siltstone, very light grey.
5,7 –6,1	0,4	*Clay*, flint; light grey.
6,1 –6,2	0,1	*Clay*, plastic; yellowish-grey.
6,2 –11,3	5,1	Sandstone, very light grey.
11,3 –11,4	0,1	Siltstone, light grey.
11,4 –11,9	0,5	Sandstone, greyish orange-pink.
11,9 –12,0	0,1	Siltstone, greyish orange-pink.
12,0 –12,15	0,15	*Clay*, flint; light grey.
12,15–12,55	0,4	Siltstone, pale red.
12,55–13,7	1,15	*Clay*, flint; medium grey to medium dark grey.
13,7 –13,85	0,15	Sandstone, light grey.
13,85–14,5	0,65	*Clay*, flint; medium grey to medium dark grey.
14,5 –23,2	8,7	Carbonaceous shale with a few thin coal bands (dull coal with bright coal stringers).
23,2 –27,0	3,8	Tillite, silty matrix; medium grey to medium dark grey.
27,0 –28,4	1,4	Tillite, silty matrix; light grey.
28,4 –29,8	1,4	Tillite, gritty matrix; very light grey.
29,8 –30,45	0,65	Siltstone, medium light grey.

Borhole KB 4 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–2,5	2,5	Soil, sandy; pale brown.
2,5 –3,2	0,7	Laterite.
3,2 –4,0	0,8	*Clay*, flint, silty; light grey.
4,0 –4,5	0,5	Sandstone, pale red.
4,5 –4,65	0,15	*Clay*, plastic; white.
4,65–5,8	1,15	*Clay*, flint; light grey.
5,8 –8,0	2,2	Sandstone, very light grey.
8,0 –9,0	1,0	Siltstone, pale yellowish-orange.
9,0 –9,75	0,75	Sandstone, very pale orange.
9,75–10,0	0,25	Siltstone, pale yellowish-orange.
10,0 –12,0	2,0	*Clay*, plastic, ferruginous; pale yellowish-orange to moderate yellowish-brown.
12,0 –12,2	0,2	*Clay*, plastic; pinkish-grey.
12,2 –13,0	0,8	*Clay*, plastic, carbonaceous; brownish-black.
13,0 –14,0	1,0	*Clay*, flint, very carbonaceous; black.
14,0 –15,0	1,0	*Clay*, medium grey.
15,0 –17,8	2,8	Tillite, silty to clayey matrix; light grey.
17,8 –18,2	0,4	Tillite, sandy matrix; very light grey.
18,2 –27,0	8,8	Felsite, weathered; very light grey.

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Borehole KB 5 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–1,6	1,6	Soil, sandy; pale brown.
1,6 –2,2	0,6	*Clay*, flint; very light grey.
2,2 –2,7	0,5	Siltstone, multicoloured.
2,7 –3,2	0,5	*Clay*, flint; very light grey.
3,2 –3,4	0,2	Siltstone, pinkish-grey.
3,4 –4,1	0,7	Sandstone, greyish orange-pink.
4,1 –6,0	1,9	*Clay*, flint; very light grey.
6,0 –6,9	0,9	Sandstone, greyish orange-pink.
6,9 –11,0	4,1	*Clay*, flint; very light grey.
11,0 –16,2	5,2	Shale, carbonaceous.

Borehole KB 6 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–0,2	0,2	Soil, pale brown.
0,2 –0,9	0,7	Sand and grit, unconsolidated.
0,9 –10,5	9,6	Felsite, weathered; pinkish-grey to yellowish-grey.

Borehole KB 7 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–0,6	0,6	Soil, sandy; pale brown.
0,6 –1,8	1,2	Soil, lateritic; light brown.
1,8 –2,2	0,4	Sandstone, pinkish-grey.
2,2 –3,9	1,7	Siltstone, yellowish-grey to pinkish-grey with thin layers of plastic clay.
3,9 –5,3	1,4	*Clay*, flint; very light grey to white.
5,3 –5,4	0,1	Sandstone, moderate orange-pink.
5,4 –5,6	0,2	*Clay*, flint; very light grey.
5,6 –5,8	0,2	Siltstone, very light grey.
5,8 –6,9	1,1	*Clay*, flint; very light grey.
6,9 –7,5	0,6	*Clay*, plastic; greyish orange-pink.
7,5 –9,6	2,1	*Clay*, plastic, silty; pale red.
9,6 –12,6	3,0	Shale, carbonaceous; black.
12,6 –12,8	0,2	*Clay*, flint, very carbonaceous; dusky yellowish-brown.
12,8 –15,0	2,2	Tillite, silty matrix; medium grey.
15,0 –21,6	6,6	Tillite, silty matrix; light grey.
21,6 –26,6	5,0	Felsite, weathered; pinkish-grey to yellowish-grey.

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Borehole KB 8 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–0,6	0,6	Soil, sandy, pale brown.
0,6 –2,5	1,9	Laterite.
2,5 –4,7	2,2	Sandstone, decomposed; greyish-orange.
4,7 –6,6	1,9	Sandstone, yellowish-grey.
6,6 –7,1	0,5	Siltstone, very light grey.
7,1 –7,3	0,2	*Clay*, flint; very light grey.
7,3 –9,1	1,8	Sandstone, very light grey to pale red.
9,1 –10,7	1,6	*Clay*, flint; very light grey.
10,7 –11,3	0,6	Sandstone, very light grey to pale red.
11,3 –12,7	1,4	Siltstone, greyish-orange.
12,7 –14,2	1,5	*Clay*, flint, very light grey.
14,2 –15,1	1,9	Siltstone, medium light grey.
15,1 –27,0	11,9	Carbonaceous shale and occasional thin dull coal bands with stringers of bright coal.
27,0 –28,2	1,2	Tillite, silty matrix; medium grey.

Borehole KB 9 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–0,3	0,3	Soil, sandy; pale brown.
0,3 –3,0	2,7	Sandstone, decomposed; greyish-orange.
3,0 –4,1	1,1	Sandstone, very light grey.
4,1 –6,65	2,55	Grit, very light grey.
6,65–7,8	1,15	Siltstone, decomposed; greyish-orange.
7,8 –9,0	1,2	Grit, very light grey.
9,0 –9,6	0,6	*Clay*, flint, very light grey.
9,6 –11,0	1,4	Sandstone, pinkish-grey to very light grey.
11,0 –11,5	0,5	Siltstone, pale red to yellowish-grey.
11,5 –13,4	1,9	*Clay*, flint; light grey to very light grey.
13,4 –14,0	0,6	Sandstone, very light grey.
14,0 –20,35	6,35	Dolerite, weathered.
20,35–28,0	7,65	Shale, carbonaceous; black.

Borehole KB 10 (Locality: Kloppersbos 128 JR)

Depth (m)	Thickness (m)	Description
0–5,0	5,0	Soil, lateritic; moderate brown.
5,0 –6,0	1,0	*Clay*, plastic, silty; pinkish-grey.
6,0 –8,7	2,7	*Clay*, flint, silty; very light grey.
8,7 –11,5	2,8	*Clay*, plastic; very light grey to pinkish-grey.
11,5 –12,0	0,5	Sandstone, very light grey to pinkish-grey.
12,8 –13,5	0,7	Siltstone, light grey.

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Borehole RF 1 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–0,4	0,4	Soil, moderate yellowish-brown.
0,4 –1,5	1,1	Sandstone, soft, decomposed; pinkish-grey.
1,5 –3,5	2,0	Sandstone, fine-grained; pinkish-grey.
3,5 –4,1	0,6	Tillite, sandy matrix; very pale orange.
4,1 –4,8	0,7	*Clay*, flint, silty; pale yellowish-brown.
4,8 –5,1	0,3	Sandstone with intercalated silty flint clay; pale yellowish-brown.
5,1 –5,3	0,2	*Clay*, semi-plastic, Fe-stained; pale yellowish-brown.
5,3 –5,45	0,15	Tillite, sandy matrix; light grey.
5,45–5,6	0,15	*Clay*, semi-plastic; pale yellowish-brown.
5,6 –5,85	0,25	Tillite, sandy matrix; light grey.
5,85–5,9	0,05	*Clay*, flint; light grey.
5,9 –6,1	0,2	Tillite, sandy matrix; light grey.
6,1 –6,15	0,05	*Clay*, flint; pale yellowish-brown.
6,15–8,0	1,85	Tillite, sandy matrix; light brownish-grey.
8,0 –30,15	22,15	Tillite, sandy matrix; very light grey. Pebbles only occur in abundance at regular intervals: 14,0–14,5m 15,5–16,0m, 18,5–19,0m, 21,5–22,0m, 24,5–25,0m, 28,0–30,15m.

Borehole RF 2 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Sandstone, decomposed; pinkish-grey.
3,0 –3,5	0,5	Laterite.
3,5 –3,9	0,4	Sandstone, weathered, ferruginous; dark yellowish-orange.
3,9 –4,0	0,1	Grit, ferruginous; moderate brown.
4,0 –7,7	3,7	*Clay*, plastic, Fe-stained along joints; pinkish-grey to very light grey.
7,7 –8,35	0,65	Siltstone, pinkish-grey.
8,35–8,5	0,15	Sandstone, pale red.
8,5 –9,0	0,5	Siltstone, pale red.
9,0 –31,1	22,1	Tillite, sandy matrix; multicoloured, predominantly light grey. No pebbles were observed between 16,0 and 18,5m and between 19,5 and 23,5m.

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Borehole RF 3 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Sandstone, decomposed; pinkish-grey.
3,0 –5,85	2,85	*Clay*, semi-plastic to semi-flint; very light grey to pinkish-grey.
5,85–8,8	2,95	*Clay*, plastic; pinkish-grey to very light grey, upper 0,1m pale yellowish-orange.
8,8 –12,0	3,2	Tillite, sandy matrix; pinkish-grey to pale red. Pebbles scarce.
12,0 –12,8	0,8	Tillite, sandy matrix, small pebbles; medium light grey.
12,8 –16,9	4,1	Siltstone, light grey with medium light grey laminations.
16,9 –22,1	5,2	Sandstone, fine-grained; light grey.
22,1 –30,5	8,4	Tillite, sandy matrix, very light grey. Pebbles scarce.

Borehole RF 4 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–9,4	9,4	Soil, sandy; moderate reddish-brown.
9,4 –17,0	7,6	*Clay*, plastic; pinkish-grey to very light grey.
17,0 –17,9	0,9	Tillite, small pebbles in a sandy matrix; light grey.
17,9 –19,6	1,7	Tillite, occasional small pebbles in a silty to clayey matrix; brownish-grey.
19,6 –20,0	0,4	Tillite, sandy matrix; light grey.
20,0 –23,25	3,35	Siltstone, medium light grey to very light grey.
23,35–28,0	4,65	Tillite, sandy matrix; yellowish-grey. Occasional slumping structures.

Borehole RF 5 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Sandstone, decomposed; dark yellowish-orange.
3,0 –3,1	0,1	Sandstone, ferruginous; pale red.
3,1 –4,5	1,4	*Clay*, plastic; pinkish-grey.
4,5 –6,8	2,3	*Clay*, semi-plastic to semi-flint; light grey to pinkish-grey.
6,8 –9,0	2,2	Siltstone, decomposed; dark yellowish-orange.
9,0 –10,0	1,0	*Clay*, plastic; pinkish-grey to very light grey.
10,0 –30,15	20,15	Tillite, sandy matrix, very light grey to pale red. Pebbles are scarce except for thin zones at 22,5, 25,5 and 29,8m where pebbles dominate the structure.

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Borehole RF 6 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–5,8	5,8	Sandstone, decomposed; dark yellowish-orange.
5,8 –11,0	5,2	*Clay*, plastic; pinkish-grey to very light grey.
11,0 –13,9	2,9	Siltstone, pale red to light grey.
13,9 –30,65	16,75	Tillite, sandy matrix; light grey. Pebbles dominate the structure from 18,6 m downwards.

Borehole RF 7 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–2,8	2,8	Sandstone, decomposed; dark yellowish-orange.
2,8 –3,1	0,3	Grit, ferruginous; moderate brown.
3,1 –5,4	2,3	*Clay*, plastic; pinkish-grey.
5,4 –5,8	0,4	Siltstone, pinkish-grey.
5,8 –6,0	0,2	*Clay*, semi-flint, silty; pale yellowish-brown.
6,0 –6,2	0,2	Siltstone, decomposed; light brown.
6,2 –6,75	0,55	*Clay*, semi-flint, silty; pale yellowish-brown.
6,75–27,4	20,65	Tillite, silty matrix; very light grey to light grey. Pebbles scarce.

Borehole RF 8 (Locality: Rietfontein 470 JR)

Depth (m)	Thickness (m)	Description
0–1,8	1,8	Sandstone, decomposed; dark yellowish-orange.
1,8 –1,9	0,1	Grit, ferruginous; greyish-red.
1,9 –2,9	1,0	*Clay*, plastic; pinkish-grey.
2,9 –3,5	0,6	*Clay*, plastic; pale red.
3,5 –4,4	0,9	*Clay*, plastic; pinkish-grey.
4,4 –5,35	0,95	*Clay*, plastic; pale red.
5,35–5,55	0,2	*Clay*, flint, silty; light grey.
5,55–5,95	0,4	*Clay*, plastic; pinkish-grey.
5,95–7,3	1,35	*Clay*, plastic, silty; badly Fe-stained; pale red to moderate red.
7,3 –29,55	22,25	Tillite, silty to clayey matrix; multicoloured, carbonaceous at 17,9 m. Abundant pebbles between 22,5 and 24,0m; also at 29,35 m.

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Borehole NG 1 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–2,9	2,9	Soil, sandy to silty; moderate yellowish-brown.
2,9 –3,0	0,1	Laterite and hard siltstone pebbles; pale reddish-brown.
3,0 –3,5	0,5	Silt, unconsolidated; pinkish-grey.
3,5 –4,0	0,5	Siltstone, hard; pinkish-grey.
4,0 –5,8	1,8	Sandstone, massive hard with Fe-stained micaceous fracture zone, 50 mm thick, at 5,05 m; pinkish-grey.
5,8 –6,0	0,2	Sandstone, gritty; pinkish-grey.
6,0 –13,25	7,25	Grit, getting coarser and more ferruginous lower down; pinkish grey. Prominent ferruginous bed at 11,6 m.
13,25–14,95	1,7	Sandstone, well-bedded. Some ferruginous beds and occasional angular quartz pebbles, ± 10 mm diameter. Prominent bed of quartz pebbles, 20 mm thick, at 14,85 m. Very pale orange.
14,95–15,3	0,35	Sandstone, gritty; very pale orange.
15,3 –16,7	1,4	Grit, getting coarser lower down. From 16,1 m it contains pebbles of quartz (30 mm), reddish quartzite (20 mm) and siltstone (50 mm). Very pale orange.
16,7 –19,7	3,0	Sandstone, massive, with occasional quartz and reddish quartzite pebbles (10 mm). Light grey but pale red near top.
19,7 –20,35	0,65	*Clay*, flint, silty; light grey.
20,35–21,5	1,15	Sandstone, massive, containing occasional angular quartz pebbles. Light grey.
21,5 –25,8	4,3	Tillite, consisting of abundant angular, subrounded and some well-rounded pebbles in a sandstone matrix. General colour light grey.
25,8 –28,5	2,7	*Clay*, flint, silty; light grey. Well-developed cleavage.
28,5 –29,2	0,7	Siltstone, massive; light grey.
29,2 –31,35	2,15	Tillite; angular to subrounded pebbles in a siltstone matrix; light grey.

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Borehole NG 2 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–3,6	3,6	Soil, sandy to silty; moderate yellowish-brown.
3,6 –3,75	0,15	Grit, ferruginous; greyish-orange.
3,75–4,4	0,65	Siltstone, pinkish-grey.
4,4 –5,1	0,7	Grit, pinkish-grey.
5,1 –5,4	0,3	Siltstone, pinkish-grey.
5,4 –9,35	3,95	*Clay*, plastic to semi-flint; white to very light grey.
9,35–9,55	0,2	Siltstone, pinkish-grey.
9,55–11,0	1,45	Sandstone, gritty; very light grey.
11,0 –14,0	3,0	Grit, very light grey.
14,0 –14,45	0,45	Sandstone, massive, gritty; very light grey.
14,45–16,25	1,8	Grit, greyish-pink.
16,25–17,1	0,85	Siltstone, greyish-pink.
17,1 –18,1	1,0	*Clay*, flint, carbonaceous with frequent sandy layers; medium dark grey.
18,1 –18,2	0,1	Grit, greyish-pink.
18,2 –18,65	0,45	Siltstone, greyish-pink.
18,65–18,85	0,2	Sandstone, gritty; greyish-pink.
18,85–22,35	3,5	Grit, getting coarser lower down; grains ± 10 mm diameter at 21,0 m. Prominent pebble bed at 22,2 – 22,35 m; angular reddish quartzite and white quartz pebbles ± 50 mm diameter. Greyish-pink.
22,35–22,8	0,45	Sandstone, ferruginous; pale red.
22,8 –23,15	0,35	*Clay*, flint; light grey.
23,15–30,0	6,85	Tillite; angular to subrounded pebbles in a sandstone matrix; light grey.
30,0 –31,5	1,5	*Clay*, flint, silty; light grey.

Borehole NG 3 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–7,0	7,0	Soil, sandy to silty; moderate yellowish-brown to light brown.
7,0 –7,5	0,5	Sandstone, ferruginous; light brown.
7,5 –7,6	0,1	Siltstone, moderate orange-pink.
7,6 –9,45	1,85	*Clay*, semi-flint; very light grey to pinkish-grey.
9,45–11,3	1,85	*Clay*, semi-plastic to semi-flint; very light grey to light grey. Fe-staining along joint planes. Lower 0,2 m silty.
11,3 –27,3	16,0	Grit, massive; very light grey. Fe-stained along joints.
27,3 –29,75	2,45	*Clay*, flint, carbonaceous; medium dark grey. Frequent sandy layers.

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Borehole NG 4 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–6,85	6,85	Soil, sandy to silty; moderate yellowish-brown to light brown.
6,85–7,5	0,65	*Clay*, plastic; white. Fe-stained. Silty in upper part.
7,5 –8,8	1,3	Sand, unconsolidated; greyish orange-pink.
8,8 –9,0	0,2	*Clay*, plastic; white. Fe-stained.
9,0 –10,2	1,2	Grit, very pale orange.
10,2 –12,0	1,8	*Clay*, plastic, silty; pinkish-grey.
12,0 –13,1	1,1	Siltstone, friable; pinkish-grey.
13,1 –16,5	3,4	Grit, very light grey. Lower 10 mm ferruginous.
16,5 –17,5	1,0	Silt, unconsolidated; pinkish-grey.
17,5 –19,3	1,8	*Clay*, semi-flint; pinkish-grey to light grey.
19,3 –19,8	0,5	Sandstone, massive; pinkish-grey.
19,8 –20,4	0,6	Sandstone, massive, gritty; pinkish-grey.
20,4 –23,3	2,9	Grit, massive pinkish-grey.
23,3 –26,0	2,7	Sandstone, faintly bedded; pinkish-grey.
26,0 –30,2	4,2	*Clay*, flint, carbonaceous; medium grey to dark grey.

Borehole NG 5 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–5,7	5,7	Soil, silty to sandy; light brown. Lateritic in places.
5,7 –6,2	0,5	Sandstone, well-bedded; very light grey.
6,2 –9,0	2,8	Grit, massive; very light grey.
9,0 –9,3	0,3	Siltstone, pinkish-grey.
9,3 –9,9	0,6	*Clay*, semi-plastic, fissile; pinkish-grey.
9,9 –11,05	1,15	Sand, unconsolidated; light brownish-grey.
11,05–12,7	1,65	*Clay*, plastic, silty; pinkish grey.
12,7 –13,6	0,9	Sandstone, gritty; pinkish-grey.
13,6 –16,4	2,8	Grit, getting coarser lower down (up to ± 10 mm diameter); pinkish-grey.
16,4 –16,8	0,4	*Clay*, plastic, silty; pinkish-grey.
16,8 –17,2	0,4	Sandstone, massive; very light grey.
17,2 –17,5	0,3	*Clay*, flint, silty; pinkish-grey.
17,5 –18,0	0,5	Sandstone, massive; very light grey.
18,0 –30,2	12,2	Grit, pinkish grey; light grey for lower 4,5 m.

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Borehole NG 6 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–3,92	3,92	Soil, sandy to silty; moderate yellowish-brown to light brown.
3,92–4,5	0,58	Grit, pinkish-grey.
4,5 –6,15	1,65	Sand and grit, unconsolidated; greyish orange-pink.
6,15–8,35	2,2	Grit, pinkish-grey.
8,35–9,3	0,95	Sandstone, well-bedded; pinkish-grey.
9,3 –12,12	2,82	Grit, massive; pinkish-grey.
12,12–12,62	0,5	*Clay*, semi-flint; pinkish-grey.
12,62–13,5	0,88	Siltstone, light grey.
13,5 –30,0	16,5	Tillite with sandy to silty matrix; general colour pinkish-grey.

Borehole NG 7 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–6,6	6,6	Soil, sandy to silty; moderate reddish-orange to light brown.
6,6 –6,7	0,1	Grit, weathered; light brown.
6,7 –7,5	0,8	Shale, well-bedded; very pale orange with greyish-red purple bands.
7,5 –9,2	1,7	*Clay*, semi-flint; white to pinkish-grey.
9,2–11,33	2,13	*Clay*, semi-flint, silty; very light grey.
11,33–12,15	0,82	Sandstone, gritty; pinkish-grey.
12,15–15,85	3,7	Grit, pinkish-grey.
15,85–16,85	1,0	Sandstone, gritty; pinkish-grey.
16,85–17,9	1,05	Grit, pinkish-grey.
17,9 –18,35	0,45	*Clay*, plastic, silty; pinkish-grey.
18,35–18,85	0,5	Siltstone, friable; pinkish-grey.
18,85–19,4	0,55	Sandstone, gritty; pinkish-grey.
19,4 –29,25	9,85	Grit, pinkish-grey; light grey for lower 1,0 m. Fe-staining between 21 and 26 m. Occasional thin (20 mm) clayey and shaly interbeds.

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Borehole NG 8 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Soil, sandy to silty; moderate reddish-orange to light brown.
3,0 –3,4	0,4	Laterite.
3,4 –6,4	3,0	Sandstone, weathered, partly unconsolidated; pinkish-grey.
6,4 –8,8	2,4	Grit, pinkish-grey. Gritty sandstone between 6,5 and 6,65 m.
8,8 –9,55	0,75	Sandstone, gritty, pinkish-grey. Bottom 100 mm ferruginous.
9,55–12,05	2,5	Siltstone, pinkish-grey. Lower 500 mm cross-bedded and contains a few angular pebbles (10 mm diameter).
12,05–12,6	0,55	Grit, ferruginous; light brownish-grey.
12,6 –14,15	1,55	*Clay*, plastic, silty; pinkish-grey.
14,15–16,3	2,15	*Clay*, semi-flint; getting progressively more silty lower down. Pinkish-grey to light grey.
16,3 –16,6	0,3	Grit, ferruginous; light brownish-grey.
16,6 –16,7	0,1	*Clay*, semi-flint, silty; light grey.
16,7 –17,5	0,8	Grit, pinkish-grey.
17,5 –17,65	0,15	*Clay*, semi-flint, silty; light grey.
17,65–18,25	0,6	Grit, pinkish-grey to light brownish-grey.
18,25–21,0	2,75	*Clay*, flint, carbonaceous; medium grey. Occasional thin (50 mm) ferruginous sandy interbeds in upper 1,5 m.
21,0 –24,2	3,2	*Clay*, flint, very carbonaceous, getting progressively more silty lower down; dark grey. Thin coal stringers between 24,0 and 24,2 m.
24,2 –25,4	1,2	Sandstone with thin (few mm) carbonaceous and coal beds; medium light grey.
25,4 –27,2	1,8	Sandstone, gritty in places; pinkish-grey.
27,2 –28,3	1,1	Sandstone with thin (few mm) carbonaceous and coal beds; medium light grey.
28,3 –29,1	0,8	Siltstone, carbonaceous; medium dark grey.
29,1 –29,53	0,43	Sandstone with thin (few mm) carbonaceous coal beds; medium light grey.

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Borehole NG 9 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–3,2	3,2	Soil, sandy to silty; light brown to greyish orange-pink.
3,2 –10,5	7,3	Grit, pinkish-grey; upper part weathered, lower 0,5 m ferruginous. Silty plastic clay between 5,45 and 5,55 m.
10,5 –10,8	0,3	*Clay*, flint, ferruginous; dark reddish-brown.
10,8 –11,8	1,0	*Clay*, flint, carbonaceous, silty; medium dark grey.
11,8 –14,8	3,0	Shale, carbonaceous, fissile; medium dark grey.
14,8 –15,0	0,2	Sandstone, ferruginous; pale red.
15,0 –15,2	0,2	Shale, carbonaceous, fissile; medium dark grey.
15,2 –15,5	0,3	Sandstone, gritty; light brownish-grey.
15,5 –18,5	3,0	Grit, getting coarser lower down (to 5 mm diameter); pinkish-grey.
18,5 –18,8	0,3	Shale, carbonaceous; greyish-black. Coal beds, 5 mm thick.
18,8 –18,95	0,15	*Clay*, flint, carbonaceous; dark grey. Thin coal beds.
18,95–21,1	2,15	Siltstone, pinkish-grey.
21,1 –21,5	0,4	Sandstone, pinkish-grey.
21,5 –23,6	2,1	Grit, pinkish-grey.
23,6 –25,3	1,7	*Clay*, flint, carbonaceous, silty; medium dark grey.
25,3 –26,5	1,2	*Clay*, flint, very carbonaceous; greyish-black.
26,5 –27,6	1,1	*Clay*, flint, carbonaceous; medium dark grey. Same as 18,25 – 21,0 m in borehole NG 8.
27,6 –29,85	2,25	Sandstone, fine-grained with carbonaceous bedding; light grey.

Borehole NG 10 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–6,5	6,5	Soil, sandy to silty; light brown to greyish orange-pink.
6,5 –7,0	0,5	Shale, ferruginous; pale reddish-brown.
7,0 –7,2	0,2	Grit, ferruginous; pale red.
7,2 –9,0	1,8	*Clay*, plastic, getting silty lower down, lower 100 mm sandy. Pinkish-grey.
9,0 –9,5	0,5	Sandstone, pinkish-grey.
9,5 –11,8	2,3	Siltstone, pinkish-grey.
11,8 –14,2	2,4	Sandstone, gritty, getting coarser lower down; pinkish-grey.
14,2 –14,5	0,3	*Clay*, semi-plastic; pinkish-grey with light grey banding.
14,5 –16,35	1,85	*Clay*, flint, carbonaceous, silty; medium dark grey.
16,35–18,5	2,15	Sandstone, gritty, pinkish-grey.
18,5 –19,15	0,65	Grit, pinkish-grey.
19,15–19,5	0,35	Siltstone, clayey; pinkish-grey to light grey.
19,5 –20,8	1,3	Sandstone, gritty; pinkish-grey.
20,8 –21,7	0,9	Sandstone with carbonaceous bedding; light grey.
21,7 –22,5	0,8	Grit with carbonaceous bedding; light grey.
22,5 –23,5	1,0	*Clay*, flint, shaly, very carbonaceous; dark grey. Thin (few mm) coal beds.
23,5 –27,0	3,5	*Clay*, flint, carbonaceous, getting slightly silty lower down; dark grey.
27,0 –28,3	1,3	Siltstone, clayey, carbonaceous; medium dark grey.
28,3 –29,0	0,7	Sandstone, fine-grained with carbonaceous bedding; medium dark grey.

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Borehole NG 11 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–1,5	1,5	Soil, silty to sandy; light brown.
1,5 –5,6	4,1	Grit, unconsolidated; pinkish-grey.
5,6 –11,2	5,6	Sand, unconsolidated, pinkish-grey.
11,2 –11,5	0,3	*Clay*, plastic, ferruginous; very pale orange.
11,5 –12,2	0,7	Sand, unconsolidated; very pale orange.
12,2 –12,7	0,5	Grit, ferruginous; very pale orange.
12,7 –12,75	0,05	*Clay*, plastic; white.
12,75–15,4	2,65	Sandstone, gritty; pinkish-grey.
15,4 –17,2	1,8	Grit, pinkish-grey. Lower 0,5 m unconsolidated.
17,2 –18,7	1,5	*Clay*, plastic, getting silty lower down; greyish-pink. Lower 150 mm ferruginous.
18,7 –25,5	6,8	*Clay*, flint, carbonaceous, getting slightly silty lower down; medium dark grey. Same as 23,5 to 27,0 m in borehole NG 10.
25,5 –26,6	1,1	Siltstone, carbonaceous; dark grey. Thin (5 mm) coal beds.
26,6 –28,8	2,2	Sandstone with carbonaceous bedding; light grey.
28,8 –29,9	1,1	*Clay*, flint, carbonaceous, getting slightly silty lower down; medium dark grey.
29,9 –30,0	0,1	Sandstone with carbonaceous bedding; light grey.

Borehole NG 12 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–2,0	2,0	Soil, silty; light brown.
2,0 –8,5	6,5	Sand, unconsolidated; pinkish-grey.
8,5 –8,9	0,4	Sandstone, ferruginous, weathered; greyish-orange.
8,9 –9,3	0,4	*Clay*, plastic, Fe-stained; pinkish-grey.
9,3 –9,7	0,4	Grit, unconsolidated; pinkish-grey.
9,7 –13,4	3,7	Sand, unconsolidated; pinkish-grey.
13,4 –13,45	0,05	Grit, ferruginous, greyish orange pink.
13,45–14,45	1,0	*Clay*, plastic, silty; pinkish-grey.
14,45–15,15	0,7	Sandstone, gritty; pinkish-grey.
15,15–16,1	0,95	Grit, ferruginous; pale yellowish-brown.
16,1 –16,15	0,05	*Clay*, plastic; pale yellowish-brown.
16,15–16,25	0,1	Sandstone, gritty; pale yellowish-brown.
16,25–19,1	2,85	Sand, unconsolidated; pinkish-grey.
19,1 –19,5	0,4	*Clay*, plastic, ferruginous; moderate orange-pink.
19,5 –20,2	0,7	Shale, carbonaceous; greyish-black. Thin (1–2 mm) coal beds.
20,2 –21,0	0,8	*Clay*, plastic, ferruginous; moderate orange-pink.
21,0 –22,0	1,0	*Clay*, flint, carbonaceous; medium dark grey to medium grey.
22,0 –22,7	0,7	*Clay*, flint, very carbonaceous; dark grey.
22,7 –23,8	1,1	*Clay*, flint, silty, very carbonaceous; greyish-black. Thin coal stringers.
23,8 –24,7	0,9	Sandstone with carbonaceous bedding; medium light grey.
24,7 –26,3	1,6	*Clay*, flint, very carbonaceous; dark grey. Thin coal stringers.
26,3 –28,5	2,2	Sandstone, fine-grained with carbonaceous bedding; medium light grey.
28,5 –29,4	0,9	*Clay*, flint, very carbonaceous; dark grey.
29,4 –30,05	0,65	Coal, dull with a slight lustre and a few bright-coal stringers.

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Borehole NG 13 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–11,25	11,25	Sand and silt, unconsolidated; light brown to pinkish-grey.
11,25–12,75	1,5	Grit, weathered, very pale orange.
12,75–13,2	0,45	Sandstone, gritty, pinkish-grey.
13,2 –14,1	0,9	*Clay*, plastic, fissile; greyish orange-pink.
14,1 –14,5	0,4	*Clay*, semi-plastic, carbonaceous; medium grey.
14,5 –15,3	0,8	*Clay*, plastic, fissile, silty; greyish orange-pink.
15,3 –16,0	0,7	Sandstone, greyish orange-pink. Upper 0,25 m gritty.
16,0 –20,95	4,95	Grit, pinkish-grey.
20,95–22,5	1,55	*Clay*, plastic; pinkish-grey. Core-loss 1,5 m.
22,5 –23,34	0,84	Coal, dull with a few bright-coal bands and stringers.
23,34–23,44	0,1	Shale, carbonaceous.
23,44–23,59	0,15	Coal, bright.
23,59–23,69	0,1	Shale, carbonaceous.
23,69–23,86	0,17	Coal, dull.
23,86–24,95	1,09	Shale, carbonaceous.
24,95–25,53	0,58	Coal, dull with bright-coal stringers.
25,53–25,94	0,41	Shale, carbonaceous with bright-coal stringers.
25,94–26,16	0,22	Coal, dull, heavy with bright-coal stringers.
26,16–27,15	0,99	Shale, carbonaceous, clayey; greyish-black.
27,15–29,05	1,9	Sandstone, gritty with carbonaceous bedding; pinkish-grey to light grey.

Borehole NG 14 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–6,5	6,5	Sand, gritty, unconsolidated; light brown.
6,5 –13,3	6,8	Sand, gritty, unconsolidated; pinkish-grey.
13,3 –13,6	0,3	Sandstone, gritty; very light grey.
13,6 –14,4	0,8	*Clay*, plastic; pinkish-grey.
14,4 –15,42	1,02	Grit, very coarse-grained (up to 10 mm diameter); very light grey.
15,42–15,82	0,4	*Clay*, semi-flint; very pale orange.
15,82–17,8	1,98	Siltstone, carbonaceous; medium dark grey.
17,8 –20,25	2,45	*Clay*, flint, carbonaceous; dark grey.
20,25–22,35	2,1	Siltstone, carbonaceous; dark grey.
22,35–23,75	1,4	Sandstone with wavy carbonaceous laminations; medium light grey.
23,75–25,75	2,0	Grit (2–5 mm diameter) with occasional beds of carbonaceous siltstone; very light grey.
25,75–30,0	4,25	*Clay*, flint, carbonaceous; dark grey.

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Borehole NG 15 (Locality: Nooitgedacht 436 JR)

Depth (m)	Thickness (m)	Description
0–8,1	8,1	Sand, gritty, unconsolidated; light brown.
8,1 –10,0	1,9	*Clay*, plastic; very light grey to pinkish-grey.
10,0 –12,0	2,0	Siltstone; very light grey.
12,0 –21,1	9,1	Grit (2–4 mm diameter); very light grey, with silty clay 14,4–14,64 m and sandstone 20,6 – 20,8 m.
21,1 –21,9	0,8	Siltstone, light grey with dark reddish-brown laminae.
21,9 –22,9	1,0	Siltstone, carbonaceous; medium dark grey.
22,9 –25,5	2,6	Sandstone, fine-grained; pinkish-grey.
25,5 –25,8	0,3	*Clay*, plastic; pinkish-grey.
25,8 –28,35	2,55	Siltstone, carbonaceous, finely laminated; dark grey.
28,35–29,0	0,65	*Clay*, flint, carbonaceous; dark grey.
29,0 –29,7	0,7	Siltstone, very carbonaceous; greyish-black.
29,7 –30,0	0,3	*Clay*, flint, carbonaceous; dark grey.

Borehole RP 1 (Locality: Rooipoort 440 JR)

Depth (m)	Thickness (m)	Description
0–12,12	12,12	Sand, silty, unconsolidated; moderate reddish-brown.
12,12–18,5	6,38	Sandstone, gritty; very light grey.
18,5 –19,55	1,05	Siltstone very light grey.
19,55–19,8	0,25	Grit (2–3 mm diameter); very light grey.
19,8 –20,1	0,3	Siltstone, very light grey.
20,1 –24,15	4,05	Grit (2–3 mm diameter); very light grey.
24,15–28,0	3,85	Sandstone, silty; pinkish-grey.
28,0 –29,4	1,4	Siltstone, carbonaceous; medium light grey to medium grey.
29,4 –30,58	1,18	Sandstone, fine-grained with wavy carbonaceous laminations; light grey.

Borehole RP 2 (Locality: Rooipoort 440 JR)

Depth (m)	Thickness (m)	Description
0–16,23	16,23	Sand, silty, unconsolidated; moderate reddish brown.
16,23–16,6	0,37	Grit (2–4 mm diameter); very light grey.
16,6 –19,3	2,7	Siltstone, clayey; very light grey.
19,3 –22,5	3,2	Grit (2–6 mm diameter); very light grey.
22,5 –22,7	0,2	Siltstone, very light grey.
22,7 –25,8	3,1	Grit (2 -6 mm diameter) with subrounded pebbles in lower 0,8 m; very light grey.
25,8 –28,0	2,2	Siltstone, carbonaceous, getting coarser lower down; medium dark grey.
28,0 –28,5	0,5	Sandstone with rare wavy carbonaceous laminations; medium grey.
28,5 –29,2	0,7	Grit (2–3 mm diameter); medium light grey.
29,2 –29,8	0,6	Siltstone, carbonaceous with thin (3 mm) coal stringers; greyish-black.
29,8 –29,95	0,15	Sandstone with wavy carbonaceous laminations; medium grey.
29,95–30,78	0,83	Siltstone, carbonaceous with dull coal between 30,25 and 30,4 m.

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Borehole RP 3 (Locality: Rooipoort 440 JR)

Depth (m)	Thickness (m)	Description
0–5,15	5,15	Sand, unconsolidated; greyish-orange.
5,15–14,4	9,25	Grit (2–8 mm diameter), friable; pale yellowish-brown.
14,4 –15,0	0,6	Siltstone, very pale orange.
15,0 –18,05	3,05	Siltstone, carbonaceous with wavy carbonaceous laminations in more sandy parts; medium grey.
18,05–18,7	0,65	Siltstone, pinkish-grey with ferruginous laminations.
18,7 –19,6	0,9	Sandstone, fine-grained at the top, getting coarser lower down; pinkish-grey.
19,6 –19,9	0,3	Siltstone, pale red.
19,9 –31,58	11,68	Tillite; angular to subrounded pebbles in a sandy to silty matrix.

Borehole LS 1 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Sand, gritty, unconsolidated; pinkish-grey.
3,0 –4,5	1,5	Grit, unconsolidated, pinkish-grey.
4,5 –6,3	1,8	Sand, unconsolidated; pinkish-grey.
6,3 –6,4	0,1	Sandstone, ferruginous; light brown.
6,4 –6,75	0,35	*Clay*, plastic; pinkish-grey. Fe-stained.
6,75–12,75	6,0	Sand, unconsolidated; pinkish-grey.
12,75–12,8	0,05	Siltstone, clayey with worm burrows; pinkish-grey.
12,8 –12,9	0,1	Grit, pinkish-grey.
12,9 –15,5	2,6	Sand, unconsolidated; pinkish-grey.
15,5 –17,65	2,15	Grit, pinkish-grey. Lower 0,6 m ferruginous.
17,65–20,2	2,55	*Clay*, flint, carbonaceous, slightly silty; medium dark grey to dark grey.
20,2 –20,95	0,75	Siltstone, carbonaceous, well-bedded; medium dark grey.
20,95–21,05	0,1	Grit, carbonaceous; medium dark grey.
21,05–22,2	1,15	Shale, carbonaceous; dark grey.
22,2 –22,55	0,35	Sandstone with carbonaceous bedding; medium dark grey.
22,55–23,5	0,95	Grit, very light grey.
23,5 –23,65	0,15	*Clay*, plastic; greyish orange-pink.
23,65–24,41	0,76	Shale, carbonaceous, clayey; greyish-black.
24,41–25,51	1,1	Coal, mixed bright and dull.
25,51–25,61	0,1	Shale, carbonaceous.
25,61–26,16	0,55	Coal, dull with bright-coal stringers.
26,16–26,24	0,08	Shale, carbonaceous.
26,24–26,65	0,41	Coal, dull, heavy with bright-coal bands and stringers.
26,65–26,78	0,13	Shale, carbonaceous.
26,78–26,85	0,07	Coal, dull-lustrous with thin carbonaceous shale bands.
26,85–27,0	0,15	Shale, carbonaceous with a few bright-coal stringers.
27,0 –27,36	0,36	Coal, dull-lustrous and dull.
27,36–27,72	0,36	Shale, carbonaceous.
27,72–28,3	0,58	Coal, mixed bright and dull.
28,3 –28,4	0,1	Shale, carbonaceous.
28,4 –28,5	0,1	Coal, dull.
28,5 –29,07	0,57	Shale, carbonaceous with a few bright-coal stringers.
29,07–29,16	0,09	Coal, dull with bright-coal stringers.
29,16–29,45	0,29	Shale, carbonaceous with a few bright-coal stringers.
29,45–30,1	0,65	Coal, dull with a slight lustre.

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Borehole LS 2 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–2,50	2,50	Soil, sandy; light brownish-grey.
2,50–2,65	0,15	Grit, weathered, ferruginous; light brownish-grey.
2,65–5,70	3,05	Sand, unconsolidated; light brownish-grey.
5,70–6,20	0,50	Grit; very light grey.
6,20–8,00	1,80	Sand, unconsolidated; very light grey.
8,00–8,45	0,45	Grit; very light grey.
8,45–10,00	1,55	Sand, unconsolidated; pinkish-grey.
10,00–11,60	1,60	Grit, pinkish-grey; lower 0,20 m ferruginous.
11,60–13,10	1,50	*Clay*, flint, carbonaceous, silty; medium dark grey.
13,10–13,80	0,70	Grit; greyish orange-pink.
13,80–14,05	0,25	*Clay*, flint, carbonaceous, silty; medium dark grey.
14,05–17,80	3,75	Grit; greyish orange-pink. Sandstone at 15,70–15,75 and 17,20–17,40.
17,80–20,50	3,80	*Clay*, flint, carbonaceous, silty; medium dark grey.
20,50–21,86	1,36	Shale, carbonaceous; greyish-black.
21,86–22,97	1,11	Coal, dull with some bright stringers.
22,97–23,75	0,78	Shale, carbonaceous; greyish-black.
23,75–24,53	0,78	Coal, lustrous.
24,53–24,80	0,27	Shale, carbonaceous; black.
24,80–26,77	1,97	Coal, mixed; 0,34 m carbonaceous shale at bottom.
26,77–29,80	3,03	Coal, dull to lustrous; shaly bands.

Borehole LS 3 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–3,5	3,5	Soil, silty to sandy; light brown.
3,5 –3,8	0,3	Sandstone, weathered, ferruginous; moderate reddish-orange.
3,8 –4,55	0,75	*Clay*, plastic, shaly, Fe-stained; greyish-orange.
4,55–13,9	9,35	Gritstone, pinkish-grey. *Clay*, flint; light grey, 20 mm thick, at 13,05 m.
13,9 –16,3	2,4	*Clay*, flint, carbonaceous, silty; dark grey. Carbonaceous bedding.
16,3 –16,92	0,62	*Clay*, flint, very carbonaceous; greyish-black. Thin coal stringers.
16,92–17,05	0,13	Coal, dull with bright-coal stringers.
17,05–17,52	0,47	Shale, carbonaceous.
17,52–18,43	0,91	Coal, dull-lustrous.
18,43–18,77	0,34	Shale, coaly.
18,77–18,93	0,16	Coal, dull with bright-coal stringers.
18,93–19,32	0,39	Shale, coaly.
19,32–19,97	0,65	Coal, mixed dull and dull-lustrous.
19,79–20,11	0,14	Shale, grey.
20,11–21,2	1,09	Coal, mixed bright and dull-lustrous; slightly calcitic.
21,2 –21,28	0,08	Shale, coaly.
21,28–21,69	0,41	Coal, dull with a few bright-coal stringers.
21,69–21,94	0,25	Shale, carbonaceous.
21,94–24,0	2,06	Coal, dull-lustrous with bright bands and stringers; calcitic where bright.
24,0 –26,48	2,48	Coal, mixed dull and dull-lustrous with a few bright-coal stringers, slightly calcitic in places.
26,48–27,5	1,02	*Clay*, flint, carbonaceous, silty; dark grey.
27,5 –29,0	1,5	Sandstone, fine-grained; light grey.Wavy carbonaceous bedding and coal stringers.

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Borehole LS 4 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–4,5	4,5	Soil, silty; pinkish-grey to light brown.
4,5 –7,8	3,3	Grit, unconsolidated; light brown.
7,8 –11,6	3,8	Grit, very pale orange.
11,6 –11,8	0,2	*Clay*, plastic, shaly, well-bedded, Fe-stained; very pale orange.
11,8 –13,6	1,8	*Clay*, flint, carbonaceous, silty; medium dark grey. Thinly banded.
13,6 –13,93	0,33	Shale, carbonaceous, clayey, dark grey.
13,93–14,35	0,42	Coal, dull.
14,35–14,45	0,1	Shale, coaly.
14,45–14,74	0,29	Coal, dull with bright-coal stringers.
14,74–15,1	0,36	Shale, coaly.
15,1–15,45	0,35	Coal, dull with bright-coal stringers.
15,45–15,88	0,43	Shale, carbonaceous.
15,88–16,2	0,32	Coal, dull to dull-lustrous.
16,2 –16,28	0,08	Shale, coaly.
16,28–18,5	2,22	Coal, dull-lustrous with bright-coal stringers.
18,5 –18,66	0,16	Shale, carbonaceous.
18,66–18,96	0,3	Coal, dull-lustrous.
18,96–19,08	0,12	Shale, coaly.
19,08–20,67	1,59	Coal, dull-lustrous with a few bright-coal stringers, especially at the bottom.
20,67–21,0	0,33	Coal, bright, slightly calcitic.
21,0 –21,53	0,53	Coal, dull with bright-coal stringers.
21,53–21,76	0,23	Coal, mixed, mainly bright.
21,76–22,0	0,24	Shale, coaly.
22,0 –22,5	0,5	Coal, dull to dull-lustrous.
22,5 –22,64	0,14	Shale, carbonaceous.
22,64–24,15	1,51	Coal, mixed, mainly dull; pyritic over bottom 0,4 m.
24,15–24,28	0,13	Coal, mainly dull; pyritic and calcitic.
24,28–24,58	0,3	Coal, dull with a few bright-coal stringers; calcitic.
24,58–25,5	0,92	Shale, carbonaceous, clayey; dark grey.
25,5 –28,5	3,0	*Clay*, flint, carbonaceous, silty; medium dark grey. Thinly banded.
28,5 –28,75	0,25	Shale, carbonaceous, clayey; dark grey.
28,75–30,1	1,35	Coal, dull.
30,1 –30,5	0,4	Shale, carbonaceous, clayey; dark grey.
30,5 –31,5	1,0	*Clay*, flint, carbonaceous, silty; medium dark grey.
31,5 –32,5	1,0	Sandstone, fine-grained; light grey. Wavy carbonaceous bedding.
32,5 –32,8	0,3	Grit, light grey.
32,8 –33,0	0,2	Sandstone, fine-grained; light grey. Wavy carbonaceous bedding.
33,0 –33,2	0,2	Grit, light grey.
33,2 –33,43	0,23	Sandstone, fine-grained; light grey. Wavy carbonaceous bedding.

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Borehole LS 5 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–9,8	9,8	Soil, silty to sandy; pale reddish-brown.
9,8 –10,0	0,2	Sandstone, gritty, ferruginous; pale red.
10,0 –12,0	2,0	Silt, unconsolidated; pale reddish-brown.
12,0 –13,0	1,0	*Clay*, plastic, Fe-stained; multicoloured, generally greyish orange-pink.
13,0 –14,5	1,5	Sand, unconsolidated, ferruginous; pale reddish-brown.
14,5 –16,0	1,5	Silt, unconsolidated, carbonaceous; medium light grey.
16,0 –18,5	2,5	Shale, carbonaceous, clayey; greyish-black. Some dull and bright-coal bands.
18,5 –19,0	0,5	*Clay*, flint, carbonaceous; medium grey. Thinly banded.
19,0 –20,5	1,5	Sandstone, light grey. Carbonaceous bedding.
20,5 –21,8	1,3	Siltstone, medium dark grey. Carbonaceous bedding.
21,8 –22,0	0,2	Sandstone, light grey with carbonaceous bedding.
22,0 –22,8	0,8	Grit, light grey.
22,8 –26,6	3,8	Sandstone, light grey. Carbonaceous bedding and coal stringers.
26,6 –29,0	2,4	Grit, light grey.
29,0 –29,3	0,3	Sandstone, light grey. Carbonaceous bedding.

Borehole LS 6 (Locality: Loopspruit 435 JR)

Depth (4)	Thickness (m)	Description
0–9,7	9,7	Soil, silty to sandy; pale reddish-brown.
9,7 –10,55	0,85	*Clay*, plastic, Fe-stained; generally very pale orange.
10,55–13,0	2,45	Silt, unconsolidated; light brown.
13,0 –13,2	0,2	*Clay*, plastic, Fe-stained; generally very pale orange.
13,2 –18,5	5,3	*Clay*, flint, carbonaceous; medium dark grey. Lower 0,5 m silty.
18,5 –20,4	1,9	Sandstone, fine-grained; light grey. Wavy carbonaceous bedding.
20,4 –20,89	0,49	Shale, carbonaceous, clayey; greyish-black. Occasional sub-rounded pebbles.
20,89–20,96	0,07	Coal, dull, heavy.
20,96–21,11	0,15	Shale, carbonaceous, clayey; greyish-black.
21,11–22,16	1,05	Coal, mixed bright and dull.
22,16–22,93	0,77	Shale, carbonaceous and coaly with grit and conglomerate.
22,93–23,29	0,36	Coal, mixed bright and dull; mainly dull.
23,29–23,65	0,36	Shale, coaly.
23,65–23,81	0,16	Coal, dull-lustrous with bright-coal stringers.
23,81–23,85	0,04	Shale, coaly.
23,85–24,73	0,88	Coal, dull-lustrous with bright-coal stringers.
24,73–25,44	0,71	Shale, carbonaceous, coaly at top and gritty at bottom.
25,44–26,4	0,96	*Clay*, plastic, Fe-stained; generally very pale orange. Small (5 mm diameter) pebbles near base.
26,4 –29,1	2,7	Tillite; angular to well-rounded pebbles in a fine-grained sandstone matrix; light grey.

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Borehole LS 7 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–11,2	11,2	Sand and silt, unconsolidated; pale reddish-brown. Gritty sandstone (50 mm thick) at 9,0 m.
11,2 –13,3	2,1	*Clay*, plastic, Fe-stained; generally very pale orange.
13,3 –16,4	3,1	*Clay*, flint, carbonaceous; dark grey. Lower 1,0 m silty.
16,4 –19,05	2,65	Sandstone, fine-grained; light grey. Carbonaceous bedding.
19,05–23,4	4,35	Shale, carbonaceous, clayey; greyish-black. Some dull-coal bands. Occasional subrounded pebbles.
23,4 –29,3	5,9	Tillite; angular to well-rounded pebbles in a fine-grained sandstone matrix; light brownish-grey. Carbonaceous stringers in upper 0,8 m. Pebbles scarce in lower 4,5 m.

Borehole LS 8 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–7,2	7,2	Soil, silty; pale reddish-brown.
7,2 –11,3	4,1	*Clay*, plastic, Fe-stained; generally very pale orange.
11,3 –12,6	1,3	*Clay*, flint; medium light grey to light brownish-grey.
12,6 –12,7	0,1	*Clay*, plastic; pinkish-grey.
12,7 –13,24	0,54	*Clay*, flint, very carbonaceous; greyish-black.
13,24–13,5	0,26	Coal, dull.
13,5 –13,8	0,3	*Clay*, flint, very carbonaceous; greyish-black.
13,8 –21,45	7,65	Sandstone, light grey with carbonaceous bedding.
21,45–23,6	2,15	Shale, carbonaceous, clayey; greyish-black. Thin coal stringers.
23,6 –25,65	2,05	Sandstone, light grey with carbonaceous bedding.
25,65–28,5	2,85	Tillite; angular to subrounded pebbles in a fine-grained sandstone matrix; light brownish-grey. Carbonaceous stringers in upper and lower parts.

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Borehole LS 9 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–6,9	6,9	Soil, silty; pale reddish-brown.
6,9 –7,0	0,1	Grit, ferruginous; light brown.
7,0 –7,8	0,8	*Clay*, flint; light grey. Fe-stained along joints.
7,8 –8,65	0,85	*Clay*, plastic; pinkish-grey.
8,65–8,75	0,1	*Clay*, flint; light grey. Fe-stained along joints.
8,75–9,0	0,25	*Clay*, plastic, pinkish-grey.
9,0 –10,7	1,7	Siltstone, dark grey with carbonaceous bedding.
10,7 –12,9	2,2	Sandstone, fine-grained; light grey with carbonaceous bedding. Lower 0,3 m gritty.
12,9 –13,45	0,55	Siltstone, carbonaceous; dark grey.
13,45–14,4	0,95	Sandstone, fine-grained; light grey with carbonaceous bedding.
14,4 –16,7	2,3	Grit, light grey with carbonaceous bedding.
16,7 –17,5	0,8	Sandstone, fine-grained; light grey with carbonaceous bedding. Lower 0,2 m gritty.
17,5 –18,3	0,8	Siltstone, carbonaceous; dark grey.
18,3 –18,9	0,6	Sandstone, fine-grained; light grey with carbonaceous bedding.
18,9 –20,8	1,9	Grit, light grey.
20,8 –21,3	0,5	Sandstone, fine-grained; light grey with carbonaceous bedding.
21,3 –21,45	0,15	Siltstone, carbonaceous, dark grey.
21,45–22,0	0,55	Sandstone, fine-grained. light grey with carbonaceous bedding.
22,0 –25,0	3,0	Tillite; angular to subrounded pebbles in a sandstone matrix; pinkish-grey. Matrix gritty for upper 0,3 m.

Borehole LS 10 (Locality: Loopspruit 435 JR)

Depth (m)	Thickness (m)	Description
0–3,0	3,0	Soil, silty; light brown.
3,0 –3,05	0,05	Sandstone, weathered, ferruginous; pale reddish-brown.
3,05–3,3	0,25	*Clay*, plastic, ferruginous; greyish orange-pink.
3,3 –3,8	0,5	Laterite.
3,8 –5,4	1,6	*Clay*, plastic, Fe-stained; pinkish-grey.
5,4 –6,0	0,6	*Clay*, flint, Fe-stained, silty in places; pinkish-grey.
6,0 –8,5	2,5	Sandstone, fine-grained; light grey with carbonaceous bedding.
8,5 –9,9	1,4	Sandstone, gritty; pinkish-grey.
9,9 –10,95	1,05	Grit, light grey.
10,95–14,9	4,05	Siltstone, medium light grey with carbonaceous bedding.
14,9 –15,0	0,1	Tillite, angular to subrounded pebbles in a gritty matrix; light grey.
15,0 –29,85	14,85	Felsite with flow banding in upper 9,0 m.

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Borehole RF 1 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–3,70	3,70	Sand, unconsolidated, coarse-grained; pinkish-grey.
3,70–4,20	0,50	Sandstone, coarse-grained; very light grey.
4,20–5,05	0,85	Grit, Fe-stained; very light grey.
5,05–5,15	0,10	Siltstone, weathered; pinkish-grey.
5,15–6,30	1,15	Grit, pinkish-grey.
6,30–6,40	0,10	*Clay*, plastic; pinkish-grey.
6,40–9,10	2,70	Sandstone, coarse-grained; very light grey. Thin carbonaceous stringer at 8,80 m.
9,10–9,70	0,60	Sandstone, light grey to medium light grey with wavy carbonaceous laminations.
9,70–11,60	1,90	Sandstone, light grey with occasional carbonaceous laminations.
11,60–12,40	0,80	Grit, very light grey.
12,40–15,48	3,08	Sandstone, very light grey with a thin carbonaceous stringer near the top.
15,48–16,20	0,72	Grit, pinkish-grey.
16,20–16,30	0,10	Siltstone, carbonaceous; medium dark grey.
16,30–16,37	0,07	Sandstone, slightly Fe-stained; pinkish-grey.
16,37–17,97	1,60	Coal, dull with a few thin bands of carbonaceous shale.
17,97–18,57	0,60	Siltstone, carbonaceous; light grey.
18,57–18,80	0,23	*Clay*, flint, carbonaceous; dark grey. 0,1 m of dull coal near top.
18,80–22,10	3,30	Tillite, silty to sandy matrix; light grey. Angular quartzite inclusions.
22,10–22,25	0,15	*Clay*, flint, silty; medium grey.
22,25–30,48	8,23	Tillite, silty to sandy matrix; light grey.

Borehole RF 2 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–6,30	6,30	Silt, unconsolidated; light brown.
6,30–6,50	0,20	*Clay*, plastic, Fe-stained; pinkish-grey.
6,50–7,80	1,30	Sandstone, coarse-grained; very light grey.
7,80–13,20	5,40	Grit, very light grey.
13,20–13,70	0,50	Siltstone, micaceous, carbonaceous; medium dark grey.
13,70–14,50	0,80	Sandstone, gritty; very light grey.
14,50–14,80	0,30	Siltstone, micaceous, carbonaceous; medium dark grey.
14,80–16,20	1,40	Sandstone, coarse-grained with carbonaceous and coal stringers; light grey.
16,20–16,70	0,50	The same as 14,50–14,80 m.
16,70–17,00	0,30	Sandstone, carbonaceous; medium grey.
17,00–17,30	0,30	*Clay*, flint, silty, carbonaceous; dark grey.
17,30–21,90	4,60	The same as 14,80–16,20 m.
21,90–21,96	0,06	Coal, bright.
21,96–22,20	0,24	The same as 14,80–16,20 m.
22,20–25,30	3,10	Coal, dull with a few bright-coal stringers. Numerous interbeds of carbonaceous shale and coaly shale.
25,30–27,33	2,03	Sandstone, fine-grained, carbonaceous; medium light grey.
27,33–30,48	3,15	Tillite, fine sandy matrix with occasional small clasts; light grey. Lower 0,60 m is carbonaceous and silty to clayey.

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Borehole RF 3 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–7,40	7,40	*Clay*, plastic, silty; light brown.
7,40–7,50	0,10	Grit, Fe-stained; pale brown.
7,50–8,50	1,00	*Clay*, plastic; very pale orange to pinkish-grey.
8,50–9,00	0,50	*Clay*, flint, slightly carbonaceous; light grey.
9,00–9,24	0,24	*Clay*, plastic; greyish orange-pink.
9,24–9,54	0,30	*Clay*, flint, slightly carbonaceous; light grey.
9,54–10,10	0,56	Siltstone, carbonaceous; dark grey.
10,10–10,30	0,20	Siltstone, light brownish-grey.
10,30–10,55	0,25	Sandstone, coarse-grained; pinkish-grey.
10,55–14,50	3,95	Grit, pinkish-grey.
14,50–15,20	0,70	Siltstone, carbonaceous; dark grey.
15,20–16,20	1,00	Sandstone, fine-grained with carbonaceous laminations; very light grey.
16,20–18,50	2,30	The same as 15,20–16,20 m, but less carbonaceous.
18,50–19,20	0,70	Grit, very light grey with rare carbonaceous stringers.
19,20–19,60	0,40	Siltstone, carbonaceous, laminated; dark grey.
19,60–23,30	3,70	The same as 16,20–18,50 m.
23,30–23,40	0,10	Coal, bright.
23,40–23,95	0,55	Grit, medium light grey with carbonaceous stringers.
23,95–24,31	0,36	Coal, dull-lustrous.
24,31–24,80	0,49	Shale, carbonaceous.
24,80–25,40	0,60	Coal, dull with slight lustre; occasional bright-coal stringers.
25,40–25,65	0,25	Siltstone, carbonaceous; greyish-black.
25,65–28,50	2,85	Sandstone, fine-grained; medium dark grey.
28,50–30,48	1,98	Dolerite, weathered.

Borehole RF 4 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–6,20	6,20	Sand, unconsolidated; light brown.
6,20–7,30	1,10	Grit, Fe-stained; pinkish-grey.
7,30–9,00	1,70	Tillite, silty to clayey matrix; predominantly felsite clasts; very light grey.
9,00–16,94	7,94	Felsite, weathered and jointed.

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Borehole RF 5 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–1,10	1,10	Sand, unconsolidated; light brown.
1,10–3,10	2,00	Grit, slightly Fe-stained; very light grey.
3,10–13,20	10,10	Tillite, silty matrix with angular clasts of sandstone and flint clay; light brownish-grey.
13,20–15,25	2,05	*Clay*, plastic, silty, micaceous, Fe-stained; pinkish-grey.
15,25–30,48	15,23	*Clay*, flint, silty; light brownish-grey to brownish-grey.

Borehole RF 6 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–4,90	4,90	Silt, unconsolidated; pinkish-grey.
4,90–5,75	0,85	*Clay*, semi-flint; light grey to medium light grey.
5,75–6,00	0,25	Sandstone, fine-grained; greyish orange-pink.
6,00–7,60	1,60	Grit, light grey.
7,60–7,65	0,05	*Clay*, semi-flint; light grey.
7,65–7,70	0,05	Siltstone, carbonaceous; dark grey.
7,70–7,80	0,10	Sandstone, gritty; pinkish-grey.
7,80–8,00	0,20	Siltstone, carbonaceous; dark grey.
8,00–8,35	0,35	Sandstone, gritty; pinkish-grey.
8,35–8,50	0,15	Siltstone, carbonaceous; dark grey.
8,50–8,70	0,20	Sandstone, gritty; pinkish-grey.
8,70–8,90	0,20	Siltstone, carbonaceous; dark grey.
8,90–10,30	0,40	Sandstone, gritty; pinkish-grey.
10,30–12,50	2,20	Grit, light grey.
12,50–16,00	3,50	Sandstone, gritty; light grey.
16,00–16,08	0,08	Coal, bright.
16,08–16,83	0,75	Shale, carbonaceous and coaly.
16,83–16,96	0,13	Coal, dull.
16,96–17,66	0,70	Shale, carbonaceous and coaly.
17,66–17,83	0,17	Coal, dull.
17,83–25,10	7,27	Tillite, silty to clayey matrix with rare inclusions; light grey.
25,10–30,50	5,40	*Clay*, flint, slightly silty; light grey.

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Borehole RF 7 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–3,50	3,50	Sand, unconsolidated; light brown.
3,50–4,50	1,00	Sandstone, coarse-grained; light grey.
4,50–6,10	1,60	Grit, light grey.
6,10–9,60	3,50	Sandstone, fine-grained, ferruginous, micaceous; pinkish-grey.
9,60–21,80	12,20	Siltstone, Fe-stained; light grey.

Borehole RF 8 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–1,90	1,90	Sand, silty, unconsolidated; greyish orange-pink.
1,90–8,00	6,10	Grit, light grey.
8,00–8,40	0,40	Sandstone, fine-grained, carbonaceous; light grey.
8,40–10,20	1,80	Sandstone, coarse-grained; light grey.
10,20–10,70	0,50	Sandstone, fine-grained, carbonaceous; light grey.
10,70–12,70	2,00	Sandstone, fine-grained with rare carbonaceous laminations; light grey.
12,70–13,03	0,33	Coal, dull.
13,03–13,60	0,57	Siltstone, carbonaceous; dark grey.
13,60–18,60	5,00	Siltstone, light grey to medium light grey.
18,60–34,78	16,18	*Clay*, flint, slightly silty; light grey.

Borehole RF 9 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–5,50	5,50	Sand, silty, unconsolidated; pinkish-grey.
5,50–5,90	0,40	Grit, light grey.
5,90–6,10	0,20	Siltstone, sandy; very light grey.
6,10–8,00	1,90	Grit, light grey.
8,00–11,50	3,50	Sandstone, fine-grained with wavy carbonaceous laminations; light grey.
11,50–15,48	3,98	Sandstone, fine-grained with rare carbonaceous laminations; light grey.
15,48–17,10	1,62	The same as 8,00–11,50 m.
17,10–17,66	0,56	Coal, dull, weathered.
17,66–17,84	0,18	Shale, carbonaceous and coaly.
17,84–18,35	0,51	Coal, dull.
18,35–20,90	2,55	Tillite, silty to sandy matrix; light grey.
20,90–21,50	0,60	*Clay*, flint, silty; medium light grey.
21,50–23,50	2,00	Tillite, silty to sandy matrix; light grey.
23,50–30,03	6,53	Dolerite.

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Borehole RF 10 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–0,30	0,30	Silt, unconsolidated; pinkish-grey.
0,30–2,97	2,67	Shale, silty; very light grey.
2,97–8,08	5,11	Sandstone, coarse-grained; very light grey.
8,08–10,20	2,12	Grit, very light grey.
10,20–13,66	3,46	Siltstone, clayey; pinkish-grey.
13,66–24,50	10,84	Dolerite.

Borehole RF 11 (Locality: Rietfontein 314 JS)

Depth (m)	Thickness (m)	Description
0–2,11	2,11	Sand, silty, unconsolidated; light brown.
2,11–3,85	1,74	Sandstone, coarse-grained; very light grey.
3,85–9,18	5,33	Grit, very light grey.
9,18–10,23	1,05	Coal, dull with a few bright-coal stringers.
10,23–10,70	0,47	Grit, light grey.
10,70–10,94	0,24	Coal, mixed.
10,94–11,04	0,10	Shale, coaly.
11,04–11,18	0,14	Coal, dull with a slight lustre.
11,18–11,48	0,30	Shale, coaly and coal, shaly.
11,48–13,90	2,42	Coal, dull with a few bright-coal stringers.
13,90–14,20	0,30	Siltstone, carbonaceous; dark grey.
14,20–14,90	0,70	Sandstone, fine-grained with occasional wavy carbonaceous laminations; light grey.
14,90–15,20	0,30	Siltstone, carbonaceous; dark grey.
15,20–15,25	0,05	Coal, dull.
15,25–17,75	2,50	Sandstone, fine-grained with carbonaceous laminations; light grey.
17,75–22,89	5,14	Tillite; fine sandy matrix with felsite inclusions; light grey.

Borehole HF 1 (Locality: Hartbeestfontein 339 JS)

Depth (m)	Thickness (m)	Description
0–9,00	9,00	Sand and silt, unconsolidated; greyish-orange.
9,00–21,80	12,80	Tillite, sandy to silty matrix; light brownish-grey.
21,80–24,40	2,60	*Clay*, flint, sligthly silty and micaceous; light grey.
24,40–27,60	3,20	Siltstone, light grey to dusky red.
27,60–28,40	0,80	*Clay*, flint, silty and micaceous; light grey.
28,40–30,70	2,30	Siltstone, light grey to dusky red.

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Borehole HF 2 (Locality: Hartbeestfontein 339 JS)

Depth (m)	Thickness (m)	Description
0–10,70	10,70	Soil, clayey; dark reddish-brown.
10,70–30,03	19,33	Tillite with sandy to silty matrix; light brownish-grey. Occasional silty flint clay inclusions from 23 m downwards.

Borehole HF 3 (Locality: Hartbeestfontein 339 JS)

Depth (m)	Thickness (m)	Description
0–4,00	4,00	Soil, sandy to gritty; moderate reddish-brown.
4,00–5,60	1,60	*Clay*, plastic; moderate orange-pink.
5,60–9,15	3,55	Tillite with a fine sandy matrix; light brownish-grey. Inclusions small and rare.
9,15–21,40	12,25	Tillite, silty matrix; light grey to medium light grey. Inclusions become larger and more abundant from 14 m downwards.
21,40–22,10	0,70	*Clay*, flint, silty; medium grey.
22,10–30,48	8,38	Tillite, silty matrix; light grey to medium light grey.

Borehole KF 1 (Locality: Klipfontein 385 JS)

Depth (m)	Thickness (m)	Description
0–4,50	4,50	Silt, unconsolidated; light grey.
4,50–7,90	3,40	Siltstone, micaceous; very pale orange. Lower 0,1 m clayey.
7,90–9,30	1,40	Sandstone, fine-grained; getting coarser lower down; very pale orange.
9,30–12,48	3,18	*Clay*, plastic, slightly silty and micaceous; very pale orange.
12,48–15,50	3,02	Siltstone, very pale orange.
15,50–18,45	2,95	Sandstone, fine-grained; very pale orange.
18,45–21,60	3,15	*Clay*, plastic; pinkish-grey.
21,60–25,40	3,90	Siltstone, pinkish-grey.
25,40–25,50	0,10	Tillite, silty matrix; light grey.

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Borehole KF 3 (Locality: Klipfontein 385 JS)

Depth (m)	Thickness (m)	Description
0–0,60	0,60	Siltstone, unconsolidated; very light grey.
0,60–1,50	0,90	Sandstone, medium-grained; moderate orange-pink.
1,50–2,80	1,30	*Clay*, plastic, Fe-stained; greyish orange-pink.
2,80–5,50	2,70	Siltstone, slightly carbonaceous; greyish orange-pink.
5,50–6,40	0,90	Sandstone, fine-grained; medium light grey.
6,40–7,00	0,60	Tillite, silty matrix; light grey.
7,00–20,88	13,88	Siltstone, laminated; light grey.

Borehole DR 1 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–6,30	6,30	Sand, gritty; pale reddish-brown.
6,30–7,00	0,70	*Clay*, plastic; pinkish-grey.
7,00–8,60	1,60	Grit, pinkish-grey.
8,60–10,10	1,50	Sandstone, fine-grained; very light grey.
10,10–11,20	1,10	Grit, very light grey.
11,20–11,50	0,30	Sandstone, fine-grained; very light grey.
11,50–12,60	1,10	Siltstone, carbonaceous, laminated; medium grey.
12,60–13,40	0,80	Sandstone, fine-grained; light grey.
13,40–26,58	13,18	Grit, light grey.
26,58–30,40	3,82	Conglomerate, fluvio-glacial; gritty to sandy matrix; light grey.
30,40–31,18	0,78	Siltstone, carbonaceous with thin coal stringers; dark grey.

Borehole DR 2 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–7,00	7,00	Sand, gritty; pale reddish-brown.
7,00–9,15	2,15	*Clay*, plastic; pinkish-grey.
9,15–10,70	1,55	Siltstone, clayey; very light grey.
10,70–20,90	10,20	Grit, very light grey. Carbonaceous siltstone and coal stringers between 16,40 and 17,20 m.
20,90–22,50	1,60	Sandstone, fine-grained; medium light grey to light grey.
22,50–30,33	7,83	Grit, very light grey. Occasional stringers of carbonaceous siltstone and coal.

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Borehole DR 3 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–7,00	7,00	Sand, gritty; pale reddish-brown.
7,00–7,46	0,46	Siltstone, pinkish-grey.
7,46–15,20	7,74	Grit, very light grey.
15,20–27,00	11,80	Sandstone, fine-grained; light grey. 3 mm coal at 15,90 m and 30 mm coal at 16,75 m. Conglomerate at the base.
27,00–28,40	1,40	Siltstone, laminated; light grey.
28,40–30,55	2,15	Sandstone, medium-grained; medium light grey to light grey.
30,55–30,77	0,22	Grit, very light grey.

Borehole DR 4 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–6,00	6,00	Sand, gritty; pale reddish-brown. Lower part clayey.
6,00–6,40	0,40	*Clay*, plastic; moderate orange-pink to very light grey.
6,40–7,60	1,20	*Clay*, plastic, slightly fissile, silty, micaceous; greyish-orange.
7,60–9,00	1,40	*Clay*, plastic, slightly silty; moderate orange-pink to very light grey.
9,00–12,90	3,90	*Clay*shale, micaceous; greyish-orange.
12,90–16,40	3,50	Grit, very light grey.
16,40–16,90	0,50	Siltstone, sandy; light grey.
16,90–27,30	10,40	Grit, very light grey.
27,30–27,60	0,30	Sandstone, coarse-grained, carbonaceous; medium grey.
27,60–28,05	0,45	Sandstone, fine-grained, carbonaceous; dark grey. Thin interbeds of carbonaceous siltstone.
28,05–30,50	2,45	Tillite; silty to sandy matrix; medium light grey.

Borehole DR 5 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–4,50	4,50	Sand, gritty, becoming clayey lower down; pale reddish-brown.
4,50–4,70	0,20	*Clay*, plastic; moderate orange-pink.
4,70–6,70	2,00	Siltstone, very light grey.
6,70–18,48	11,78	Grit, very light grey.
18,48–30,48	12,00	Tillite; silty matrix with rare small inclusions; very light grey to very dark red.

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Borehole DR 6 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–7,50	7,50	Sand, gritty; very light grey.
7,50–19,20	11,70	Dolerite, weathered, clayey.
19,20–30,48	11,28	Dolerite, fine-grained,fresh.

Borehole DR 7 (Locality: Doornrug 302 JS)

Depth (m)	Thickness (m)	Description
0–2,60	2,60	Sand, gritty; pale reddish-brown.
2,60–6,40	3,80	Siltstone, ferruginous; very light grey to very dark red.
6,40–17,85	11,45	Dolerite, weathered, clayey.
17,85–30,50	12,65	Dolerite, fine-grained, fresh.

Borehole HB1 (Locality: Hartbeestspruit 281 JS)

Depth (m)	Thickness (m)	Description
0–8,50	8,50	Sand, unconsolidated; very light grey.
8,50–26,50	18,00	Sandstone, fine-grained, feldspathic; light grey. Carbonaceous laminations from 19 m downwards. Occasional small pebbles.
26,50–30,18	3,68	Siltstone, carbonaceous, laminated; medium grey. Occasional small pebbles.

Borehole HB 2 (Locality: Hartbeestspruit 281 JS)

Depth (m)	Thickness (m)	Description
0–8,50	8,50	Sand, unconsolidated; very light grey.
8,50–18,30	9,80	Sandstone, fine-grained, feldspathic; light grey. Carbonaceous laminations from 17 m downwards.
18,30–30,50	12,20	Siltstone, carbonaceous, laminated, becoming more carbonaceous lower down; medium grey to greyish-black.

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Borehole HB 3 (Locality: Hartbeestspruit 281 JS)

Depth (m)	Thickness (m)	Description
0–8,00	8,00	Sand, unconsolidated; very light grey.
8,00–22,00	14,00	Sandstone, fine-grained, feldspathic; light grey. Carbonaceous laminations from 16,50 m downwards. Occasional small subrounded pebbles.
22,00–30,48	8,48	Siltstone, carbonaceous, laminated, becoming more carbonaceous lower down; medium grey to greyish black. Occasional small pebbles.

Borehole BF 1 (Locality: Bankfontein 375 JS)

Depth (m)	Thickness (m)	Description
0–7,50	7,50	Sand, unconsolidated; light brown.
7,50–11,00	3,50	Sandstone, gritty, becoming finer lower down; very light grey.
11,00–15,45	4,45	Siltstone, very light grey.
15,45–18,00	2,55	Siltstone, medium grey. Rare, small angular inclusions.
18,00–22,20	4,20	Siltstone, ferruginous; greyish-red.
22,20–30,08	7,88	Siltstone, carbonaceous; dark grey.

Borehole BF 2 (Locality: Bankfontein 375 JS)

Depth (m)	Thickness (m)	Description
0–3,55	3,55	Sand, clayey; light brown.
3,55–8,20	4,65	Sandstone, gritty; pale reddish-brown.
8,20–13,90	5,70	Siltstone, clayey; pinkish-grey.
13,90–16,50	2,60	Siltstone, carbonaceous, laminated; medium grey.
16,50–17,10	0,60	Siltstone, ferruginous; greyish-red.
17,10–21,50	4,40	The same as 13,90–16,50 m.
21,50–23,70	2,20	Siltstone, ferruginous; greyish-red.
23,70–30,48	6,78	Tillite; silty matrix; light grey. Abundant inclusions of carbonaceous siltstone.

Borehole BF 3 (Locality: Bankfontein 375 JS)

Depth (m)	Thickness (m)	Description
0–4,50	4,50	Silt, clayey; light brownish-grey.
4,50–4,70	0,20	Siltstone, ferruginous; dark reddish-brown.
4,70–14,10	9,40	Siltstone, greyish-pink with interbedded greyish-red shale.
14,10–14,30	0,20	Siltstone, carbonaceous; dark grey.
14,30–30,48	16,18	Tillite; silty matrix; medium light grey.

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APPENDIX 5

CORRELATION MATRIX FOR SOME OF THE MORE IMPORTANT CHEMICAL AND PHYSICAL PARAMETERS

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	CT	AP	BD	PH	QUARTZ	SIO2	TIO2	AL2O3	FE2O3	MGO	K2O	CO2	H2OP
CT	1.00000	0.21992	-0.27171	-0.36201	-0.45500	-0.46715	0.46308	0.74455	-0.54802	-0.67714	-0.81482	-0.10958	0.69853
	0.0000	0.0133	0.0021	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2219	0.0001
AP	0.21992	1.00000	-0.98693	0.63330	-0.42073	-0.34795	0.31475	0.28775	0.16082	-0.11253	-0.37128	-0.07020	0.45519
	0.0133	0.0000	0.0001	0.0001	0.0001	0.0001	0.0003	0.0011	0.0720	0.2096	0.0001	0.4347	0.0001
BD	-0.27171	-0.98693	1.00000	-0.60703	0.43776	0.38145	-0.32812	-0.32041	-0.11923	0.13045	0.43459	0.01745	-0.48256
	0.0021	0.0001	0.0000	0.0001	0.0001	0.0001	0.0002	0.0003	0.1836	0.1454	0.0001	0.8462	0.0001
PH	-0.36201	0.63330	-0.60703	1.00000	0.14524	0.19685	-0.02412	-0.33462	0.29539	0.28065	0.14277	-0.02567	-0.15195
	0.0001	0.0001	0.0001	0.0000	0.1047	0.0272	0.7887	0.0001	0.0008	0.0015	0.1108	0.7754	0.0894
QUARTZ	-0.45500	-0.42073	0.43776	0.14524	1.00000	0.84319	-0.43031	-0.78396	0.03161	0.21793	0.34111	-0.02669	-0.71896
	0.0001	0.0001	0.0001	0.1047	0.0000	0.0001	0.0001	0.0001	0.7253	0.0142	0.0001	0.7667	0.0001
SIO2	-0.46715	-0.34795	0.38145	0.19685	0.84319	1.00000	-0.41891	-0.85792	0.05540	0.17391	0.39660	-0.20606	-0.77966
	0.0001	0.0001	0.0001	0.0272	0.0001	0.0000	0.0001	0.0001	0.5378	0.0515	0.0001	0.0206	0.0001
TIO2	0.46308	0.31475	-0.32812	-0.02412	-0.43031	-0.41891	1.00000	0.48459	-0.25030	-0.33119	-0.47162	-0.10511	0.52705
	0.0001	0.0003	0.0002	0.7887	0.0001	0.0001	0.0000	0.0001	0.0047	0.0002	0.0001	0.2415	0.0001
AL2O3	0.74455	0.28775	-0.32041	-0.33462	-0.78396	-0.85792	0.48459	1.00000	-0.39565	-0.43447	-0.57262	-0.08242	0.83696
	0.0001	0.0011	0.0003	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.3589	0.0001
FE2O3	-0.54802	0.16082	-0.11923	0.29539	0.03161	0.05540	-0.25030	-0.39565	1.00000	0.25414	0.31966	-0.03870	-0.17833
	0.0001	0.0720	0.1836	0.0008	0.7253	0.5378	0.0047	0.0001	0.0000	0.0041	0.0003	0.6670	0.0457
MGO	-0.67714	-0.11253	0.13045	0.28065	0.21793	0.17391	-0.33119	-0.43447	0.25414	1.00000	0.59782	0.21566	-0.46886
	0.0001	0.2096	0.1454	0.0015	0.0142	0.0515	0.0002	0.0001	0.0041	0.0000	0.0001	0.0153	0.0001
K2O	-0.81482	-0.37128	0.43459	0.14277	0.34111	0.39660	-0.47162	-0.57262	0.31966	0.59782	1.00000	0.07218	-0.68990
	0.0001	0.0001	0.0001	0.1108	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0000	0.4219	0.0001
CO2	-0.10958	-0.07020	0.01745	-0.02567	-0.02669	-0.20606	-0.10511	-0.08242	-0.03870	0.21566	0.07218	1.00000	-0.24875
	0.2219	0.4347	0.8462	0.7754	0.7667	0.0206	0.2415	0.3589	0.6670	0.0153	0.4219	0.0000	0.0050
H2OP	0.69853	0.45519	-0.48256	-0.15195	-0.71896	-0.77966	0.52705	0.83696	-0.17833	-0.46886	-0.68990	-0.24875	1.00000
	0.0001	0.0001	0.0001	0.0894	0.0001	0.0001	0.0001	0.0001	0.0457	0.0001	0.0001	0.0050	0.0000
AL2O3CAL	0.74288	0.29908	-0.33656	-0.32787	-0.79803	-0.88676	0.48486	0.99441	-0.38431	-0.42710	-0.58844	-0.00125	0.84630
	0.0001	0.0007	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.9889	0.0001
RB	-0.72578	-0.43845	0.50654	0.06237	0.42258	0.43051	-0.38555	-0.54637	0.27930	0.52865	0.89863	-0.03270	-0.64311
	0.0001	0.0001	0.0001	0.4878	0.0001	0.0001	0.0001	0.0001	0.0015	0.0001	0.0001	0.7162	0.0001
S	0.07258	0.30010	-0.31493	0.17493	-0.20631	-0.22973	0.07823	0.07276	-0.05225	-0.01007	-0.00935	0.38230	0.14569
	0.4193	0.0006	0.0003	0.0501	0.0205	0.0097	0.3839	0.4181	0.5612	0.9109	0.9172	0.0001	0.1036
X_	0.65978	0.29061	-0.32502	-0.30088	-0.81999	-0.92698	0.44239	0.96031	-0.29190	-0.34506	-0.52367	0.08169	0.80318
	0.0001	0.0010	0.0002	0.0006	0.0001	0.0001	0.0001	0.0001	0.0009	0.0001	0.0001	0.3632	0.0001

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	CT	AP	BD	PH	QUARTZ	SIO2	TIO2	AL2O3	FE2O3	MGO	K2O	CO2	H2OP
FE	-0.72539	-0.00508	0.03801	0.31687	0.18470	0.15055	-0.35729	-0.56464	0.89177	0.46972	0.46905	0.13744	-0.38629
	0.0001	0.9550	0.6726	0.0003	0.0384	0.0924	0.0001	0.0001	0.0001	0.0001	0.0001	0.1249	0.0001
XY	0.42117	-0.21226	0.17333	-0.49374	-0.21158	-0.26579	0.23091	0.44301	-0.47419	-0.21065	-0.33103	0.12354	0.21691
	0.0001	0.0170	0.0523	0.0001	0.0174	0.0026	0.0093	0.0001	0.0001	0.0179	0.0002	0.1682	0.0147
FLUX	-0.74540	-0.32818	0.37486	0.30066	0.78803	0.91123	-0.47971	-0.96842	0.36889	0.41489	0.62576	-0.09130	-0.86218
	0.0001	0.0002	0.0001	0.0006	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3093	0.0001
Z	0.71760	0.25308	-0.29196	-0.34681	-0.78518	-0.88511	0.44091	0.97517	-0.38691	-0.39778	-0.56858	0.05598	0.80092
	0.0001	0.0042	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.5336	0.0001

	AL203CAL	RB	S	X	FE	XY	FLUX	Z
CT	0.74288	-0.72578	0.07258	0.65978	-0.72539	0.42117	-0.74540	0.71760
	0.0001	0.0001	0.4193	0.0001	0.0001	0.0001	0.0001	0.0001
AP	0.29908	-0.43845	0.30010	0.29061	-0.00508	-0.21226	-0.32818	0.25308
	0.0007	0.0001	0.0006	0.0010	0.9550	0.0170	0.0002	0.0042
BD	-0.33656	0.50654	-0.31493	-0.32502	0.03801	0.17333	0.37486	-0.29196
	0.0001	0.0001	0.0003	0.0002	0.6726	0.0523	0.0001	0.0009
PH	-0.32787	0.06237	0.17493	-0.30088	0.31687	-0.49374	0.30066	-0.34681
	0.0002	0.4878	0.0501	0.0006	0.0003	0.0001	0.0006	0.0001
QUARTZ	-0.79803	0.42258	-0.20631	-0.81999	0.18470	-0.21158	0.78803	-0.78518
	0.0001	0.0001	0.0205	0.0001	0.0384	0.0174	0.0001	0.0001
SIO2	-0.88676	0.43051	-0.22973	-0.92698	0.15055	-0.26579	0.91123	-0.88511
	0.0001	0.0001	0.0097	0.0001	0.0924	0.0026	0.0001	0.0001
TIO2	0.48486	-0.38555	0.07823	0.44239	-0.35729	0.23091	-0.47971	0.44091
	0.0001	0.0001	0.3839	0.0001	0.0001	0.0093	0.0001	0.0001
AL2O3	0.99441	-0.54637	0.07276	0.96031	-0.56464	0.44301	-0.96842	0.97517
	0.0001	0.0001	0.4181	0.0001	0.0001	0.0001	0.0001	0.0001
FE2O3	-0.38431	0.27930	-0.05225	-0.29190	0.89177	-0.47419	0.36889	-0.38691
	0.0001	0.0015	0.5612	0.0009	0.0001	0.0001	0.0001	0.0001
MGO	-0.42710	0.52865	-0.01007	-0.34506	0.46972	-0.21065	0.41489	-0.39778
	0.0001	0.0001	0.9109	0.0001	0.0001	0.0179	0.0001	0.0001
K2O	-0.58844	0.89863	-0.00935	-0.52367	0.46905	-0.33103	0.62576	-0.56858
	0.0001	0.0001	0.9172	0.0001	0.0001	0.0002	0.0001	0.0001
CO2	-0.00125	-0.03270	0.38230	0.08169	0.13744	0.12354	-0.09130	0.05598
	0.9889	0.7162	0.0001	0.3632	0.1249	0.1682	0.3093	0.5336
H2OP	0.84630	-0.64311	0.14569	0.80318	-0.38629	0.21691	-0.86218	0.80092
	0.0001	0.0001	0.1036	0.0001	0.0001	0.0147	0.0001	0.0001

	AL203CAL	RB	S	X	FE	XY	FLUX	Z
AL203CAL	1.00000	-0.57220	0.12220	0.97702	-0.54470	0.44382	-0.98593	0.98736
	0.0000	0.0001	0.1728	0.0001	0.0001	0.0001	0.0001	0.0001
RB	-0.57220	1.00000	-0.14972	-0.53365	0.39523	-0.27387	0.61368	-0.56888
	0.0001	0.0000	0.0943	0.0001	0.0001	0.0019	0.0001	0.0001
S	0.12220	-0.14972	1.00000	0.15403	-0.05072	-0.06021	-0.18842	0.12318
	0.1728	0.0943	0.0000	0.0851	0.5727	0.5030	0.0346	0.1694
X	0.97702	-0.53365	0.15403	1.00000	-0.42112	0.40631	-0.96701	0.99069
	0.0001	0.0001	0.0851	0.0000	0.0001	0.0001	0.0001	0.0001
FE	-0.54470	0.39523	-0.05072	-0.42112	1.00000	-0.52621	0.51570	-0.51884
	0.0001	0.0001	0.5727	0.0001	0.0000	0.0001	0.0001	0.0001
XY	0.44382	-0.27387	-0.06021	0.40631	-0.52621	1.00000	-0.43406	0.47751
	0.0001	0.0019	0.5030	0.0001	0.0001	0.0000	0.0001	0.0001
FLUX	-0.98593	0.61368	-0.18842	-0.96701	0.51570	-0.43406	1.00000	-0.97392
	0.0001	0.0001	0.0346	0.0001	0.0001	0.0001	0.0000	0.0001
Z	0.98736	-0.56888	0.12318	0.99069	-0.51884	0.47751	-0.97392	1.00000
	0.0001	0.0001	0.1694	0.0001	0.0001	0.0001	0.0001	0.0000

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EXPLANATION OF ABBREVIATIONS AND SYMBOLS

AP = Apparent porosity

BD = Bulk density

CT = Equivalent cone temperature

AL_2O_3CAL = Al_2O_3 on a calcined basis

X = Al_2O_3/SiO_2

FE = Fe_2O_3 + FeO

XY = Al_2O_3/FE

FLUX = $SiO_2 + TiO_2 + Fe_2O_3 + FeO + MnO + MgO + CaO + Na_2O + K_2O + P_2O_5$

Z = $Al_2O_3/FLUX$

H_2OP = H_2O^+

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