

THE GENESIS OF ILMENITE-RICH HEAVY MINERAL DEPOSITS
IN THE BOTHAVILLE/DELMAS AREA, AND AN ECONOMIC
ANALYSIS OF TITANIUM, WITH PARTICULAR REFERENCE
TO THE DWARSFONTEIN DEPOSIT, DELMAS DISTRICT.

by

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ABSTRACT.

A number of ilmenite-rich heavy mineral deposits occur along the northern margin of the intracratonic Karoo basin, and are hosted by the fluvio-deltaic Middle Ecca Group. Coastal reworking of delta front sands within a regressive, microtidal shoreline may be considered as a depositional model for the development of the heavy mineral deposits.

An economic analysis of titanium suggests long term positive demand, and sustained high prices for this commodity.

An evaluation of the Dwarsfontein ilmenite-rich heavy mineral deposit, using available data, indicates how important it is for deposits of this type to be situated close to an upgrading plant or export harbour.

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INTRODUCTION.

The lithologies of the Karoo Supergroup have accumulated within a tectonically controlled intracratonic basin, and comprise; i) a basal Permo-Carboniferous glacial tillite; ii) an overlying sequence of argillaceous and arenaceous sediments, and; iii) an intrusion of basaltic lavas and late widespread Jurassic dolerite.

Along the northern margin of the main Karoo basin the Vryheid Formation sediments host a number of ilmenite-rich heavy mineral deposits. The aim of this dissertation is to clearly understand the genesis of these deposits, and then to combine this with their economic viability. With regard to the former, the lower portion of the northern Karoo Supergroup is reviewed, and a provenance study of ilmenites from the Delmas deposits is undertaken.

In order to evaluate an ore deposit it is important to establish a comprehensive knowledge of the specific commodity/s involved. Therefore, a thorough analysis of titanium is undertaken in terms of; i) beneficiation and uses; ii) resources; iii) pricing, and; iv) the future supply/demand outlook.

Finally, the Dwarsfontein ilmenite-rich heavy mineral deposit which occurs as part of a number of small deposits in the Delmas area is evaluated, using the data available.

SECTION A: A REVIEW OF THE STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT OF THE LOWER PORTION OF THE NORTHERN KAROO SUPERGROUP.

The Karoo Supergroup comprises a sequence of sediments and late volcanics and hypabyssal rocks which accumulated within an intracratonic basin during the Permo-Carboniferous (280 M.a.), through to the earliest Jurassic (180 M.a.). The rock types of the supergroup accumulated under a range of climatic regimes and a variety of tectonically controlled depositories. Large numbers of fossils have been preserved within the various sedimentary units of the supergroup, and erosion of these units has exposed a major fossil reserve.

The Karoo Supergroup has been subdivided on the basis of lithological, palaeontological and tectonic criteria into a basal Dwyka Tillite Group, a sequence of alternating argillaceous and arenaceous rocks, of the Ecca, Beaufort and Stormberg Groups, basaltic lavas of the Drakensberg Group, and finally a late phase widespread intrusion of dolerite dykes. Figure 1.1 shows the location of the Karoo Supergroup, and Table 1.1 shows the stratigraphy.

Two major troughs have been developed within the basin; i) an east-west trending trough in the main basin (Karoo Trough), which lies immediately north of the Southern Cape Conductor Fold Belt, and; ii) a north-south trough (Natal Trough), the axis of which approximately parallels the Natal coast. Note that these troughs occur along the southern and eastern margins of the Kaapvaal craton, thus they would form ideal regions for downwarp and intracratonic basin formation (see Figure 1).

In the Karoo Trough sedimentation was continuous, and the Karoo sediments rest conformably on rocks of the older Cape Supergroup (Ryan and Whitfield, 1979). Outside the troughs and on the shelf areas, the Karoo strata are not only represented by abbreviated sequences, but stratigraphic disconformities are common, resulting in the absence of considerable thicknesses of strata.

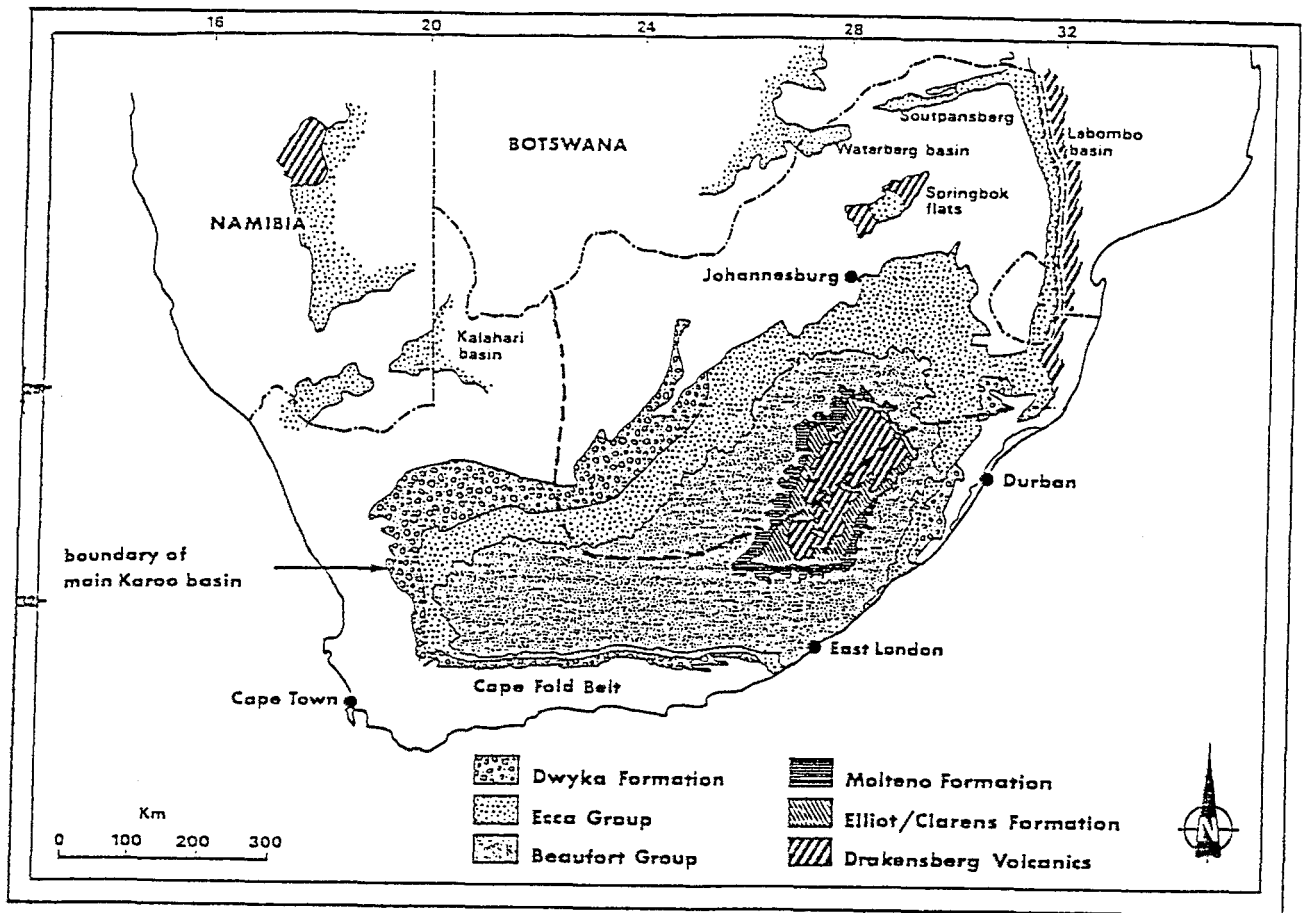


Figure 1.1. Map showing the outcrop area of the Karoo Supergroup in southern Africa (dotted line shows the southern craton boundary) (modified after Smith, 1990).

PERIOD	GROUP	SUBGROUP	FORMATION			VERTEBRATE BIOZONES
Jurassic	Drakensberg (volcanics)		SW	Central and SE	E to NE	<u>Massospondylus-Euskelosaurus</u>
	(previously Stormberg)			Clarens Elliot Moltano		
Triassic	Beaufort	Tarkastad		Burgersdorp Katberg	Otterburn Belsont	<u>Kannemeyeria-Diademodon</u> <u>Lystrosaurus-Thrinaxodon</u>
		Adelaide	Teekloof	Balfour	Estcourt	<u>Dicynodon-whaitsia</u> <u>Aulaceonaiodon-Cistecephalus</u> <u>Troosdostoma-Endothiodon</u>
				Middleton		
				Abrahamkraal	Koonap	
Permian	Ecca		Waterford Fort Brown	Volkarust Vryheid	<u>Eodicynodon</u>	
			Laingsburg Vischkuil Collingham Whitehill Prince Albert	Ripon Pietarmaritzburg	<u>Mesosaurus</u>	
- 270 my - Carboniferous			Dwyka			

Table 1.1. The stratigraphy of the Karoo Supergroup (after Smith, 1990).

The type of lithological unit in the Karoo was controlled predominantly by continental drift. It is widely accepted that during the Permo-Carboniferous Gondwanaland was in existence, and that Southern Africa was positioned over the south pole, thus resulting in an ice cap over highland areas. As the supercontinent drifted out of the polar climates in a northwesterly direction, the depositional style of sediments accumulating in the Karoo intracratonic basin was one of progressive aridification. Combined with climatic drying was a gradual shrinking of the basin, brought about by the northward migration of the subducting palaeo-Pacific plate margin to the south. Figure 1.2 shows the major stratigraphic subdivisions, depositional systems and lithologies in a generalised southwest-northeast cross-section of the main Karoo basin, and Table 1.2 shows a summary of the depositional and tectonic environments of Karoo Supergroup.

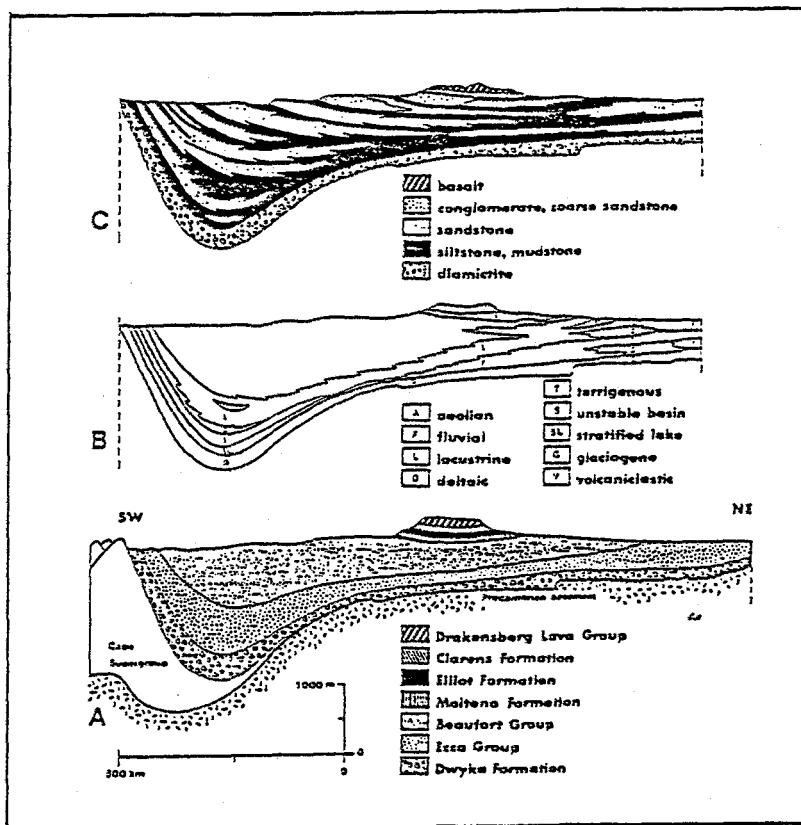


Figure 1.2. A generalised cross-section of the main Karoo basin showing lithologies, depositional environments, and stratigraphy (after Smith, 1990).

PERIOD	DEPOSITIONAL/TECTONIC	GROUP/FM.
Jurassic (210 - 150 M.a.)	Voluminous basaltic outpourings into fault-controlled basins that continued to subside. Extensive basinwide dolerite intrusion.	Drakensb. Grp. Karoo dolerite
Late Triassic (230 - 210 M.a.)	Progressive aridification, playa-lake/wadi-type environments to a dune sand dominated system.	Elliot Fm. Clarens Fm.
Early Triassic (250 - 230 M.a.)	Northward migration of Cape Fold Belt into south of basin reaches a maximum. Renewed uplift in south results in coarse-grained fluvial deposits.	Molteno Fm.
Permo-Triassic (260 - 250 M.a.)	Fluvially dominated alluvial plain deposits within shallow lake resulting from prograding deltas. Formation of uranium deposits.	Beaufort Grp.
Early Permian - Late Permian (270 - 260 M.a.)	Black muds and clays on submerged platform to the south. Deformation in the south (initial stages of Cape Fold Belt orogeny). Deepening of Karoo and Natal troughs (along edge of craton). Fluvio-deltaic deposits in northern platform margin and formation of coal and heavy mineral deposits. Flysch-type/turbidite deposits in the south and Natal Trough. Fluvio-deltaic-lacustrine deposits.	PMB Shale Fm. Vryheid Fm. Volksrust Shale Fm.
Carboniferous - Early Permian (330 - 270 M.a.)	Glaciation. Ice cap over highlands in north and large floating ice sheet in south.	Dwyka Grp.

Table 1.2. A summary of the depositional and tectonic environments of the Karoo Supergroup.

The tectonic setting and genesis of the ilmenite-rich heavy mineral deposits in the northern Vryheid Formation of the main Karoo basin are inextricably linked to the development of the Dwyka Formation and overlying Ecca sediments in this region. Thus a clear understanding of the lower part of the Karoo Supergroup is important, and this section reviews the depositional environments of the Dwyka and Ecca sediments of the northern part of the Karoo basin.

1. The Glacial Environment.

Before the depositional environment of the Dwyka Group is discussed it is pertinent to review glacial environments in general.

A fundamental classification of glaciers is based on the thermal regime of the ice, and one may distinguish between cold dry-based, and temperate wet-based glaciers. The temperature of cold glaciers is well below the pressure melting point, free water is lacking, thus movement is restricted due to the absence of lubricating water near the base of the glacier. The temperature of temperate glaciers is at the pressure melting point, therefore water is present accumulating in surface lakes, crevasses and at the base of the glacier, thus glacial movement is enhanced.

Holmes (1965) recognised three basic types of glaciers:

1. Valley glaciers (generally temperate glaciers). These are ice masses confined within the walls of a mountain and fed by cirques and ice fields higher up. Modern examples are the Rhone Glacier, Alps, Gangotri glaciers, and Himalayas.
2. Piedmont glaciers (generally temperate glaciers). These are sheets of ice formed by the coalescence of valley glaciers, and spread out beyond their valleys into lowland areas. A modern example is the Malaspina glacier of the coastal plain of southeastern Alaska.
3. Ice sheets or caps (generally cold glaciers). These are ice masses of continental proportions, several thousand metres thick, and may extend into the sea as ice shelves from which icebergs calve out. Large ice sheets exist in Greenland and

Antarctica, and smaller sheets exist in Spitsbergen and Iceland from which smaller valley glaciers flow out.

Figure 1.3 shows a schematic diagram of the three basic types of glacier.

Valley and piedmont glaciers may be defined as masses of ice which, under the influence of gravity, flow out from the snowfields where they originate. There is a constant exchange of mass and heat between the glacier and both the atmosphere above and the bed or water body below. The continual transfer of mass and heat, which ultimately responds to variations in climate, controls the sedimentary balance between erosion and deposition and the nature of the sedimentary process (Reading, 1981).

Glacial environments are restricted to regions of low temperature, combined with high precipitation and extremely low rates of evaporation. Accumulating snow is buried and compacted into ice by the loading of new snowfalls. All processes by which a glacier gains ice are called accumulation. In the lower reaches of the glacier, principally near the glacier snout, ice is lost by melting, evaporation, and calving of icebergs. These processes are collectively known as ablation. Thus the mass balance or difference between the rate of accumulation and ablation of a glacier will determine whether the glacier margin is advancing, retreating or stationary.

Glaciers may be divided into three main zones; i) the subglacial or basal zone where erosion and deposition can take place; ii) the supraglacial zone or upper zone where seasonal influence is strong, and where deposition may occur in areas of ablation, chiefly at the glacier margin, and; iii) the englacial zone, which does not play a major part in sedimentation.

Glaciers are active erosional agents, and a characteristic landscape is produced under the action of moving ice. Two important erosion processes are plucking and abrasion. Plucking refers to the quarrying of large rock fragments from the bedrock, due to repeated freezing of meltwater within natural joints, thus loosening the rock fragments.

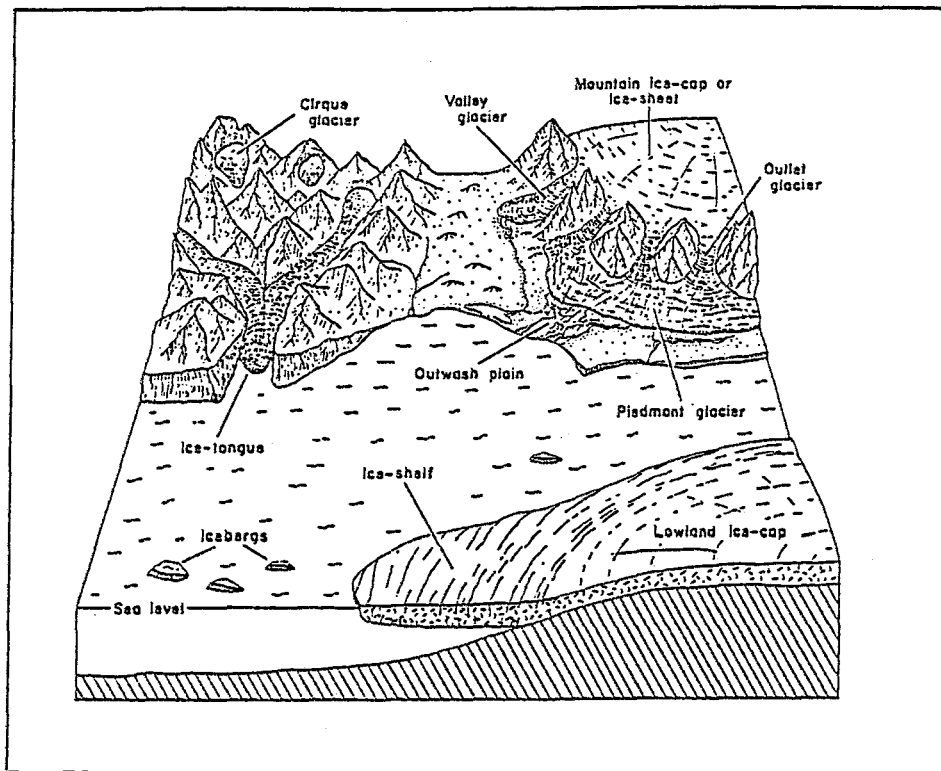


Figure 1.3. Schematic diagram showing the three basic types of glacier (after Allen, 1970).

Rock debris moving along the base and sides of the glacier act as tools which scrape, scratch, scour, grind, and polish the underlying rock surface. Characteristic striations, grooves and crescentic fractures or pressure cracks are produced. Melt water occurring at the base of temperate glaciers also provides an active erosional medium through the action of hydrolysis and subsequent decomposition of the underlying rock.

In addition to basal zone and water erosion, rock fragments may be weathered out from the steep slopes above a glacier and fall into the supraglacial zone, due to headward erosion of cirques.

The debris transported within a glacier is termed moraine, and Figure 1.4 shows a schematic diagram of the various types of moraine within glaciers. The deposition of glacial moraine takes place predominantly in the lower reaches of a glacier (zone of ablation). Here the various types of moraine combine and are deposited in front of the glacier snout as terminal or end

moraine.

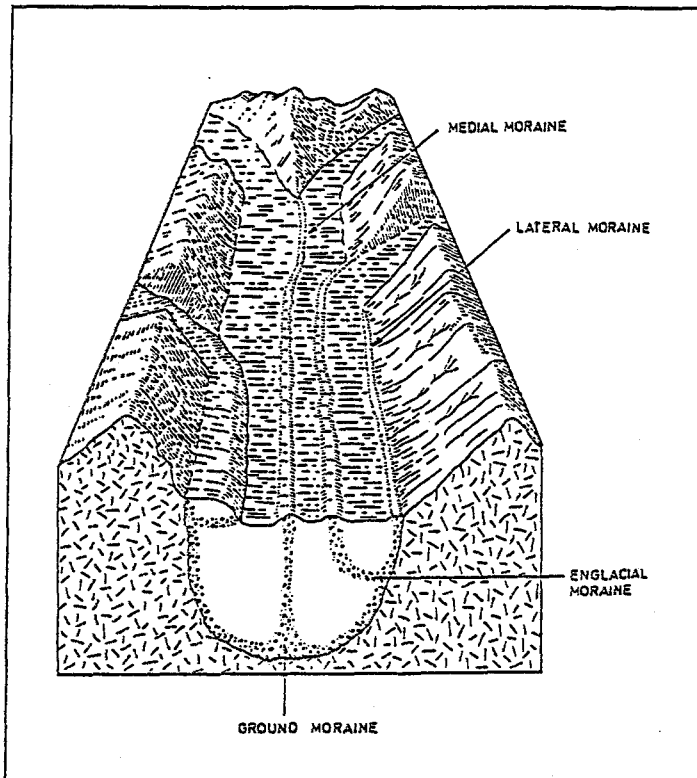


Figure 1.4. Schematic diagram showing the various types of moraine within a glacier (after Reineck and Singh, 1980).

Boulton (1972) distinguished between three basic types of glacial deposit or till:

1. Flow till - released supraglacially, due to high water content flowing down the glacier surface and accumulating at low slopes. Subaerial flow results in deformation structures, and this till is equivalent to ablation till.
2. Meltout till - essentially an englacial deposit released from stagnant ice beneath a confining overburden, and in which some of the original englacial features are preserved.
3. Lodgement till - deposited beneath actively moving ice, and commonly shows deformation due to the shear imposed by the overlying ice.

In a broad sense glacial deposits may be considered to be unstratified and stratified. Unstratified deposits are often

designated as basal deposits, boulder clay or till. They are unsorted, unstratified, have a large range in clast size, and essentially represent basal moraines. Stratified deposits are often designated as ablation deposits, and are sorted and stratified to varying degrees. Meltwater produced by the rapid melting of ice plays an important role in stratification which may be due to the reworking of previous glacial deposits. Ice contact stratified deposits which are water laid sediments deposited in contact with glacial ice include drumlins, eskers, terminal moraines, and kames (Figure 1.5).

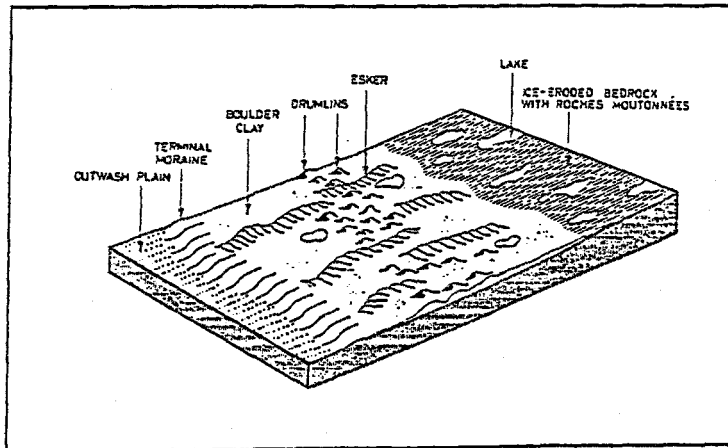


Figure 1.5. Schematic diagram showing the characteristic features of a glaciated area (after Reineck and Singh, 1980).

The proglacial environment occurs at the glacial margin and includes glacio-fluvial and glacial outwash plain deposits, braided stream and deltaic deposits, and deposits associated with glaciolacustrine and glaciomarine environments. Figure 1.6 shows a schematic diagram of these depositional environments and associated landforms, and Table 1.3 outlines the main glacial facies, their chief process of deposition, and the environments in which they form.

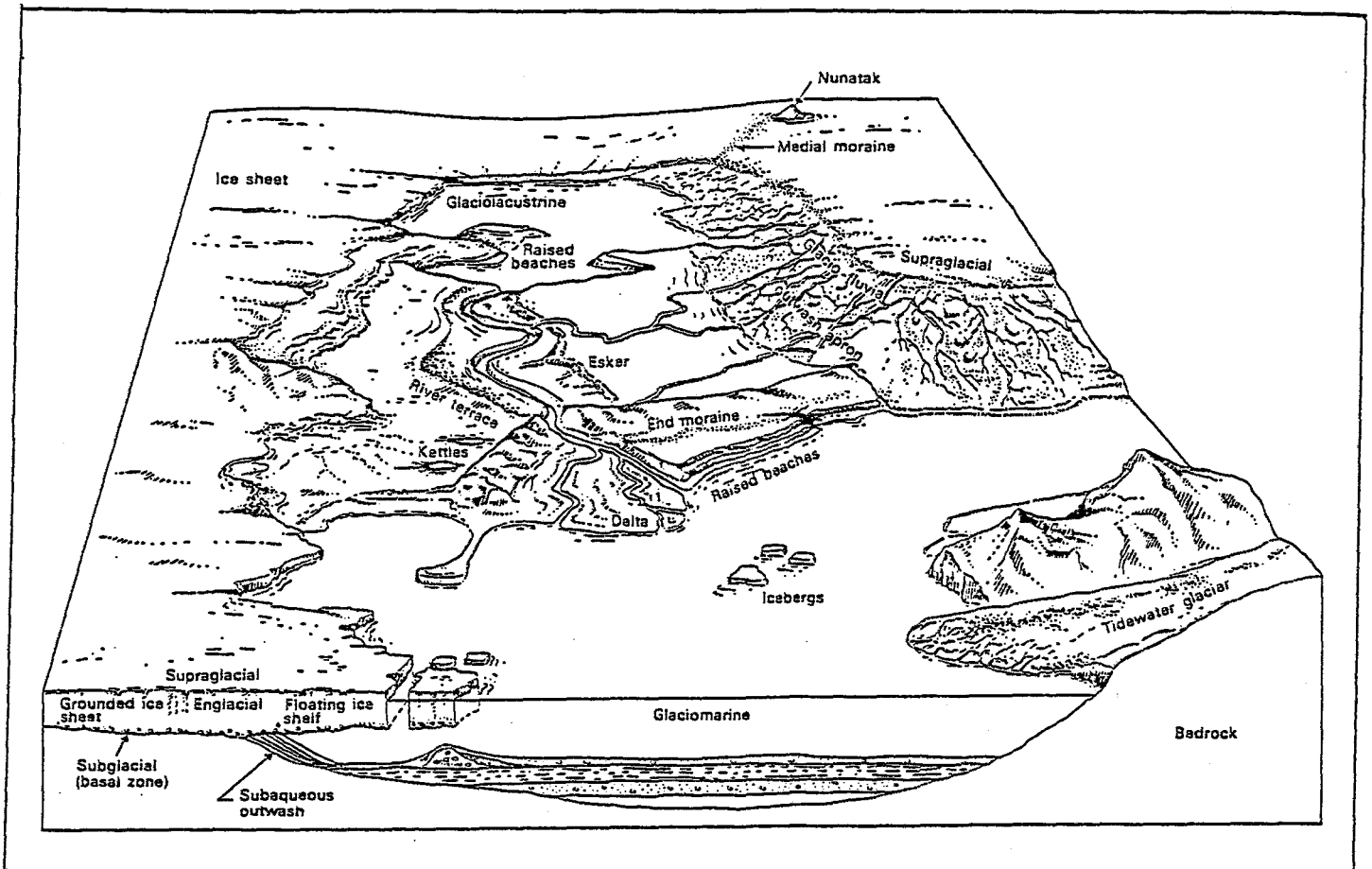


Figure 1.6. Schematic diagram of glacially related depositional environments and associated landforms (after Reading, 1981).

<i>Facies lithology</i>	<i>Depositional process</i>	<i>Environments</i>
Massive mixtite Banded mixtite	Basal till deposited below active ice	Subglacial
Stratified sandstone and conglomerate	Deposition in flowing water	Supraglacial, englacial, subglacial, proglacial (incl. subaqueous)
Beds and lenses of mixtite in sandstone and conglomerate	Mass flow of mixton (flow till) and flowing water	Supraglacial, ice-contact proglacial (incl. subaqueous)
Rhythmically laminated siltstone and claystone	Varves, seasonal deposits	Glaciolacustrine
Randomly laminated mudstone with dropstones	Deposition from suspension and rafting by ice in agitated water	Glaciomarine
Massive mixtite	Aquatill, deposition from suspension and ice rafting in quiet water	

Table 1.3. An outline of the main glacial facies, depositional processes and environments (after reading, 1981).

2. Carboniferous Dwyka Glaciation.

The supercontinent of Gondwanaland existed prior to and during the Dwyka glaciation period, which began in the Mid-Carboniferous and culminated in the Early Permian (see Table 1.2).

Crowell and Frakes (1972) regrouped the central Gondwana continents at the 2000m isobath (Figure 1.7), and incorporated palaeomagnetic data to show that the south pole was contained within the dotted circle of Figure 1.7. The palaeomagnetic data indicate a northwesterly movement of Gondwanaland across the pole.

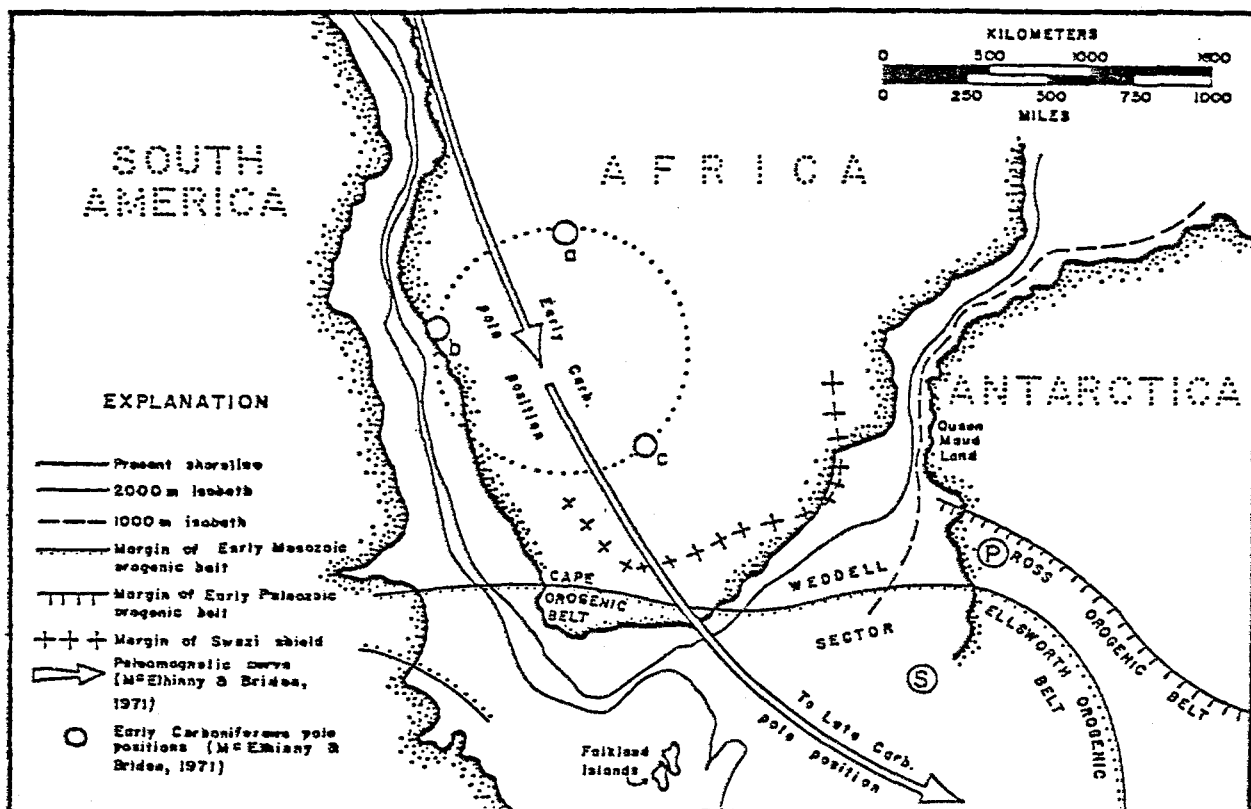


Figure 1.7. Map of regrouped Gondwana continents showing the Early Carboniferous pole positions and palaeomagnetic polar curve. S = Sentinel Mountains, P = Pensacola Mountains (after Crowell and Frakes, 1972).

It is known that for widespread continental glaciation to occur, high rates of precipitation in addition to a near polar situation is required. Crowell and Frakes (1970) suggest that both the

Palaeo-Pacific and its extension through the Falkland region to South Africa, and the Tethys between India and Australia may have provided the moisture required. They note that climatic conditions were moist and just cold enough to support glaciation under the conditions of atmospheric conditions prevailing, because forests were thriving not far away. Such conditions were conducive for the development of temperate glaciers. Gondwana glaciation lasted for as much as 70 m.y., and the huge glacial centers presumably moved with the drift of Gondwanaland from Carboniferous glaciation in South America and southern Africa to Permian glaciation in Antarctica and Australia.

There has been extensive work done by numerous workers on likely highland or source areas for the ice in the Carboniferous. In this regard glacial movement directions have been established by the orientation of glacial valleys (Visser and Kingsley, 1982), grooves on pavements (Von Brunn, 1977; Stratten, 1977; Visser et al., 1978), facies changes (Visser, 1986), and inferred source of intraclasts (Du Toit, 1921; Visser and Lock, 1982). Crowell and Frakes (1972) note that the record of ice movements is unusually satisfactory around the periphery of the Dwyka outcrop belt. Figure 1.8 shows the approximate positions of the highlands producing the Dwyka ice sheets in South Africa, and the directions of ice flow.

Of particular interest to this study is the Transvaal Ice sheet, as portions of this sheet would have provided part of the protore of the ilmenite-rich heavy mineral deposits of the northern Vryheid Formation. The source area and flow directions of the Transvaal Ice sheet is given in Figure 1.9, including the positions of the heavy mineral deposits in the Delmas and Bothaville areas, and a number of alkaline/carbonatitic complexes in the region. The spatial location of the sub-volcanic, volcanic lithologies outcropping on the present day surface may have important implications for the palaeogeography in this region. Upon deglaciation during the Permian, tectonic uplift of the ice source area was likely due to isostatic rebound of the crust resulting from unloading of the ice cap. This region of uplift could have presumably been expected to have provided a portion of the post-Dwyka sedimentation in the Karoo basin.

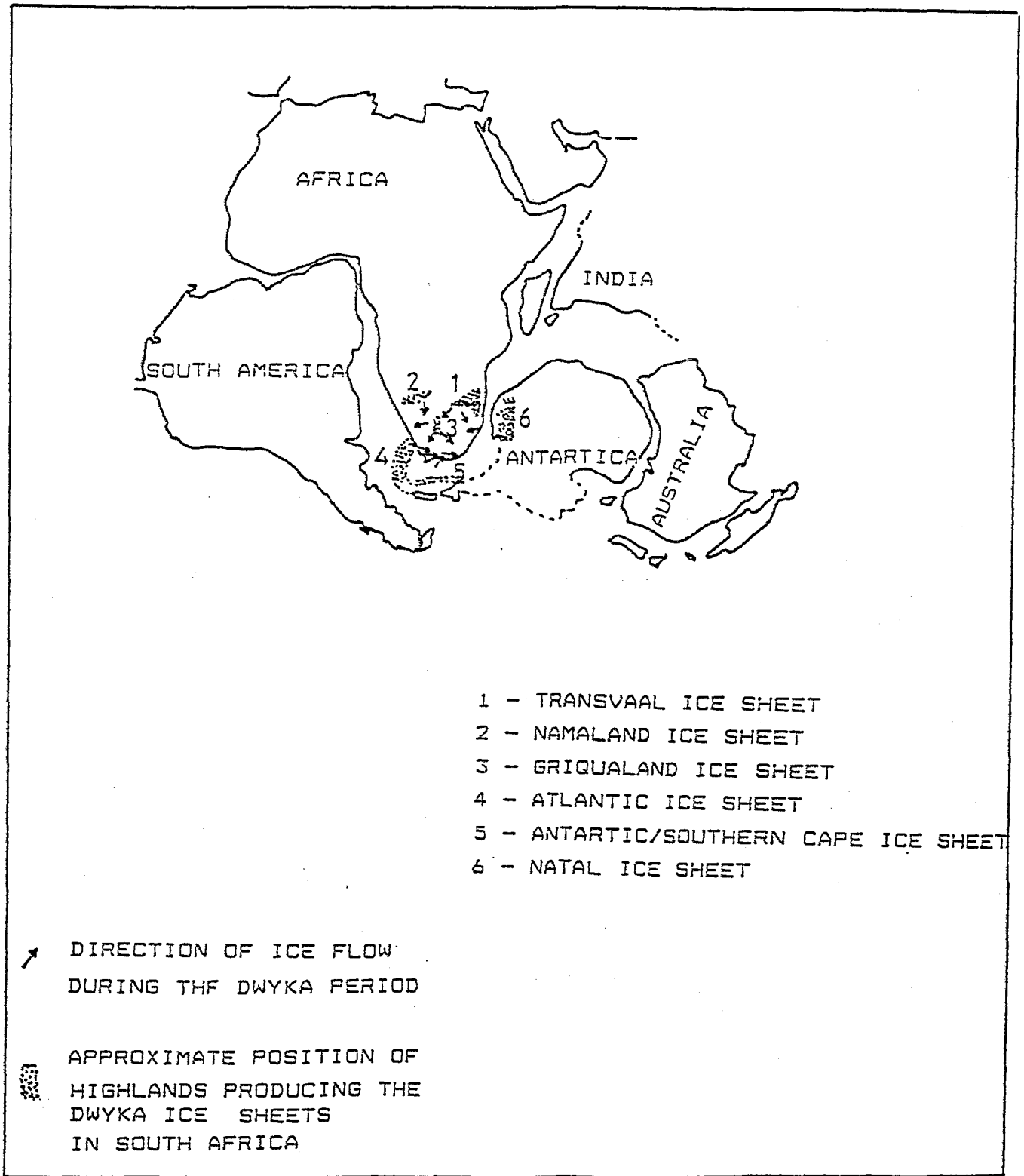


Figure 1.8. Reassembly of Gondwanaland during the Dwyka Period showing likely highland areas, and ice movement directions (modified after Stratten, 1968).

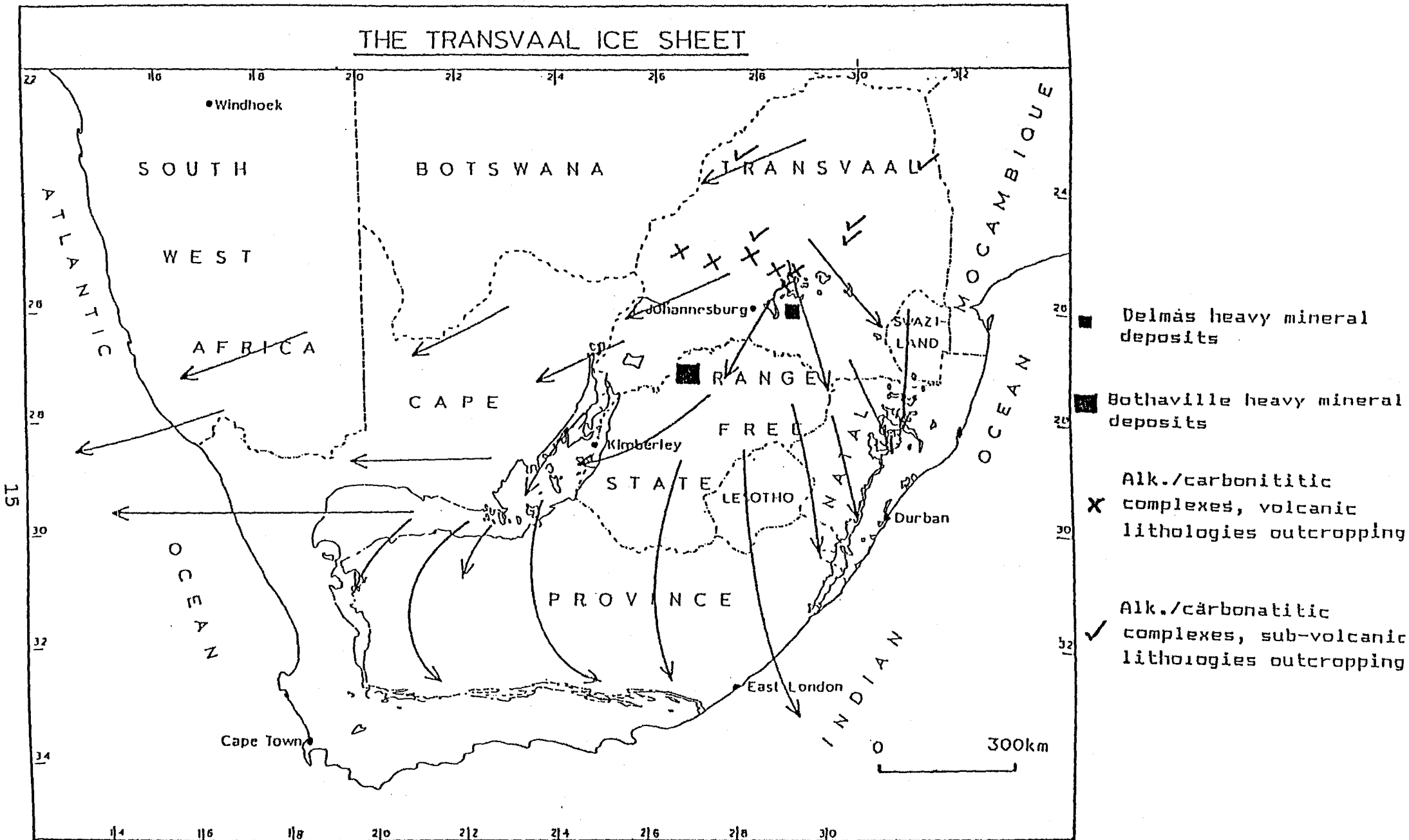


Figure 1.9. Map showing the Transvaal Ice sheet movement directions, alkaline/carbonatite complexes, and the Delmas and Bothaville heavy mineral deposits (modified after Stratten, 1967).

Thus extensive erosion of the pre-Karoo rocks can be expected to have occurred in the northern Transvaal region, however minimal erosion in the southern and western Transvaal. This is verified by the outcropping lithologies of the alkaline/carbonatitic complexes which are predominantly sub-volcanic in the north, and volcanic in the south (see Figure 1.9).

Visser (1986) used a lithofacies approach in which he grouped mutually related lithofacies together to define two fundamentally different facies within the Dwyka Formation, namely a northern and southern facies. He interprets these two facies as having accumulated on two distinctively different geomorphic regions. The northern facies comprises a highly mixed association with a low order of facies arrangement, and was deposited on a glacially incised northern highland area. The southern facies comprises a more homogeneous association with a high order of facies arrangement, and was deposited in a southern submerged platform. Tectonically the basin thus consisted of a northern incised highland area which was separated from a southern submerged platform area by a prominent palaeoescarpment (Visser, 1986). The major differences between the facies sequences reflect deposition in the north by largely continental ice sheets and valley glaciers, and in the south by predominantly marine ice sheets (Visser, 1986).

Lithologically, the northern glacially incised valley facies association contains well defined laminated mudstone units interbedded with laminated stratified diamictite, stratified conglomerate and pebbly sandstone, with only minor massive diamictite. This association is interpreted as a random assortment of; i) deposition in ice-dammed lakes preserved in the topographic lows of the highland area (producing laminated diamictite/mudstones); ii) reworked supraglacial ablation tills, englacial and marginal moraines, and glacial outwash (producing stratified sandstones and conglomerates); iii) sediment gravity flows and subglacial lodgement till (producing stratified diamictites), and; iv) subglacial lodgement (producing massive diamictites).

Visser and Kingsley (1982) studied the sedimentation of the

Virginia glacial valley in the Orange Free State, and noted that the glaciers flowing down this valley were wet-based (temperate), as evidenced by the erosion and volume of sediment transported.

The lithology of the clasts in the northern facies assemblages is varied and includes quartz, quartzite, banded ironstone, dolomite, slate, granite, gneiss, quartz porphyry, and amygdaloidal lava (Stratten, 1977; Visser et al., 1982). Stratten (1967) observed that the composition of the clasts within the tillite in the Transvaal were predominantly Waterberg quartzite.

The temperate valley glaciers of the northern highland region therefore transported great amounts of detritus, including heavy minerals, into the northern margin of the main Karoo basin.

The diamictites of the northern facies are distinguishable from those of the southern platform facies, in that they are more thinly bedded and stratified. The predominant clast-poor massive diamictites of the southern facies are interpreted as having been deposited beneath semi-grounded and rafted ice sheets (Visser and Loock, 1982; Visser, 1986). Figure 1.10 shows the valley (northern), and platform (southern) facies sequences in the Dwyka Group, based on facies relationship diagrams and the average thickness of each lithofacies. It is noted that the valley facies sequence is only applicable to the Virginia Valley.

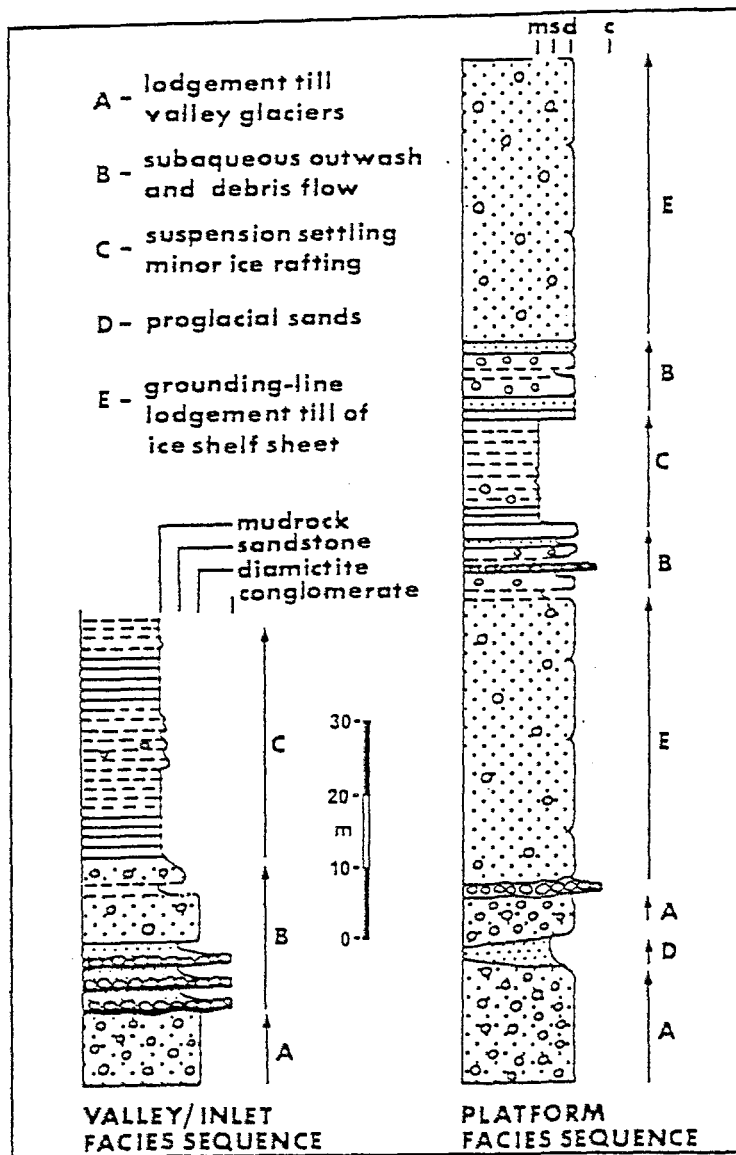


Figure 1.10. Valley inlet (northern) and platform (southern) facies sequences in the Dwyka Group (after Smith, 1990).

A simplified depositional model for the Dwyka Group in southern Africa is given in Figure 1.11.

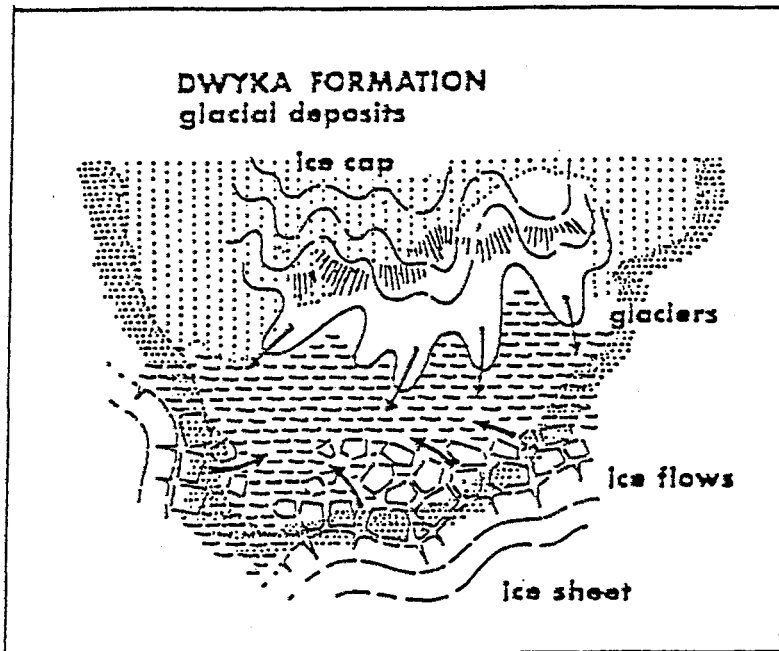


Figure 1.11. A simplified depositional model for the Dwyka Group in southern Africa (after Smith, 1990).

3. Post-Glacial Permian Ecca Sedimentation of the Northern Ecca Facies.

During the early Permian southern Africa had drifted northwestwards out of the polar latitudes, the glaciers began to retreat, and Ecca sedimentation occurred within an essentially landlocked sea which experienced periodic influxes of saline water. Visser and Loock (1978) suggest that these marine influxes were probably due to eustatic changes in the sea-level (Permian glaciation in Antarctica and Australia). Ryan and Whitfield (1979) suggest the earth's crust was probably deeply depressed where the Natal and Karoo troughs met, thus formed an ideal area for inundation by the Permian seas. Böhmann and Böhmann (1990) analysed whole rock and clay mineral compositions using X-ray diffraction techniques, of Dwyka and Ecca sediments from the Bothaville area, and thus used a mineralogical approach to evaluate the palaeoenvironment in this region. In this regard literature data indicates that 2:1 layer silicates (chlorite, mica, smectite) are the dominant clay components in marine basins, bordering cold zones (Biscaye, 1965). Fresh water

effectively dissolves 2:1 layer silicates and promotes the formation of kaolinite (Keller, 1976). Thus alkaline pore fluid compositions indicate marine conditions with the preservation and genesis of mica, chlorite and smectite, whereas acid pore fluid compositions indicate fresh water conditions, and would promote the development of kaolinite. Böhmann and Böhmann (1990) established that marine conditions predominated during the accumulation of the Dwyka tillite, and lower third of the Vryheid Formation. Two minor 'acid' fresh water periods are identified in the lower Vryheid. The middle part of the Vryheid marks a well developed transition from marine through brackish to freshwater conditions. Figure 1.12 shows a vertical distribution of clay mineral associations within the Dwyka and Ecca sediments in the Bothaville area.

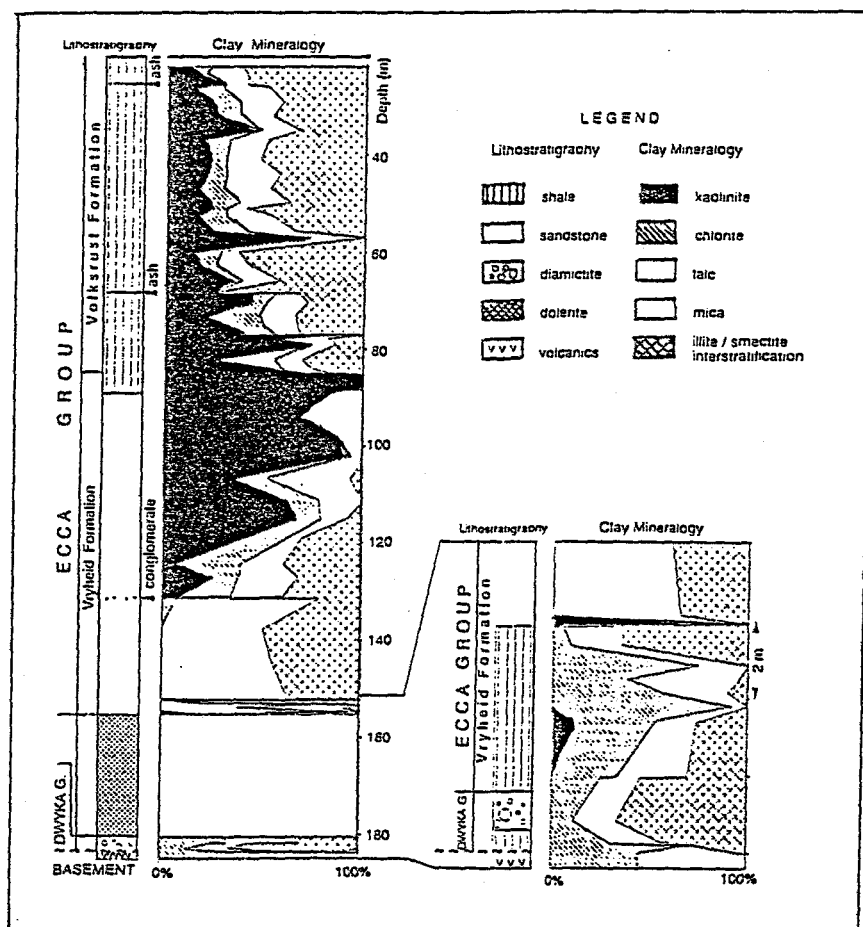


Figure 1.12. Vertical distribution of clay mineral associations in the Bothaville area (after Böhmann and Böhmann, 1990).

Thus it would appear that saline marine conditions predominated during the accumulation of the Dykwa and lower part of the Eccca. Thereafter the landlocked sea became progressively less saline, and in time freshwater conditions prevailed (especially due to the increasing volumes of meltwater from the ice caps). Periodic influxes of marine water probably occurred from time to time.

In a study of lithological sequences, mineralogy and fossils Visser and Loock (1978) concluded that Eccca sedimentation occurred within shallow water conditions. However as deposition proceeded water depth in the south probably increased. The major palaeoscarp that conforms in part to the southern edge of the Kaapvaal craton, and separates the dissected northern highland area from the low undulating plain, underlain by granites and schists to the south (Tankard et al., 1982), thus played an important role, tectonically in post-glacial sedimentation. The Eccca depository consisted of a broad, southward deepening shelf flanked by the more rapidly subsiding Karoo Trough to the south, and Natal Trough to the east which accumulated 3000m and 100m of sediment respectively (Smith, 1990). The troughs filled with flysch-type and turbidite deposits, whereas the platform and marginal area comprised predominantly fluvio-deltaic depositional systems.

The Eccca Group may be sub-divided on the basis of lithology, tectonics, and provenance into the Northern, Southern, Western, and central Facies (Ryan and Whitfield, 1979). Of interest in this report is the Northern Facies, particularly the Vryheid Formation, as it is this lithological unit that hosts the ilmenite-rich heavy mineral deposits.

Ryan and Whitfield (1979) studied the regional sediment transport directions, major provenance areas, and the controlling palaeotectonic and palaeogeographic frameworks of Karoo sedimentation during the Permian. Figure 1.13 shows the regional palaeocurrent trends within the different facies of the Eccca, and the positions of the Delmas and Bothaville heavy mineral deposits. The diagram indicates the trends in these areas to be south to southeast, which clarifies a northerly source area as previously mentioned.

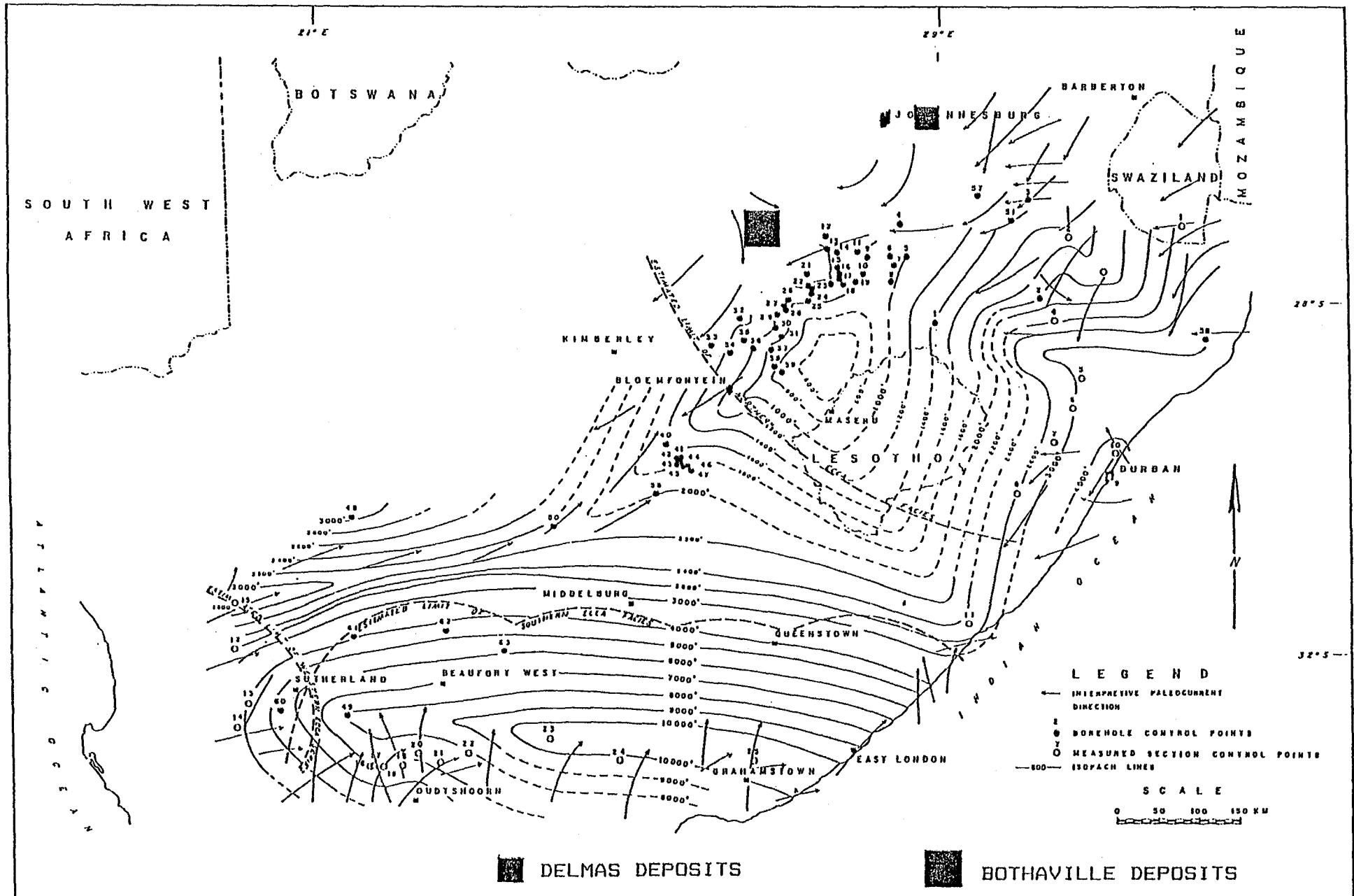


Figure 1.13. Isopach, palaeocurrent and facies map of the Ecca Group in the Karoo basin (modified after Ryan and Whitfield, 1979).

In addition, the effect of the pre-Karoo topography, with its large north-south trending valleys, no doubt exercised a major control on the southerly flow trends of sedimentary detritus.

The Vryheid Formation rests directly on the Dwyka Group in the Delmas/Bothaville region, and comprises a regressive fluviodeltaic wedge of predominantly coarse clastics. The wedge is a composite of as many as eight episodes of delta progradation and transgression (Hobday, 1973; van Vuuren and Cole, 1979). The dominant rock types are coarse grained arkose, conglomerate, micaceous siltstone, carbonaceous shale, coal seams and thin beds of limestone. Large-scale planar and trough cross-bedding, ripple marks, fluvial conglomerates, scour channels and slump structures imply deposition by shifting variable currents in a shallow water, predominantly fluvio-deltaic environment (Ryan and Whitfield, 1979). Figure 1.14 shows a schematic reconstruction of a typical Vryheid Formation lobate delta. The shallowness of the water and low rate of subsidence resulted in the delta-front sands being spread out over a wide area to form extensive sand sheets. An extensive thin bed of glauconite sandstone which occurs immediately above a coal seam in the south eastern Transvaal coalfields suggests a period of extensive marine transgression (Ryan and Whitfield, 1979).

It is within the shoreline, delta-front sand environment that the heavy mineral rich deposits of the Vryheid Formation occur. In broad terms, periods of coastal reworking of delta-front sands during periods of marine regression on a slowly subsiding platform may be considered as a model for the development of the heavy mineral deposits (Ryan and Whitfield, 1979; Behr, 1965, 1985). This depositional model will be examined in greater detail with regard to the Delmas and Bothaville deposits in the following section.

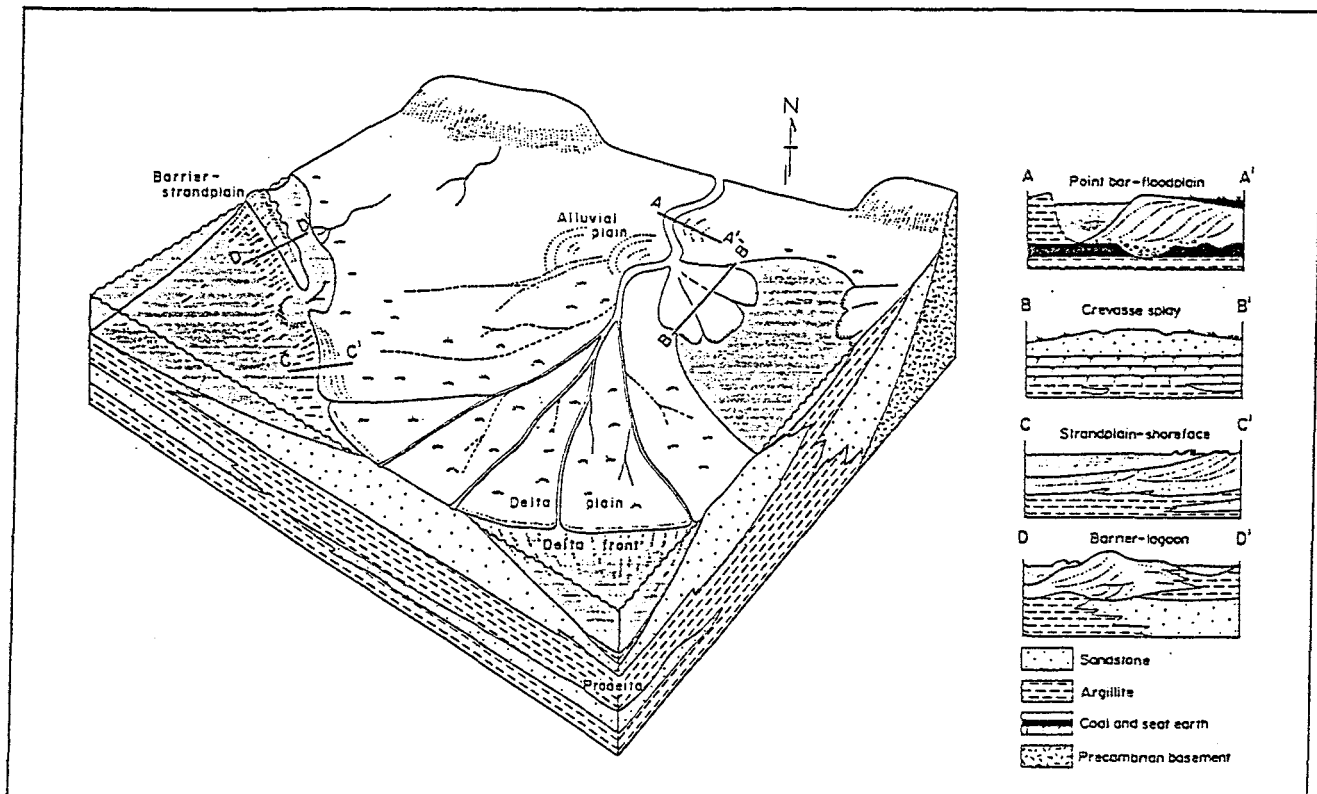


Figure 1.14. Schematic reconstruction of a typical Vryheid Formation lobate delta fed by meandering, mixed load channels through Precambrian residuals (after Tankard, 1982).

A simplified depositional model for the Ecca Group, which includes the argillaceous, deltaic-lacustrine deposits of the Volksrust Formation (Upper Ecca) is shown in Figure 1.15.

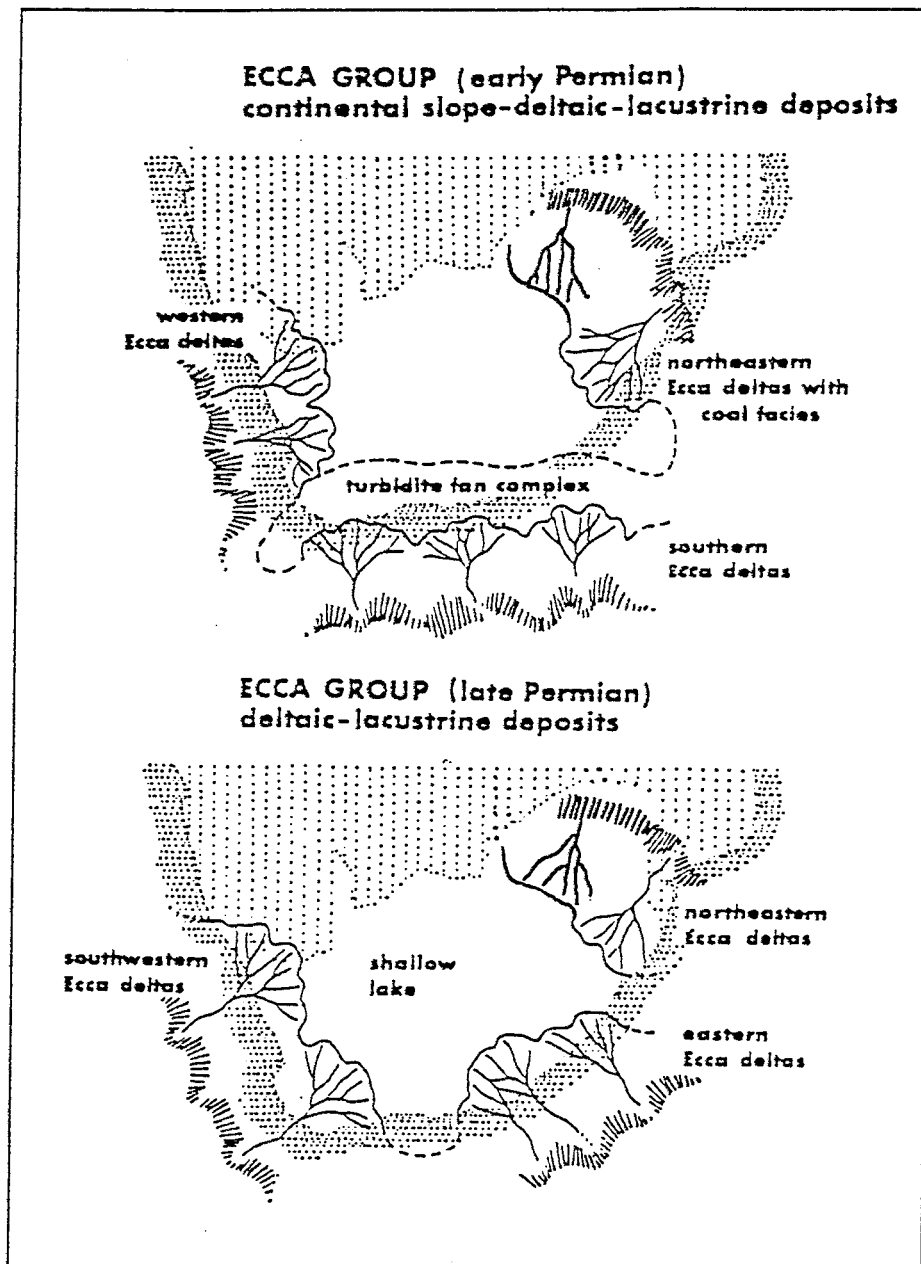


Figure 1.15. A simplified depositional model for the Eccca Group in southern Africa (modified after Smith, 1990).

4. The Depositional Environment of the Heavy Mineral Deposits in the Delmas/Bothaville Region of the Vryheid Formation.

The heavy mineral deposits of the Bothaville, Delmas, and Carolina areas were studied in some detail by Behr (1965). The deposits comprise in approximate order of abundance, altered and semi-altered ilmenite, goethite, leucoxene, zircon, garnet, rutile, anatase, monazite, chromite, staurolite, tourmaline, pyroboles, spinel, and xenotime. Behr (1965) established that the heavy minerals were deposited on the foreshores of regressive shorelines. Evidence cited is the concentration of heavy minerals in consistently planar, laminated, fine-grained, well-sorted sandstones. The laminations comprise thin bands rich and poor in heavy minerals and dip with consistent typical foreshore dips, seaward, and equally consistently, strike parallel to the rectilinear long axes of the deposits.

Vos and Hobday (1977) developed a storm beach model for the genesis of the Bothaville heavy mineral deposits, which may be applicable to the Delmas deposits. They interpret the Ecca sandstones in this region as regressive beach deposits, the vertical succession of facies representing a coarsening-upward transition from a lower shore through upper shoreface to foreshore sub-environments. Figure 1.16 shows the vertical sequence through the three facies and Figure 1.17 shows the various beach face sub-environments.

The lower shoreface deposits, characterised by bedding units of fine-grained, horizontal and ripple laminated sandstone separated by erosion surfaces, are believed to record episodes of storm wave surge (bottom currents caused by passing waves) seaward of the breaker line.

The upper shoreface deposits, consist of medium to coarse-grained sandstone, and are characterised by erosively-based, lenticular cosets of offshore directed medium to large-scale trough cross-bedding. These are interpreted as having resulted from short lived depositional events related to channelised and subsequent waning rip-current flow associated with storm activity. Rip currents form only when high wave storm related conditions are

present (Vos and Hobday, 1977).

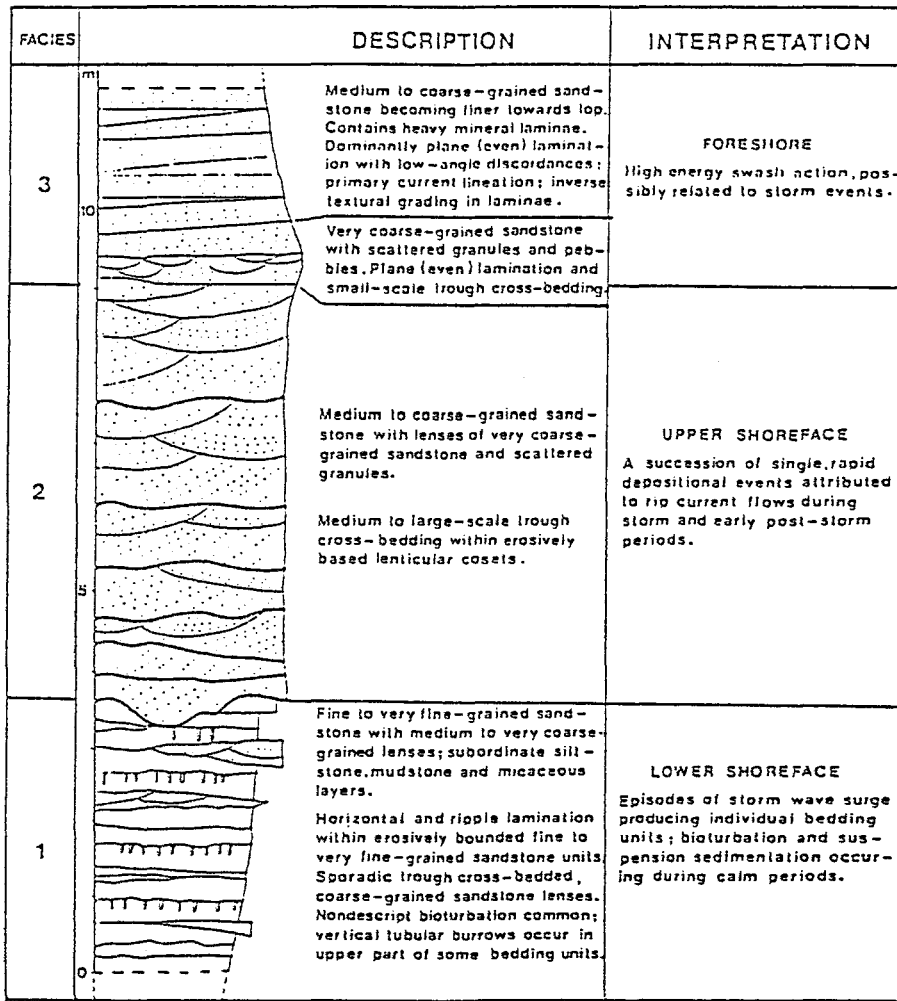


Figure 1.16. Vertical sequence of Ecca facies in the Bothaville area (after Vos and Hobday, 1977).

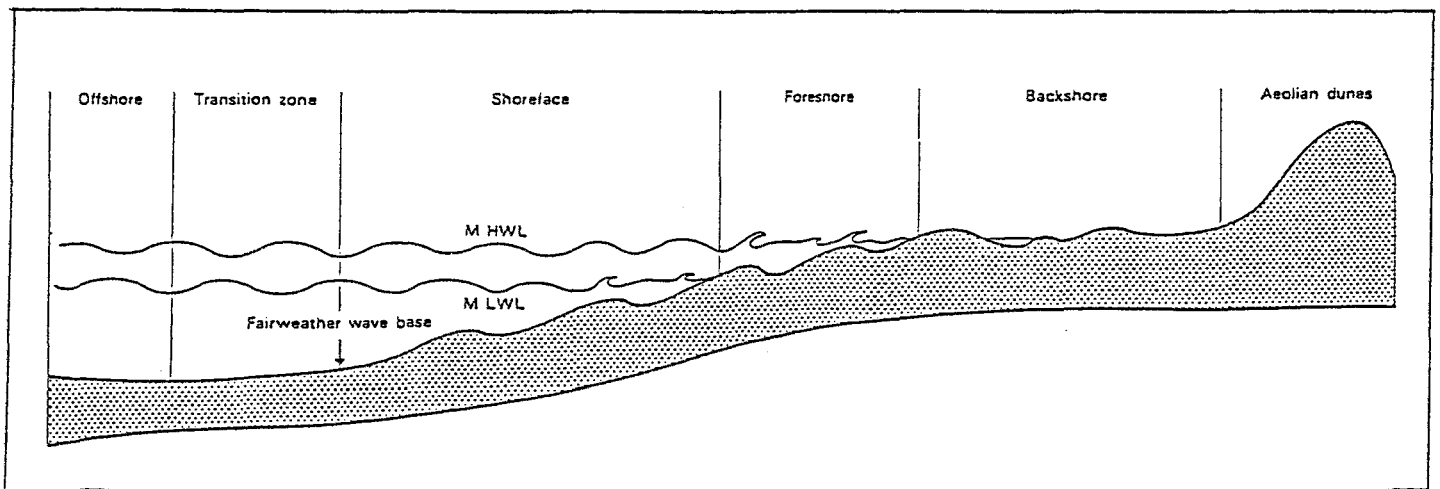


Figure 1.17. Beach face sub-environments (after Reading, 1981).

The foreshore deposits are characterised by gently dipping, evenly laminated or plane-bedded, fine to coarse-grained sandstone containing heavy mineral laminae and surfaces of low angle truncation. Normal and inverse textural grading occurs within the laminae. In the later case a basal fine-grained heavy mineral rich layer is overlain by a coarser-grained light mineral layer. The laminations are attributed to grain segregation under conditions of plane-bed sediment transport during swash-backwash flow (Reading, 1981), and are probably high energy storm related (Vos and Hobday, 1977). It is known that for the same size of obstacle on its down-current side, a large grain can more easily be pivoted over than a small one and thus become more mobile before the small one even if both are in hydraulic equilibrium. Larger grains will have more momentum than small hydraulically equivalent grains, thus the actions of swash-backwash flow and longshore drift will result in differentiation of larger light and generally smaller heavy minerals.

The heavy mineral deposits probably represent concentrations on beach ridges (Vos and Hobday, 1977) which have been reworked by longshore drift processes. The beach ridges (certainly with regard to the Bothaville deposits) and the apparent absence of any associated tidal deposits (tidal inlet and back-barrier tidal flats) would indicate a non-tidal or microtidal setting (see Figure 1.18). Reading (1981) notes that where tidal currents are absent the main sources of energy are meteorologically induced, notably by waves and storms. In addition, the absence of tidal processes will result in a high preservation potential of the beach depositional sequences.

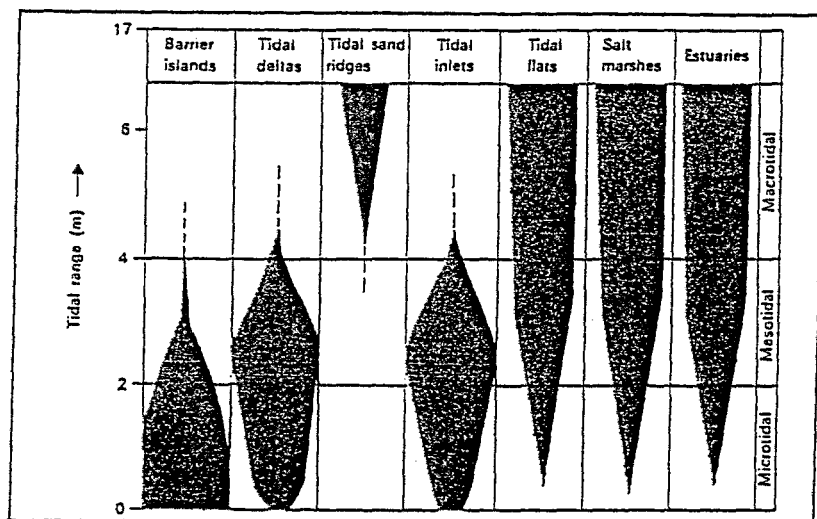


Figure 1.18. Relationship between tidal range and coastal morphology (after Reading, 1981).

SECTION B: THE SOURCE OF THE ILMENITES IN THE DELMAS DEPOSITS -
THE USE OF MINERAL CHEMISTRY AS A PROVENANCE INDICATOR.

The proto-ore of the ilmenites in the Delmas deposits can be considered in part to be; i) ilmenite bearing reworked glacial deposits along the northern margin of the Karoo basin, and; ii) pre-Karoo rocks which were eroded by southward flowing fluvial systems of the Northern Ecca Facies. Thus these ilmenite bearing fluvial systems would have eroded the glacial deposits, and deposited their debris within sand dominated deltaic systems along the northern margin of the Karoo sea. Coastal reworking of the delta-front sands took place by storm and longshore drift processes within a regressive microtidal shoreline.

Figure 2.1 shows the orientation of the Delmas and Bothaville heavy mineral deposits, and the transport directions of the Dwyka glacial and Ecca fluvial sediments.

Ilmenites have been collected over parts of the Transvaal, which includes the Delmas area, and areas to the northwest of Delmas, as part of regional exploration programmes. These grains have been analysed with the microprobe and the chemical analyses provides useful data for provenance studies. The size of the ilmenites for which data is available is within the range 0.5mm - 1.0mm. This relatively large grain size will restrict the rock types from which the grains were derived to predominantly plutonic, and to a minor extent in hypabyssal types. Volcanic rock types can only be expected to produce ilmenites of 0.5mm - 1.0mm in size if they are xenocrystic in origin i.e. probably formed as a result of mantle metasomatism within the lithosphere, and incorporated in the uprising magma.

The objective of this section is to establish the usefulness of ilmenite mineral chemistry as a provenance indicator. In this regard the chemistry of the ilmenites overlying the Delmas deposits and surrounds are compared to those from possible source rock types to the north.

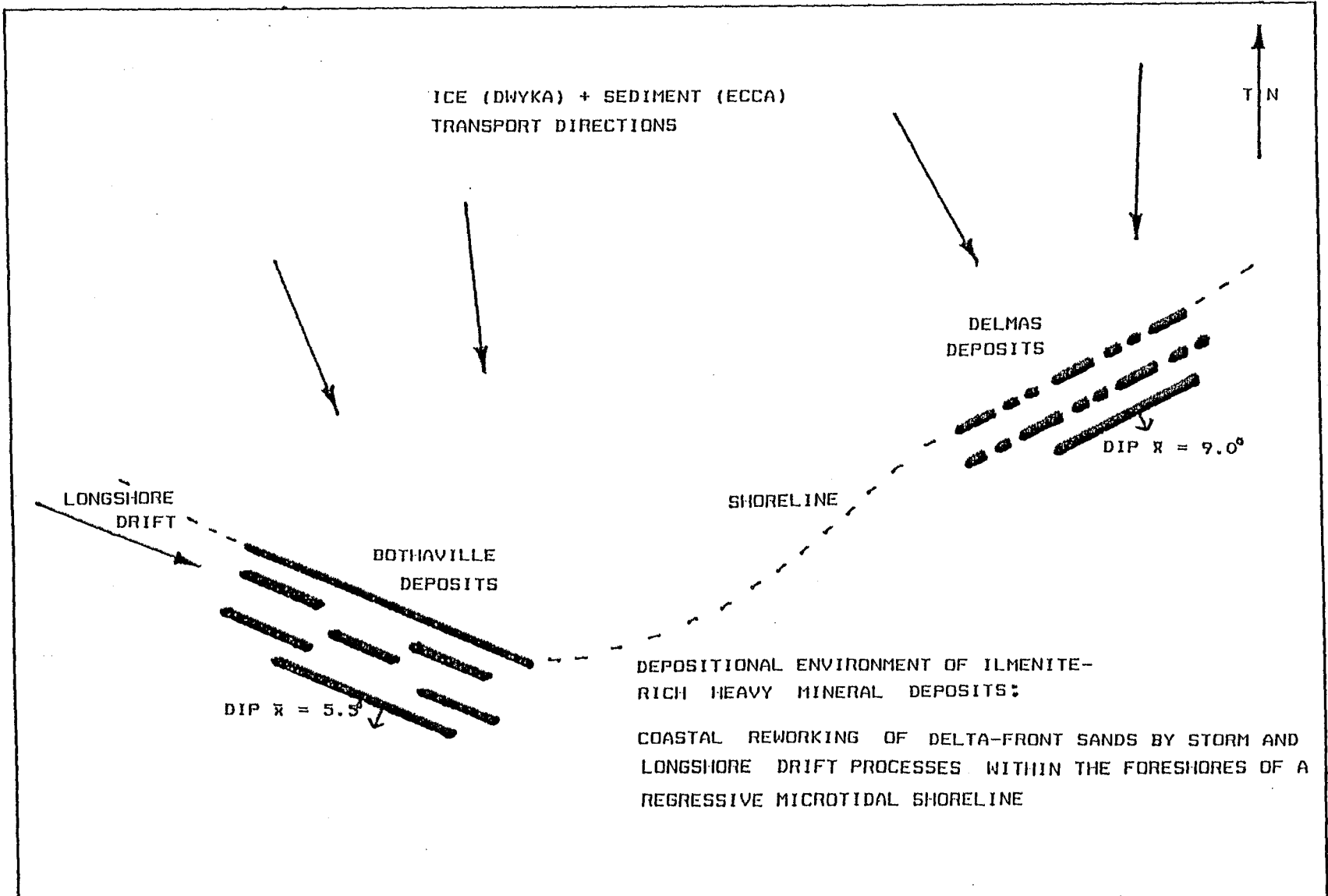


Figure 2.1. Schematic diagram of ore transport directions and orientation of the Delmas and Bothaville heavy mineral deposits.

1. Grain Size Distribution of Ilmenites within the Delmas/Bothaville Heavy Mineral Deposits.

Before an analysis of the ilmenites is undertaken it is important to establish the grain size distribution of heavy minerals within the storm beach deposits of the Vryheid Formation, and in particular the Delmas deposits.

Emery and Stevenson (1950) note that the foreshores of beaches, especially those rich in heavy minerals, have an almost perfect degree of sorting, and that the light and dark laminae differ in grain size, sorting and thickness. In his work Behr (1965) showed that heavy mineral grains of samples from the Bothaville deposits have a high degree of sorting, and a median size of 0.19mm. The light grains had median sizes of 0.26mm and 0.28mm. He noted the heavy mineral laminae to have higher sorting indices and kurtosis.

The alternating laminae along the upper foreshore may be deposited at varying dips towards the water. The variance in slope of the laminae along the foreshore may be related to grain size variance (Bascom, 1951), with coarser material showing steeper slopes. In this regard it is noted that the laminae of the Dwarsfontein deposit (as measured by Behr, 1965) have a steeper dip than those at Bothaville (see Figure 2.1). Behr noted that the Delmas deposits are not as uniformly grained and sorted as those at Bothaville, with quartz grains up to an inch across in an apparently fine grained sandstone.

Plates 1-3 show the grain size distribution of random ore samples taken from the Dwarsfontein deposit. Note the plane-bedded ilmenite-rich and quartz-rich laminae in Plates 1 and 2, and the large quartz grain in Plate 3. The polished sections show the ilmenite to be relatively poorly sorted with grains present within the 0.5mm - 1.0mm size range.

2. A Review of Ilmenite Mineralogy.

Ilmenite, a titanate of ferrous ion ($\text{FeO} \cdot \text{TiO}_2$), is a hard, heavy, black, opaque mineral which crystallises in the hexagonal

system, and is a major ore of titanium. The cations Mg^{2+} and Mn^{2+} may substitute for Fe^{2+} , and Cr^{3+} and Al^{3+} for Ti^{4+} in the ilmenite lattice to varying degrees. In this regard ilmenite may form end member solid solution series with Mn (pyrophanite $MnTiO_3$), and Mg (geikilite $MgTiO_3$). Within the Fe^{2+} , Fe^{3+} , Ti system ilmenite forms a complete solid solution series with haematite at 1050 C, and may form a discontinuous series with magnetite ($Fe^{2+} Fe^{3+}_2O_4$ which crystallises in the isometric crystal system) at higher temperatures (1250 C). Figure 2.2 shows a review of the mineralogy of the FeO , TiO_2 , Fe_2O_3 system, including magnetic data.

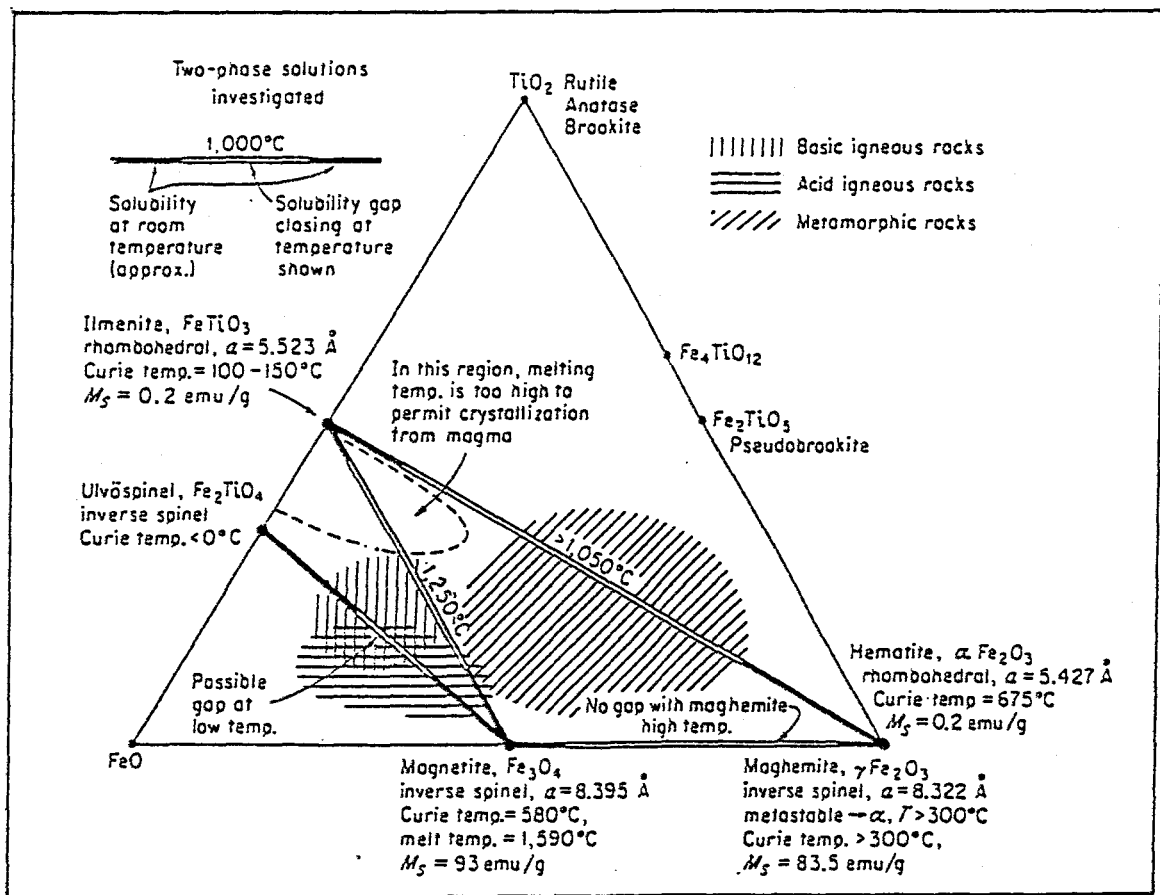


Figure 2.2. A review of mineralogical and magnetic data concerning the system FeO , TiO_2 , Fe_2O_3 (after Corner, 1990).

The foregoing indicates that the mineral composition of an ilmenite will be dependent on the type and specific conditions of the magma in which it crystallises.

Ilmenites generally occur as accessory minerals in predominantly mafic, and to a lesser extent in silicic rocktypes. In more detail, thoeleitic magmas which generally show Fe-enrichment in the early stages of differentiation of a magma sequence, result in Fe and Ti being incompatible and crystallising to form magnetite and co-existing ilmenite during the later stages of magma crystallisation. However, calc-alkaline and alkaline magmas generally do not show early Fe-enrichment, thus magnetite and ilmenite crystallise during the early stages of magma crystallisation. These trends may be due to the Eh conditions of the magma i.e. oxidising conditions result in early crystallisation of magnetite and visa versa.

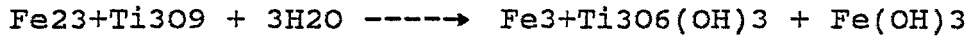
Large differentiated complexes (e.g. the BIC mafic phase) have resulted from large degrees of partial melting within the upper mantle. The differentiation of such sub-alkalic thoeleitic magmas result in the crystallisation of Fe-Ti oxides at a late stage in the crystallisation sequence. Thus in the case of the BIC, Fe and Ti have been concentrated in the form of titaniferous magnetite within the differentiated Upper Zone. In this regard Hatch and Wells (1980) note that some of the largest ilmenite deposits occur in anorthosites, as for example, in the Adirondacks. Ilmenite has also reached economic concentrations in the Tellnes deposit in Norway.

In areas of high seasonal rainfall, acid, oxidising conditions occur within the subsurface, and under these conditions chemical weathering proceeds to the greatest degree with resultant mature soil profiles. Ilmenites subject to such conditions will alter to leucoxene and finally to rutile, by a process of Fe leaching and hydration. Mucke and Chaudhuri (1991) studied this process in detail, and established the alteration to comprise essentially three stages. The following equations summarise the alteration process:

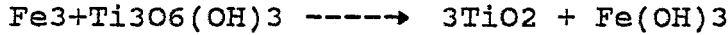
Stage 1: Alteration of ilmenite to pseudorutile by oxidation and leaching.



Stage 2: Alteration of pseudorutile to leucoxene by leaching and hydrolysis.



Stage 3: Alteration of leucoxene to rutile by leaching.



Under acid, oxidising conditions $\text{Fe}(\text{OH})_3$ remains stable in solution and is precipitated to goethite by the following dehydration reaction.

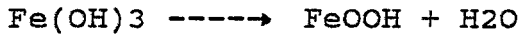


Figure 2.3 shows the increase in Ti with decreasing Fe as alteration proceeds, and Figure 2.4 shows this antipathetic relationship with data from the Dwarsfontein deposit. The natural increase in Ti due to natural weathering processes obviously has positive implications for the economic viability of ilmenite deposits.

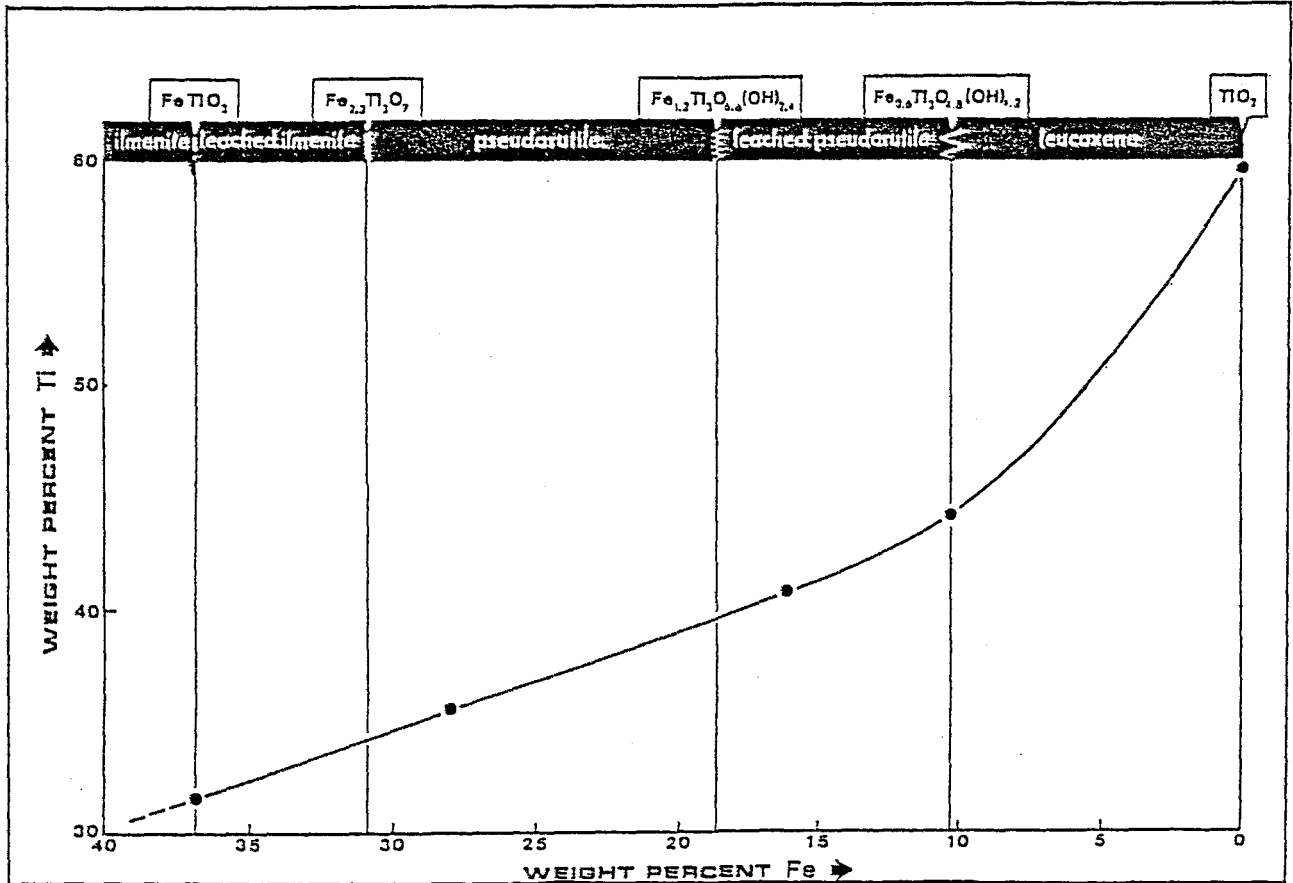


Figure 2.3. Relationship of Ti and Fe as ilmenite alters to rutile (modified after Mucke and Chaudhuri, 1991).

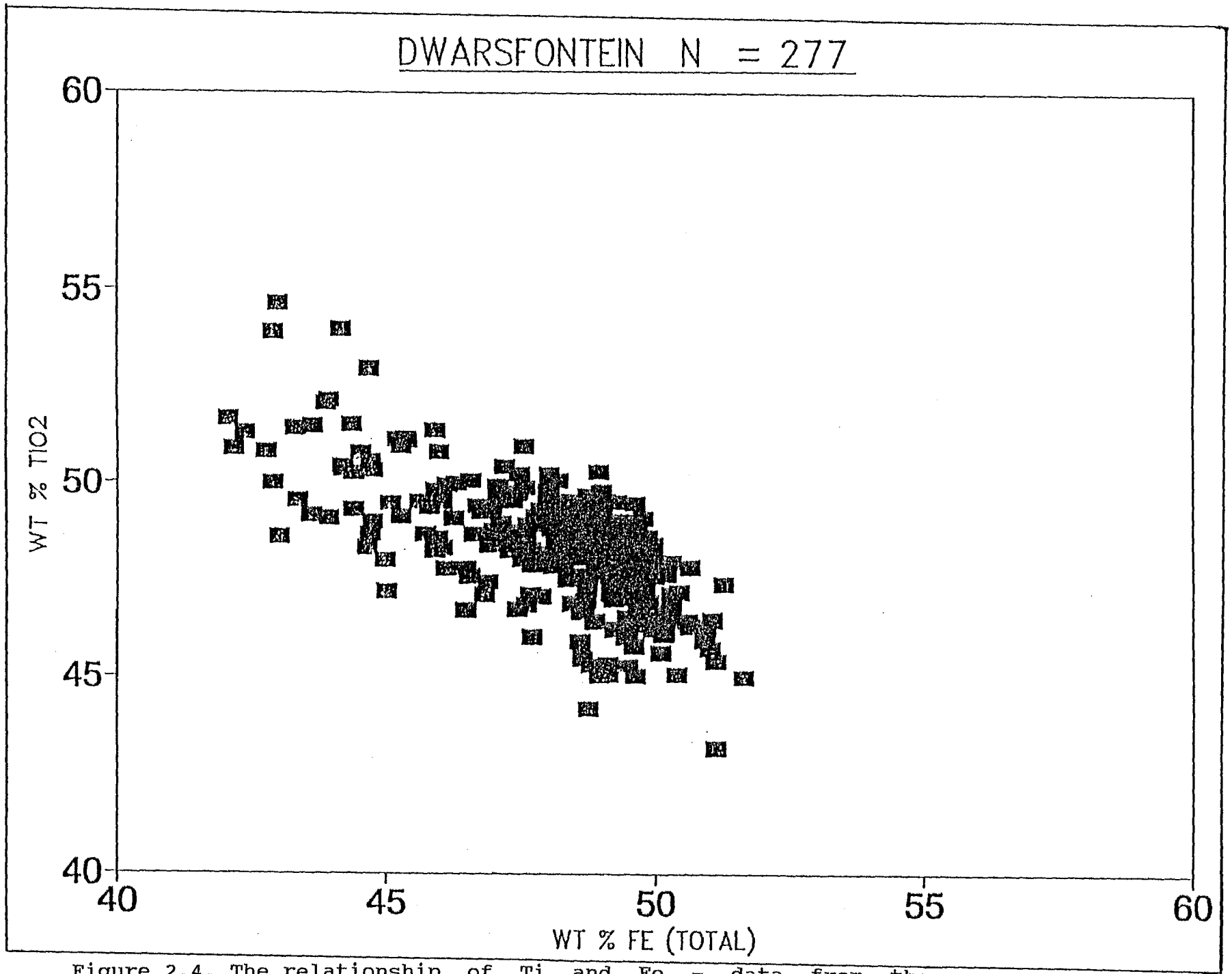


Figure 2.4. The relationship of Ti and Fe - data from the Dwarsfontein heavy mineral deposit.

Plates 4 - 9 show examples of altered ilmenites from the Dwarsfontein deposit. From the thin sections it is noted that complete alteration of ilmenite to leucoxene has not yet occurred. Generally, leached ilmenites and pseudorutiles are enclosed by mantles of leucoxene.

The variability of Fe and Ti in ilmenites due to chemical weathering renders them unacceptable for use in provenance studies, and in this regard only Mg, Cr, Mn and Al will be used.

3. Ilmenite Mineral Chemistry Analysis.

The concentration of the elements Mg, Cr, Mn, and Al within a magma are controlled by the sequence of minerals crystallising from the magma. Figure 2.5 shows the general trends of these elements within a fractionation sequence. The diagram also shows the stage of ilmenite crystallisation in the sequence within calc-alkaline and alkaline, kimberlite and related magmas, and thoeleitic magmas.

Sample populations of ilmenites from different magma types may thus be expected to show fractionation trends, which forms the basis for the use of ilmenite mineral chemistry as a provenance indicator. These trends would form structural domains which would be distinguishable from one another, thus providing a means of determining whether or not a rock suite contributed ilmenites to the concentrations within the Northern Ecca Facies.

In addition it is noted that alkaline magmas which are derived as a result of small degrees of partial melting are generally enriched in incompatible elements including Mn. These magmas are generally depleted in refractory elements such as Mg and Cr.

Figure 2.6 shows the expected ilmenite fractionation trends with regard to alkaline magmas, continental flood basalt type magmas (e.g. dolerite), BIC mafic phase thoeleitic type magmas, and kimberlite related type magmas (e.g. Derdepoort Complex).

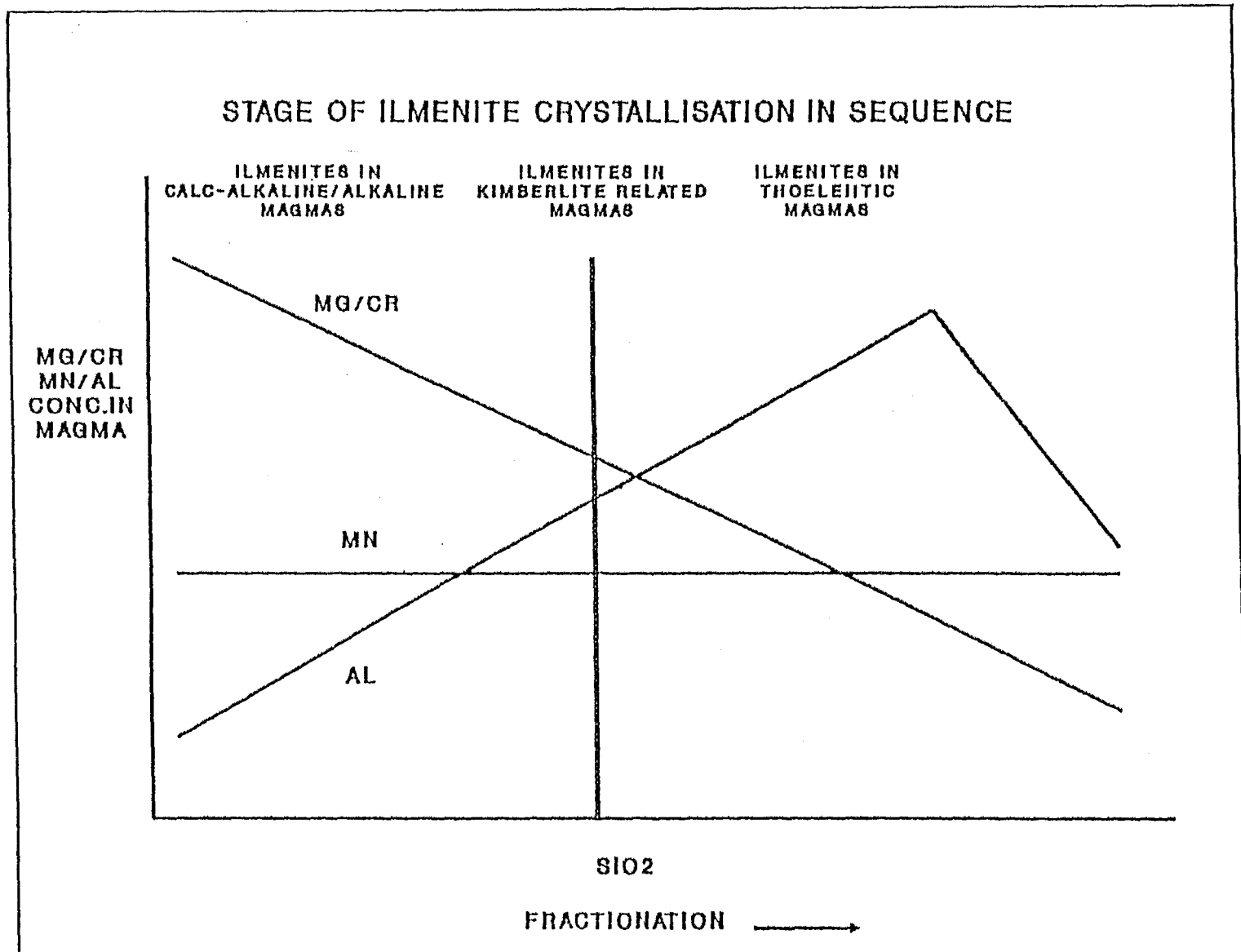
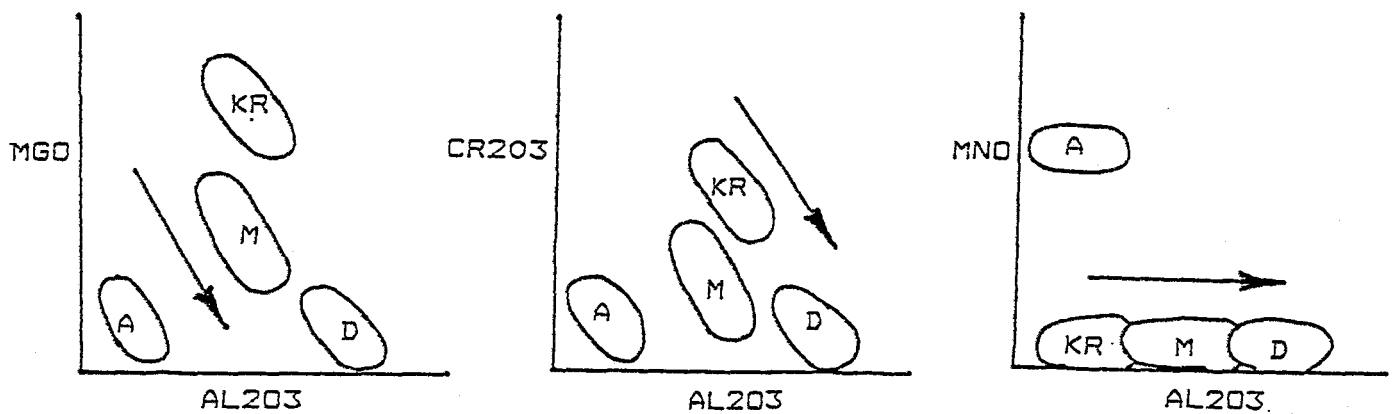
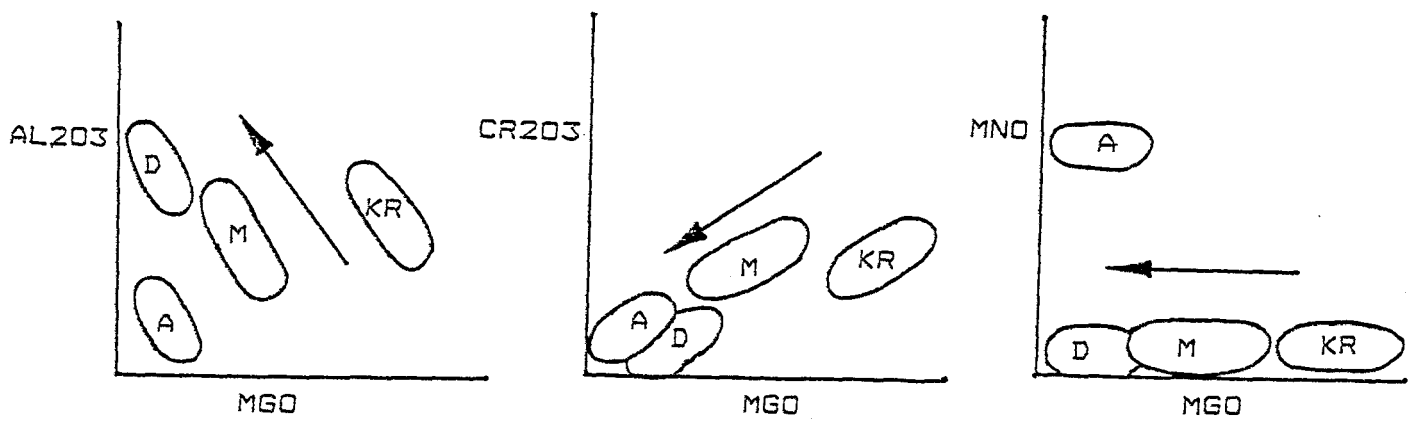


Figure 2.5. General fractionation trends of Mg, Cr, Mn, and Al.



A - ALKALINE MAGMAS
 D - CONTINENTAL FLOOD BASALT (DOLERITE)
 M - BIC MAFIC PHASE
 KR - KIMBERLITE RELATED MAGMAS
 FRACTIONATION TREND \longrightarrow

Figure 2.6. Expected fractionation trends of Mg, Cr, Mn, and Al in selected magma types.

Figure 2.7 shows a portion of the 1:1000000 geological map with the overlay showing the locations of the available mineral chemistry data i.e. ilmenite distributions I1 to I12 and Dwarsfontein. It should be noted that it is considered that all the grains with the exception of those occurring along the edge of the Karoo (Dwarsfontein and population I1) are residual, and reflect the underlying lithologies. It is noted that the surface textures of optically examined grains from population I1 show abrasion and are rounded, thus strongly indicating transportation. Figure 2.8 shows the spatial distribution of the ilmenites in the Delmas area, overlain on part of the 1:250000 geological map, and Table 2.1 shows the lithologies underlying the ilmenite distributions and the residual/transported nature of the grains.

Figures 2.9 and 2.10 show the ilmenite element distributions of population I1, which are compared to the distributions of; i) the alkaline complexes (populations I2 and I3); ii) a kimberlite related complex (population I4); iii) the BIC mafic phase (populations I5 - I9); iv) the BIC silicic phase (populations I10 and I11), and; v) a dolerite (population I12). The average element percentages and corresponding standard deviations (s) for the Dwarsfontein data have been plotted, and indicate that the ilmenites comprise part of the I1 population.

The structural domains or fractionation trends of the sample populations generally conform to the expected trends. However there are two notable variations. Firstly, the alkaline complexes and kimberlite related complex show a distinct late stage phase of ilmenite crystallisation (probably related to late phase metasomatising fluids). The early phase ilmenites of the kimberlite related complex have low Mg and Cr values, and the late phase ilmenites of the alkaline complexes have high Cr values. Secondly, the ilmenites from the dolerite would appear to have crystallised over a long period of time, as indicated by the large range in Al values. Obviously Karoo dolerite could not be considered a possible source rock for the ilmenites in the heavy mineral deposits, as it is post-Middle Ecca in age. The ilmenite data from the dolerite was included as a control for the analysis.

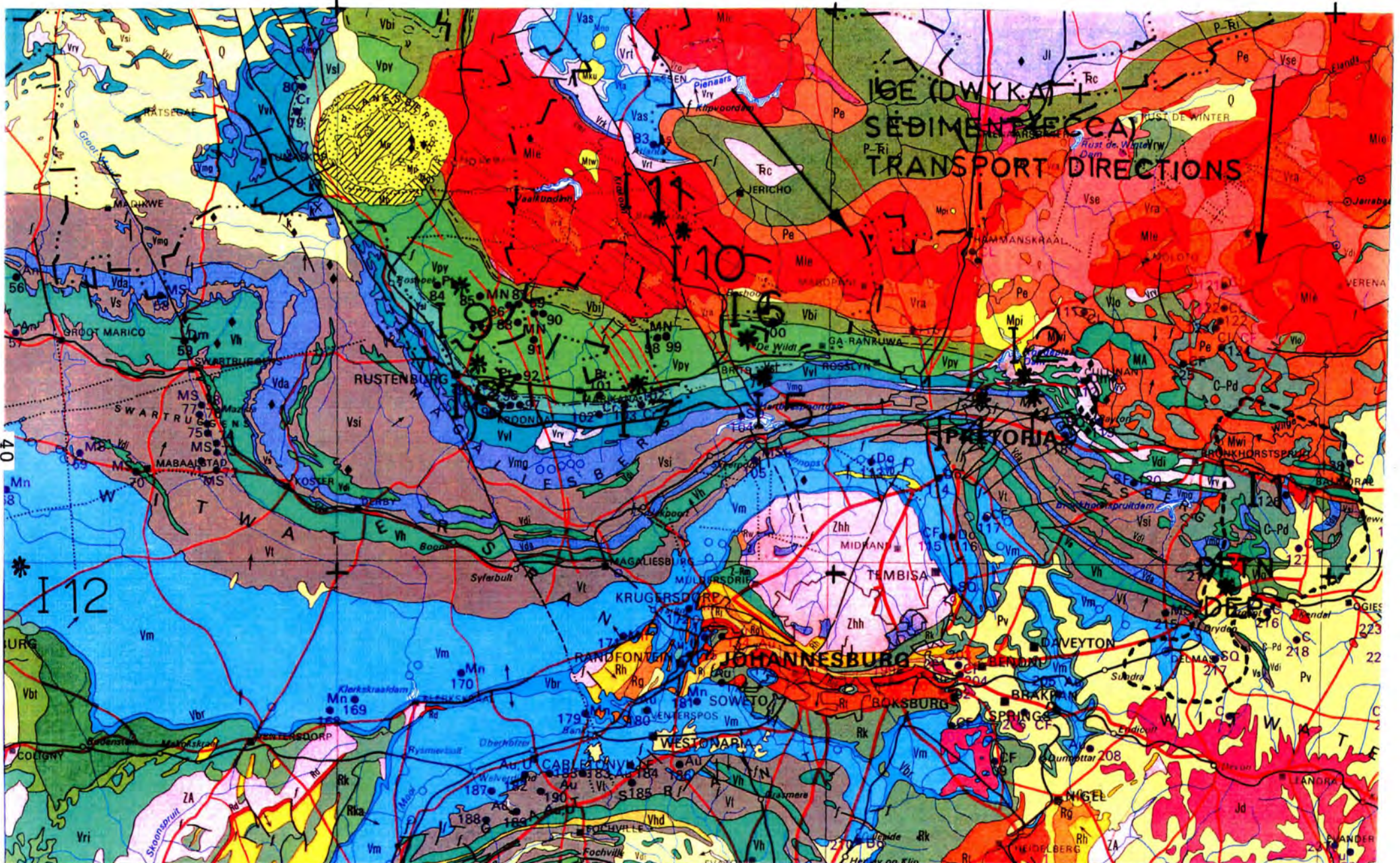


Figure 2.7. Portion of the 1:1000000 geological map showing locations of available mineral chemistry data.

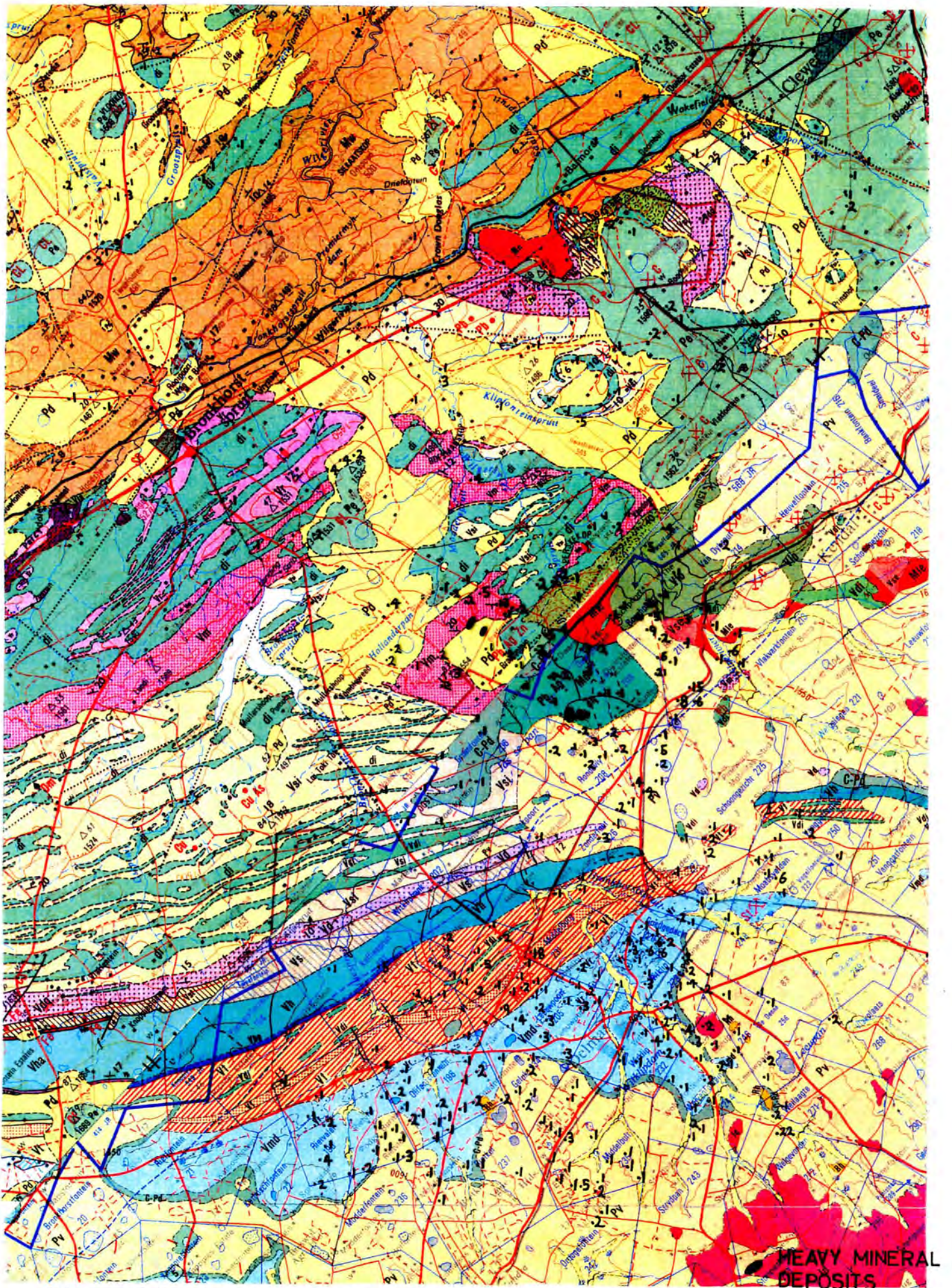
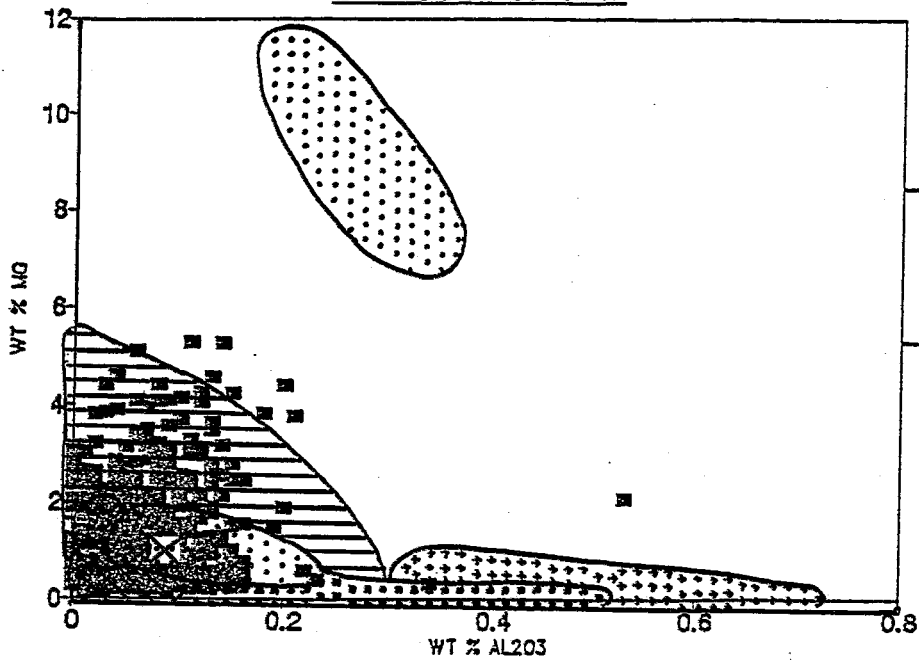



Figure 2.8. Portion of the 1:250000 geological map showing the spatial distribution of ilmenites in the Delmas area.

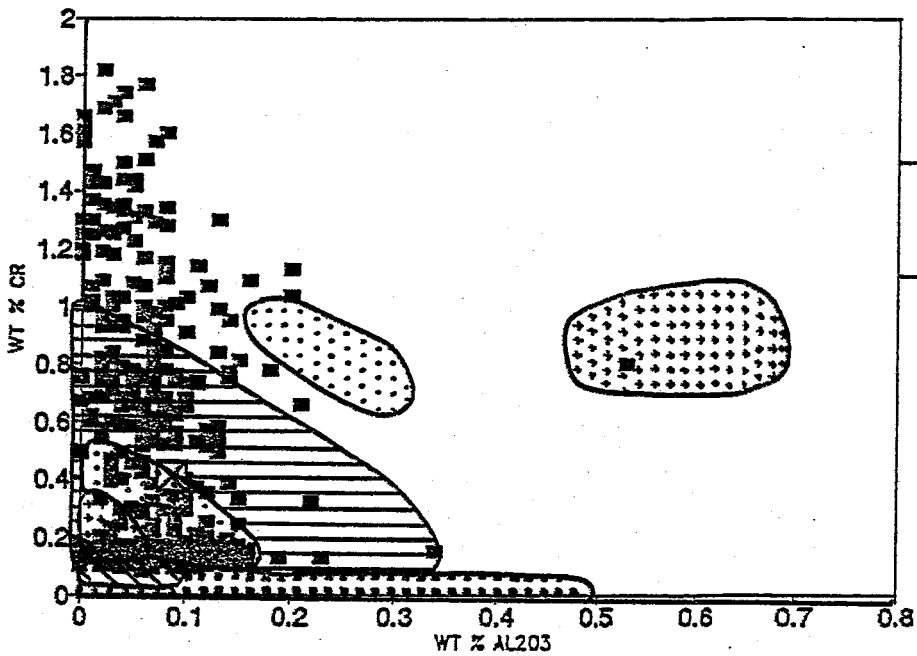
ILMENITE DISTRIBUTION	NO. GRAINS	UNDERLYING LITHOLOGY	RESIDUAL/ TRANSPORTED
DWARSFTN	277	HEAVY MINERAL DEPOSIT WITHIN MIDDLE ECCA	TRANSPORTED
11	487	EDGE OF KAROO S.G.	TRANSPORTED
12	19	LEEUFONTEIN ALKALINE COMPLEX: SATURATED/UNDERSAT. ALKALINE ROCKTYPES - PLUTONIC, HYPABYSSAL AND VOLCANIC PHASES EXPOSED	RESIDUAL
13	38	FRANSPOORT ALKALINE COMPLEX: UNDERSAT. ROCK TYPES - PLUTONIC, HYPABYSSAL AND VOLCANIC PHASES EXPOSED	RESIDUAL
14	31	DERDEPOORT COMPLEX: CARBONATISED MELNOITE DYKE/KIMBERLITE RELATED ROCK TYPE	RESIDUAL
15	13	BIC LOWER/CRITICAL ZONE: NORITES, PYROXENITES, CHROMITES, NORITES	RESIDUAL
16	12	BIC MAIN ZONE GABBROS	RESIDUAL
17	174	BIC MAIN ZONE GABBROS	RESIDUAL
18	27	BIC MAIN ZONE GABBROS	RESIDUAL
19	55	BIC MAIN ZONE GABBROS	RESIDUAL
110	13	BIC GRANITIC PHASE ALKALI GRANITE	RESIDUAL
111	6	BIC GRANITIC PHASE ALKALI GRANITE	RESIDUAL
112	18	DOLERITE (KAROO?)	RESIDUAL


Table 2.1. Number of grains, underlying lithologies and residual / transported nature of the ilmenite distributions.

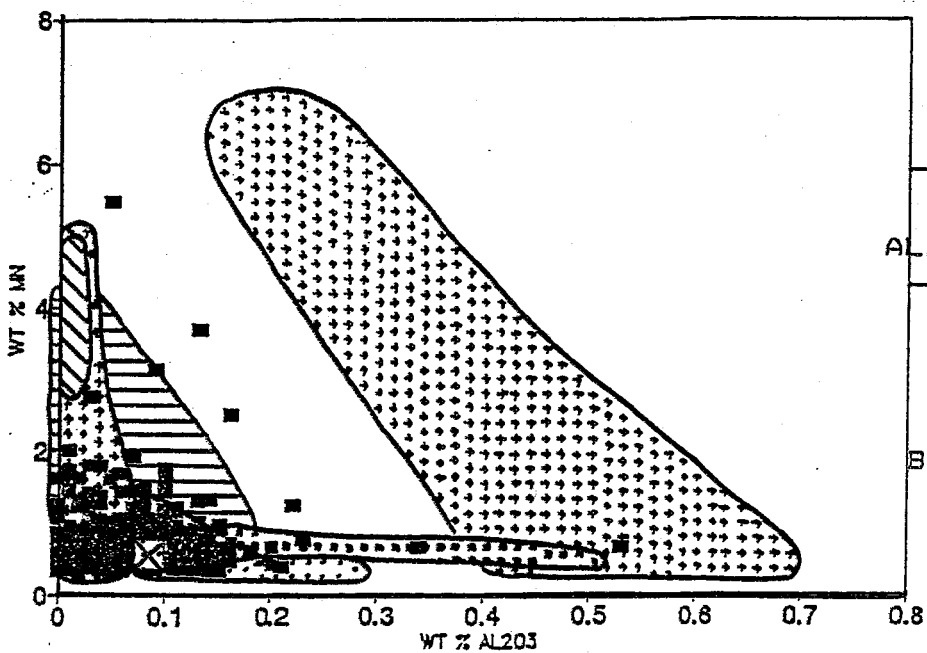
ILMENITE DISTRIBUTION 11



DWARSFTN AVG 
 S MG 1.07
 S AL 0.06



DWARSFTN AVG 
 S CR 0.49









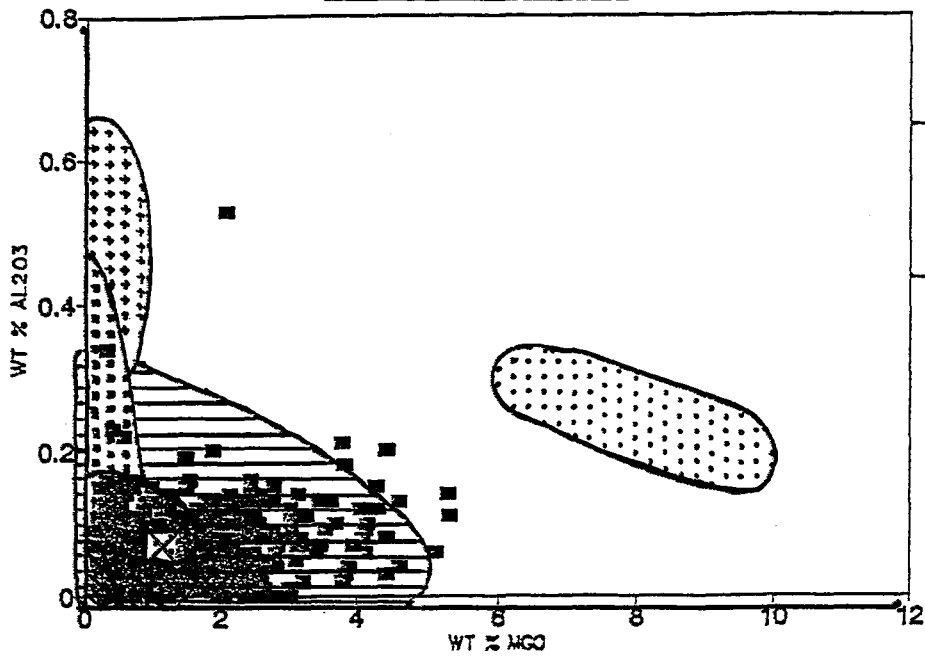
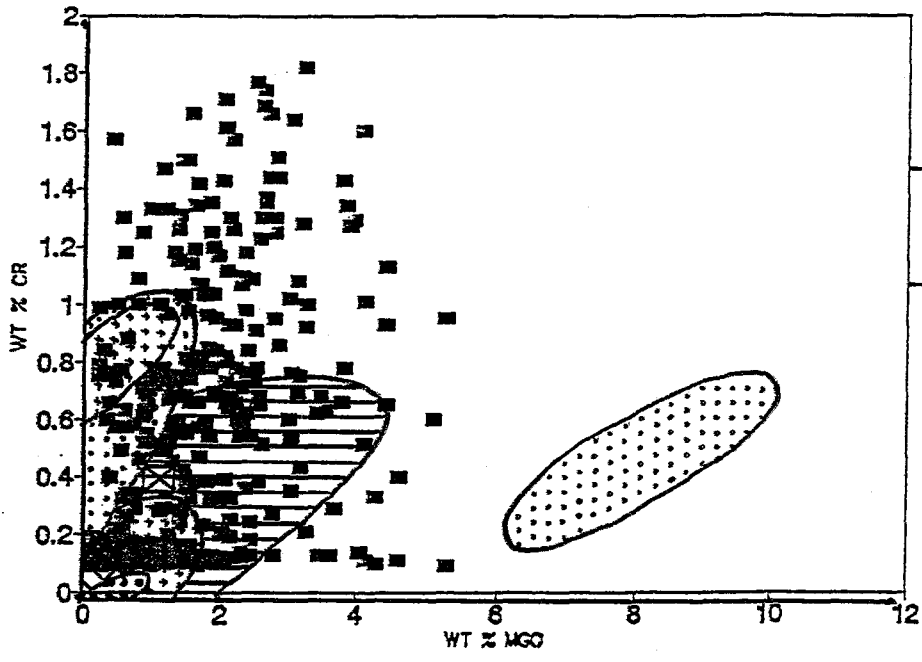
DWARSFTN AVG 
 S MN 0.17
 ALKALINE COMPLEXES 
 DOLERITE 
 BIC MAFIC PHASE 
 BIC SILICIC PHASE 
 KIMBERLITE RELATED COMPLEX 

Figure 2.9. Plots of Mg, Cr and Mn vs Al.

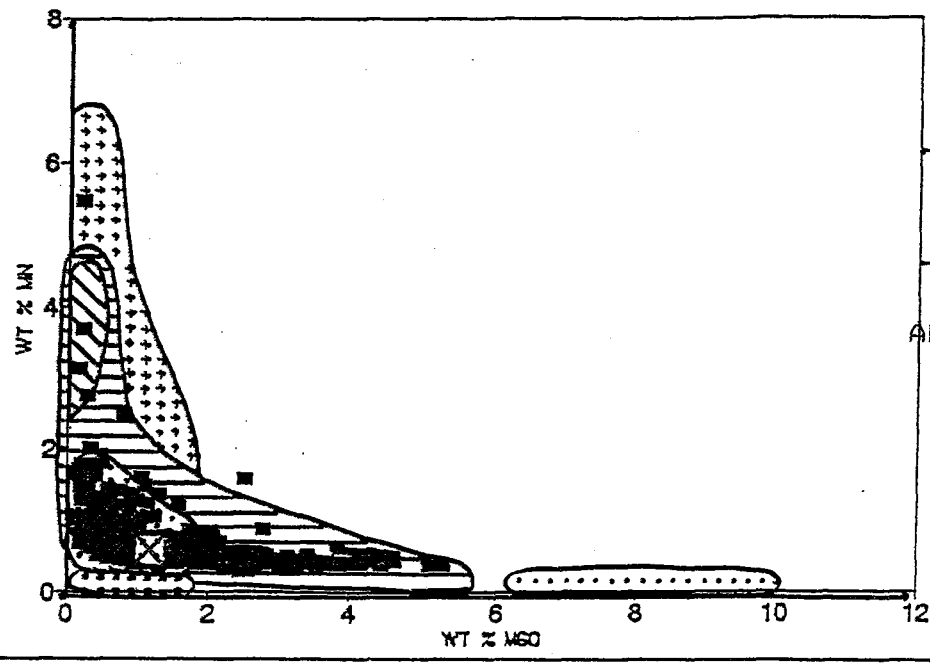
ILMENITE DISTRIBUTION 11



DWARSFTN AVG \boxtimes
 S AL 0.06
 S MG 1.07



DWARSFTN AVG \boxtimes
 S CR 0.49



DWARSFTN AVG \boxtimes
 S MN 0.19

- ALKALINE COMPLEXES \square (dotted pattern)
- DOLERITE \square (dotted pattern)
- BIC MAFIC PHASE \square (horizontal lines)
- BIC SILICIC PHASE \square (diagonal lines)
- KIMBERLITE \square (dotted pattern)
- RELATED COMPLEX \square (dotted pattern)

Figure 2.10. Plots of Al, Cr and Mn vs Mg.

The important point to note with regard to provenance studies is that in all cases the BIC mafic phase sample population correlates most closely to the population I1. The alkaline complexes show a reasonable correlation with I1.

In conclusion the available data indicates that:

1. Ilmenite mineral chemistry is useful for provenance studies.
2. The BIC mafic phase and possibly the alkaline complexes of the PRAC (Pienaars River Alkaline Complex) most likely contributed ilmenites to the heavy mineral deposits along the northern edge of the Karoo sediments.
3. The data supports a south to southeasterly transport direction for the glacial/fluvial systems of the lower portion of the Karoo Supergroup in this region.
4. The data provides information which will assist in a clearer understanding of heavy mineral distributions along the northern edge of the Karoo sediments. This will be useful for primary diamond deposit exploration in this region.

SECTION C: ECONOMIC VIABILITY - TITANIUM.

1. A Review of Titanium.

It is important to conduct an appraisal on the commodity/s under evaluation, in order to establish; i) a comprehensive knowledge of the commodity/s in terms of uses, beneficiation, resources, and pricing, and; ii) the present and likely future demand situation.

1.1. Beneficiation and Uses.

Titanium is a metal which has seen spectacular development during the past four decades. Only three tons were made in 1948, and by the late 1980s free world production of wrought titanium had increased to about 30000 tons per annum (Street and Alexander, 1989). Riding the crest of the longest sustained worldwide economic boom in history, demand for titanium dioxide pigment soared, growing at between 5% and 6% per annum in the 1985-1989 period. Although increased exploration and development of resources have increased feedstock supplies by 40% from 1985-1989, the minerals used as feedstock to create this product have been in short supply (MEG, 1990).

Titanium is the ninth most abundant element in the earth's crust, however only occurs in a few minerals that make its extraction economically feasible. In this regard, and at present, rutile and ilmenite are the main sources of titanium ores. Rutile generally contains about 95% TiO_2 , and ilmenite has a theoretical composition of 52,7% TiO_2 . However, as previously mentioned natural beneficiation due to chemical weathering of ilmenites may result in much higher concentrations of TiO_2 . Ilmenites and rutiles also contain chemical impurities to varying extents, due to the parental magmas in which they crystallised. The precise nature and concentration of the impurities found within a particular feedstock source will determine its saleability. Chromium oxide and vanadium pentoxide should not exceed about 0.2% and 0.5% respectively (Behr, 1965). Table 3.1 shows the compositions of ilmenite and rutile from selected worldwide resources.

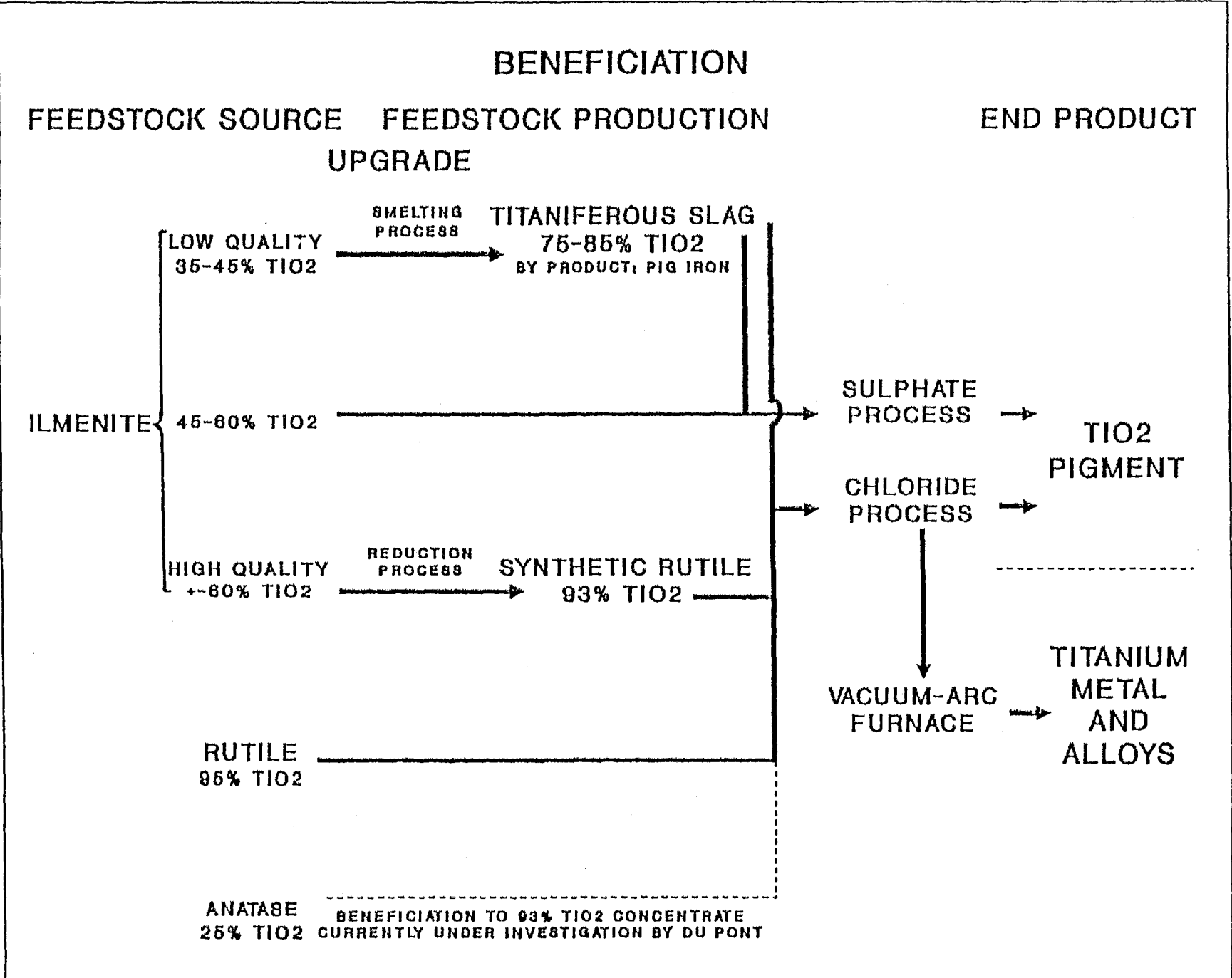
Per cent	TiO ₂	FeO	Fe ₂ O ₃	Cr ₂ O ₃	V ₂ O ₅
<i>Ilmenite</i>					
St. Lucia (K.R.C.).....	49,0	32,5	14,3	0,38	—
Richards Bay.....	49,7	36,6	11,1	0,19	0,29
Isipingo.....	46,6	39,5	9,1	0,10	2,76
Umgababa (Langton & Jackson).....	49,9	37,2	10,5	0,16	0,33
Sandy Point (K.R.C.).....	50,3	36,5	10,9	0,07	—
Morgan Bay (K.R.C.).....	50,0	38,0	13,1	0,05	—
West coast (Coetzee).....	41,6	34,1	19,7	0,0	0,92
Florida (T.M.).....	57,5	12,3	24,6	—	—
Quebec (T.M.).....	70,7	12,2	1,5	0,25	0,55
Malaya, Amang (T.M.).....	53,1	33,6	8,7	0,005	0,02
India, Q grade (T.M.).....	60,6	9,3	24,2	0,12	0,15
Australia, Western Titanium (T.M.).....	55,43	22,5	11,11	0,03	0,13
Australia, Westralian Sands (T.M.).....	56,0	14,0	26,0	0,04	0,21
Brazil (T.M.).....	48,3	32,4	16,6	0,5	0,06
<i>Rutile</i>					
St. Lucia, crude rutile (K.R.C.).....	71,6	—	0,45	—	—
Richards Bay (I.D.C.).....	96,5	—	0,61	0,16	0,63
Umgababa (Langton & Jackson).....	95,5	—	1,1	0,12	0,47
Sandy Point (K.R.C.).....	95,8	—	0,82	—	—
Morgan Bay (K.R.C.).....	95,0	—	0,50	—	—
K.R.C.—K.R.C. Resources, S.A. (Pty) Ltd.					
I.D.C.—Industrial Development Corp. of S.A. Ltd.					
T.M.—Titanium Minerals, 1971.					

Table 3.1. The composition of ilmenite and rutile from selected worldwide resources (after Hammerbeck, 1976).

The beneficiation process of titanium feedstock sources, which comprise ilmenite, rutile and possibly anatase in the near future is shown in Figure 3.1. The beneficiation of titanium feedstocks results in two principle end products, namely, non-metallic TiO₂ pigment, and titanium metal and alloys.

The TiO₂ pigment industry, which consumes approximately 94% of all titanium feedstocks mined outside the USSR, is by far the most important end user (MEG, 1990). TiO₂ pigment is unmatched for its qualities of whiteness, brightness, and opacity. In addition it is also completely non-toxic, thus is an important constituent of paints, high quality papers, and plastics (especially PVC). TiO₂ pigment may be considered as a 'quality of life' product, the demand for which reflects a country's overall levels of economic development and consumption.

TiO₂ pigment is produced by; i) the sulphate process which uses lower quality ilmenites and slag, and will account for 54% of all 1990 pigment production (MEG, 1990), and; ii) the newer chloride process which requires higher quality feedstocks and produces titanium tetrachloride as an intermediate product towards the pigment (see Figure 3.1).



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Figure 3.1. The beneficiation process of ilmenite, rutile and (anatase?).

Increased worldwide environmental awareness has resulted in increasingly stringent regulations with regard to industrial pollution. In this regard the sulphate process requires 2mt of ilmenite plus 4mt of sulphuric acid and scrap iron to produce 1mt of pigment, and produces large volumes of acidic effluent. This process is facing increasing environmental pressures, and acid recycling/ neutralising systems and higher percentages of slag are being introduced. However, controlling the amount of effluent generated remains a significant issue for the future. The chloride process is a chemically more complex process than the sulphate route, however is more 'environmentally friendly'. The principle waste is a relatively low amount of ferric chloride that can be economically recycled. It is noted that Du Pont, the world's largest pigment company, uses a chloride-ilmenite process that can use high quality ilmenites (+- 60% TiO₂) as feedstocks (MEG, 1990).

The production of metallic titanium and titanium alloys requires feedstocks with high TiO₂ contents i.e. rutile, titaniferous slag and synthetic rutile. Spongy titanium metal is produced by roasting TiCl₄ in an atmosphere of non-reactive argon, with additions of Na or Mg. The extreme reactivity of titanium in the molten state makes it impossible to melt in normal crucibles because no refractory will resist it. Thus consumable-electrode vacuum-arc furnaces are used, in which there is a direct current arc between an electrode made of the metal to be melted (spongy titanium), and the base of a copper crucible cooled by water or by a liquid sodium potassium alloy. The entire arrangement is housed in a vessel which contains argon or is evacuated. Axel Johnson Metals of the USA has developed a new electron beam cold hearth furnace for the production of ultra clean titanium alloys and nickel superalloys (MBM, 1990).

About half the annual production of metallic titanium is used as pure metal which is strong and ductile, the remainder is required as alloys. The combination of high strength, lightness and corrosion-resistance accounts for the value of titanium and its alloys in modern technology. The aerospace industry is the principle user of titanium alloys. Current alloys contain up to 25% of added elements such as aluminium, vanadium, molybdenum,

niobium, zirconium, and tin. These alloys are fabricated into complex high integrity parts for aircraft structures, where maximum strength per unit weight and fatigue resistance are essential. The 6% aluminium, 4% vanadium is the predominant aerospace titanium alloy, and is used world-wide in gas turbine engines and airframes.

Current designs of civil aircraft contain up to 10% of titanium alloys, while military aircraft may contain much more. The Lockheed Blackbird, capable of over Mach 3, is said to contain about 85% of its structural weight in titanium alloys (Street and Alexander, 1989).

Outside the aerospace industry, titanium is being specified for many engineering purposes that call for a high strength-to-weight ratio. Typical applications include steam-turbine blading, and components in high performance engines. Titanium also finds a major use in the welding rod industry, and to a lesser extent in the ceramics and chemical industries. Because of its complete inertness to body fluids, titanium is now widely used in the medical sector for surgical implants.

1.2. Resources.

The deposits of heavy mineral sands in Australia are the dominant sources of titanium feedstocks, and account for approximately 45% and 52% of worldwide ilmenite and rutile production in 1990 respectively (MEG, 1990). Other significant current sources include Canada, Norway, South Africa, and the United States. Table 3.2 shows the estimated 1990 production of the world's major sources and production of titanium feedstocks.

There is no shortage of unexploited titanium resources. Some such resources include:

1. A major deposit of high quality (60% TiO₂) ilmenite in Madagascar, held by RTZ.
2. A large heavy mineral sands deposit in the Congolone region of Mozambique, which has estimated reserves of 300000 t/y of ilmenite and 8000 t/y of rutile for a period of nine to ten

years (MEG, 1990). Kenmare Resources, a Dublin based company has an interest in this deposit.

3. Du Pont is evaluating a potentially significant find in Senegal.
4. The Rotifunk deposit in Sierra Leone, which runs at 1.41 mt rutile and 128000 t of zircon, and is currently being investigated by Pioneer Resources (Mining Journal, 1991).
5. An ancient coastal area in the southeastern US has recently emerged as an area of great potential for mineral sands production (MEG, 1990).
6. Two ilmenite, zircon and rutile deposits along the Transkei and Northern Natal coastlines which are currently being evaluated by Rhombus Exploration Ltd, South Africa (Mining Mirror, 1991). It appears that the viability of the Transkei and Natal deposits will depend on the ability to upgrade the ilmenites into a titaniferous slag and synthetic rutile respectively.

It should be noted that in addition to ilmenite and rutile, heavy mineral sand deposits generally contain concentrations of zircon and monazite, which make important contributions to the profitability of titanium ore mines. Zircon is widely used in the steel refractory industry, in the manufacture of high quality ceramics, titanium alloys, and as a foundry sand. Monazite is an important source of rare earth metals, which are used in various high 'tech' applications.

1.3. Pricing.

Most titanium feedstocks are sold to pigment producers under long term contracts, which tend to stabilise prices. Sales of ilmenite and rutile are quoted in Australian dollars, reflecting that country's dominance in the market.

Figure 3.2 shows the rand/Australian dollar exchange rate from 1979-1990, and Figure 3.3 shows the price trends of titanium commodities. Although the data is incomplete, an upward trend for ilmenite and rutile is indicated, which reflects increasing demand for these commodities.

Country	Rutile	Synthetic Rutile	Chlorinatable Slag	Ilmenite	Sulfatable Slag
Australia					
AMC (RGC)	95	160	0	400	0
Cable Sands	0	0	0	244	0
Consolidated Rutile	90	0	0	280	0
Mineral Deposits	35	0	0	0	0
RZ Mines	34	0	0	10	0
Tiwest	13	0	0	263	0
Westralian	0	100	0	363	0
North America					
Du Pont	0	0	0	200	0
Kerr-McGee	0	100	0	0	0
QIT Slag	0	0	0	0	1050
Europe					
Tellnes	0	0	0	550	0
Tinfos	0	0	0	0	150
South Africa					
Richards Bay	80	0	625	0	100
Sierra Leone					
Sierra Rutile	130	0	0	45	0
Totals	477	360	625	2345	1300
% of World Production From Listed Companies	92	84	100	68	99

Table 3.2. Estimated 1990 production of the major titanium mining companies (in millions of tons) (after MEG, 1990).

The slight drop in early 1991 prices was due to a general downturn in world economic conditions, which still persists at the time of writing. However, the long term trend for these commodities is generally considered to be positive as is indicated in the following section.

Prices for synthetic rutile and slags are at their highest levels, with synthetic rutile at about US\$410, chlorinatable slag at US\$310, and sulphatable slag at US\$290 (MEG, 1990) (Figure 3.3).

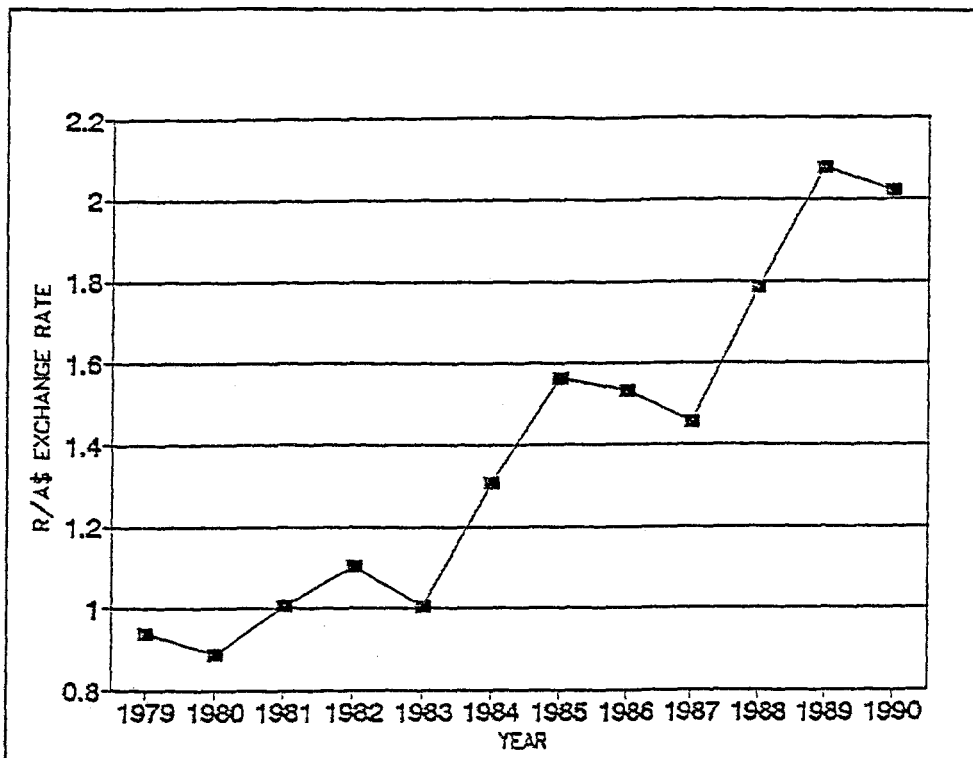


Figure 3.2. Rand/Australian \$ exchange rate.

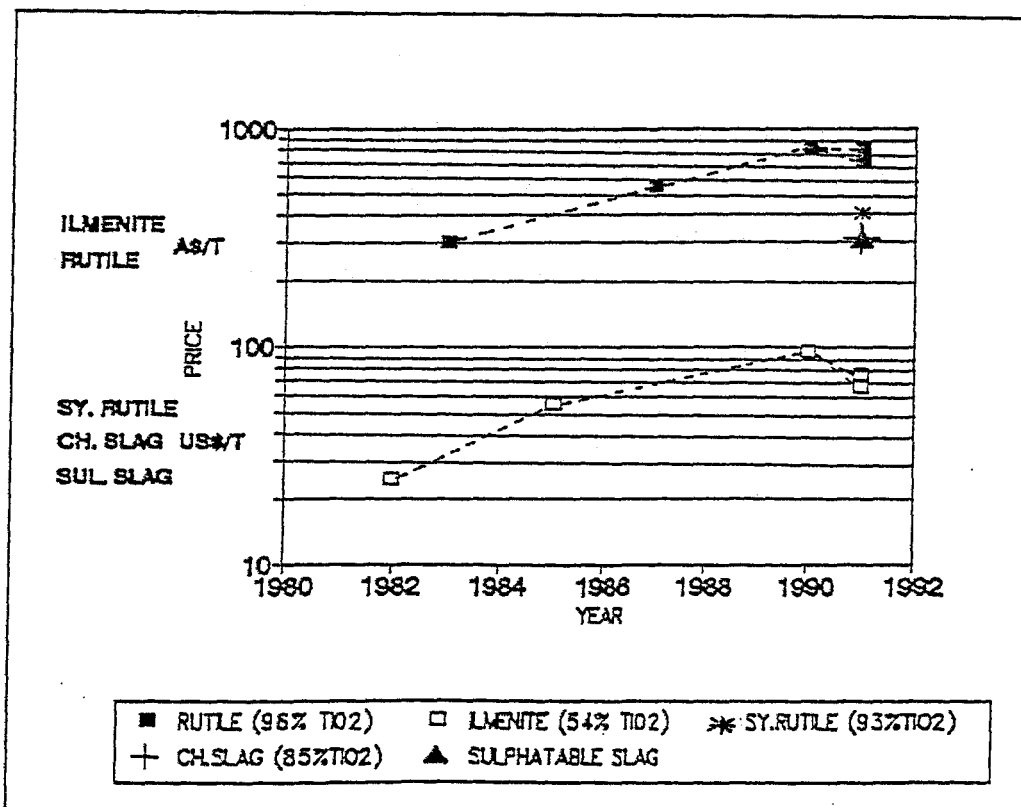


Figure 3.3. Titanium prices (ilmenite and rutile quoted in constant 1985 A\$).

1.4. Future Outlook.

The future outlook for titanium is positive. Long term demand for titanium pigment, the so called 'quality of life product is most certainly likely to continue. Pigment sales during 1991 will probably continue to be depressed due to the downturn in the world economy. The MEG (1990) notes that several pigment plants are under construction in Asia, to serve the growing market on the Pacific rim. Eastern Europe will presumably also be a relatively new and strong market-place for this commodity.

With regard to titanium metal and alloys, there has been some negative feelings towards demand in some sectors. This is due to cutbacks in military spending as a result of the so-called 'peace dividend' now that Nato and the Warsaw Pact countries are on friendly terms. However, as a whole the mood remains positive, with agreement by most titanium metal/alloy producers that commercial aerospace demand will more than compensate for the cutbacks. The world's aircraft fleets are ageing and need to be replaced, while more and more people are flying so more aircraft in service are needed (MBM, 1990). Medical opportunities for titanium are positive. An expanding prosthetics market is likely because titanium is more biocompatible than the cobalt-based alloys which are now being used (MBM, 1990).

In addition, demand for titanium in the engineering field will probably remain positive as more 'high tech' uses for the metal are found.

Thus it is likely that the increase in supply of titanium feedstocks to the market, due to greater exploitation of resources will be taken up by increased demand, and consequent sustained high prices.

2. The Dwarsfontein Ilmenite-Rich Heavy Mineral Deposit: An Economic Appraisal.

A number of heavy mineral deposits occur within the Vryheid Formation of the Karoo Supergroup in the Delmas area (Figure 3.4). In fact the first discovery of heavy mineral deposits in

the Karoo Supergroup was made in 1951 by Rand Mines Limited in the Delmas area, and this company subsequently prospected the Dwarsfontein deposit in 1952. Borehole data from this work in addition to data from Behr (1965) is used to carry out an economic appraisal of the Dwarsfontein deposit. It should be noted that the available borehole data is limited, therefore a geostatistical analysis is not possible, and the ore reserve estimate will only be a rough figure.

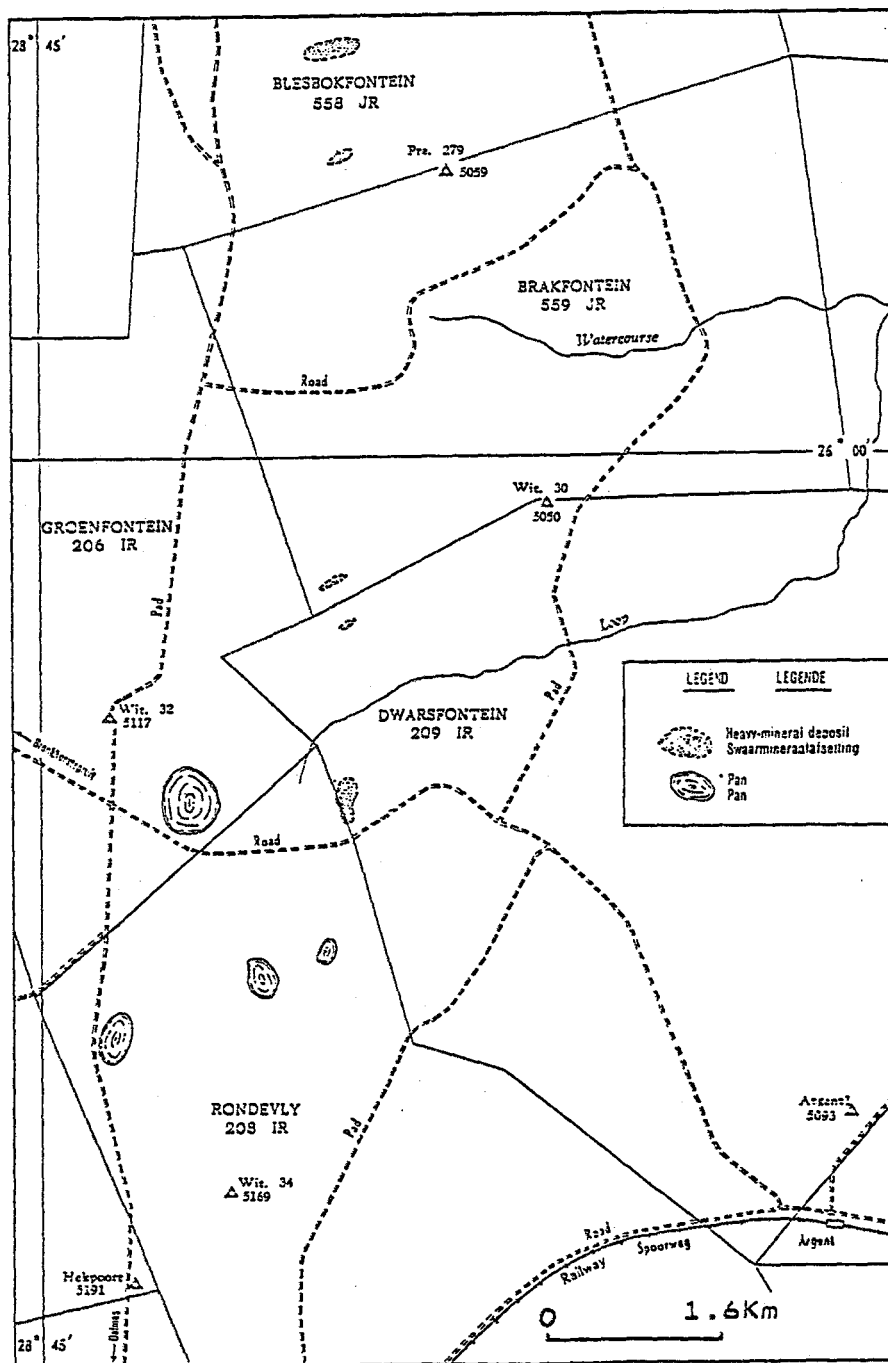


Figure 3.4. Heavy mineral deposits near Delmas (after Behr, 1965).

The basic mining and ore processing procedure envisaged for a heavy mineral deposit of this type would be as follows:

1. Quarrying with mechanical excavators. In this regard it is noted that the rock is friable to semi-friable, and little or no explosives would be required.
2. Crushing, milling and initial concentration using cyclones down to the -80 +200 mesh size fraction.
3. Final concentration of ilmenite concentrate using a spiral system.

The ilmenite concentrate would then be sold at the prevailing market rate.

2.1. Metallurgical Analysis.

In this section metallurgical problems with regard to ore beneficiation, as well as titanium ore mineral percentage recovery are addressed.

2.1.1. Metallurgical problems.

There is essentially one main problem relating to the beneficiation of the titanium ore minerals in the Dwarsfontein deposit. This is the contamination by a secondary predominant goethite cement, which coats and impregnates the altered ilmenite grains. In addition, this chemical weathering product (as previously discussed) causes the grains to be friable, with resultant slimming losses.

Electron microprobe work on ilmenite concentrate from the Bothaville heavy mineral deposit was conducted by van Zyl (1970). He concluded that the main sources of ilmenite/leucoxene contamination, namely;

- i) an iron-silicon-aluminium cement (secondary) coating on nearly all the grains present, and;
- ii) silicon (secondary) dispersed throughout highly weathered ilmenite grains,

are too intergrally associated with the titanium minerals present to allow any form of physical separation, even if the samples are ground to a much smaller particle size.

Behr (1965) notes that for successful beneficiation the removal of the goethite cement, by means other than acid treatment could be solved by careful grinding and scrubbing of the grains.

With ever increasing advances in mining technology it is most likely that further testwork would prove to be successful in overcoming the above metallurgical problem.

2.1.2. Titanium ore mineral percentage recovery.

Behr (1965) took two representative channel samples from the ore within the Dwarsfontein deposit, and performed detailed mineralogical and chemical analyses, from which titanium ore mineral grades and a percentage recovery could be established. Percentage recovery refers to the total amount of material recovered in a particular size fraction. Table 3.3 shows a summary of the analyses and the titanium ore mineral grade (based on the -115 +150 mesh fraction) and percent recoveries (based on the -115 +150 and -115 +200 mesh fractions). Note that the titanium ore minerals comprise ilmenite and leucoxene and will be referred to as ore minerals.

Behr (1965) notes that crushing to -115 mesh liberated all the grains, but grinding to a slightly coarser limit of -80 mesh would probably be equally effective. Thus a size fraction of -80 +200 mesh, and an associated ore mineral percentage recovery of 60% will be used in the following economic analysis. Note that the 57% recovery for the -115 +200 mesh fraction (see Table 3.3) is upgraded to 60%. It is also assumed that the ore mineral grade for the -80 +200 mesh fraction remains at 63%.

2.2. Basic Pit Design and Ore Reserve Calculation.

The Dwarsfontein deposit is shown in Figure 3.5, and Table 3.4 shows the borehole data, which includes TiO₂ percentages per one metre borehole lengths, and corresponding TiO₂ values and grades of the ore minerals. It is noted that this data has been modified

from the borehole data shown in Behr (1965). It is assumed that the ore body has relatively sharp contacts with the host sediments, thus the upper and lower values in each borehole indicate the corresponding upper and lower ore body contacts. The rough design of the open pit is shown in Figure 3.6. The pit was designed from the bottom upwards, thus design was initiated from the deepest borehole (11m). Figure 3.6 also shows the sub-surface depth to the ore body. The overburden would have to be stripped off first, and the ore reserve calculated only for the ore body is 0.42 mt i.e. 101110 cubic metres x specific gravity of 4.15. The average TiO₂ content of the ore minerals is 57.6% (see Table 3.4), and the average ore mineral grade is 56.6% (see Table 3.4).

MINERALOGICAL ANALYSIS			CHEMICAL ANALYSIS					
MINERALOGICAL COMPOSITION -115 (125µm) +150 (100µm) MESH SIZE FRACTION			ORE SAMPLE		CONCENTRATES			
		SPECIFIC GRAVITY PROPORTIONAL			DIFFERENT MAGNETIC FRACTIONS DECREASING MAG. SUSCEPTIBILITY →			
ILMENITE	56.5%	2.66	SI02	27.62	0.56	1.68	6.72	
LEUCOXENE	6.5%	0.273	FE2O3	26.85	28.42	34.96	31.29	
ZIRCON	0.1%	0.0046	FEO	0.57	15.8	6.47	1.44	
GARNET	0.1%	0.0042	MGO	1.22	1.42	1.21	1.13	
QUARTZ/FELDSPAR	23.2%	0.626	TI02	32	46.14	46.17	48.01	
GOETHITE	13.8%	0.58	CR2O3	0.05	0.02	0.051	0.074	
TOTAL	100.2%	S.G. OF ORE 4.15			ORE MINERAL GRADE			
TITANIUM ORE MINERAL GRADE 63%			ORE MINERAL TI02%	50.9	46.6	48.1	49	
ORE MINERAL GRADE: 63% (BASED ON -115 +150 MESH)								
% RECOVERY GRADES (% OF TOTAL MATERIAL RECOVERED):								
-115 (125µm) +150(100µm) MESH: 28.7%								
-115 (125µm) + 200 (75µm) MESH: 57%								

Table 3.3. Mineralogical and chemical analyses of two channel samples from the Dwarsfontein deposit (data taken from Behr, 1965, 1985).

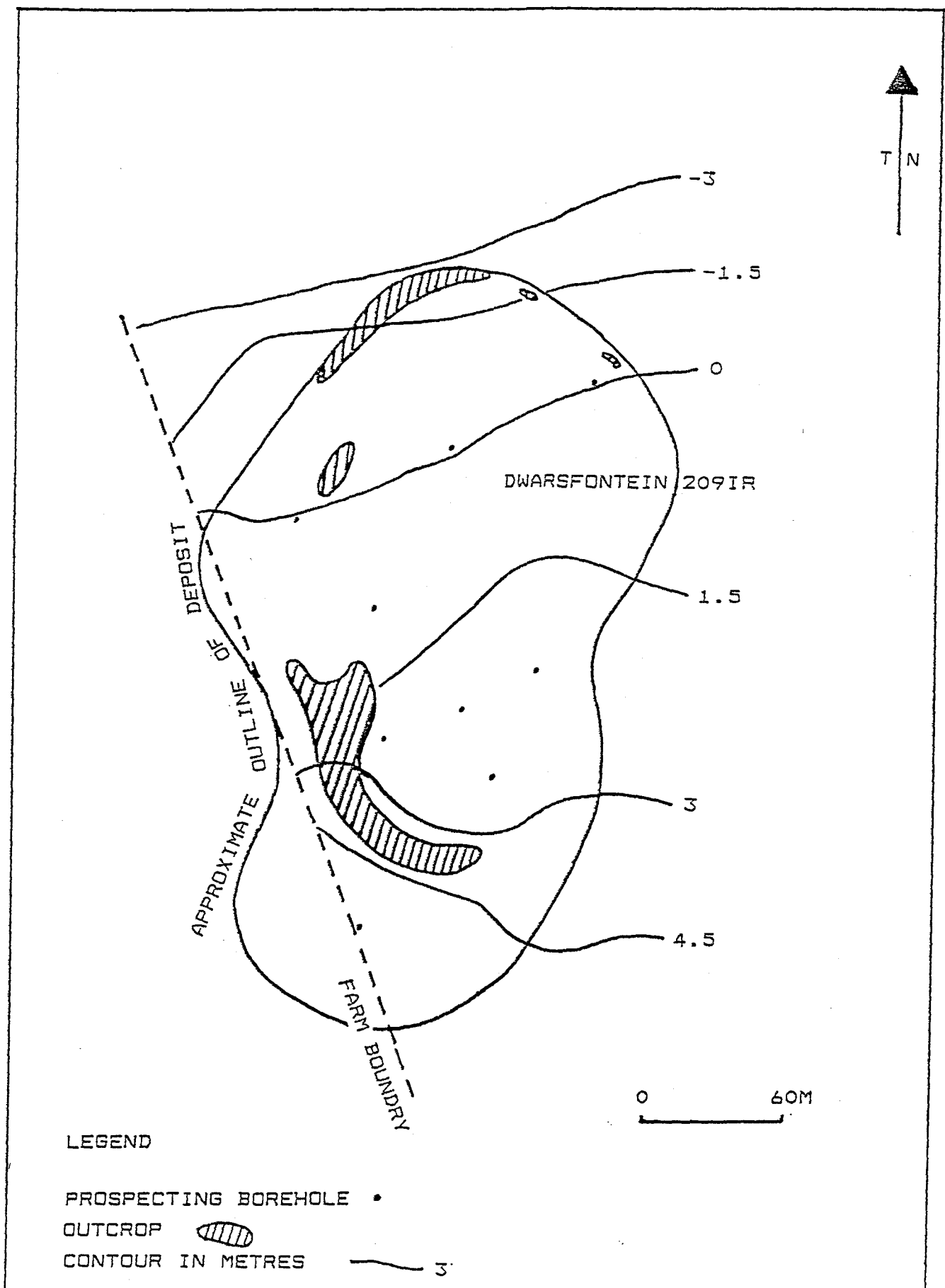


Figure 3.5. The Dwarsfontein ilmenite-rich heavy mineral deposit (modified after Behr, 1965).

BH 1				BH 2			BH 3			BH 5		
DEPTH	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.
0 - 1M	40.1	63.7	63		59.5			51.7		34.1	63.7	
1 - 2M	39.1	62.1	63		59.5			51.7		34.1	63.7	
2 - 3M	36.1	57.3	63		59.5			51.7		34.1	63.7	
3 - 4M	32.9	58.4	56.3		59.5			51.7		34.1	63.7	
4 - 5M	26.9	54.5	49.4		59.5			51.7		34.1	63.7	53.5
5 - 6M	29.9	60.5	49.4	37.5	59.5	63		51.7		19.1	65.4	29.2
6 - 7M	32	51.9	61.6	37.5	59.5	63		51.7		33	66.7	49.5
7 - 8M								51.7				
8 - 9M								51.7				
9 - 10M							32.6	51.7	63			
10 - 11M							32.6	51.7	63			
BH 6				BH 9			BH 13			BH 14		
DEPTH	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.
0 - 1M	44.3	70.3	63		50.8			58.7			56.2	
1 - 2M					50.8			58.7			56.2	
2 - 3M				32	50.8	63	37	58.7	63		56.2	
3 - 4M				32	50.8	63	37	58.7	63	35.4	56.2	63
4 - 5M										35.4	56.2	63
5 - 6M										34.8	74.4	46.8
6 - 7M										25.8	56.3	45.8
7 - 8M										25.8	56.3	45.8
8 - 9M										25.8	56.3	45.8
BH 16				<p>AVERAGE TiO2 CONTENT OF ORE MINERALS (EXCLUDING BH 16): 57.6%</p> <p>AVERAGE ORE MINERAL GRADE (EXCLUDING BH 16): 56.6%</p>								
DEPTH	% TiO2	% TiO2 ORE MIN.	% GRADE ORE MIN.									
0 - 1M												
1 - 2M												
2 - 3M												
3 - 4M												
4 - 5M												
5 - 6M												
6 - 7M	20.7											
7 - 8M	20.7											
8 - 9M	20.7											

Table 3.4. Borehole data - Dwarsfontein deposit (data modified after Behr, 1965).

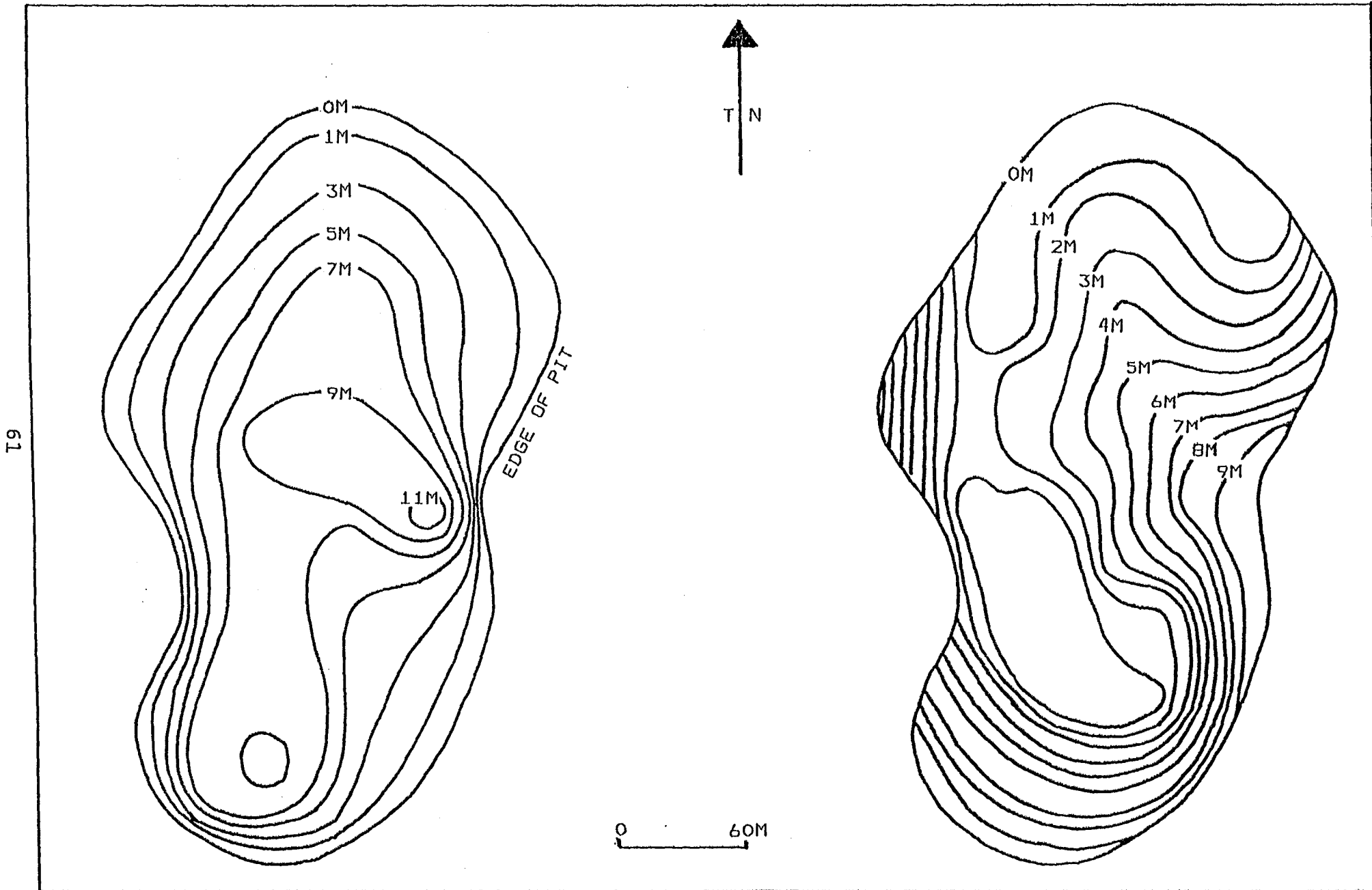


Figure 3.6. Basic design of open pit (left), and the sub-surface depth to the top of the ore body (right).

2.3. Statistical Analysis of the Borehole Data.

The titanium values of the ore minerals are represented in the form of a histogram in Figure 3.7. The small sample size of 25 and the relatively limited range of values makes it difficult to identify the population type, however it appears that a log normal population is indicated. A cumulative frequency curve of the data is also shown in Figure 3.7, and Figure 3.8 shows the data plotted as a cumulative frequency polygon on log probability paper. The straight line in Figure 3.8 indicates that the population is log normal, and a factor of 1 was introduced to improve the data (i.e. pull up the 'tail'). The data was plotted on arithmetic probability paper however a curve was obtained suggesting the population to be log normal.

The variance, mean grade estimate, and 90% confidence limits for the mean are calculated as follows:

1. Calculation of variance:

$$\sigma^2 = (\ln A - \ln B/2)^2 = 0.009 \text{ (logarithmic)} \quad (\text{A and B taken from Figure 3.7})$$

2. Estimate of mean:

$$\hat{\mu} = \text{G.M.} \times (\gamma_n(V)) - \beta = 59.9\% \quad (\text{geometric mean (G.M.) and taken from Figure 3.7).}$$

$\gamma_n(V)$ = Sichel's t estimator and read from tables.

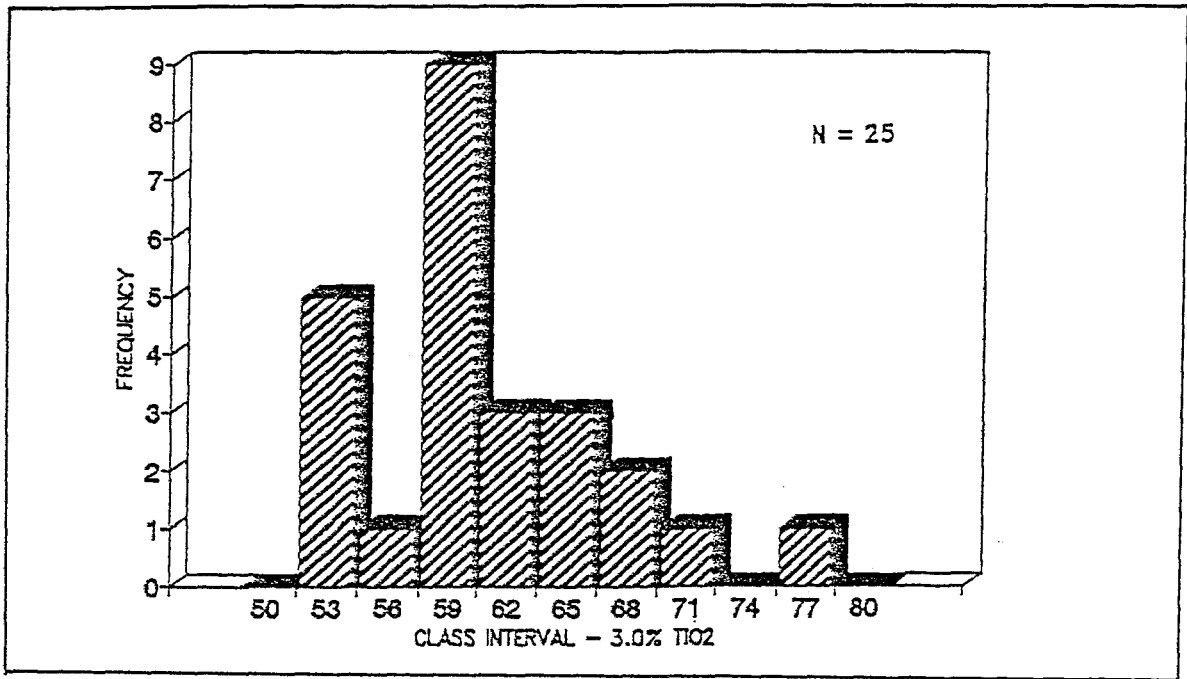
Variance of actual values

$$= (\mu + \beta)^2 \times (e^{\sigma^2} - 1) = 33.5$$

3. Application of 90% confidence limits for the mean:

$$= \mu + \beta \times \begin{cases} \text{reading from Sichel's Table} - \beta \\ \text{reading from Sichel's Table} - \beta \end{cases}$$

Therefore, $p(58.3\% < \mu < 62.0\%) = 90\%$.



CLASS INTERVAL	FREQ.	CUMULATIVE FREQUENCY	CUMULATIVE FREQUENCY %
50	0	0	0
54	5	5	20
58	7	12	48
62	6	18	72
66	4	22	88
70	1	23	92
74	1	24	96
78	1	25	100
82	0	25	100
86	0	25	100

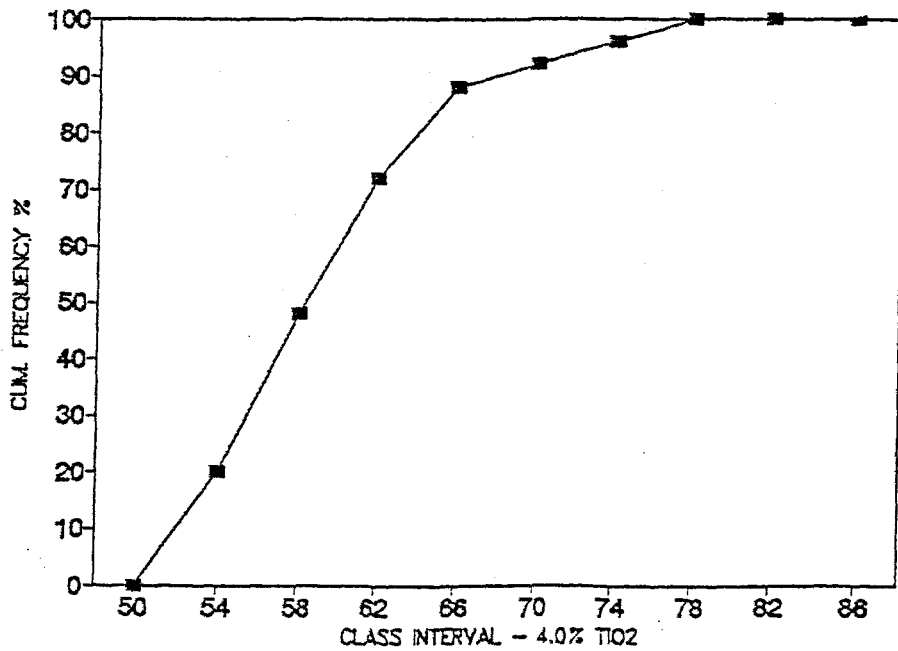


Figure 3.7. A histogram (top), and cumulative frequency curve of the Dwarsfontein borehole data.

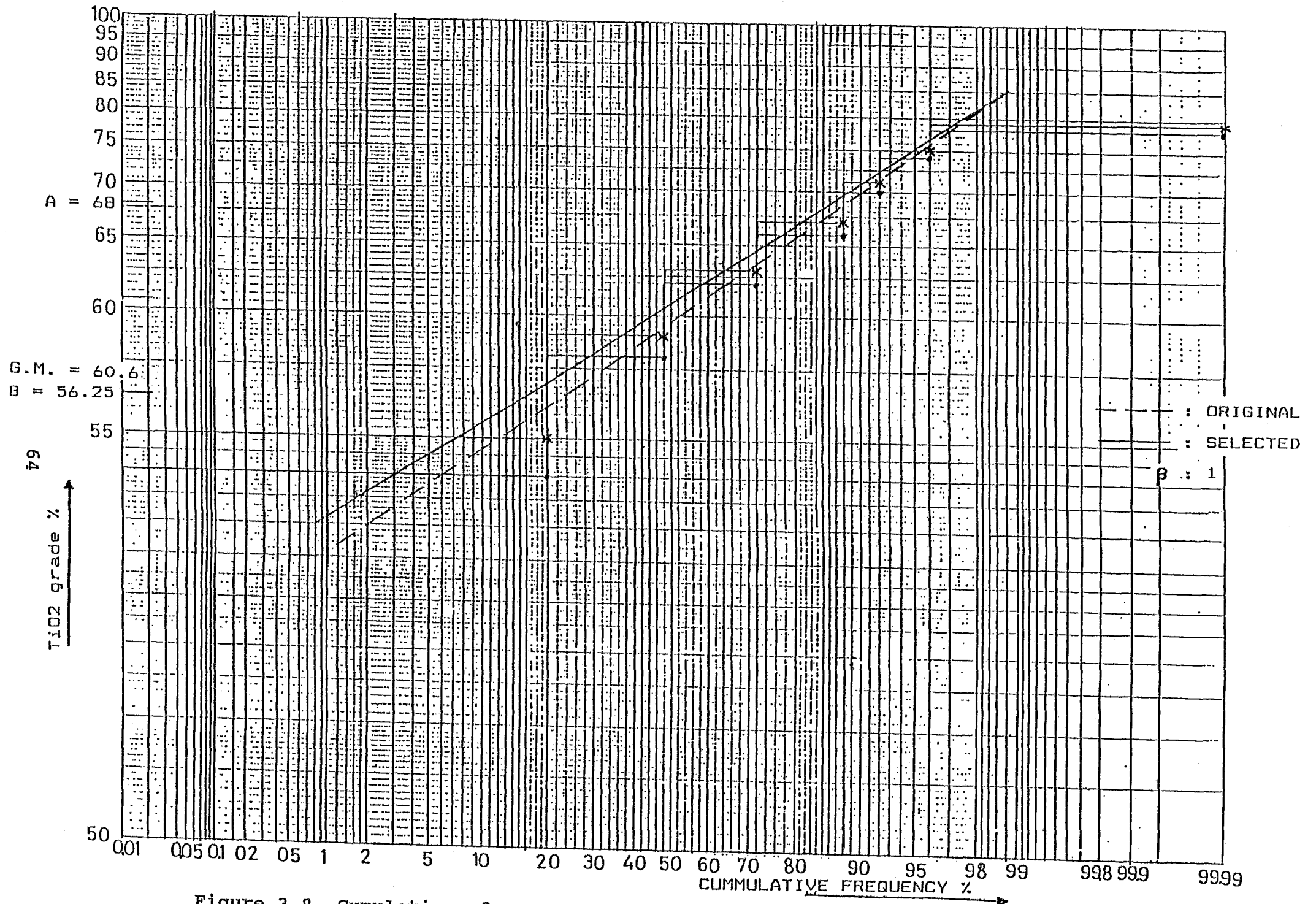


Figure 3.8. Cumulative frequency polygon describing a three parameter log normal distribution.

Note the difference between the graphically calculated and borehole data mean ore mineral TiO₂ content, and that the estimate of the mean is relatively tightly constrained between the lower and upper 90% confidence limits. The later point indicates limited variance of the data. The variance of titanium values is predominantly due to post-depositional chemical weathering. This has occurred during various stages, and has resulted in varying concentrations of titanium within the ore deposit. Therefore, had the deposit been in the order of tens of millions of tons, selective mining could have been considered, even though the available data at Dwarsfontein shows limited variance. The size of the Dwarsfontein deposit is such that all the estimated 0.42 mt of ore running at an average ore mineral TiO₂ content of 59.9% would be required to be mined.

2.4. Financial Analysis.

A financial analysis establishes whether or not bringing the project to account will result in an acceptable rate of return on investment. The analysis involves the calculation of capital expenditure required, and a series of cash flows (usually a ten year period) either in constant or real money terms. Obviously the later approach will be more accurate especially if the rate of price inflation differs from the rate of cost escalation. An internal rate of return (IRR) and total potential revenue (TPR) are calculated which provide a measure of the quality and quantity of the investment respectively.

In order to achieve the highest degree of confidence in a financial analysis it is important that a risk analysis is implemented. A risk analysis attaches a degree of risk to the variables, and will result in iterations of IRR and TPR.

For the purposes of this work a simple single analysis cash flow approach is used for the Dwarsfontein deposit, and although this method is subjective it will provide a rough idea of the viability of the deposit. It is envisaged that the deposit would be worked over a two year period by a suitably established company, thus reducing capital expenditure to a minimum.

Table 3.5 shows three cash flows using total costs of R93/t, R98/t and R103/t. The costs have been established from the following information:

1. On mine working costs; i) comparison with the working costs of two Anglo American Corporation mining ventures of similar mining rates, and; ii) inflation to present-day money terms of the on mine working cost estimate of R2/t taken from Behr (1965).
2. Transportation costs; a direct quote from Transnet.

In all cases an operating loss is indicated, however an important point to note is that if the transportation costs are excluded then an operating profit is indicated in all three cases. In addition there is no additional revenue from other heavy minerals e.g. zircon and monazite.

The financial analysis may be represented in a quick, less manner by the following:

Price received/t of ore:	1.0 x 0.6 x 0.566 x 0.9 = R45.85		
Cost/t of ore:			
On mine working costs	@ R35	@ R40	@ R45
Profit (loss):	R10.85	R5.85	R0.85
Total costs (including transportation)	R93	R98	R103
Profit (loss):	(R47.15)	(R52.15)	(R57.15)

This work indicates that for ilmenite-rich heavy mineral deposits to be viable economies of scale are required, in that the ore reserves should be extremely large. In addition the deposits should be situated close to an export harbour, thus reducing transportation costs. Figure 3.9 illustrates these points in the relationship of the variables, on mine working costs, revenue/t, and total profit, with increasing tonnage mined.

TOTAL TONS MILLED (MT):	0.21		
MILL HEAD GRADE (%): ORE MINERAL Tio2 CONTENT	59.9		
% RECOVERY (-80+200 MESH) (MT): (-175+75 um) % RECOVERY GRADE: 60% THEREFORE INITIAL RECOVERY= 0.126 MT ORE MINERAL GRADE: 56.6% LOSSES: 10% THEREFORE ORE MINERAL RECOVERY	0.064		
METAL PRICE (R/T): ILMENITE CONCENTRATE	150		
SALES REVENUE (MR):	9.6	9.6	9.6
ON MINE WORKING COSTS (R/T): MINING, MILLING CONCENTRATION, ADMIN.	@ 35 7.35	@ 40 8.4	@ 45 9.5
TRANSPORTATION COSTS (R/T):	58 12.2	58 12.2	58 12.2
TOTAL COSTS:	19.6	20.6	21.7
OPERATING PROFIT (LOSS) (MR):	(10)	(11)	(12.1)

Table 3.5. Single analysis cash flows - Dwarsfontein.

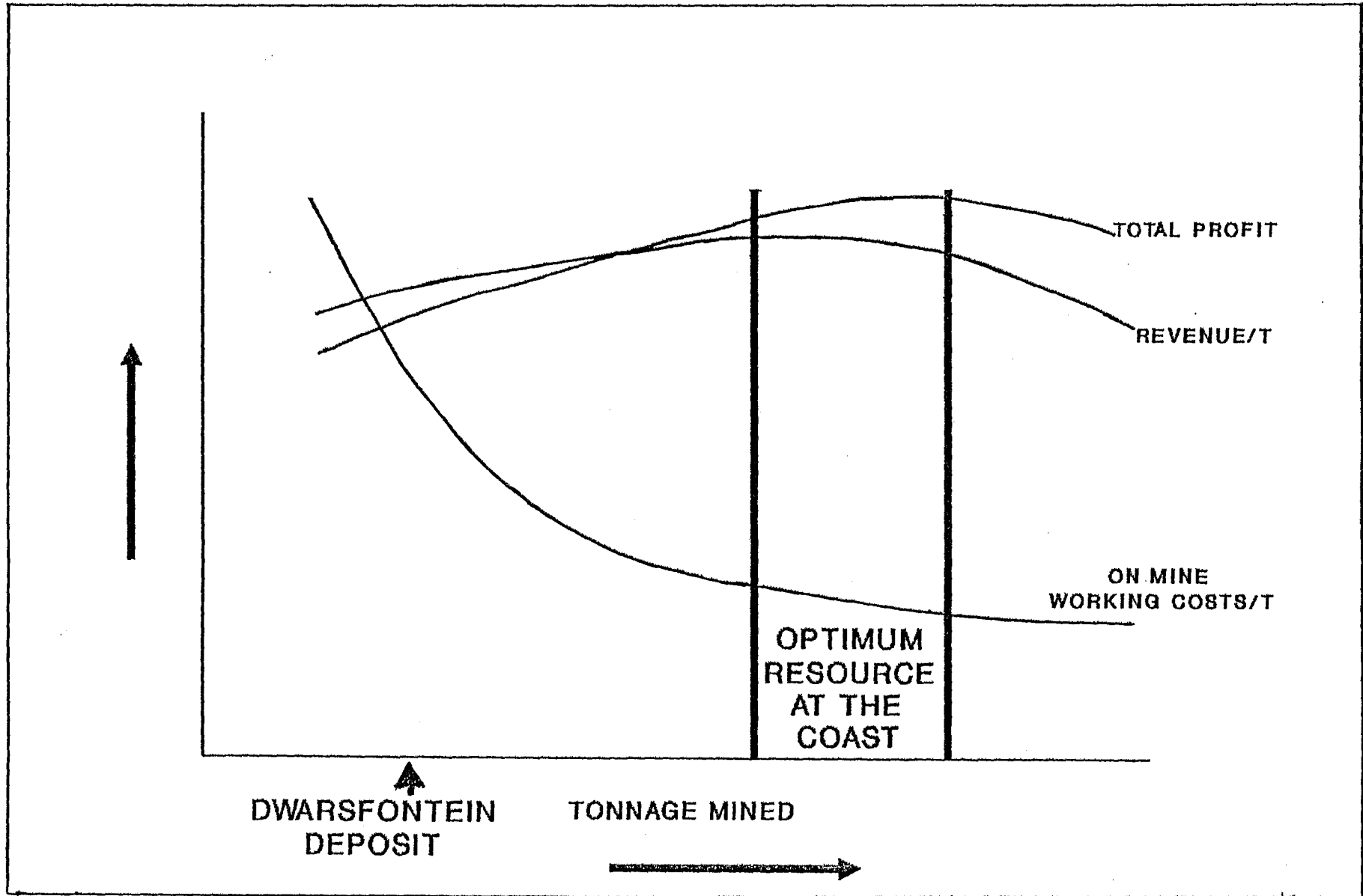


Figure 3.9. An optimisation graph showing the position of the Dwarsfontein deposit, and an optimum coastal located heavy mineral resource.

CONCLUSIONS.

A number of ilmenite-rich heavy mineral deposits occur along the northern margin of the main Karoo basin, and are hosted by the sediments of the Vryheid Formation. The genesis of these deposits is inextricably linked to the Carboniferous to Early Permian temperate valley-type glaciation, and Early to Mid-Permian fluvio-deltaic Eccla systems which occurred in this region.

The proto-ore of the ilmenites in the heavy mineral deposits is considered in part to be; i) ilmenite bearing reworked glacial deposits along the northern margin of the Karoo basin, and; ii) pre-Karoo rocks which were eroded by southward flowing fluvial systems of the Northern Eccla Facies. A depositional model for these deposits is coastal reworking of delta front sands in a beach foreshore environment, by storm and longshore drift processes, within a regressive microtidal shoreline.

The use of ilmenite mineral chemistry as a provenance indicator for ilmenites from the Delmas heavy mineral deposits provided the following important conclusions with regard to the data used:

1. The mineralogy and crystallisation of ilmenites from different magma types provides enough mineral element variance to be useful for provenance studies.
2. The BIC mafic phase, and possibly the alkaline complexes of the PRAC, most likely contributed ilmenites to these deposits.
3. A south to south-easterly transport direction for the glacial/fluvial systems of the lower portion of the Karoo Supergroup is supported.

An economic analysis of titanium suggests that the demand for this commodity will remain positive in the long term due to; i) increasing demand for TiO₂ pigment, the so called 'quality of life' product, and; ii) increasing usage of titanium metal and alloys in the aircraft industry, and the medical and engineering sectors. Therefore, although titanium resources are great, the exploration for this commodity remains an economically viable target.

An economic evaluation of the Dwarsfontein deposit, using limited borehole data, and with the saleable revenue being ilmenite concentrate concludes that;

- i) the location of the deposit (+- 600 km from Richards Bay), and;
- ii) the small size of the deposit (0.42 mt of titanium ore)

is such that bringing the deposit to account would not be a viable proposition at all. However, an important point to note is that the deposit does show an operating profit if transport costs are excluded. Therefore, economically viable heavy mineral deposits where the saleable product is ilmenite concentrate, would have to be located close to an upgrading plant or export harbour.

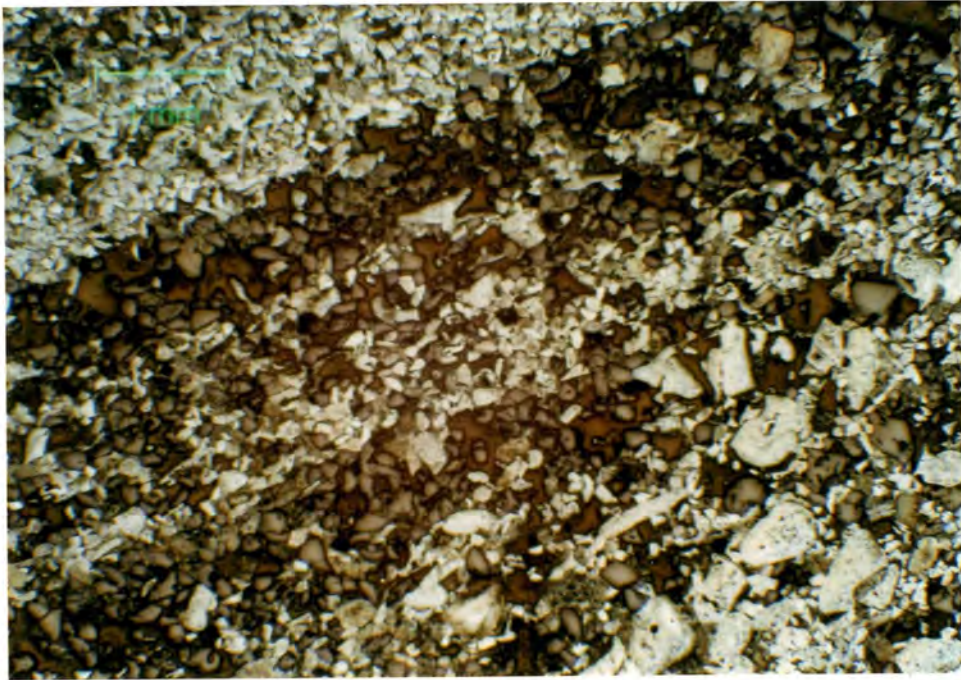


Plate 1. Grain size distribution (well sorted top left, poorly sorted bottom right), and light (dark quartz) and dark (light ilmenite) laminations. Reflected light, plane polarised.

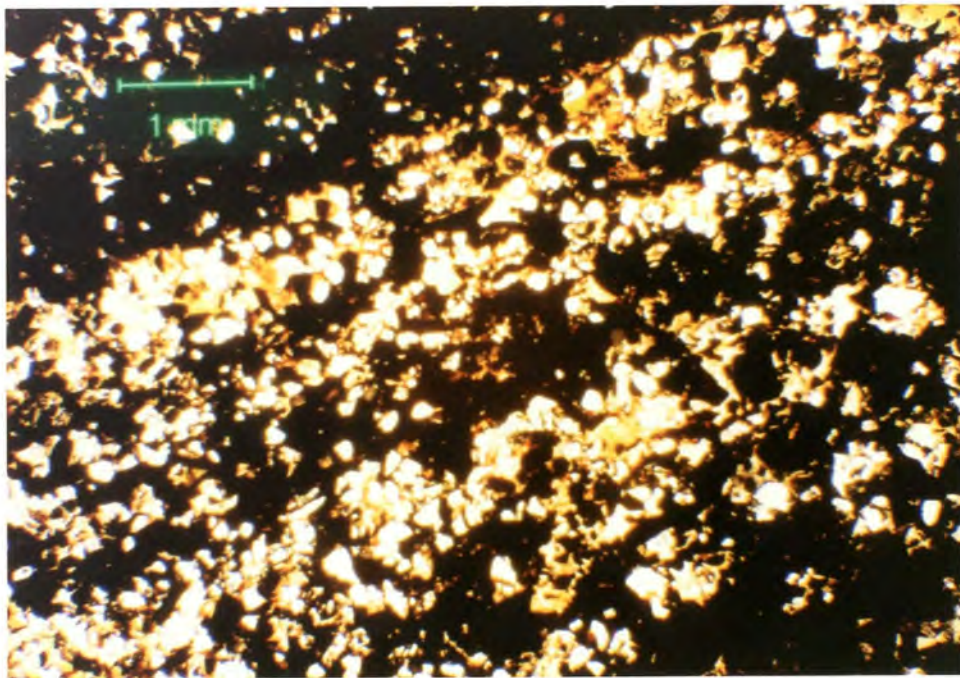


Plate 2. Same as Plate 1, dark bands comprise predominantly ilmenite and goethite cement. Transmitted light, plane polarised.



Plate 3. Plate shows the relatively poorly sorted nature of the grains. The large quartz grain (Q) is nearly 3mm along its long axis.
Reflected light, plane polarised.

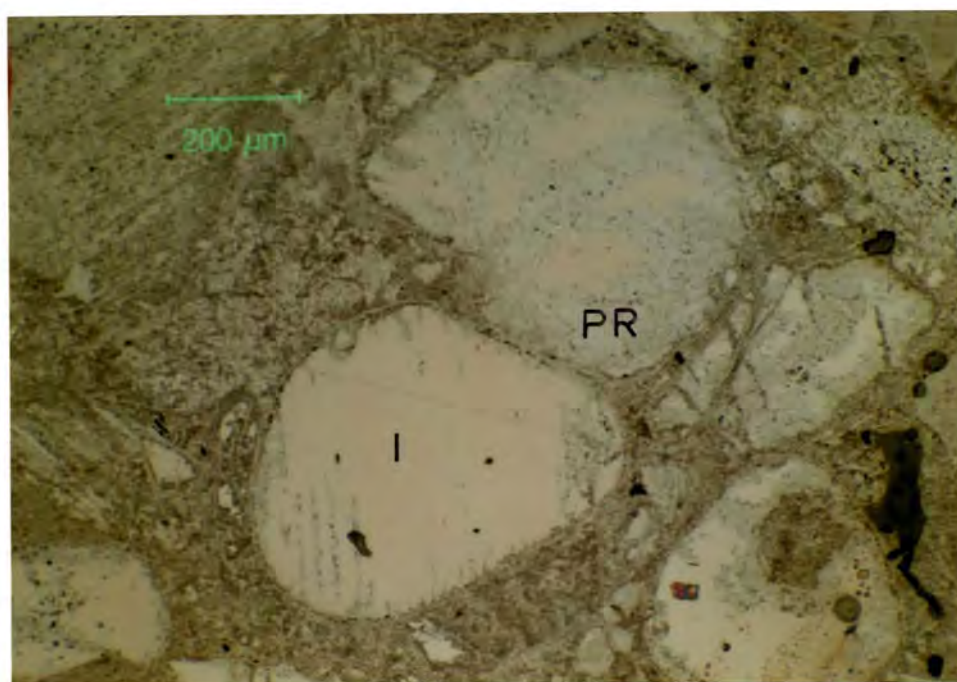


Plate 4. Ilmenite (I) altering to pseudorutile (PR). Note the preferential alteration along a fixed direction in the lower grain. These were probably either; i) haematite exsolution lamellae in the original ilmenite which preferentially altered due to the high Fe content by the rxn. $\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O} \rightarrow 2\text{Fe}(\text{OH})_3$, therefore the lamellae had a control on the initial alteration of ilmenite, or; ii) the alteration is directed parallel to the basal (0001) crystallographic plane, and this basal cleavage exercised a controlling influence on the initial alteration of the ilmenite.
Reflected light, plane polarised.

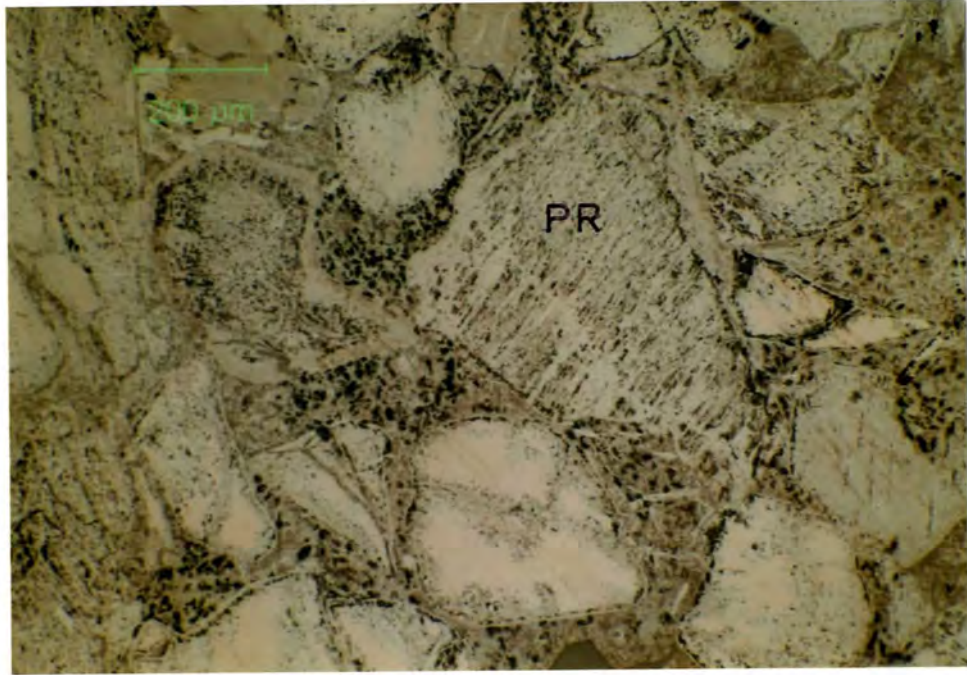


Plate 5. Exsolution lamellae in pseudorutile (PR).
Reflected light, plane polarised.

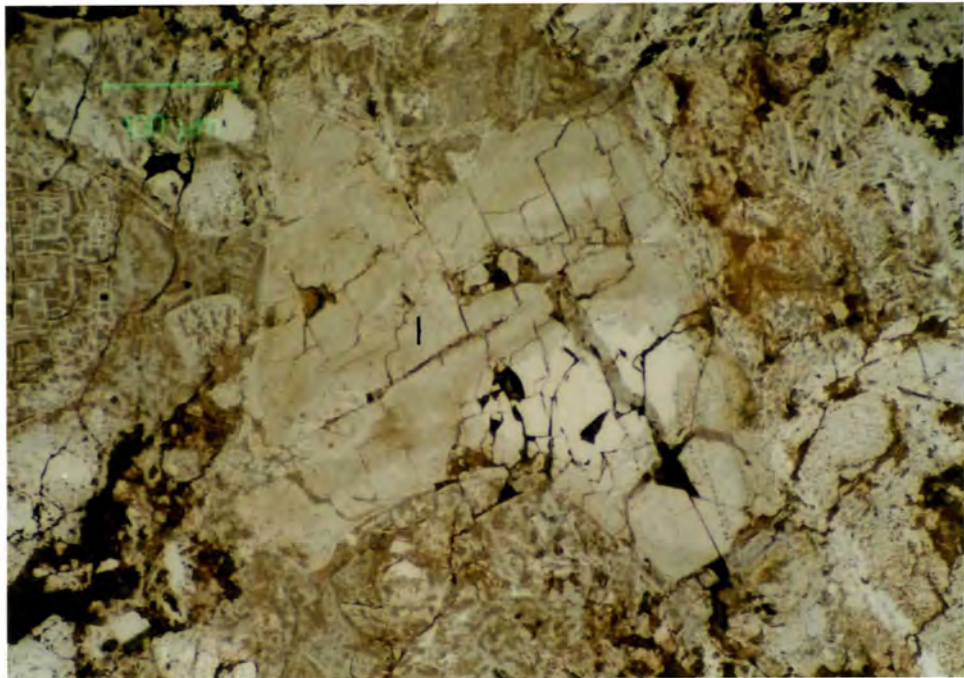


Plate 6. Shrinkage cracks within an altering ilmenite.
Reflected light, plane polarised.



Plate 7. Ilmenite (I) within an alteration corona, which shows alteration from leached ilmenite to leucoxene (L). The leucoxene occurs as a very thin mantle. Reflected light, plane polarised.



Plate 8. An altered ilmenite - leached ilmenite (LI) with a leached pseudorutile (LPR) centre, and a leucoxene (L) mantle. Reflected light, plane polarised.

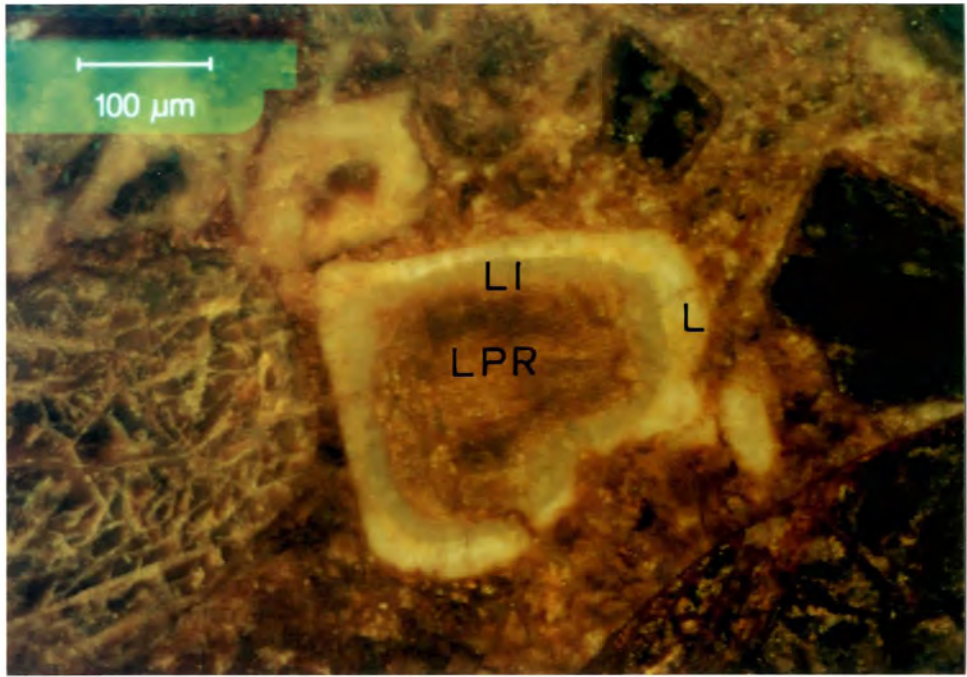


Plate 9. Same as Plate 8.
Reflected light, cross polars.

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APPENDIX.

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

CHEMISTRY WT %	MN	AL	FE	SI	TI	CA	CR	MG	TOTAL
ILMENITE DISTRIBUTION									
DWARSFONTEIN DEPOSIT	0.60	0.11	49.53	0.00	48.45	0.00	0.04	0.36	99.09
	0.28	0.16	45.96	0.00	49.81	0.00	0.23	2.86	99.30
	0.74	0.04	49.14	0.00	48.82	0.01	0.09	0.51	99.35
	0.43	0.04	42.92	0.00	53.91	0.02	0.43	2.83	100.58
	0.53	0.12	48.10	0.00	48.78	0.00	0.13	0.94	98.60
	0.87	0.29	49.50	0.12	45.27	0.03	0.70	0.53	97.31
	0.37	0.13	42.39	0.00	51.33	0.02	0.07	4.22	98.59
	0.65	0.19	46.62	0.00	48.01	0.03	0.13	0.45	99.28
	0.53	0.11	48.21	0.00	47.99	0.00	0.15	1.07	98.06
	0.30	0.05	43.65	0.00	49.14	0.01	0.80	4.61	98.56
	0.48	0.00	48.03	0.00	48.05	0.00	0.08	1.09	97.73
	0.51	0.24	48.90	0.00	49.57	0.00	0.09	0.39	99.70
	0.71	0.07	49.70	0.00	48.72	0.00	0.11	0.25	99.56
	0.55	0.08	49.97	0.00	46.25	0.02	0.89	0.94	98.70
	1.51	0.27	33.57	0.11	59.54	0.02	0.52	0.87	96.41
	0.48	0.17	46.66	0.00	48.63	0.00	0.16	2.08	98.18
	0.40	0.25	43.68	0.00	51.51	0.00	0.09	4.39	100.32
	0.47	0.20	44.22	0.00	50.45	0.00	1.15	3.21	99.70
	0.58	0.09	49.00	0.00	48.24	0.00	0.10	0.58	98.59
	0.73	0.12	49.39	0.00	48.99	0.03	0.06	0.34	99.66
	0.51	0.10	49.09	0.00	49.54	0.00	0.12	0.54	99.90
	0.51	0.22	48.39	0.00	47.49	0.02	0.12	1.03	97.78
	0.67	0.15	48.83	0.00	49.61	0.01	0.11	0.38	99.76
	0.39	0.03	47.01	0.00	48.65	0.02	0.90	1.86	98.86
	0.73	0.06	48.01	0.00	49.62	0.03	0.07	0.39	98.91
	1.51	0.03	48.12	0.00	47.62	0.00	1.10	0.32	98.90
	0.73	0.07	47.14	0.00	48.93	0.00	1.12	1.29	99.28
	0.79	0.04	48.48	0.00	49.13	0.01	0.12	0.47	99.04
	0.63	0.07	48.46	0.00	48.89	0.00	0.09	0.15	98.08
	0.40	0.23	42.21	0.00	50.89	0.00	1.38	5.00	100.11
	0.69	0.01	45.93	0.00	51.41	0.00	0.94	1.21	100.19
	0.49	0.20	51.03	0.00	45.75	0.00	0.11	0.51	98.09
	0.43	0.06	48.67	0.00	45.51	0.01	1.30	1.39	97.37
	0.52	0.09	48.30	0.00	48.65	0.02	0.11	0.84	98.53
	0.64	0.06	48.76	0.00	48.60	0.00	0.03	0.38	98.47
	0.65	0.17	48.80	0.00	48.61	0.00	0.07	0.49	98.79
	0.60	0.01	48.47	0.00	48.03	0.01	0.11	0.40	97.63
	0.69	0.03	49.46	0.00	47.01	0.00	0.10	0.27	97.56
	0.32	0.03	47.72	0.00	46.04	0.00	1.12	2.30	97.53
	0.47	0.10	47.90	0.00	49.26	0.02	0.09	0.95	98.79
	0.70	0.17	45.84	0.00	49.34	0.00	0.11	2.17	98.33
	0.78	0.00	49.32	0.00	48.22	0.04	0.05	0.15	98.56
	0.55	0.00	48.19	0.00	49.53	0.02	0.11	0.86	99.26
	0.66	0.09	49.28	0.00	48.44	0.02	0.11	0.34	98.94
	0.51	0.05	48.76	0.00	48.75	0.01	0.30	0.92	99.30
	0.63	0.01	47.59	0.00	49.87	0.00	0.11	0.77	98.98
	1.14	0.07	48.31	0.00	48.31	0.00	0.73	0.87	99.43
	0.47	0.10	50.30	0.00	46.85	0.00	0.38	1.19	99.29

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.64	0.11	49.19	0.00	49.01	0.00	0.07	0.43	99.45
0.65	0.08	45.32	0.00	50.97	0.00	1.54	2.27	100.83
0.74	0.09	48.29	0.00	49.25	0.00	0.09	0.38	98.84
0.38	0.04	47.70	0.00	47.09	0.03	0.87	1.59	97.70
0.81	0.10	49.21	0.00	48.40	0.00	0.07	0.23	98.82
0.50	0.12	51.65	0.00	45.00	0.02	0.09	0.49	97.87
0.56	0.00	49.76	0.00	46.36	0.00	0.63	1.21	98.52
0.42	0.09	47.58	0.00	50.98	0.00	0.12	1.56	100.75
0.37	0.15	47.00	0.00	49.35	0.01	0.10	2.33	99.31
0.77	0.05	50.21	0.00	47.93	0.01	0.11	0.11	99.19
0.76	0.07	49.50	0.00	46.52	0.01	0.10	0.40	97.36
0.83	0.05	49.13	0.00	48.50	0.00	0.10	0.25	98.86
0.56	0.05	46.73	0.00	48.52	0.02	0.07	0.88	98.83
0.41	0.10	47.78	0.00	48.16	0.00	1.29	2.36	100.10
0.47	0.07	45.24	0.00	51.16	0.00	0.37	1.13	98.44
0.87	0.09	48.65	0.00	46.67	0.00	1.08	1.17	98.53
0.71	0.10	48.80	0.00	49.47	0.01	0.11	0.34	99.54
0.56	0.03	48.85	0.00	48.34	0.01	0.19	0.49	98.47
0.42	0.05	45.03	0.00	47.15	0.01	1.80	2.35	96.81
0.74	0.19	49.00	0.00	48.89	0.00	0.06	0.30	99.18
0.62	0.11	48.88	0.00	48.30	0.02	0.09	0.62	98.64
0.45	0.09	49.27	0.00	46.24	0.00	0.74	1.67	98.46
0.80	0.12	49.37	0.00	48.10	0.02	0.14	0.13	98.68
0.61	0.19	49.05	0.00	49.20	0.02	0.07	0.28	99.42
0.65	0.07	47.69	0.00	48.25	0.01	0.62	1.64	98.93
0.62	0.13	49.17	0.00	48.79	0.00	0.07	0.40	99.18
0.57	0.03	49.63	0.00	45.03	0.04	0.77	1.34	97.41
0.51	0.17	48.64	0.00	48.59	0.00	0.11	0.79	98.81
0.47	0.05	48.25	0.00	48.99	0.02	0.19	1.14	99.11
0.68	0.03	46.33	0.00	49.98	0.02	0.79	0.67	98.50
0.59	0.07	48.93	0.00	48.51	0.01	0.16	0.28	98.55
0.69	0.16	48.89	0.00	49.11	0.00	0.12	0.60	99.57
0.54	0.07	49.22	0.00	47.61	0.01	0.14	0.55	98.14
0.42	0.08	47.22	0.00	48.68	0.01	1.24	1.77	99.42
0.40	0.14	49.34	0.00	48.02	0.00	0.06	1.09	99.05
0.56	0.05	49.10	0.00	48.34	0.00	0.09	0.64	98.78
0.39	0.14	44.44	0.00	50.26	0.02	0.13	3.58	98.96
0.78	0.07	48.17	0.00	49.02	0.00	0.10	0.45	98.59
0.36	0.19	44.75	0.00	50.57	0.00	0.12	3.66	99.65
0.59	0.05	49.49	0.00	48.37	0.00	0.09	0.49	99.08
0.59	0.11	48.61	0.00	48.89	0.01	0.12	0.36	98.69
0.36	0.04	42.93	0.00	50.00	0.00	1.38	3.32	98.03
0.78	0.15	49.90	0.00	46.47	0.00	0.88	0.77	98.95
0.61	0.06	47.74	0.00	48.88	0.00	0.11	0.86	98.26
0.58	0.13	47.48	0.00	49.73	0.00	0.07	1.01	99.00
0.78	0.07	48.56	0.00	48.14	0.01	0.04	0.34	97.94
0.70	0.04	48.92	0.00	47.86	0.00	0.12	0.40	98.04
0.67	0.18	49.14	0.00	48.36	0.02	0.12	0.28	98.77
0.76	0.14	48.78	0.00	49.07	0.00	0.04	0.32	99.11
0.69	0.12	51.12	0.00	45.42	0.02	0.12	0.25	97.74
0.31	0.17	45.10	0.00	49.44	0.00	0.17	3.12	98.31
0.42	0.03	49.13	0.00	45.06	0.00	1.46	1.75	97.85
0.77	0.05	49.40	0.00	48.19	0.02	0.12	0.34	98.89
0.80	0.15	49.99	0.00	47.53	0.04	0.06	0.23	98.80
0.46	0.12	47.33	0.00	48.61	0.01	0.23	2.52	99.28
0.67	0.05	49.25	0.00	46.99	0.00	0.11	0.75	97.82

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.48	0.13	46.74	0.00	49.39	0.00	0.09	2.13	98.96
0.39	0.02	44.39	0.00	51.55	0.00	0.65	3.27	100.27
0.77	0.07	48.75	0.00	48.45	0.00	0.11	0.32	98.49
0.77	0.04	46.60	0.00	50.06	0.02	1.58	1.71	100.78
0.47	0.03	44.71	0.00	52.99	0.01	0.67	1.42	100.30
0.75	0.09	48.76	0.00	49.67	0.01	0.07	0.24	99.59
0.50	0.07	45.77	0.00	48.65	0.00	1.13	2.26	98.38
0.72	0.05	48.57	0.00	48.73	0.02	0.08	0.56	98.73
0.55	0.02	45.42	0.00	51.10	0.02	0.47	0.87	98.45
0.35	0.11	47.38	0.00	49.51	0.00	0.43	1.69	99.47
0.44	0.04	49.82	0.00	47.24	0.00	0.27	1.02	98.83
0.66	0.01	49.47	0.00	46.01	0.03	1.45	1.24	98.87
0.40	0.11	49.23	0.00	48.37	0.00	0.14	0.73	98.98
0.73	0.07	49.33	0.00	47.53	0.00	0.08	0.85	98.59
0.62	0.07	49.23	0.00	48.26	0.00	0.10	0.49	98.77
0.64	0.12	49.98	0.00	47.53	0.00	0.12	0.60	98.99
0.45	0.07	48.46	0.00	46.87	0.00	1.37	1.46	98.68
0.53	0.06	50.26	0.00	46.46	0.00	0.11	0.81	98.23
1.35	0.03	49.18	0.00	47.12	0.01	0.63	0.45	98.77
0.58	0.19	49.21	0.00	47.93	0.00	0.10	0.68	98.69
0.82	0.05	48.82	0.00	45.31	0.01	1.45	1.78	98.24
0.44	0.13	44.25	0.00	50.36	0.02	0.15	4.06	99.41
0.88	0.05	49.64	0.00	47.19	0.00	0.11	0.28	98.15
0.68	0.07	49.05	0.00	48.61	0.01	0.09	0.25	98.76
0.45	0.16	49.18	0.00	47.39	0.00	0.08	1.16	98.42
0.67	0.09	48.49	0.00	49.52	0.00	0.07	0.79	99.63
0.95	0.08	49.91	0.00	47.64	0.02	0.13	0.40	99.13
0.85	0.09	50.22	0.00	46.64	0.02	0.57	0.57	98.96
0.41	0.06	42.80	0.00	50.82	0.02	0.08	4.60	98.79
0.51	0.03	50.42	0.00	45.07	0.02	1.25	1.27	98.57
0.42	0.03	47.03	0.00	48.73	0.00	1.54	1.36	99.11
0.53	0.09	48.38	0.00	48.42	0.01	0.08	0.71	98.22
0.71	0.13	49.43	0.00	48.58	0.00	0.14	0.19	99.18
0.53	0.08	50.32	0.00	47.95	0.00	0.11	0.62	99.61
0.69	0.00	47.75	0.00	48.88	0.00	0.59	0.92	98.83
0.76	0.04	48.97	0.00	50.30	0.01	0.06	0.60	100.74
0.75	0.12	49.57	0.00	47.97	0.01	0.09	0.40	98.91
0.74	0.15	48.92	0.00	48.91	0.00	0.10	0.49	99.31
0.69	0.08	49.92	0.00	48.01	0.00	0.08	0.40	99.18
0.41	0.04	48.70	0.00	46.73	0.03	1.14	1.70	98.75
0.58	0.04	49.58	0.00	47.12	0.01	0.06	0.42	97.81
0.39	0.07	48.98	0.00	45.03	0.01	1.45	1.69	97.62
0.89	0.02	51.12	0.00	43.15	0.01	0.93	0.51	98.63
0.81	0.12	48.08	0.00	49.11	0.00	0.10	0.53	98.75
0.41	0.06	48.61	0.00	45.91	0.00	1.31	1.67	97.97
0.53	0.10	49.24	0.00	47.93	0.00	0.07	0.64	98.51
0.47	0.00	46.90	0.00	47.40	0.00	1.70	1.90	98.37
1.16	0.07	49.62	0.00	45.81	0.04	1.15	0.79	98.64
0.85	0.05	45.32	0.00	49.09	0.00	1.53	1.89	98.73
0.38	0.09	46.05	0.00	49.79	0.00	0.12	2.25	98.68
0.77	0.11	50.95	0.00	46.28	0.00	0.07	0.25	98.43
0.74	0.10	48.02	0.00	49.82	0.00	0.07	0.62	99.37
0.36	0.13	46.00	0.00	50.83	0.01	0.07	2.30	99.70
0.67	0.26	48.16	0.00	46.35	0.02	0.13	0.60	98.19
1.14	0.05	48.02	0.00	47.99	0.01	0.56	0.88	98.65
0.70	0.13	49.97	0.00	48.34	0.00	0.09	0.47	99.70

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.71	0.30	49.14	0.00	48.41	0.00	0.08	0.43	99.07
0.78	0.07	49.48	0.00	47.30	0.00	0.13	0.36	98.12
0.58	0.10	49.60	0.00	48.11	0.00	0.08	0.30	98.77
0.61	0.11	48.81	0.00	49.07	0.02	0.12	0.24	98.98
0.43	0.03	48.53	0.00	47.59	0.00	0.08	1.11	97.77
0.57	0.11	50.12	0.00	45.65	0.00	0.96	0.76	98.17
0.82	0.08	48.85	0.00	47.55	0.01	0.07	0.17	97.55
0.60	0.02	48.31	0.00	47.96	0.00	0.41	1.38	98.68
0.41	0.02	48.90	0.00	46.41	0.00	0.45	1.07	97.26
0.63	0.17	48.04	0.00	50.23	0.00	0.08	0.39	99.54
0.36	0.04	47.56	0.00	48.01	0.00	1.02	1.81	98.80
0.58	0.13	38.34	0.00	55.86	0.00	0.49	1.08	96.48
0.57	0.09	47.10	0.00	49.48	0.00	0.08	1.15	98.47
0.57	0.04	47.79	0.00	49.11	0.00	0.08	0.80	98.39
0.39	0.18	43.96	0.00	52.16	0.01	0.09	3.33	100.12
0.57	0.02	49.57	0.00	47.66	0.00	0.14	0.28	98.24
0.67	0.05	48.78	0.01	44.15	0.03	1.30	1.62	96.61
0.48	0.06	43.03	0.00	54.63	0.04	0.60	1.72	100.56
0.57	0.03	48.44	0.00	48.69	0.03	0.09	0.36	98.21
0.42	0.14	43.34	0.00	51.42	0.00	0.05	2.69	98.06
0.55	0.07	47.17	0.00	48.52	0.02	0.08	0.90	97.31
0.58	0.08	47.73	0.00	47.85	0.00	0.09	0.99	97.32
0.77	0.23	38.06	0.00	56.15	0.03	0.47	1.08	96.79
0.34	0.03	47.91	0.00	47.04	0.01	0.86	2.50	98.69
0.61	0.09	48.95	0.00	49.49	0.02	0.08	0.45	99.69
0.56	0.02	50.19	0.00	46.14	0.03	0.41	1.18	98.53
0.73	0.08	48.95	0.00	47.60	0.03	0.41	1.56	99.36
0.43	0.15	45.02	0.00	47.97	0.00	0.71	4.35	98.63
0.89	0.11	50.62	0.00	46.41	0.00	0.14	0.17	98.34
0.57	0.06	48.92	0.00	48.22	0.02	0.69	0.73	99.21
0.65	0.08	48.96	0.00	48.36	0.03	0.11	0.30	98.49
0.66	0.07	48.68	0.00	48.23	0.00	0.85	0.91	99.40
0.64	0.15	49.86	0.00	48.57	0.00	0.12	0.34	99.68
0.72	0.05	49.54	0.00	47.62	0.00	0.11	0.34	98.38
0.77	0.09	48.74	0.00	48.04	0.00	0.63	0.86	99.13
0.31	0.13	43.98	0.00	49.08	0.00	0.53	3.56	97.59
0.54	0.00	44.18	0.00	53.99	0.01	0.56	1.78	101.06
0.90	0.03	49.49	0.00	46.18	0.00	0.04	0.44	97.08
0.49	0.09	49.63	0.00	47.86	0.00	0.12	0.38	98.57
0.33	0.11	44.79	0.00	48.96	0.00	1.39	2.95	98.53
0.52	0.05	50.46	0.00	47.16	0.00	0.09	0.34	98.62
0.60	0.08	50.30	0.00	47.10	0.01	0.07	0.30	98.46
0.42	0.00	46.07	0.00	48.29	0.00	1.33	1.69	97.80
0.68	0.10	49.03	0.00	47.78	0.00	0.09	0.25	97.93
0.56	0.02	43.93	0.00	52.10	0.00	0.66	1.24	98.51
0.78	0.17	48.51	0.00	48.79	0.02	0.10	0.19	98.56
0.69	0.09	48.92	0.00	49.25	0.02	0.07	0.28	99.32
0.37	0.10	45.94	0.00	48.21	0.02	1.13	2.94	98.71
0.49	0.08	49.32	0.00	48.62	0.01	0.09	0.95	99.46
0.82	0.06	46.12	0.00	47.75	0.00	1.21	1.97	97.93
0.99	0.12	49.36	0.00	49.00	0.01	0.04	0.32	99.84
0.50	0.07	46.51	0.00	46.71	0.00	1.75	2.51	98.05
0.65	0.04	50.65	0.00	46.32	0.00	0.06	0.53	98.25
0.36	0.14	48.72	0.00	46.96	0.02	0.39	1.95	98.54
0.48	0.04	49.42	0.00	48.26	0.00	0.13	1.17	99.50
0.77	0.17	49.50	0.00	48.16	0.01	0.11	0.08	98.80

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.73	0.09	47.45	0.00	46.74	0.00	1.34	1.69	98.04
0.50	0.03	48.21	0.00	50.05	0.02	0.08	0.75	99.64
0.33	0.12	46.07	0.00	49.50	0.00	1.34	3.08	100.44
0.42	0.04	49.31	0.00	48.36	0.00	0.11	0.85	99.09
0.38	0.15	44.69	0.00	48.29	0.03	1.12	4.45	99.11
0.30	0.14	47.42	0.00	48.70	0.00	0.21	2.67	99.44
0.49	0.11	47.43	0.00	49.71	0.01	0.08	2.41	100.24
0.39	0.04	47.62	0.00	48.61	0.01	0.73	1.75	99.15
0.68	0.11	50.16	0.00	47.94	0.02	0.07	0.28	99.26
0.72	0.08	48.57	0.00	49.38	0.02	0.11	0.34	99.22
0.51	0.04	48.18	0.00	48.07	0.02	0.90	1.44	99.16
0.51	0.06	48.12	0.00	48.86	0.03	0.08	1.05	98.71
0.57	0.13	48.66	0.00	49.51	0.03	0.09	0.53	99.52
0.49	0.17	49.68	0.00	46.74	0.00	0.08	1.11	98.27
0.68	0.14	49.61	0.00	48.24	0.00	0.11	0.32	99.10
0.32	0.17	42.11	0.00	51.68	0.02	0.08	5.11	99.49
0.43	0.16	48.75	0.00	47.21	0.02	0.08	2.17	98.82
0.70	0.07	49.64	0.00	49.45	0.02	0.06	0.45	100.39
0.94	0.05	49.28	0.00	49.49	0.01	0.05	0.34	100.16
0.46	0.03	46.26	0.00	49.05	0.00	1.69	2.37	99.88
0.41	0.27	46.96	0.00	48.36	0.03	1.21	2.21	99.45
0.62	0.04	47.11	0.00	49.90	0.02	0.66	2.02	100.37
0.45	0.07	44.78	0.00	50.32	0.00	1.11	2.77	99.50
0.54	0.12	49.02	0.00	49.78	0.00	0.11	0.36	99.93
0.76	0.09	49.31	0.00	48.62	0.01	0.11	0.41	99.31
0.50	0.15	43.39	0.00	49.51	0.00	1.45	4.41	99.41
0.56	0.00	49.47	0.00	48.01	0.00	0.09	0.64	98.77
0.88	0.09	50.93	0.00	45.97	0.02	0.08	0.34	98.31
0.46	0.16	51.08	0.00	46.45	0.02	0.08	0.10	98.35
0.59	0.16	50.21	0.00	47.63	0.01	0.12	0.32	99.04
0.62	0.09	48.81	0.00	48.48	0.00	0.09	0.47	98.56
0.73	0.08	51.27	0.00	47.35	0.01	0.08	0.30	99.82
0.69	0.06	49.89	0.00	46.90	0.02	0.11	0.32	97.99
0.68	0.05	49.51	0.00	48.78	0.02	0.12	0.30	99.46
0.50	0.07	44.57	0.00	50.79	0.00	1.57	4.00	101.50
0.46	0.12	48.32	0.00	49.07	0.00	0.10	1.55	99.62
0.85	0.08	50.67	0.00	47.80	0.00	0.13	0.44	99.97
0.72	0.12	47.51	0.00	50.23	0.00	0.09	0.95	99.62
0.31	0.10	46.50	0.00	47.77	0.02	0.85	2.70	98.25
0.64	0.15	49.80	0.00	49.08	0.00	0.06	0.51	100.24
0.65	0.04	48.22	0.00	49.14	0.00	0.08	0.68	98.81
0.65	0.02	47.66	0.00	48.88	0.03	0.07	0.64	97.95
0.57	0.05	49.15	0.00	45.36	0.03	1.27	1.41	97.84
0.61	0.16	48.05	0.00	49.70	0.01	0.09	0.56	99.18
0.71	0.06	48.21	0.00	49.06	0.00	0.13	0.34	98.51
0.51	0.05	46.81	0.00	49.23	0.00	0.64	1.17	98.41
0.61	0.07	50.17	0.00	46.10	0.00	0.25	0.32	97.52
0.43	0.06	46.86	0.00	47.08	0.00	1.78	2.29	98.50
0.43	0.16	45.38	0.00	51.18	0.01	0.09	2.07	99.32
0.36	0.21	44.44	0.00	49.28	0.02	1.31	3.65	99.27
0.68	0.09	48.68	0.00	48.69	0.02	0.10	0.60	98.86
0.55	0.21	46.16	0.00	49.94	0.02	0.16	1.54	98.58
0.47	0.13	47.62	0.00	46.83	0.03	0.88	2.48	98.44
1.17	0.07	47.22	0.00	50.44	0.00	0.10	0.41	99.41
0.51	0.11	43.05	0.00	48.57	0.03	1.83	2.56	96.66
0.44	0.14	46.59	0.00	47.56	0.01	1.61	1.88	98.23

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

	0.51	0.14	45.98	0.00	48.52	0.02	0.04	1.14	96.35
	0.58	0.14	47.32	0.00	48.23	0.01	0.02	0.47	96.77
	0.80	0.12	45.66	0.00	49.48	0.01	0.09	0.41	96.57
	0.25	0.08	44.73	0.00	48.64	0.00	0.60	2.56	96.86
	1.01	0.09	50.21	0.00	46.66	0.00	0.74	0.59	99.30
AVG.	0.60	0.09	47.94	0.00	48.53	0.01	0.41	1.19	98.78

I1	0.64	0.05	49.03	0.00	46.60	0.04	1.42	1.65	99.43
	1.14	0.11	48.42	0.00	48.72	0.03	0.15	0.89	99.46
	0.44	0.15	46.47	0.00	49.27	0.02	0.13	2.78	99.26
	0.46	0.05	48.91	0.00	49.08	0.02	0.13	0.97	99.62
	0.73	0.09	50.35	0.00	48.66	0.04	0.17	0.38	100.42
	0.44	0.00	46.98	0.00	48.24	0.08	1.66	2.70	100.10
	0.44	0.01	48.19	0.00	47.29	0.03	1.30	2.10	99.36
	0.44	0.08	49.64	0.00	49.34	0.02	0.14	0.97	100.83
	0.36	0.02	44.77	0.00	48.90	0.05	1.43	3.80	99.33
	0.39	0.08	48.18	0.00	47.45	0.03	0.68	2.55	99.36
	0.43	0.01	47.23	0.00	48.69	0.04	0.62	2.37	99.59
	0.92	0.06	49.83	0.00	48.25	0.04	0.16	0.28	99.54
	0.93	0.05	49.62	0.00	48.81	0.05	0.14	0.21	99.81
	0.57	0.06	49.87	0.00	48.84	0.03	0.15	0.75	100.27
	0.51	0.02	49.22	0.00	49.01	0.03	0.14	1.04	99.97
	1.60	0.05	49.38	0.00	46.22	0.03	0.78	1.04	99.10
	0.73	0.04	49.50	0.00	48.69	0.02	0.13	0.28	99.39
	0.68	0.06	49.55	0.00	48.99	0.04	0.15	0.69	100.16
	0.43	0.09	48.04	0.00	48.56	0.04	0.13	1.76	99.05
	0.72	0.00	50.10	0.01	48.65	0.02	0.17	0.28	99.95
	0.48	0.07	47.97	0.00	48.20	0.03	0.84	1.93	99.52
	0.64	0.04	47.13	0.00	49.83	0.04	1.03	1.41	100.12
	0.78	0.05	49.24	0.00	46.69	0.03	1.31	1.40	99.50
	0.66	0.07	50.79	0.00	47.49	0.02	0.13	0.28	99.44
	1.61	0.00	48.49	0.00	47.07	0.04	1.57	0.40	99.18
	0.89	0.14	48.95	0.00	49.81	0.05	0.10	0.31	100.25
	0.51	0.05	49.46	0.01	46.34	0.03	0.78	1.85	99.03
	0.95	0.09	50.36	0.01	48.49	0.03	0.13	0.30	100.36
	0.68	0.02	47.58	0.02	49.09	0.05	1.26	2.16	100.86
	1.02	0.07	49.59	0.00	47.26	0.05	0.72	1.06	99.77
	0.55	0.05	50.42	0.00	47.18	0.05	0.12	0.78	99.15
	0.52	0.08	47.92	0.00	49.20	0.03	0.12	2.14	100.01
	0.51	0.13	48.03	0.00	48.81	0.03	0.13	1.89	99.53
	0.35	0.11	47.03	0.11	46.08	0.22	0.74	2.50	97.14
	0.69	0.08	48.16	0.00	48.41	0.04	0.11	0.47	97.96
	0.55	0.05	48.22	0.03	47.11	0.02	0.13	1.04	97.15
	0.38	0.04	41.97	0.00	50.39	0.04	1.27	3.89	97.98
	0.41	0.12	41.76	0.00	50.95	0.05	0.10	4.28	97.67
	0.41	0.09	47.43	0.00	47.23	0.06	0.40	1.23	96.85
	0.29	0.05	46.10	0.02	46.65	0.02	1.23	2.56	96.92
	0.57	0.15	48.86	0.00	46.69	0.04	0.17	0.72	97.20
	0.69	0.03	46.64	0.00	45.88	0.04	0.82	2.04	96.14
	0.38	0.02	47.98	0.00	47.83	0.06	0.33	1.50	98.10
	0.48	0.13	42.01	0.03	50.43	0.04	0.11	4.58	97.81
	0.44	0.04	48.86	0.00	45.72	0.03	0.16	1.45	96.70
	0.56	0.04	46.24	0.01	47.77	0.03	0.66	1.54	96.85
	0.33	0.09	45.25	0.00	47.45	0.04	0.63	3.55	97.34

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.39	0.11	41.57	0.00	50.94	0.03	0.09	5.30	98.43
0.56	0.15	46.80	0.00	46.99	0.01	0.14	1.00	97.65
0.41	0.08	47.99	0.00	46.20	0.03	0.66	2.21	97.58
0.38	0.05	46.82	0.00	46.28	0.04	0.69	1.91	96.17
0.50	0.05	49.87	0.00	44.62	0.05	0.16	0.84	96.09
0.58	0.09	48.08	0.00	45.80	0.04	0.23	1.74	96.56
0.37	0.21	45.66	0.02	46.51	0.03	0.66	3.79	97.25
0.58	0.09	49.13	0.00	45.91	0.03	0.14	0.59	96.47
0.74	0.08	48.46	0.00	46.80	0.02	0.15	0.81	97.06
0.68	0.03	47.98	0.01	48.35	0.03	0.11	0.53	97.72
0.44	0.06	47.53	0.00	47.65	0.03	0.13	0.88	96.72
0.31	0.06	45.51	0.00	47.53	0.02	1.00	3.27	97.70
0.39	0.10	41.11	0.05	50.99	0.04	0.11	4.15	96.94
0.69	0.12	46.30	0.00	46.29	0.03	1.07	1.65	96.15
0.71	0.09	48.40	0.00	46.74	0.03	0.12	1.22	97.31
0.47	0.08	47.95	0.00	47.29	0.04	0.16	1.44	97.43
0.76	0.04	49.29	0.00	47.50	0.05	0.11	0.38	98.13
0.51	0.08	47.74	0.00	47.52	0.04	0.15	1.23	97.27
0.42	0.05	47.63	0.00	44.26	0.04	1.08	3.13	96.61
0.89	0.04	47.10	0.00	48.87	0.03	0.09	0.39	97.41
0.45	0.16	46.65	0.00	48.89	0.04	0.15	1.55	97.89
0.52	0.06	48.97	0.00	46.83	0.08	0.12	0.83	97.41
0.50	0.11	48.78	0.00	46.46	0.05	0.10	0.61	96.61
0.39	0.13	43.41	0.00	50.16	0.02	0.13	3.64	97.88
0.64	0.08	48.61	0.03	47.41	0.04	0.16	0.60	97.57
0.55	0.04	48.82	0.00	45.76	0.03	1.33	0.97	97.50
1.00	0.13	49.63	0.00	45.26	0.02	0.17	1.02	97.23
0.70	0.01	48.24	0.00	46.00	0.05	1.00	0.78	96.78
0.58	0.09	48.37	0.00	46.32	0.01	0.10	0.79	96.26
0.53	0.05	48.99	0.00	47.55	0.01	0.14	0.45	97.72
0.58	0.06	48.03	0.00	47.35	0.05	0.12	0.96	97.15
0.74	0.06	48.53	0.02	47.37	0.05	0.13	0.40	97.30
0.34	0.13	47.49	0.02	45.12	0.05	0.51	2.60	96.26
0.43	0.06	45.63	0.00	46.31	0.06	1.51	2.81	96.61
0.36	0.07	44.68	0.00	47.80	0.03	0.92	3.26	97.12
1.05	0.09	47.84	0.00	45.84	0.03	0.74	1.24	96.83
0.65	0.34	50.02	0.00	46.01	0.03	0.15	0.31	97.51
0.48	0.06	48.66	0.00	45.28	0.00	0.98	2.34	97.80
0.71	0.07	49.17	0.00	47.56	0.04	0.14	0.40	98.09
1.02	0.06	48.60	0.00	47.87	0.06	0.13	0.47	98.21
1.00	0.06	47.28	0.00	48.18	0.03	0.12	0.34	97.01
0.44	0.02	48.70	0.04	45.84	0.03	0.54	1.84	97.45
0.62	0.07	48.33	0.00	46.73	0.06	0.16	0.95	96.92
0.45	0.11	44.90	0.00	47.67	0.02	0.21	3.28	96.64
0.63	0.11	47.29	0.00	47.31	0.02	0.12	0.83	96.31
0.65	0.06	46.32	0.00	49.31	0.04	0.10	1.42	97.90
0.66	0.02	45.92	0.00	49.35	0.02	0.12	1.03	97.12
1.47	0.08	48.03	0.00	45.20	0.05	1.00	1.11	96.94
0.70	0.07	48.36	0.00	48.33	0.04	0.12	0.38	98.00
0.66	0.53	45.08	0.00	49.12	0.03	0.80	2.08	98.30
0.66	0.06	48.63	0.00	47.58	0.04	0.14	0.36	97.47
0.50	0.03	48.85	0.00	45.08	0.03	0.60	2.24	97.33
0.73	0.01	47.68	0.00	46.60	0.01	0.12	0.57	97.72
0.55	0.10	45.32	0.00	47.81	0.03	0.91	2.51	97.23
0.58	0.09	49.72	0.02	46.29	0.04	0.26	0.64	97.64
1.35	0.03	45.74	0.03	49.35	0.03	0.73	1.30	98.56

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.53	0.08	46.07	0.00	48.88	0.04	0.85	1.82	98.27
1.23	0.03	48.78	0.01	46.46	0.03	1.18	0.59	98.31
0.56	0.05	48.66	0.00	48.34	0.01	0.13	0.64	98.39
0.45	0.00	47.56	0.00	45.44	0.04	0.76	2.36	96.61
0.73	0.03	48.08	0.00	48.29	0.03	0.23	0.59	97.98
0.81	0.07	49.63	0.00	46.46	0.02	0.17	0.24	97.40
1.24	0.04	45.23	0.00	51.07	0.05	0.17	0.34	98.14
0.66	0.20	46.43	0.04	46.53	0.02	1.04	1.88	96.80
0.39	0.13	45.45	0.05	46.17	0.04	1.30	2.78	96.31
0.58	0.10	47.46	0.00	46.75	0.03	1.03	1.48	97.43
0.70	0.16	48.87	0.00	45.42	0.04	0.12	0.59	95.90
0.58	0.08	47.37	0.04	47.33	0.03	0.29	1.17	96.89
0.72	0.09	48.06	0.00	48.59	0.03	0.11	0.76	98.36
0.77	0.13	49.05	0.00	46.85	0.01	0.13	0.43	97.37
0.59	0.11	47.06	0.02	47.39	0.02	0.09	1.67	96.95
0.63	0.15	47.45	0.01	46.83	0.02	0.81	1.51	97.41
1.13	0.10	50.50	0.00	43.67	0.03	0.73	0.45	96.61
1.01	0.07	48.51	0.00	47.56	0.01	0.15	0.29	97.60
0.71	0.05	48.15	0.01	47.34	0.01	0.45	1.29	98.01
0.78	0.14	48.49	0.00	48.82	0.05	0.14	0.33	98.75
0.87	0.11	48.34	0.00	47.63	0.03	0.10	0.38	97.46
0.66	0.08	47.99	0.00	46.44	0.02	0.40	1.47	97.06
0.99	0.10	49.42	0.00	47.96	0.05	0.13	0.26	98.91
0.75	0.07	50.00	0.00	44.80	0.02	0.16	0.30	96.10
0.48	0.10	46.12	0.00	48.25	0.05	0.68	2.10	97.78
0.75	0.23	49.76	0.08	45.12	0.06	0.13	0.40	96.53
1.02	0.09	49.21	0.00	44.82	0.05	0.34	0.62	96.15
1.57	0.10	43.02	0.05	50.75	0.03	0.65	2.52	98.69
0.77	0.12	49.07	0.00	46.63	0.03	0.14	0.35	97.11
0.53	0.12	44.56	0.04	49.61	0.07	0.14	4.05	99.12
0.55	0.14	49.40	0.00	47.81	0.02	0.12	1.17	99.21
0.32	0.14	49.60	0.00	46.78	0.06	0.14	1.29	98.33
0.67	0.10	48.54	0.00	48.55	0.03	0.14	0.47	98.50
0.47	0.06	46.93	0.01	46.97	0.06	1.77	2.50	98.77
0.67	0.13	46.67	0.01	51.01	0.01	0.58	1.77	100.85
0.86	0.12	50.52	0.00	48.54	0.08	0.17	0.23	100.52
0.75	0.11	50.47	0.01	49.09	0.06	0.18	0.60	101.27
0.76	0.03	44.25	0.00	52.57	0.02	0.39	2.06	100.08
0.96	0.15	50.50	0.01	48.15	0.05	0.13	0.59	100.54
1.17	0.10	50.38	0.00	47.15	0.05	0.40	0.38	99.63
0.53	0.09	46.23	0.00	47.66	0.04	0.27	2.77	97.59
0.41	0.20	45.03	0.00	47.92	0.04	1.13	4.42	99.15
3.13	0.09	48.09	0.00	47.32	0.03	0.19	0.15	99.00
0.68	0.10	50.26	0.03	48.12	0.03	0.15	0.60	99.97
0.61	0.08	50.52	0.00	47.67	0.03	0.17	0.74	99.82
0.89	0.15	49.99	0.01	48.47	0.04	0.15	0.23	99.93
0.81	0.12	45.36	0.00	50.31	0.05	0.57	1.72	98.94
1.12	0.10	49.46	0.02	47.60	0.04	0.10	0.63	99.07
0.77	0.13	48.61	0.02	49.89	0.03	0.55	0.52	100.92
0.88	0.08	50.89	0.04	47.27	0.05	0.11	0.21	99.53
0.93	0.07	50.01	0.03	48.42	0.07	0.12	0.32	99.97
1.27	0.08	49.52	0.00	47.96	0.04	0.52	0.50	100.29
0.71	0.10	47.24	0.00	49.15	0.04	0.73	2.08	100.05
1.40	0.10	49.45	0.01	46.51	0.04	0.34	0.75	98.60
0.86	0.08	47.22	0.00	48.66	0.05	0.95	2.78	100.60
0.52	0.09	50.11	0.00	48.78	0.04	0.13	0.85	100.52

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.54	0.09	48.39	0.01	46.59	0.03	0.54	2.44	98.63
0.80	0.05	49.88	0.00	48.07	0.05	0.15	0.52	99.52
0.55	0.06	48.60	0.01	47.76	0.05	0.57	1.69	99.29
0.95	0.11	50.75	0.02	45.24	0.03	0.10	0.41	97.61
0.61	0.18	45.83	0.00	49.22	0.05	0.78	3.83	100.50
0.78	0.08	47.86	0.01	48.22	0.03	0.59	1.38	98.95
0.41	0.10	49.11	0.08	46.11	0.02	0.32	1.55	97.70
1.33	0.08	50.05	0.02	44.95	0.02	0.63	0.60	97.68
0.76	0.11	50.27	0.10	45.11	0.04	0.73	1.36	98.48
0.53	0.13	41.18	0.01	49.83	0.05	0.84	2.39	94.96
0.61	0.06	47.34	0.00	46.99	0.04	0.75	1.51	97.30
0.97	0.09	47.27	0.00	46.29	0.04	0.62	0.89	96.17
2.50	0.16	46.71	0.00	43.42	0.03	1.09	0.78	94.69
0.60	0.05	47.52	0.01	46.69	0.02	0.17	0.61	95.67
0.59	0.06	47.70	0.00	46.16	0.03	0.08	0.63	95.25
5.46	0.05	43.75	0.02	51.23	0.04	0.16	0.19	100.90
0.36	0.14	46.34	0.02	48.71	0.03	0.75	3.16	99.51
1.78	0.04	50.18	0.00	45.85	0.03	0.79	0.21	98.88
0.77	0.04	50.64	0.00	47.48	0.05	0.09	0.31	99.38
0.56	0.04	47.55	0.00	47.45	0.04	1.50	1.50	98.64
0.48	0.06	50.20	0.00	47.81	0.02	0.28	1.13	99.98
0.60	0.08	49.43	0.00	49.78	0.06	0.12	0.30	100.37
1.91	0.07	49.64	0.00	46.62	0.06	0.57	0.45	99.32
0.95	0.01	48.03	0.01	51.40	0.03	0.14	0.16	100.73
0.53	0.12	50.26	0.00	46.28	0.02	0.51	1.17	98.89
0.51	0.08	44.95	0.03	49.00	0.05	0.65	4.42	99.69
0.47	0.10	48.47	0.00	47.47	0.04	0.18	2.43	99.16
0.50	0.14	48.91	0.00	47.74	0.01	0.19	2.14	99.63
0.46	0.03	47.88	0.00	48.15	0.01	0.21	2.00	98.74
0.64	0.05	49.97	0.00	47.55	0.04	0.12	0.35	98.72
0.42	0.09	45.89	0.00	49.68	0.04	0.76	3.05	99.93
0.89	0.02	48.97	0.00	49.42	0.03	0.14	0.83	100.30
1.17	0.03	49.58	0.00	48.57	0.04	0.15	0.57	100.11
0.52	0.06	42.31	0.00	53.95	0.05	0.62	3.42	100.93
1.61	0.02	46.23	0.00	51.84	0.03	0.16	0.15	100.04
0.83	0.05	49.38	0.00	48.65	0.05	0.14	0.35	99.45
0.46	0.05	47.18	0.00	51.30	0.04	0.14	0.57	99.74
1.44	0.07	49.07	0.02	47.43	0.05	0.24	0.57	98.89
0.79	0.03	47.76	0.02	50.46	0.06	0.13	0.45	99.70
1.23	0.22	37.82	0.09	57.74	0.07	0.32	0.58	98.07
3.69	0.13	48.03	0.00	46.07	0.07	0.99	0.21	99.19
0.71	0.06	50.01	0.00	48.71	0.01	0.14	0.47	100.11
1.05	0.03	47.56	0.00	50.73	0.02	0.17	0.14	99.70
0.48	0.01	49.04	0.00	46.50	0.04	1.25	1.85	99.17
0.64	0.00	47.38	0.03	50.50	0.04	0.15	0.35	99.09
0.52	0.03	47.52	0.00	50.48	0.03	0.16	0.54	99.28
0.53	0.00	47.83	0.01	47.95	0.03	0.75	1.06	98.16
0.77	0.03	47.44	0.01	51.85	0.04	0.12	0.69	100.95
0.77	0.04	47.18	0.00	51.00	0.06	0.14	0.28	99.47
1.46	0.01	47.17	0.00	50.79	0.03	0.15	0.19	99.80
1.41	0.03	46.92	0.00	51.26	0.04	0.14	0.29	100.08
0.65	0.10	50.50	0.00	47.98	0.06	0.14	1.06	100.49
1.43	0.01	46.29	0.03	51.09	0.03	0.13	0.29	99.30
0.87	0.06	48.74	0.06	48.31	0.04	0.46	0.83	99.37
1.25	0.03	46.50	0.01	51.75	0.04	0.14	0.33	100.05
1.29	0.03	47.29	0.04	50.85	0.02	0.14	0.50	100.16

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

1.67	0.01	46.97	0.00	49.90	0.02	0.14	0.10	98.81
1.74	0.10	46.91	0.00	50.68	0.03	0.10	0.24	99.80
1.72	0.01	46.82	0.00	50.32	0.05	0.16	0.22	99.30
0.61	0.08	48.33	0.00	46.87	0.05	0.16	0.47	96.57
0.49	0.12	47.35	0.01	47.05	0.03	0.25	2.15	97.45
0.76	0.10	48.36	0.00	47.96	0.04	0.12	0.67	98.01
0.54	0.10	46.72	0.00	47.47	0.03	0.11	1.49	96.46
0.60	0.01	48.92	0.00	45.67	0.02	0.68	1.26	97.16
0.42	0.06	43.29	0.00	47.80	0.02	0.51	4.11	96.21
0.76	0.07	47.61	0.00	47.79	0.20	0.14	0.56	97.13
0.62	0.04	48.13	0.00	45.90	0.01	0.68	1.49	96.87
0.43	0.00	48.35	0.00	46.99	0.02	0.10	1.05	96.94
1.06	0.03	47.85	0.00	49.01	0.05	0.15	0.17	98.32
0.45	0.06	48.61	0.00	44.96	0.04	0.64	2.10	96.86
0.87	0.00	48.79	0.00	45.39	0.02	0.49	1.02	96.58
0.81	0.05	47.95	0.00	48.05	0.05	0.16	0.22	97.29
0.42	0.04	43.76	0.00	48.68	0.01	0.40	4.60	97.91
0.58	0.10	48.87	0.03	45.92	0.05	0.14	0.70	96.39
0.75	0.11	48.56	0.09	47.67	0.06	0.13	0.41	97.78
0.61	0.04	47.55	0.00	44.95	0.05	1.50	1.45	96.15
0.55	0.10	48.30	0.00	48.09	0.02	0.14	0.86	98.06
0.37	0.10	47.18	0.00	45.49	0.02	0.65	2.55	96.36
1.26	0.00	45.61	0.00	50.92	0.00	0.16	0.57	98.52
0.48	0.05	47.68	0.00	47.24	0.04	0.14	1.30	96.93
0.96	0.05	47.57	0.00	48.34	0.04	0.12	0.24	97.32
0.67	0.07	44.63	0.00	49.14	0.02	1.57	2.16	98.26
0.65	0.08	49.14	0.00	46.76	0.06	0.11	0.90	97.70
0.53	0.04	47.31	0.06	48.85	0.05	0.14	0.71	97.69
0.35	0.08	45.95	0.00	46.76	0.06	0.43	3.18	96.81
0.36	0.12	47.61	0.00	46.60	0.04	0.12	2.15	97.00
1.22	0.02	46.20	0.00	49.18	0.05	0.16	0.40	97.23
0.39	0.10	46.75	0.00	48.97	0.03	0.13	1.16	97.53
0.43	0.10	48.66	0.00	46.79	0.02	0.16	1.55	97.71
0.32	0.15	47.44	0.00	45.79	0.03	0.24	2.43	96.40
0.39	0.00	45.12	0.00	47.63	0.02	1.25	2.78	97.19
0.76	0.02	50.34	0.10	48.45	0.05	0.16	0.32	100.20
0.59	0.03	50.49	0.00	47.45	0.00	0.17	0.41	99.14
0.66	0.07	50.41	0.00	45.81	0.04	0.53	1.22	98.74
1.23	0.02	49.73	0.00	45.28	0.06	0.78	1.14	98.24
0.69	0.09	51.39	0.00	47.19	0.05	0.14	0.32	99.87
0.49	0.06	48.82	0.04	48.55	0.03	1.17	1.96	101.12
0.42	0.09	49.83	0.00	47.15	0.03	0.56	1.46	99.54
0.83	0.03	47.68	0.00	48.19	0.03	1.71	2.03	100.50
0.43	0.08	47.46	0.03	48.57	0.04	0.60	3.00	100.23
0.70	0.14	50.68	0.00	48.53	0.04	0.10	0.62	100.81
0.73	0.03	48.75	0.02	48.72	0.03	1.03	1.75	101.06
0.84	0.06	49.49	0.05	49.83	0.03	0.12	0.46	100.88
0.44	0.13	45.46	0.00	51.25	0.01	0.13	3.46	100.88
0.77	0.06	49.85	0.00	49.56	0.06	0.11	0.55	100.96
0.36	0.06	44.18	0.04	50.26	0.00	0.60	5.11	100.61
0.41	0.08	46.38	0.03	49.51	0.04	1.28	3.20	100.93
0.66	0.03	48.57	0.00	50.55	0.01	0.11	0.98	100.91
1.29	0.02	49.80	0.00	49.42	0.05	0.14	0.23	100.95
0.63	0.09	50.16	0.03	48.39	0.04	0.09	0.57	100.02
0.54	0.01	48.71	0.00	49.47	0.05	0.13	1.40	100.31
0.86	0.03	50.31	0.01	48.39	0.02	0.14	0.14	99.90

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.40	0.00	49.14	0.00	47.96	0.04	1.20	1.88	100.62
1.26	0.02	49.48	0.01	50.04	0.01	0.14	0.21	101.17
1.06	0.07	49.93	0.03	48.47	0.05	0.09	0.09	99.79
0.50	0.02	50.06	0.00	45.83	0.02	1.19	1.61	99.23
0.50	0.09	45.29	0.01	49.55	0.04	1.01	4.11	100.60
0.99	0.03	49.70	0.03	49.30	0.02	0.14	0.30	100.51
0.41	0.10	46.29	0.00	49.33	0.03	0.29	3.70	100.15
0.75	0.14	49.82	0.00	49.16	0.01	0.13	0.28	100.29
0.66	0.08	50.34	0.00	49.29	0.03	0.11	0.46	100.97
0.39	0.05	47.76	0.01	47.53	0.05	1.44	2.70	99.93
0.92	0.09	49.79	0.01	49.07	0.04	0.11	0.28	100.31
0.47	0.05	47.96	0.04	49.72	0.03	0.66	2.08	101.01
0.73	0.04	49.77	0.00	50.52	0.03	0.14	0.67	101.90
0.75	0.07	49.70	0.01	48.80	0.04	0.14	0.27	99.78
0.60	0.10	49.04	0.02	48.12	0.07	0.13	1.02	99.10
0.68	0.07	50.12	0.00	49.13	0.05	0.14	0.46	100.65
0.78	0.06	48.01	0.04	50.08	0.04	0.96	1.81	101.78
0.51	0.07	49.71	0.00	49.05	0.05	0.09	1.00	100.48
0.47	0.07	50.72	0.01	45.89	0.05	0.76	1.08	99.05
0.64	0.00	49.39	0.00	48.40	0.01	0.67	1.25	100.36
0.40	0.08	45.77	0.00	51.61	0.04	0.36	2.38	100.64
1.36	0.04	48.92	0.00	48.63	0.00	0.65	0.93	100.53
0.99	0.08	49.86	0.00	48.85	0.04	0.15	0.30	100.27
0.74	0.09	50.65	0.02	48.85	0.05	0.15	0.42	100.97
0.65	0.15	49.92	0.04	48.65	0.06	0.11	0.48	100.06
1.08	0.00	50.28	0.01	45.70	0.02	1.30	0.55	98.94
0.36	0.03	43.39	0.00	50.02	0.06	0.93	4.42	99.21
0.33	0.00	47.85	0.00	46.20	0.04	1.30	2.59	98.31
0.53	0.04	49.43	0.00	49.57	0.03	0.14	0.79	100.53
0.86	0.02	46.52	0.00	50.56	0.03	0.82	1.72	100.53
0.74	0.11	50.33	0.00	47.81	0.02	0.10	0.42	99.53
0.69	0.08	49.91	0.00	48.86	0.02	0.13	0.55	100.24
2.75	0.03	50.84	0.03	44.20	0.03	0.84	0.27	98.99
0.37	0.02	48.76	0.00	47.27	0.02	1.35	1.83	99.62
0.38	0.07	45.23	0.00	51.97	0.03	0.68	3.49	101.85
0.60	0.09	49.73	0.00	49.56	0.03	0.10	0.49	100.60
0.52	0.03	49.14	0.01	49.83	0.05	0.11	0.83	100.52
0.50	0.00	49.21	0.00	46.69	0.05	0.12	0.65	99.22
0.51	0.09	49.44	0.02	49.60	0.09	0.28	1.44	100.47
0.86	0.08	49.46	0.02	46.17	0.04	0.58	0.71	97.92
0.43	0.03	48.44	0.00	48.11	0.04	0.47	1.70	99.22
0.49	0.04	47.03	0.00	49.12	0.02	0.59	2.32	99.61
0.80	0.03	49.53	0.06	50.13	0.05	0.15	0.25	101.00
0.49	0.04	48.88	0.02	47.84	0.06	0.24	1.42	98.99
0.38	0.05	49.78	0.00	46.09	0.06	0.71	2.30	99.37
0.66	0.10	48.87	0.00	50.49	0.01	0.18	0.39	100.70
0.36	0.07	45.85	0.00	51.48	0.07	0.32	2.13	100.28
0.71	0.05	49.60	0.00	50.02	0.04	0.14	0.42	100.98
0.64	0.01	48.86	0.01	47.62	0.04	1.07	1.70	99.95
0.77	0.02	50.29	0.00	48.79	0.05	0.11	0.30	100.33
0.35	0.00	46.77	0.00	48.21	0.01	1.64	3.05	100.03
0.67	0.11	50.37	0.03	48.61	0.03	0.15	0.19	100.16
0.50	0.07	47.88	0.00	48.77	0.04	0.80	1.52	99.58
0.79	0.05	50.01	0.03	47.64	0.06	0.12	0.57	99.27
0.50	0.07	45.09	0.01	50.93	0.05	0.69	3.14	100.48
0.59	0.08	49.99	0.00	50.68	0.02	0.15	0.40	101.91

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.67	0.03	50.42	0.00	48.75	0.03	0.12	0.49	100.51
0.79	0.03	50.19	0.03	48.69	0.05	0.14	0.25	100.17
0.84	0.09	50.07	0.03	48.87	0.04	0.13	0.18	100.25
0.71	0.02	50.05	0.02	50.07	0.04	0.13	0.44	101.48
0.33	0.04	49.38	0.00	46.60	0.05	0.93	2.20	99.53
0.50	0.11	48.92	0.00	49.32	0.07	0.12	1.89	100.93
1.11	0.08	52.03	0.00	44.28	0.03	0.66	0.38	98.57
0.58	0.00	49.76	0.00	48.36	0.03	0.14	0.76	99.63
0.34	0.14	48.96	0.00	46.93	0.01	0.38	2.54	99.30
0.51	0.16	47.60	0.00	49.31	0.02	0.13	2.43	100.16
0.71	0.11	50.22	0.03	47.72	0.04	0.12	0.21	99.16
0.86	0.03	49.52	0.00	48.98	0.05	0.16	0.33	99.93
0.51	0.05	49.73	0.00	47.91	0.02	0.13	0.81	99.16
0.44	0.08	48.68	0.00	49.92	0.07	0.11	2.06	101.36
0.50	0.10	50.13	0.05	48.41	0.04	0.14	0.63	100.00
0.71	0.02	43.51	0.00	54.88	0.08	0.20	2.04	101.44
0.49	0.05	49.54	0.00	48.16	0.04	0.14	0.88	99.30
0.78	0.01	50.44	0.00	49.04	0.06	0.15	0.21	100.69
0.92	0.08	49.79	0.00	49.23	0.04	0.11	0.28	100.45
0.56	0.11	47.86	0.00	49.71	0.02	0.14	2.28	100.68
0.63	0.05	50.76	0.00	48.40	0.03	0.12	0.42	100.41
0.88	0.03	50.43	0.00	47.97	0.03	0.16	0.27	99.77
0.56	0.04	46.51	0.03	47.88	0.03	1.74	2.62	99.41
0.43	0.02	45.99	0.00	48.59	0.04	1.82	3.22	100.11
0.81	0.04	49.55	0.00	50.22	0.04	0.15	0.21	101.04
1.42	0.06	51.36	0.03	46.21	0.03	0.75	0.21	100.07
0.43	0.00	46.90	0.00	48.71	0.04	1.18	2.35	99.61
0.83	0.04	49.32	0.00	49.67	0.03	0.16	0.39	100.44
0.58	0.09	50.42	0.00	49.24	0.03	0.12	0.51	100.99
0.75	0.09	51.08	0.00	48.36	0.05	0.12	0.50	100.95
0.86	0.06	49.67	0.00	48.26	0.29	0.18	0.41	99.73
0.74	0.13	50.36	0.03	48.30	0.05	0.17	0.35	100.13
0.86	0.06	49.68	0.07	48.94	0.13	0.16	0.46	100.36
0.89	0.11	49.71	0.00	48.53	0.01	0.13	0.21	99.59
0.52	0.03	49.90	0.00	48.06	0.05	0.10	1.15	99.81
0.49	0.07	49.39	0.00	48.57	0.03	0.10	1.14	99.79
0.72	0.04	49.11	0.00	48.82	0.05	0.12	0.60	99.46
0.54	0.05	49.34	0.00	48.96	0.03	0.10	1.28	100.30
0.63	0.05	50.57	0.00	48.37	0.04	0.13	0.30	100.09
0.76	0.10	49.64	0.00	49.32	0.04	0.12	0.37	100.35
1.20	0.11	47.34	0.03	49.99	0.04	1.14	1.57	101.42
0.76	0.09	49.60	0.00	49.05	0.05	0.15	0.39	100.09
0.72	0.11	49.90	0.00	49.19	0.05	0.15	0.19	100.31
0.45	0.08	50.18	0.00	47.77	0.02	0.78	1.55	100.83
0.38	0.07	45.83	0.00	48.64	0.05	1.29	3.95	100.21
0.52	0.05	49.29	0.00	49.46	0.03	0.13	0.51	99.99
0.39	0.12	47.40	0.00	48.97	0.04	0.54	3.05	100.51
0.71	0.04	49.85	0.00	46.05	0.01	1.66	1.57	99.89
0.71	0.00	47.84	0.00	46.89	0.02	1.61	2.06	99.13
0.80	0.10	50.11	0.02	49.27	0.04	0.13	0.37	100.84
0.72	0.07	50.47	0.01	47.85	0.04	0.16	0.34	99.66
0.37	0.06	48.69	0.00	46.60	0.04	1.07	2.28	99.11
0.38	0.04	49.52	0.00	46.13	0.04	0.78	2.53	99.42
0.65	0.03	49.29	0.00	47.15	0.03	1.18	1.32	99.65
0.51	0.04	46.52	0.00	48.78	0.03	1.44	2.84	100.16
0.56	0.06	47.94	0.00	49.94	0.04	0.55	1.50	100.59

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.48	0.03	48.34	0.00	49.32	0.05	0.74	1.55	100.51
0.46	0.03	49.90	0.00	47.25	0.03	0.71	0.86	99.24
0.70	0.06	49.50	0.00	49.05	0.03	0.14	0.49	99.97
0.67	0.06	50.90	0.00	48.42	0.04	0.13	0.26	100.48
0.81	0.13	51.04	0.03	48.34	0.04	0.12	0.35	100.86
0.74	0.07	47.90	0.02	49.39	0.04	0.98	1.52	100.66
0.51	0.10	48.81	0.00	49.33	0.03	0.11	1.90	100.79
0.35	0.01	46.35	0.01	51.21	0.03	1.02	3.01	101.99
0.32	0.08	48.08	0.00	47.61	0.06	1.10	2.30	99.55
1.67	0.06	48.90	0.04	47.99	0.05	0.76	0.37	99.84
0.28	0.02	48.13	0.00	47.70	0.04	1.09	2.44	99.70
0.36	0.14	42.77	0.00	51.62	0.02	0.95	5.29	101.15
0.76	0.04	49.65	0.00	49.76	0.05	0.10	0.61	100.97
0.49	0.11	48.63	0.00	49.38	0.05	0.15	1.38	100.19
0.34	0.12	49.42	0.03	47.03	0.04	0.35	3.05	100.38
0.61	0.03	47.73	0.00	49.79	0.05	1.26	1.39	100.86
0.54	0.02	48.99	0.00	49.48	0.04	0.10	0.96	100.13
0.65	0.10	49.71	0.00	49.33	0.05	0.12	0.44	100.40
0.67	0.08	49.16	0.00	47.55	0.05	1.15	1.39	100.05
1.32	0.14	50.18	0.02	47.39	0.02	0.77	0.53	100.37
0.59	0.11	49.46	0.00	48.86	0.03	0.12	0.65	99.82
0.83	0.06	50.95	0.00	45.71	0.04	0.88	0.62	99.09
0.43	0.09	50.24	0.00	48.83	0.03	0.14	0.76	100.52
0.43	0.12	50.00	0.00	47.48	0.05	0.20	1.25	99.53
0.53	0.08	48.11	0.01	47.77	0.05	1.12	2.08	99.75
0.75	0.07	50.30	0.00	48.66	0.06	0.15	0.30	100.29
0.55	0.09	52.20	0.00	45.59	0.03	0.52	1.26	100.24
0.75	0.08	49.61	0.00	49.93	0.03	0.14	0.49	101.03
0.52	0.02	47.95	0.00	46.93	0.03	1.69	2.60	99.74
0.48	0.01	49.83	0.00	45.40	0.03	1.43	2.02	99.20
0.65	0.08	47.27	0.00	49.82	0.04	1.34	1.62	100.82
0.39	0.11	49.92	0.10	46.40	0.04	0.37	1.57	98.90
0.34	0.01	48.01	0.00	47.42	0.02	1.37	2.65	99.82
0.53	0.15	44.87	0.00	50.30	0.03	0.33	4.26	100.47
0.54	0.03	48.41	0.00	48.57	0.02	0.42	1.38	99.37
0.49	0.06	47.58	0.00	47.71	0.03	0.54	2.28	98.69
0.57	0.06	50.20	0.00	47.30	0.04	0.29	0.76	99.22
0.45	0.11	47.93	0.00	48.96	0.03	0.53	3.03	101.04
0.50	0.06	47.74	0.00	50.38	0.05	0.59	2.27	101.59
0.49	0.19	50.05	0.00	48.22	0.05	0.13	1.49	100.62
1.28	0.13	50.90	0.00	46.66	0.04	0.49	0.55	100.05
0.80	0.07	51.57	0.00	46.23	0.03	0.73	0.97	100.40
0.36	0.03	45.46	0.00	50.45	0.04	1.34	3.85	101.53
1.79	0.03	48.79	0.00	46.43	0.03	1.00	0.49	98.56
0.43	0.06	50.26	0.00	47.63	0.03	0.42	1.44	100.27
0.65	0.07	48.37	0.00	49.37	0.04	0.38	1.81	100.69
1.30	0.02	50.89	0.03	47.02	0.05	0.57	0.62	100.50
0.77	0.04	49.19	0.04	49.99	0.05	0.15	0.46	100.69
0.77	0.05	48.78	0.00	49.11	0.05	0.75	1.29	100.80
0.42	0.12	49.85	0.00	48.47	0.06	0.14	0.88	99.94
0.73	0.02	49.98	0.00	49.15	0.04	0.13	0.60	100.65
0.43	0.04	46.24	0.00	49.84	0.02	0.78	2.20	99.55
0.62	0.04	50.06	0.01	48.56	0.05	0.12	0.74	100.20
0.53	0.04	49.34	0.00	49.28	0.04	0.16	0.60	99.99
0.60	0.07	49.56	0.00	50.55	0.04	0.17	0.77	101.76
0.52	0.10	47.00	0.00	50.50	0.02	0.12	2.32	100.58

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

	0.55	0.12	51.91	0.00	46.10	0.03	0.16	0.55	99.42
	0.37	0.04	50.31	0.00	49.63	0.03	0.11	0.93	101.42
	0.56	0.04	47.76	0.02	48.26	0.05	1.35	2.64	100.68
	0.54	0.02	49.60	0.00	48.20	0.04	0.18	1.26	99.84
	0.46	0.04	51.15	0.00	45.83	0.03	0.78	1.78	100.07
	2.00	0.01	49.14	0.00	48.54	0.04	0.60	0.33	100.66
	0.67	0.10	50.34	0.00	49.36	0.06	0.12	0.28	100.93
	0.52	0.06	48.44	0.00	48.66	0.06	0.66	1.66	100.06
	1.20	0.07	49.69	0.00	47.74	0.02	0.61	0.86	100.19
	0.44	0.02	49.58	0.00	45.88	0.04	0.93	2.10	98.99
	0.51	0.05	49.71	0.00	48.08	0.04	0.58	1.32	100.29
	1.17	0.07	49.42	0.03	49.75	0.05	0.22	0.44	101.15
	0.97	0.09	49.25	0.00	49.93	0.04	0.12	0.46	100.86
	0.75	0.02	49.27	0.00	48.38	0.04	0.74	1.26	100.46
	0.69	0.08	49.30	0.01	49.25	0.04	0.15	1.00	100.52
	0.61	0.03	49.96	0.00	47.03	0.02	1.25	0.85	99.75
	0.68	0.04	50.17	0.00	48.12	0.05	0.15	0.85	100.06
	0.58	0.13	49.86	0.04	47.64	0.05	0.12	1.27	99.69
	0.70	0.05	49.68	0.00	47.90	0.05	0.12	0.49	98.99
	0.45	0.07	44.95	0.00	52.82	0.04	0.32	1.87	100.52
	0.54	0.04	50.61	0.00	47.12	0.04	0.49	1.20	100.04
	0.39	0.08	43.41	0.00	51.47	0.02	1.60	4.08	101.05
	0.71	0.16	51.17	0.00	47.39	0.00	0.10	0.32	99.85
	0.62	0.04	50.40	0.00	48.31	0.04	0.17	0.58	100.16
	0.77	0.06	49.22	0.00	49.68	0.04	0.15	0.28	100.20
	0.42	0.07	47.55	0.00	48.42	0.06	0.86	2.86	100.24
	0.61	0.01	48.51	0.01	47.77	0.04	1.47	1.16	99.58
	0.51	0.02	47.79	0.00	49.88	0.04	0.69	0.90	99.83
	0.59	0.02	49.78	0.00	50.06	0.02	0.12	0.57	101.16
	0.83	0.02	49.50	0.02	49.21	0.03	0.15	0.28	100.04
	0.68	0.05	50.01	0.00	49.34	0.04	0.16	0.33	100.61
	1.03	0.04	44.34	0.03	53.08	0.03	0.29	1.19	100.03
	0.96	0.07	49.44	0.00	48.63	0.04	0.14	0.35	99.63
	0.68	0.07	50.07	0.00	48.67	0.02	0.13	0.35	99.99
	0.41	0.06	48.81	0.00	49.15	0.06	0.14	1.21	99.84
	0.71	0.10	50.15	0.02	48.93	0.03	0.13	0.64	100.71
	0.50	0.01	50.52	0.02	47.40	0.04	0.14	0.42	99.05
	0.43	0.04	47.97	0.00	48.37	0.03	0.95	1.93	99.72
	1.05	0.06	45.89	0.00	48.97	0.03	1.33	1.19	98.52
	0.82	0.09	49.23	0.00	49.02	0.05	0.13	0.40	99.74
	0.75	0.08	48.69	0.01	49.97	0.04	0.14	0.45	100.13
	0.71	0.06	50.28	0.01	47.96	0.03	0.13	0.33	99.51
	0.61	0.02	48.80	0.00	47.89	0.04	0.97	1.21	99.54
	0.52	0.08	49.35	0.00	46.71	0.05	0.84	1.84	99.39
	0.57	0.04	50.03	0.00	48.40	0.03	0.12	0.43	99.62
	0.99	0.05	50.18	0.00	48.07	0.01	0.30	0.70	100.30
	0.53	0.14	50.71	0.00	46.30	0.05	0.16	1.24	99.13
	0.67	0.02	50.27	0.00	48.12	0.04	0.15	0.40	99.67
AVG.	0.71	0.07	48.39	0.01	48.24	0.04	0.45	1.29	99.19
12	3.29	0.00	45.94	0.00	50.38	0.01	0.08	0.28	99.98
	3.33	0.00	45.42	0.00	50.99	0.04	0.09	0.26	100.13
	4.08	0.00	45.12	0.00	49.60	0.02	0.09	0.22	99.13
	1.93	0.00	47.00	0.00	49.69	0.00	0.05	0.22	98.89

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

	3.72	0.00	45.29	0.00	49.38	0.00	0.10	0.20	98.69
	3.60	0.01	45.60	0.00	48.66	0.01	0.07	0.20	98.15
	1.96	0.02	47.14	0.00	49.21	0.00	0.08	0.51	98.92
	3.91	0.00	44.35	0.00	50.00	0.03	0.05	0.24	98.58
	3.68	0.00	43.83	0.00	49.85	0.00	0.03	0.13	97.52
	4.26	0.00	44.13	0.00	49.06	0.04	0.06	0.20	97.75
	1.91	0.03	47.37	0.00	49.66	0.01	0.06	0.35	99.39
	1.31	0.05	47.46	0.00	51.29	0.03	0.08	0.81	101.03
	4.02	0.00	45.34	0.00	48.58	0.01	0.05	0.35	98.35
	4.23	0.00	44.75	0.00	49.83	0.03	0.12	0.35	99.31
	1.48	0.00	47.33	0.00	50.07	0.01	0.05	0.44	99.38
	3.60	0.00	45.36	0.00	49.50	0.00	0.06	0.24	98.76
	1.78	0.00	47.35	0.00	50.54	0.04	0.05	0.17	99.93
	1.61	0.00	46.83	0.00	49.88	0.03	0.08	0.47	98.90
	3.58	0.00	46.64	0.00	47.79	0.03	0.06	0.45	98.55
AVG.	3.01	0.01	45.91	0.00	49.68	0.02	0.07	0.32	99.02

13	4.09	0.00	44.59	0.00	50.26	0.03	0.06	0.23	99.26
	3.16	0.00	45.88	0.00	49.18	0.04	0.05	0.23	98.54
	1.09	0.00	46.19	0.00	51.52	0.04	0.14	0.43	99.41
	0.83	0.00	45.36	0.00	51.06	0.04	0.04	1.42	98.75
	0.51	0.01	45.33	0.00	51.72	0.03	0.03	1.69	99.32
	0.46	0.04	49.33	0.00	47.71	0.01	0.06	0.42	98.03
	1.51	0.04	47.88	0.00	47.71	0.01	0.14	0.63	97.92
	0.50	0.05	45.99	0.00	51.99	0.04	0.08	0.89	99.54
	0.78	0.00	45.82	0.00	52.24	0.01	0.09	1.21	100.15
	3.04	0.00	44.25	0.00	51.51	0.02	0.05	0.33	99.20
	1.59	0.00	47.77	0.00	45.89	0.00	0.27	0.91	96.43
	3.76	0.46	40.56	0.00	51.22	0.04	0.95	1.67	98.66
	5.64	0.60	37.15	0.06	53.58	0.02	0.94	0.16	98.15
	9.96	0.43	34.62	0.00	52.46	0.04	0.96	0.36	98.83
	0.67	0.54	43.72	0.00	52.09	0.08	0.96	0.94	99.00
	0.16	0.61	45.39	0.00	50.32	0.06	1.22	0.89	98.65
	4.57	0.38	41.97	0.00	50.66	0.03	0.64	0.64	98.89
	0.66	0.73	44.79	0.00	51.34	0.07	0.84	0.06	98.49
	0.26	0.56	44.58	0.00	51.85	0.05	0.72	0.92	98.94
	0.32	0.31	46.03	0.00	50.92	0.08	0.73	0.19	98.58
	3.97	0.40	40.90	0.00	50.45	0.03	0.90	0.98	97.63
	0.46	0.50	44.49	0.00	50.51	0.05	0.68	1.05	97.74
	4.30	0.41	41.82	0.00	51.04	0.07	0.61	0.83	99.08
	3.80	0.39	40.48	0.00	52.71	0.05	0.67	0.74	98.84
	10.08	0.15	37.68	0.00	48.84	0.03	0.97	0.32	98.07
	0.44	0.00	48.95	0.03	48.76	0.04	0.08	0.89	99.19
	2.74	0.00	44.94	0.00	50.94	0.01	0.08	0.30	99.01
	2.45	0.00	44.51	0.00	51.47	0.01	0.06	0.53	99.03
	1.39	0.05	47.19	0.00	48.68	0.00	0.20	1.07	98.58
	3.06	0.00	45.00	0.00	48.85	0.02	0.07	0.22	97.22
	0.48	0.00	49.48	0.00	48.08	0.01	0.07	0.72	98.84
	3.05	0.54	43.84	0.00	50.94	0.04	0.74	0.09	99.24
	3.17	0.00	45.52	0.00	48.67	0.01	0.06	0.13	97.56
	1.91	0.03	47.42	0.00	50.02	0.03	0.01	0.22	99.64
	20.28	0.00	28.02	0.00	51.83	0.05	0.05	0.18	100.41
	0.94	0.31	52.21	0.00	44.28	0.07	0.08	0.64	98.53
	0.87	0.01	44.88	0.00	51.10	0.01	0.08	0.18	97.13

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

	0.22	0.53	46.43	0.00	50.18	0.04	1.00	0.22	98.62	
AVG.	2.82	0.21	44.24	0.00	50.33	0.03	0.40	0.62	98.66	
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14	0.67	0.02	46.30	0.00	52.35	0.10	0.17	1.22	100.83	
	0.36	0.38	30.67	0.00	54.93	0.10	0.69	12.28	99.41	
	0.42	0.24	39.86	0.00	50.85	0.07	0.74	8.73	100.91	
	2.24	0.02	49.35	0.02	47.73	0.09	0.32	0.34	100.11	
	0.49	0.18	39.59	0.00	50.77	0.10	0.67	8.06	99.86	
	0.74	0.18	45.31	0.00	52.54	0.08	0.10	1.65	100.60	
	0.50	0.17	43.39	0.00	53.24	0.07	0.07	0.17	97.61	
	12.23	0.29	37.40	0.00	48.29	0.08	0.61	0.15	99.05	
	1.69	0.01	48.47	0.00	49.22	0.06	0.45	0.78	100.68	
	0.78	0.01	48.33	0.00	52.44	0.05	0.09	0.25	101.95	
	0.44	0.04	54.02	0.00	43.17	0.10	0.44	0.66	98.87	
	4.65	0.06	44.57	0.00	49.75	0.09	0.88	0.29	100.29	
	0.96	0.05	48.97	0.00	49.68	0.06	0.07	0.21	100.00	
	0.60	0.06	47.99	0.06	52.92	0.05	0.07	0.20	101.95	
	0.97	0.04	49.02	0.00	50.37	0.09	0.15	0.26	100.90	
	0.80	0.04	49.33	0.00	50.33	0.05	0.07	0.25	100.87	
	0.34	0.28	41.38	0.00	50.29	0.09	0.52	6.47	99.37	
	1.03	0.25	37.04	0.00	50.13	0.13	0.62	9.78	98.98	
	0.54	0.32	39.45	0.00	51.01	0.09	0.16	7.83	99.40	
	1.92	0.00	47.36	0.00	50.76	0.06	0.37	0.26	100.73	
1.54	0.10	52.17	0.03	44.58	0.05	0.12	0.59	99.18		
0.61	0.15	47.57	0.00	51.86	0.05	0.12	0.83	101.19		
0.85	0.05	39.85	0.00	55.95	0.06	0.11	0.62	97.49		
1.17	0.01	48.12	0.00	50.04	0.07	0.11	0.45	99.97		
0.29	0.08	47.01	0.00	53.99	0.06	0.06	0.27	101.76		
1.64	0.02	46.20	0.02	52.30	0.05	0.14	0.22	100.59		
0.36	0.28	40.42	0.00	49.56	0.19	0.51	7.08	98.40		
0.67	0.10	45.76	0.00	51.95	0.06	0.08	1.65	100.27		
1.52	0.00	45.89	0.00	53.72	0.04	0.09	0.18	101.44		
7.19	0.00	38.78	0.00	52.44	0.08	0.32	0.17	98.98		
1.45	0.03	47.65	0.00	50.96	0.06	0.08	0.42	100.65		
AVG.	1.60	0.11	44.75	0.00	50.91	0.08	0.29	2.33	100.07	
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15	0.61	0.02	48.32	0.00	49.48	0.06	0.20	0.22	98.91	
	0.65	0.03	44.29	0.00	50.57	0.04	0.24	1.92	97.74	
	0.59	0.00	43.57	0.00	51.39	0.07	0.29	2.04	97.95	
	0.54	0.01	46.55	0.00	51.44	0.08	0.19	1.83	100.64	
	0.54	0.01	44.83	0.00	51.80	0.10	0.25	2.06	99.59	
	0.72	0.07	47.03	0.00	52.01	0.07	0.09	1.71	101.70	
	0.53	0.07	45.75	0.00	52.42	0.07	0.11	2.15	101.10	
	0.53	0.10	48.89	0.00	48.79	0.07	0.09	0.54	99.01	
	0.46	0.00	45.20	0.00	51.63	0.10	0.38	1.75	99.52	
	0.63	0.02	46.66	0.00	51.37	0.08	0.09	1.63	100.48	
	0.62	0.09	45.17	0.00	53.36	0.08	0.17	1.34	100.83	
	1.14	0.08	48.49	0.00	50.03	0.07	0.11	1.82	101.74	
	0.85	0.04	46.68	0.00	50.58	0.07	0.38	1.52	100.12	
	AVG.	0.65	0.04	46.26	0.00	51.14	0.07	0.20	1.58	99.95

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

16	0.78	0.04	48.18	0.00	51.08	0.10	0.10	0.20	100.48
	0.71	0.03	48.28	0.00	51.08	0.10	0.09	0.11	100.40
	1.22	0.01	48.69	0.00	49.81	0.09	0.08	0.27	100.17
	1.13	0.10	46.40	0.00	51.26	0.07	0.12	0.34	99.42
	0.99	0.01	46.81	0.02	51.58	0.08	0.06	0.40	99.95
	1.08	0.03	47.79	0.00	51.26	0.08	0.13	0.19	100.56
	1.07	0.05	47.98	0.00	50.81	0.06	0.08	0.27	100.32
	0.94	0.00	47.52	0.00	50.54	0.08	0.12	0.33	99.53
	1.21	0.05	48.83	0.00	48.03	0.09	0.18	0.98	99.37
	1.49	0.54	47.55	0.00	49.94	0.04	0.07	0.87	100.50
	1.16	0.07	45.86	0.00	50.49	0.10	0.06	2.07	99.81
	0.81	0.08	48.52	0.00	51.21	0.08	0.07	0.86	101.63
	AVG.	1.05	0.08	47.70	0.00	50.59	0.08	0.10	0.57
17	0.70	0.07	49.06	0.03	50.72	0.13	0.17	0.61	101.49
	0.56	0.16	47.65	0.01	50.20	0.11	0.22	1.57	100.48
	0.61	0.05	46.89	0.03	51.55	0.11	0.15	1.79	101.18
	0.62	0.10	47.67	0.04	49.95	0.11	0.13	1.37	99.99
	0.56	0.15	45.86	0.02	51.41	0.10	0.24	1.55	99.89
	0.60	0.09	48.80	0.00	50.30	0.12	0.18	0.81	100.90
	0.66	0.03	47.12	0.08	50.59	0.09	0.17	1.27	100.01
	0.76	0.08	48.04	0.02	49.68	0.08	0.16	0.35	99.17
	0.54	0.09	47.80	0.00	50.30	0.11	0.15	1.36	100.35
	0.51	0.07	50.62	0.06	48.27	0.12	0.20	0.37	100.22
	0.88	0.08	48.16	0.01	51.08	0.10	0.14	0.33	100.78
	0.64	0.11	47.73	0.04	50.51	0.11	0.17	1.18	100.49
	0.55	0.15	47.90	0.00	50.20	0.11	0.14	1.40	100.45
	1.53	0.06	47.34	0.00	50.62	0.11	0.19	0.71	100.56
	0.58	0.16	47.34	0.01	50.64	0.11	0.15	1.16	100.15
	0.84	0.09	48.38	0.02	50.27	0.11	0.14	0.67	100.52
	0.67	0.14	47.93	0.00	50.20	0.13	0.15	1.20	100.42
	0.99	0.11	48.08	0.00	50.11	0.10	0.15	0.29	99.83
	0.75	0.15	48.76	0.00	50.38	0.09	0.13	0.46	100.72
	1.57	0.09	47.60	0.06	50.06	0.10	0.12	0.41	100.01
	1.57	0.15	48.52	0.03	50.15	0.09	0.17	0.52	101.20
	0.65	0.10	48.25	0.00	50.21	0.12	0.17	0.94	100.44
	0.59	0.13	46.23	0.04	51.36	0.12	0.14	1.75	100.36
	0.52	0.10	48.01	0.00	50.60	0.10	0.12	1.47	100.92
	0.59	0.12	47.96	0.01	50.46	0.13	0.14	1.10	100.51
	0.69	0.06	48.03	0.01	51.34	0.11	0.17	1.25	101.66
	0.75	0.11	48.02	0.06	51.42	0.11	0.13	0.95	101.55
	3.78	0.08	40.54	0.09	52.76	0.14	0.27	0.82	98.48
	0.74	0.11	48.04	0.00	51.22	0.13	0.21	1.17	101.62
	0.76	0.08	48.54	0.00	50.04	0.11	0.17	0.52	100.22
	0.85	0.31	48.37	0.05	50.58	0.08	0.15	0.32	100.71
	1.24	0.08	48.21	0.05	50.01	0.12	0.21	0.43	100.35
	0.67	0.19	48.12	0.02	50.57	0.14	0.17	1.26	101.14
	0.67	0.16	47.98	0.05	50.53	0.10	0.11	1.09	100.69
0.67	0.11	47.79	0.02	50.10	0.10	0.17	1.69	100.65	
0.56	0.13	47.64	0.00	50.15	0.09	0.16	1.27	100.00	
0.66	0.21	48.26	0.02	50.77	0.08	0.20	1.07	101.27	
0.48	0.18	48.08	0.01	50.24	0.12	0.17	0.33	99.61	
0.88	0.07	47.74	0.06	50.05	0.10	0.12	0.64	99.66	

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.65	0.11	46.36	0.06	51.39	0.07	0.16	0.90	99.70
0.68	0.20	47.12	0.03	51.44	0.09	0.25	1.28	101.09
1.22	0.19	46.74	0.02	51.13	0.09	0.15	0.85	100.39
1.03	0.16	47.86	0.04	50.68	0.12	0.15	0.64	100.68
0.56	0.08	47.99	0.00	50.96	0.12	0.16	1.29	101.16
0.61	0.25	47.77	0.01	50.32	0.09	0.18	1.20	100.43
0.55	0.09	47.80	0.06	51.48	0.11	0.15	1.22	101.46
0.86	0.14	47.91	0.04	50.61	0.08	0.18	1.03	100.85
0.70	0.14	46.80	0.04	51.32	0.12	0.14	1.53	100.79
2.59	0.10	46.93	0.03	49.89	0.08	0.23	0.24	100.09
0.77	0.16	51.03	0.04	46.96	0.11	0.25	0.66	99.98
0.58	0.12	49.64	0.00	48.61	0.10	0.27	0.43	99.75
0.49	0.18	50.23	0.00	46.75	0.12	0.29	1.84	99.90
2.21	0.12	47.95	0.02	48.26	0.11	0.36	0.54	99.57
0.46	0.11	43.90	0.04	50.86	0.10	0.63	4.17	100.27
0.37	0.20	49.70	0.00	47.05	0.11	0.36	1.40	99.19
1.09	0.14	48.42	0.03	49.62	0.11	0.13	0.48	100.02
1.26	0.15	49.67	0.08	46.94	0.11	0.52	0.62	99.35
0.91	0.16	49.99	0.01	46.44	0.13	0.23	0.88	98.75
0.96	0.26	49.60	0.03	48.18	0.15	0.11	0.58	99.87
0.94	0.14	48.48	0.00	46.37	0.10	0.28	2.22	98.53
0.54	0.17	50.11	0.00	47.87	0.14	0.29	0.62	99.74
0.93	0.10	49.80	0.04	46.87	0.10	0.15	0.50	98.49
0.83	0.14	50.40	0.07	48.36	0.11	0.14	0.23	100.28
0.59	0.21	50.14	0.00	46.60	0.07	0.68	1.10	99.39
0.73	0.12	50.09	0.02	47.46	0.13	0.21	0.48	99.24
0.60	0.10	47.11	0.00	50.68	0.08	0.16	0.72	99.45
0.77	0.08	50.86	0.00	46.78	0.12	0.22	0.75	99.58
0.58	0.14	49.82	0.00	47.92	0.11	0.17	1.21	99.95
0.53	0.07	49.48	0.06	48.52	0.10	0.31	1.01	100.08
0.45	0.11	46.50	0.00	50.01	0.12	0.22	2.30	99.71
0.42	0.03	49.16	0.01	47.55	0.10	0.45	2.68	100.40
0.81	0.15	49.93	0.05	47.34	0.09	0.29	1.16	99.82
0.69	0.08	47.91	0.00	50.16	0.09	0.15	0.86	99.94
0.58	0.11	46.64	0.00	49.55	0.13	0.30	2.44	99.75
0.58	0.13	49.85	0.03	47.95	0.12	0.21	0.59	99.46
0.55	0.17	50.19	0.00	47.86	0.09	0.34	1.22	100.42
0.54	0.09	49.39	0.07	47.67	0.09	0.22	1.38	99.45
1.29	0.21	47.31	0.03	50.73	0.11	0.15	0.59	100.42
1.00	0.12	48.63	0.01	47.00	0.11	0.38	1.36	98.61
1.01	0.04	47.00	0.00	50.20	0.15	0.35	1.64	100.39
0.93	0.18	50.48	0.00	46.86	0.11	0.17	0.73	99.46
1.26	0.15	45.72	0.00	49.80	0.11	0.39	2.03	99.46
0.62	0.14	48.10	0.04	51.14	0.12	0.16	1.12	101.44
0.68	0.16	50.88	0.05	46.22	0.10	0.17	0.97	99.23
0.60	0.13	47.43	0.00	51.26	0.09	0.16	1.31	100.98
0.66	0.07	48.30	0.01	50.89	0.10	0.15	0.93	101.11
0.67	0.06	51.41	0.01	46.14	0.12	0.34	1.29	100.04
0.40	0.17	49.91	0.06	49.37	0.11	0.39	0.32	100.73
0.84	0.18	51.21	0.02	47.76	0.12	0.15	1.00	101.28
0.68	0.13	47.81	0.05	50.06	0.11	0.15	1.86	100.85
0.68	0.16	47.66	0.00	51.33	0.10	0.15	0.89	100.97
0.44	0.14	47.08	0.00	49.06	0.10	0.41	3.29	100.52
0.57	0.14	46.26	0.05	52.31	0.10	0.14	1.93	101.50
0.69	0.10	48.91	0.04	50.02	0.11	0.15	0.57	100.59
0.64	0.17	47.42	0.02	50.99	0.09	0.18	1.29	100.80

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

0.61	0.14	48.96	0.00	48.05	0.08	0.35	1.71	99.90
0.54	0.13	49.38	0.05	46.96	0.11	0.24	1.86	99.27
0.62	0.04	49.63	0.04	48.62	0.11	0.15	0.90	100.11
0.62	0.05	47.14	0.00	51.12	0.12	0.21	2.20	101.46
0.63	0.03	49.56	0.00	48.87	0.11	0.13	0.68	100.01
0.54	0.13	49.80	0.05	48.53	0.10	0.17	1.59	100.91
0.49	0.02	46.42	0.03	49.75	0.09	0.58	2.49	99.87
0.81	0.00	48.31	0.05	50.97	0.09	0.13	0.31	100.67
0.56	0.03	49.42	0.03	50.03	0.11	0.15	0.25	100.58
0.61	0.16	48.08	0.00	50.30	0.10	0.12	0.89	100.26
1.24	0.01	47.99	0.00	51.10	0.14	0.17	0.55	101.20
0.74	0.19	47.83	0.00	50.07	0.10	0.13	1.05	100.11
3.26	0.10	47.50	0.02	47.03	0.09	0.18	0.73	98.91
0.59	0.13	46.81	0.00	51.34	0.07	0.23	1.50	100.67
0.83	0.11	49.01	0.00	49.85	0.09	0.14	0.29	100.32
0.66	0.11	46.87	0.00	50.68	0.07	0.30	1.39	100.08
0.90	0.06	49.38	0.03	50.42	0.10	0.14	0.40	101.43
1.25	0.10	48.63	0.02	50.43	0.09	0.16	0.47	101.15
0.65	0.18	48.14	0.07	50.40	0.08	0.14	0.66	100.32
0.81	0.15	48.48	0.00	49.13	0.09	0.15	0.33	99.14
0.64	0.17	50.05	0.02	48.28	0.10	0.39	0.59	100.24
0.51	0.18	46.93	0.00	50.90	0.10	0.25	1.39	100.26
0.91	0.14	48.59	0.07	50.10	0.09	0.17	0.68	100.75
0.88	0.09	48.71	0.00	51.35	0.11	0.19	0.26	101.59
0.65	0.09	47.62	0.08	50.55	0.09	0.18	0.87	100.13
0.89	0.15	47.85	0.04	50.57	0.10	0.17	0.24	100.01
0.60	0.14	47.33	0.07	50.48	0.14	0.19	1.38	100.33
0.54	0.14	48.69	0.02	50.29	0.11	0.16	0.77	100.72
1.39	0.18	47.05	0.02	49.47	0.08	0.19	0.78	99.16
0.53	0.10	46.65	0.01	49.80	0.09	0.13	1.47	98.78
0.67	0.22	47.63	0.00	49.95	0.13	0.20	1.10	99.90
0.60	0.14	47.62	0.02	49.59	0.09	0.20	1.22	99.48
0.81	0.11	47.67	0.00	49.91	0.11	0.16	0.34	99.11
0.61	0.13	46.34	0.00	50.37	0.10	0.18	1.37	99.10
0.74	0.11	47.90	0.05	49.78	0.08	0.12	1.22	100.00
0.60	0.04	48.09	0.02	49.96	0.10	0.16	1.14	100.11
0.61	0.10	48.25	0.00	49.74	0.11	0.17	0.83	99.81
0.69	0.11	48.14	0.00	50.84	0.08	0.16	1.02	101.04
0.74	0.04	47.45	0.00	51.93	0.11	0.15	0.98	101.40
1.44	0.03	48.09	0.03	51.22	0.10	0.18	0.72	101.81
0.91	0.13	48.56	0.00	50.04	0.13	0.15	0.68	100.60
0.67	0.05	48.70	0.00	50.67	0.11	0.17	1.00	101.37
0.60	0.10	48.32	0.03	50.58	0.12	0.19	1.34	101.28
0.58	0.06	47.27	0.03	51.31	0.09	0.21	1.87	101.42
0.63	0.00	45.73	0.00	52.18	0.07	0.16	1.09	99.86
0.63	0.00	45.01	0.00	53.59	0.13	0.16	1.27	100.79
0.65	0.00	45.43	0.13	53.35	0.11	0.19	0.86	100.72
0.92	0.00	46.01	0.06	50.32	0.10	0.23	2.07	99.71
0.61	0.17	46.25	0.00	53.03	0.13	0.20	1.14	101.53
0.72	0.03	47.55	0.04	51.97	0.11	0.16	1.03	101.61
0.54	0.00	45.63	0.06	52.59	0.09	0.23	1.89	100.83
1.01	0.00	46.06	0.00	53.91	0.12	0.17	0.61	101.88
1.09	0.01	45.73	0.01	53.46	0.12	0.18	0.73	101.33
0.55	0.15	47.29	0.02	51.22	0.12	0.24	1.43	101.02
0.59	0.14	48.60	0.01	50.50	0.09	0.17	1.07	101.17
0.65	0.05	47.70	0.00	50.74	0.15	0.20	1.07	100.56

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

	0.53	0.09	47.51	0.03	51.88	0.10	0.19	1.47	101.80
	0.61	0.12	47.50	0.04	49.98	0.10	0.13	0.81	99.29
	0.73	0.16	47.46	0.00	50.85	0.14	0.15	1.04	100.53
	0.62	0.16	46.26	0.00	51.30	0.09	0.14	1.76	100.33
	0.64	0.08	49.68	0.00	50.14	0.09	0.17	0.82	101.62
	0.80	0.18	48.64	0.06	51.08	0.09	0.18	0.49	101.52
	0.61	0.19	47.17	0.00	52.16	0.10	0.12	1.64	101.99
	0.66	0.28	47.43	0.00	50.32	0.12	0.23	1.04	100.08
	0.64	0.24	47.27	0.01	49.05	0.14	0.14	1.24	98.73
	1.23	0.15	45.90	0.00	48.55	0.11	0.13	0.38	96.45
	1.16	0.06	47.93	0.04	49.50	0.08	0.17	0.55	99.49
	1.40	0.04	48.15	0.00	50.53	0.08	0.15	0.41	100.76
	1.02	0.13	48.28	0.06	50.71	0.07	0.17	0.33	100.77
	0.82	0.22	47.26	0.02	51.59	0.10	0.18	0.88	101.07
	0.59	0.23	45.83	0.00	49.85	0.09	0.24	1.55	98.38
	0.74	0.18	45.71	0.00	50.14	0.12	0.17	1.61	98.67
	1.49	0.14	49.81	0.00	49.39	0.09	0.16	0.65	101.73
	0.54	0.10	48.23	0.00	50.38	0.10	0.15	1.66	101.16
	0.78	0.09	47.27	0.04	50.73	0.08	0.16	0.93	100.08
	0.87	0.18	48.99	0.01	50.94	0.10	0.18	0.44	101.71
	0.60	0.12	48.05	0.02	50.23	0.12	0.16	1.00	100.30
	0.69	0.12	47.21	0.01	51.26	0.11	0.16	1.25	100.81
	1.10	0.12	50.38	0.06	46.29	0.08	0.17	1.78	99.98
AVG.	0.80	0.12	48.02	0.02	50.00	0.10	0.20	1.06	100.33
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18	0.55	0.06	45.62	0.00	53.66	0.06	0.22	1.47	101.64
	0.59	0.03	44.96	0.00	52.74	0.07	0.31	1.80	100.50
	0.57	0.03	44.74	0.00	52.58	0.05	0.32	1.48	99.77
	0.51	0.03	45.16	0.03	52.60	0.06	0.33	1.37	100.09
	0.58	0.01	46.24	0.00	52.11	0.06	0.26	1.73	100.99
	0.66	0.03	45.74	0.00	53.61	0.06	0.27	1.22	101.59
	0.58	0.08	44.96	0.00	53.15	0.06	0.29	1.48	100.60
	0.83	0.02	45.47	0.00	52.97	0.07	0.23	1.33	100.92
	0.58	0.07	45.78	0.00	53.25	0.07	0.19	1.43	101.37
	0.57	0.07	46.19	0.00	51.76	0.05	0.15	1.63	100.42
	0.59	0.05	45.48	0.00	53.04	0.08	0.31	1.75	101.30
	0.60	0.03	44.78	0.00	53.63	0.09	0.27	2.07	101.47
	0.56	0.06	45.84	0.02	53.18	0.04	0.33	1.70	101.73
	0.63	0.05	45.63	0.00	53.45	0.07	0.29	1.63	101.75
	0.54	0.00	43.80	0.00	54.24	0.04	0.34	2.87	101.83
	0.56	0.08	45.58	0.01	52.43	0.05	0.27	1.04	100.02
	0.76	0.07	45.01	0.00	52.11	0.05	0.18	0.87	99.05
	0.67	0.04	47.07	0.00	50.60	0.04	0.12	0.38	98.92
	0.74	0.06	45.82	0.00	52.09	0.05	0.14	1.08	99.98
	0.61	0.00	44.22	0.00	51.45	0.05	0.26	1.76	98.35
	1.09	0.13	46.73	0.05	50.28	0.05	0.13	0.91	99.37
	0.59	0.10	45.12	0.00	51.76	0.07	0.23	1.27	99.14
	0.53	0.04	45.85	0.02	51.86	0.06	0.25	1.52	100.13
	0.59	0.02	46.89	0.00	53.15	0.05	0.11	0.71	101.52
	0.60	0.04	45.16	0.00	51.57	0.05	0.25	1.76	99.43
	0.56	0.19	45.17	0.00	52.88	0.06	0.41	1.78	101.05
	1.42	0.01	46.84	0.00	50.00	0.06	0.16	0.55	99.84
AVG.	0.65	0.05	45.55	0.00	52.45	0.06	0.25	1.43	100.47

ILMENITE MINERAL CHEMISTRY - PROVENANCE STUDY

	0.43	0.07	46.81	0.02	50.47	0.02	0.23	1.53	99.58
AVG.	0.87	0.04	46.65	0.01	51.09	0.02	0.17	1.13	99.99

I10	2.12	0.06	46.67	0.00	50.65	0.08	0.07	0.13	99.78
	1.81	0.04	46.36	0.00	51.25	0.12	0.06	0.20	99.84
	2.00	0.08	46.17	0.00	51.11	0.08	0.05	0.20	99.69
	1.86	0.04	47.59	0.00	50.60	0.11	0.07	0.17	100.44
	1.77	0.00	47.12	0.00	51.26	0.09	0.06	0.08	100.38
	1.80	0.02	47.25	0.00	51.10	0.09	0.05	0.06	100.37
	1.86	0.00	46.73	0.00	51.64	0.11	0.06	0.04	100.44
	1.90	0.00	46.32	0.00	51.52	0.10	0.06	0.04	99.94
	1.99	0.03	45.73	0.00	51.16	0.10	0.05	0.13	99.19
	2.13	0.00	45.63	0.00	49.94	0.11	0.06	0.06	97.93
	2.05	0.04	46.60	0.00	52.23	0.11	0.07	0.13	101.23
	2.82	0.04	46.44	0.00	52.24	0.14	0.03	0.17	101.88
	2.11	0.02	46.38	0.00	51.33	0.12	0.07	0.15	100.18
AVG.	2.02	0.03	46.54	0.00	51.23	0.10	0.06	0.12	100.10

I11	2.33	0.05	46.93	0.00	51.61	0.17	0.03	0.06	101.18
	1.93	0.00	46.42	0.00	51.22	0.10	0.05	0.10	99.82
	1.55	0.05	47.45	0.00	50.79	0.14	0.08	0.13	100.19
	1.83	0.03	47.67	0.00	50.99	0.10	0.07	0.15	100.84
	2.62	0.06	46.61	0.00	51.68	0.10	0.10	0.13	101.30
	3.28	0.07	45.06	0.00	52.16	0.13	0.07	0.28	101.05
	AVG.	2.26	0.04	46.69	0.00	51.41	0.12	0.07	0.14

I12	0.41	0.11	45.31	0.02	53.12	0.00	0.01	0.41	99.38
	0.40	0.05	47.92	0.00	50.57	0.00	0.01	0.32	99.27
	0.43	0.08	44.66	0.01	53.30	0.00	0.02	0.76	99.27
	0.41	0.09	47.58	0.00	51.32	0.01	0.01	0.68	100.09
	0.38	0.48	52.57	0.13	44.20	0.01	0.02	0.38	98.19
	0.36	0.08	46.11	0.04	52.05	0.01	0.03	0.61	99.28
	0.43	0.06	47.21	0.00	50.96	0.00	0.03	0.82	99.51
	0.32	0.08	48.34	0.02	51.32	0.01	0.01	0.32	100.42
	0.38	0.07	43.58	0.05	53.47	0.03	0.04	0.69	98.32
	0.40	0.04	46.77	0.00	52.29	0.02	0.00	0.71	100.23
	0.41	0.32	48.59	0.18	48.48	0.02	0.04	0.67	98.70
	0.35	0.07	46.34	0.00	52.47	0.02	0.03	0.58	99.84
	0.38	0.47	57.20	0.12	42.26	0.03	0.02	0.37	100.84
	0.39	0.14	47.45	0.00	53.20	0.05	0.05	0.75	102.05
	0.34	0.08	47.76	0.04	51.93	0.02	0.04	0.66	100.87
	0.42	0.05	46.96	0.00	52.00	0.02	0.02	0.87	100.33
	0.43	0.03	46.96	0.00	52.18	0.01	0.04	0.91	100.56
0.30	0.08	47.56	0.02	52.07	0.02	0.01	0.32	100.39	
AVG.	0.39	0.13	47.72	0.04	50.96	0.02	0.02	0.60	99.86