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# THE STRATIGRAPHY AND GEOCHEMISTRY OF THE RIETGAT FORMATION BETWEEN ALLANRIDGE AND BOTHAVILLE, FREE STATE PROVINCE.

## By

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#### ABSTRACT

An extensive lithological and geochemical appraisal of the Rietgat Formation was undertaken. This involved the collection and analysis of 389 borehole core samples in the area between Allanridge and Bothaville, as well as 23 outcrop samples from the T'Kuip hills. Given the relative visual and petrographic homogeneity of the lavas of the Rietgat Formation, the purpose of the exercise was to establish whether these rocks may be sub-divided on the basis of their geochemistry. Five distinct lava units were identified according to their  $P_2O_5/Zr$  characteristics and accordingly named Units 1-5. Conventional discrimination diagrams were applied to the data and elucidated a rhyodacitic-andesitic-basaltic affinity for the lava series. Two sedimentary units (the Upper Sedimentary Horizon and Lower sedimentary Horizon) were also recognised.

Using a selection of incompatible elements, ( $P_2O_5$ , TiO<sub>2</sub>, Zr, Nb, V and Y) in addition to limited REE data, it was proven with reasonable confidence (in the absence of isotopic data) that the lavas of the Rietgat Formation represent the partial melting of an enriched mantle source, followed by subsequent fractionation of this material. The REE characteristics of the lavas are consistent with contamination and fractionation, which have been explained here in terms of an AFC process. It is proposed that the 5 distinct lava units were in fact consanguinous and were the product of an RTF-type magma chamber in the lower crust.

Petrographic and XRD data indicate lower greenschist facies metamorphism of the lavas. Fluid inclusion studies determined that the quartz veining in the lavas is of lower temperature and lower pressure than that characterised by the metamorphic facies. The veining is therefore interpreted as being of later origin.

Interpreted sedimentary processes facilitate the identification of graben structures due to the presence of clastic-wedge type sedimentation in the vicinity of fault scarps. Field and geochemical evidence in combination are consistent with rifting and associated magmatism of the Rietgat Formation.

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#### **CHAPTER 1: INTRODUCTION.**

#### 1.1 Background.

The late Archaean to early Proterozoic Ventersdorp Supergroup comprises a major volcano-sedimentary province situated on the Kaapvaal craton of South Africa (Figure 1.1). The succession is relatively well preserved and largely undeformed, covering an elliptical area in excess of 200,000km<sup>2</sup> (Winter, 1995; Van der Westhuizen *et al.*, 1991; Myers, 1990). The Ventersdorp Supergroup consists of three subdivisions, which in ascending order are the Klipriversberg and Platberg Groups, followed by the sediments and lavas of Bothaville and Allanridge Formations respectively (Figure 1.2). Recent isotope studies (Armstrong *et al.*, 1991; Robb *et al.*, 1991) suggest ages in the order of 2700 Ma for the entire Supergroup.

The Rietgat<sup>1</sup> Formation is the uppermost unit of the Platberg Group (Figure 1.2) and comprises a geochemically hetrogeneous assemblage of mafic and felsic lavas and tuffs in association with chemical and clastic sediments. Occasional weathering surfaces (Winter,1976) seen in the underlying Makwassie Formation, suggest local disconformity between the Makwassie and Rietgat Formations due to terrestrial exposure. Elsewhere this relationship is conformable. Over large areas the Rietgat Formation is overlain unconformably by the sediments of the Bothaville Formation. Where the Bothaville Formation is absent from the sequence, the lavas of the Allanridge Formation come into direct contact with those of the Rietgat Formation.

<sup>&</sup>lt;sup>1</sup> The name Rietgat comes from the farm 'Rietgat', on which the type borehole (RG1) for the Formation is situated (Winter, 1976; SACS, 1980).

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Figure 1.1 Distribution of the Ventersdorp Supergroup (after SACS, 1980).

d J	FORMATION		VOLCANIC ROCKS			SEDIMENTARY ROCKS		TECTONICS		
GRO	FORMATION	Felsic Porphyry	Interme – diate Porphyry	Mafic lava	Pyroclastic rocks	Rudites	Arenites	Topo- graphy	Gra - bens	Erosional Uncon- formity
	ALLANRIDGE				$\diamond$				<u>_</u>	
<u> </u>	BOTHAVILLE								1	
	RIETGAT									
BERG	MAKWASSIE			$\diamond$		· 🚷				
PLAT	GOEDGENOEG									
	KAMEELDOORNS				۲					
KLIPRIVIERS- BERG	EDENVILLE LORAINE JEANNETTE AGGLOMERATE ORKNEY ALBERTON POR- PHYRY WESTONARIA				<b>\</b>				- WW-	

**Figure 1.2** Stratigraphic subdivision, lithologies and associated tectonics of the Ventersdorp Supergroup (after Van der Westhuizen *et al.*,1991).

The stratigraphic setting of the Ventersdorp Supergroup is of particular interest to the exploration geologist since it directly overlies the gold-bearing Witwatersrand strata. Despite being a formation of considerable thickness and diversity of material, no economic mineralisation has been found within the Ventersdorp Supergroup.

#### 1.2 Study Area.

The study area (Figure 1.3) is located between the towns of Allanridge and Bothaville, in the Free State. Core from 20 holes was examined, covering an area of approximately  $127 \text{ km}^2$ .



**Figure 1.3** Map of the study area indicating borehole localities and position of structural sections (Figures 2.23a and b) (*key on following page*).

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(Key to map on previous page)

Borehole core sections and their corresponding logs were made available by the Target and Sun Divisions of Anglovaal Ltd. at both their Allanridge and Hartebeesfontein establishments. The selection of individual boreholes for examination was made on the basis of the degree of development of the Rietgat Formation contained therein, as observed in the Anglovaal logs. Additional logs of 20 other Anglovaal boreholes (the core of which was not examined during the course of this study) were provided in order to assist the process of lateral correlation. While the Rietgat Formation remains the main focus of the present study, logging and sampling of Klipriviersberg and Allanridge lavas was also undertaken in order to monitor the geochemical evolution both prior and subsequent to the emplacement of the Rietgat Formation. A list of boreholes which were relogged and sampled during the course of this study is presented in Table 1.1.

#### Explanation of sample and borehole nomenclature.

It is appropriate at this stage to provide an explanation of the system by which boreholes and samples have been named and numbered. The alphabetic sample prefix is an abbreviation of the farm name within which the borehole is situated. A summary of all farm names relevant to this study is given in Table 1.2.

Borehole	N-S*	E-W*	Acknowledged Geologist (Logging)	Date
DKL5	64,749.86	37,556.17	A. C. Owens	04-12-92
DKL6	65,861.00	38,581.07	G. W. Edwards	13-10-92
DKL8	64,410.00	39,140.00	J. Crozier (provisional logging only)	10-06-97
DKP1	57,678.80	34,639.09	J. Wiegand	09-04-86
ERO2	68,117.04	38,938.71	A. C. Goldsmith	22-03-93
ERO3	68,145.00	38,041.00	D. M. Le Roux	02-04-93
ERO4	68,043.31	38,535.88	G. W. Edwards	03-12-94
KFN2	60,450.13	39,902.46	J. Wiegand	13-10-85
LRP3	65,931.64	37,320.93	J. Nicholls	11-12-92
MAI	53,571.90	37,073.40	J. Wiegand	03-12-85
MA2	51.887.10	36,207.62	P. G. Norman	23-06-89
MALI	61,063.10	36,425.00	J. Wiegand	26-08-85
MAL4	63,513.16	39,256.55	M. A. Van den Berg	23-06-89
NVTI	44,949.49	38,723:80	··† ·	.†
PDEI	67,571.00	38,789.00	J. Nicholls	15-03-93
S3	66,311.00	38,967.00	A. C. Owens	21-11-92
S4	67,329.00	39,041.00	D. M. Le Roux	12-02-93
S5	65,876.57	39,257.62	W. Marais	19-08-91
S6	67,060.21	38,501.53	N. Williams	10-02-93
TNT2	56,093.17	38,050.41	F. Martens	01-10-90

 Table 1.1
 Location of Anglovaal boreholes investigated by the present study.

\* longitudinal and latitudinal co-ordinates.

† unavailable at time of writing.

Since many boreholes are generally sited on the same farm, the alphabetic prefix is followed by a further digit, which refers to the specific borehole. The final part of the code, separated from the borehole location by a hyphen, concerns the individual

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sample. These numbers are unique to each sample and increase with depth. For example, a sample bearing the number 'DKL6-15' originates from borehole number 6 on the Dreyerskuil farm and is the 15<sup>th</sup> sample from the surface.

Table 1.2	Summary of farm names and borehole abbreviations adopted by this
	study.

Farm Name	Abbreviation
Siberia	S
Eldorado	ERO
Paradise	PDE
Le Roex's Pan	LRP
Dreyerskuil	DKL
Mariasdal	MAL
Kruidfontein	KFN
Doornknop	DKP
Twistnet	TNT
Mara	MA
Nooitverwacht	NVT

#### 1.3 Research Objectives.

This project forms part of a greater study conducted in co-operation with Billiton SA Ltd., the intentions of which have been to elucidate the geochemical characteristics of extrusive igneous provinces. The primary aims of this study were:

- To establish a detailed stratigraphy for the Rietgat Formation, based on geochemical analyses and field observations.
- To determine, by means of correlation between holes, the nature of any post or syn-depositional crustal movements that may have taken place.
- To determine whether any stratigraphic units can be distinguished on the basis of their geochemistry and/or mineralogy. If so, whether these geochemically and/or mineralogically defined units may be correlated between boreholes as well as at remote localities.
- To develop a simple genetic model explaining the observed geochemical variations and accounting for the emplacement of the Rietgat volcanosedimentary rocks.

#### 1.4 Previous Research.

The Ventersdorp Supergroup has been the focus of much research, though only a small amount of this work pertains to the Rietgat Formation. Although previous work is alluded to throughout this study a brief literature review is presented here.

#### 1.4.1 Pioneering Studies.

Wyley (1859), Hatch (1903) and Corstorphine (1903, 1904, 1906) deserve credit for their pioneering role in Ventersdorp exploration. Their work dealt mainly with aspects of stratigraphy and lithologicical correlation. Nel (1927, 1935), Nel *et al.*,

(1935, 1939), Beetz (1937), Jacobson (1940), Matthyssen (1953), Pienaar (1956) and Haughton (1969) should also be recognised for initiating research interest in the Ventersdorp Supergroup.

### 1.4.2 Broader scale interpretation of the Ventersdorp Supergroup.

Perhaps the most comprehensive and widely acclaimed work regarding the stratigraphic subdivision of the Ventersdorp Supergroup is that of Winter (1976), a publication which represented the culmination of a number of years research work at the University of the Witwatersrand (Winter 1961, 1962, 1963, 1964, 1965, 1965b). The recommendations of Winter's 1976 paper were subsequently adopted by SACS (1980), an abridgement of which is presented in Figure 2.1.

#### 1.4.3 Structure and Tectonics.

Tectonic development during Ventersdorp times has been discussed by Bickle and Eriksson (1982), Schweitzer and Kröner (1985), Burke *et al.* (1985, 1986), Winter (1986, 1987), Stanistreet *et al.* (1986), Clendenin (1989), Clendenin *et al.* (1988a, 1988b, 1989) and McCarthy *et al.* (1990a). Most of these researchers concluded that the Ventersdorp Supergroup formed as a result of rifting associated with the collision of the Zimbabwe and Kaapvaal cratons. Visser and Grobler (1985) studied the interplay between volcanic and sedimentary processes during Rietgat and Bothaville times, while Meintjes *et al.* (1989) discussed volcano-sedimentary processes in terms of a regional structural model. Pienaar (1956), Visser (1957), Crockett (1971) and Tyler (1979 proposed that large-scale faulting acted as a conduit system for ascending magmas.

#### 1.4.4 Geochemistry.

Geochemical investigations of the Ventersdorp lavas have been undertaken throughout the area of the Witwatersrand basin by Palmer *et al.* (1986), Myers *et al.* (1990), Linton (1992) and Linton and McCarthy (1993). Similar studies were also carried out in the Western Transvaal: T. B. Bowen (1984), Schweitzer and Kröner (1985), Bowen *et al.* (1986a, 1986b) and Crow and Condie (1988) studied the geochemistry of the Ventersdorp Supergroup volcanic rocks and attempted to constrain their tectonic setting by using conventional discrimination techniques. With reference to trace element data, Myers *et al.* (1987) argued that the Kaapvaal volcanic pile is tholeiitic and of lithospheric origin; McIver *et al.* (1982) and Grobler *et al.* (1986) proposed a komatiitic affinity for the same suite of rocks.

#### 1.4.5 Mineral Paragenesis.

According to Labuschagne (1974), the mineral assemblages encountered throughout the sequence are representative of a quartz-albite-epidote-biotite sub-facies of metamorphism. Petrographic investigation by Cornell (1977, 1978) confirmed this feature. M. P. Bowen (1984) also recognised lower greenschist facies metamorphic assemblages throughout the Ventersdorp Supergroup.

#### 1.5 Analytical Methods.

Major oxide and trace element concentrations were determined by means of XRF at University of the Free State and REE's by ICP-MS at the University of Cape Town. For a comprehensive listing of all XRF analyses undertaken during the course of this study, the reader is referred to Appendix 3. It is important to note that the aforementioned data are raw and that normalisation to 100 wt.% and the omission of highly altered samples (based on variably high LOI's) was undertaken prior to inclusion in the discrimination diagrams in this study. An explanation of analytical procedures is given in Appendix 1.

#### **CHAPTER 2: THE STRATIGRAPHY OF THE RIETGAT FORMATION.**

#### 2.1 Introduction.

Although previous subdivisions of the Rietgat Formation, as seen between Bothaville and Allanridge have been considered here, greater emphasis has been placed on the synthesis of a revised system of division based on the findings of the current study (Figure 2.4). The findings of this chapter have been presented in the form of borehole logs (Figures 2.26-2.38). It should be noted that the geochemical profiles, which have been included in these sections, are of little consequence to the current chapter. For an interpretation of downhole variations in geochemistry, the reader is referred to Chapters 4 and 5.

#### 2.2 Previous Sub-divisions and Stratigraphy of the Rietgat Formation.

Winter (1976) observed a group of porphyritic lavas near the base of the Rietgat Formation. distinguishable from the underlying Makwassie Formation porphyries only by the fact that they were non-acidic. Winter named this unit the Garfield Member, suggesting that these lavas may be contemporaneous with other quartz porphyries generally occurring in the lower portion of the Rietgat. Away from the Rietgat type section of Winter (1976), (Figure 2.1), the member may contain non-porphyritic and sedimentary intercalations. Winter furthermore argued that the Garfield Member may also become a member of the Makwassie Formation where it is overlain by quartz porphyry flows. Indeed, it has been suggested by Winter (1976) that in certain places part or all of the Rietgat Formation may be contemporaneous with the Makwassie Formation.



**Figure 2.1** Type section borehole **RG1** for the Rietgat Formation, as envisaged by Winter (1976).

With regard to the upper portion of the Rietgat Formation, Winter (1976) concluded that sediments become dominant over lavas in terms of their abundance. Although of considerable thickness, these sediments never contain the large quantities of coarse clastic debris characteristic of the Kameeldoorns Formation (Figure 1.2). Winter (1963, 1976) and Buck (1980) observed algal stromatolites and lacustrine limestones, which manifest themselves in the upper portion of the Rietgat Formation. Karpeta (1989) noted that in the Hartebeestfontein area, the Rietgat Formation contains stromatolites and cherts, which he proposed formed part of a magadiitic playa lake system.

While working in the Welkom area of the Free State, Buck (1980) noted that certain fault-controlled basins did not contain any of the lavas characteristic of the Platberg Group further to the north. The absence of such lavas reveals that sedimentation was continuous in large areas that were not affected by volcanism. These observations prompted Buck (1980) to propose the localised addition of a new formation to the Ventersdorp Supergroup: this, the Klippan Formation, is a lithostratigraphic equivalent of the Kameeldoorns and Rietgat Formations as seen in the northern Free State. According to Buck (1980), the Klippan Formation comprises two fining-upward sequences, to which the names Video and Dirksburg members have been applied.

### Note on the correlation of the Platberg Group at other localities.

The Platberg Group volcano-sedimentary successions may also be recognised at localities away from their type area, an example of such an occurrence being the Sodium Group at T'Kuip (Figure 2.2). A consistent resemblance in the lithology, stratigraphy and inferred conditions of deposition may be seen between the Sodium Group and the Platberg Group in the Bothaville area, as classified by Winter in 1976 (SACS, 1980). Furthermore, Grobler *et al.* (1975) were able to distinguish the entire Platberg Group in a series of boreholes between Tuang and Britstown in the Northerm Cape province. Although the South African Committee for Stratigraphy has since accepted these correlations to be valid, a geochemical appraisal of the Sodium and

Platberg Groups has been incorporated at a later stage in the present study, in order to confirm the macroscopic observations of previous workers.



Figure 2.2 Type area of the Sodium Group, T'Kuip (after Grobler and Emslie, 1975, 1976 and SACS, 1980)

#### 2.3 Geochronology.

Apart from constraining the age of the Ventersdorp Supergroup geochronological work is of considerable importance in that it provides a minimum age for the underlying Witwatersrand Supergroup. As the worlds largest known gold deposit, the Witwatersrand Supergroup is the subject of many genetic models, essential to which are accurate age constraints. Since the sediments of the Witwatersrand basin do not lend themselves to age-dating (Armstrong *et al.*, 1986, 1991), it is evident that geochronologists must instead derive age-constraints from adjacent formations.

Much controversy exists regarding the precise age of the Ventersdorp Supergroup. A variety of geochronological techniques have been applied in an attempt to solve this problem, yielding a range in dates from a number of localities. Linton (1992) noted that these dates fall into two ranges, a younger set, ranging from 2140 Ma to 2470 Ma and an older set ranging from 2630 Ma to 2730 Ma. A summary of such age determinations for the Ventersdorp Supergroup is presented in Tables 2.1 and 2.2 (adapted from Linton, 1992), accompanied by references for each age, as well as the geochronological method used.

It may be seen that the majority of the younger ages shown in Tables 2.1 and 2.2 were determined using whole-rock methods (Rb-Sr and Pb-Pb). The preponderance of older ages were, however, determined by U-Pb or Pb-Pb techniques performed on individual zircon grains.

The most recent and reliable zircon ages of the Orkney, Goedgenoeg, Makwassie and Allanridge Formations (Figure 1.2) in the Western Transvaal (as determined by Armstrong *et al.*, 1991) are 2714 Ma, 2710 Ma, 2709 Ma and 2700 Ma, respectively. These dates were ascertained by U-Pb ion microprobe analysis and have been adopted as standards in the present study. It follows, therefore, that the Ventersdorp Supergroup was erupted over a period of 14 Ma and more specifically, that the Rietgat Formation was erupted in 9 Ma - or possibly less - between 2709 Ma and 2700 Ma.

p in the 2140-2470 Ma range.

METHOD	LOCATION	AGE (Ma)	REF.	
Rb-Sr (whole rock)	Klerksdorp (Makwassie Formation)	2140 ± 260	l	
Rb-Sr (whole rock)	Lobatse (Quartz Porphyry)	2200 ± 100	2	
Rb-Sr (whole rock)	Lobatse (Quartz Porphyry)	$2215 \pm 100$	2	
Rb-Sr (whole rock)	Lobatse (Quartz Porphyry)	2230 ± 120	2	
U-Pb (zircon)	26°52'S, 26°39'E (Ventersdorp Lava)	2238 ± 100	3	
U-Pb (zircon)	26°52'S, 26°39'E (Ventersdorp Lava)	$2245 \pm 90$	3	
U-Pb (zircon)	26°52'S, 26°39'E (Ventersdorp Lava)	2300 ± 100	4	
Pb-Pb (whole rock)	Klerksdorp (Makwassie Formation)	2350 ± 170	1	
Pb-Pb (whole rock)	Mondeor, Jhb (Klipriviersberg Group)	2360 ± 335	1	
Pb-Pb (whole rock)	Mondeor, Jhb (Klipriviersberg Group)	2368 ± 249	6	
Pb-Pb (whole rock)	Eikenhof, Jhb (Klipriviersberg Group)	2370 ± 70	1.	
Pb-Pb (zircon)	Stella, Vryburg (Zoetlief Group)	2470 ± 100	3	
U-Pb (apatite)	Taung (Zoetlief Group)	2471 ± 100	5	

Table 2.2Ages for the Ventersdorp Supergroup in the 2630-2700 Ma Range.

METHOD LOCATION		AGE (Ma)	REF.
Pb-Pb (zircon)	Lobatse (Felsite)	2630 ± 100	3
U-Pb (zircon)	Lobatse (Quartz Porphyry)	$2630 \pm 100$	3
U-Pb (zircon)	Goedehoop (Zoetlief Group)	2634 ± 100	5
Pb-Pb (whole rock)	Klerksdorp (Makwassie Formation)	2638 ± 105	5
U-Pb (zircon)	Lobatse (Quartz Porphyry)	2640 ± 100	3
U-Pb (zircon)	Klerksdorp (Makwassie Formation)	$2643 \pm 80$	. 5
U-Pb (zircon)	Klerksdorp (Makwassie Formation)	2693 ± 60	1.
Rb-Sr (whole rock)	Lobatse (Quartz Porphyry)	2695 ± 125	2
U-Pb (zircon)	Klerksdorp (Makwassie Formation)	2699 ± 18	1

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### REFERENCES USED IN THE COMPILATION OF TABLES 2.1 AND 2.2.

- 1. Armstrong *et al.* (1986)
- 2. Burger and Coertze (1973)
- 3. Van Niekerk (1968)
- 4. Van Niekerk and Burger (1964)
- 5. Van Niekerk and Burger (1968)
- 6. Walraven *et al.* (1983)

Armstrong *et al.* (1986) and Walraven *et al.* (1983) have argued that Rb-Sr age determination techniques may be prone to giving false results, probably a consequence of low-grade metamorphism of the rocks in question, which has affected the Rb-Sr isotope systematics. In short, Armstrong *et al.* (1986) have proposed that older age determinations are representative of the true age of the lavas and that any younger dates merely represent a subsequent metasomatic event, which 'reset' certain isotope systems.

Nelson *et al.* (1992) published Sm-Nd isotope data for the Alberton and Lower Orkney Formations, which indicated dates approximately 600 Ma older than those derived by U-Pb zircon results. Nelson *et al.* (1992) have suggested that their Sm-Nd data may either represent a lithospheric fractionation event, or indeed, the mixing of more than one mantle source.

#### 2.4 The Rietgat Formation in the Study Area.

The Rietgat Formation is only encountered at depth in the Allanridge-Bothaville area, and therefore all of the observations presented in this study are based on the examination of borehole core. The locations of the boreholes in question are shown on Figure 1.3. In the majority of borehole sections, the Rietgat Formation unconformably overlies the Makwassie Formation. In certain sections, however, the Makwassie, Goedgenoeg and Kameeldoorns Formations are omitted from the sequence, bringing the Rietgat and Klipriviersberg Formations into contact with one another. Examples of this relationship include boreholes AAT1, DKL1 and S2 (Kershaw, *pers. com.*, 1997). The Rietgat Formation is unconformably overlain by the Bothaville and Allanridge Formations and increases substantially in thickness from both south to north and from east to west.

#### Note regarding the approach adopted by this study.

Due to the fact that many previous studies of the Ventersdorp Supergroup have been undertaken with considerable breadth, it is possible that sub-divisions within smaller formations (such as the Rietgat) may have been overlooked. The remainder of this investigation attempts to sub-divide the Rietgat Formation on the basis of both lithological and geochemical variation.

Similar studies of other formations have in the past followed a convention whereby the petrography of the rocks in question is addressed prior to their geochemistry. Due to the fact that petrography alone is insufficient to constrain stratigraphic subdivisions, the bulk of such demarcations presented in this study are based on criteria. It is therefore necessary for the purposes of continuity to include a brief note on the geochemical subdivisions used in this study. A more comprehensive geochemical appraisal of the Rietgat Formation stratigraphy is presented in Chapter 4.

#### 2.5 Basic geochemical subdivision of the Rietgat Formation

A number of bivariate plots utilising a range of immobile elements (P, Ti, Zr, Y, V) were constructed in order to detect clustering in the data. It was found that a plot of Zr versus  $P_2O_5$  (Figure 2.3) best illustrates the clustering of data points with respect to distinct geochemical units. In addition to these geochemically-constrained subdivisions, upper and lower sedimentary horizons were identified by visual means.



Figure 2.3 Zr vs P<sub>2</sub>O<sub>5</sub> discrimination diagram for the Rietgat Formation.

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A summary of all of the units recognised by the current study are presented in Figure 2.4, in order of increasing stratigraphic height.

UNIT REFERENCE	INFORMAL DESCRIPTIVE NAME
USH	Upper Sedimentary Horizon
5	Upper Rietgat Member - Amygdaloidal
4	Upper Rietgat Member - Non-amygdaloidal
3	Central Rietgat Member
2	Upper Garfield Porphyry
1	Lower Garfield Porphyry
LSH	Lower Sedimentary Horizon

Figure 2.4 Summary of stratigraphic units recognised in the present study.

In addition to the sub-divisions outlined in Figure 2.4, coarse-grained sheeted intrusives of basaltic composition were encountered, particularly in section DKP1 (Figure 2.30). It is proposed that this material represents a feeder system for later extrusive formations, possibly the Allanridge Formation, but more probably the Karoo lavas given the basic affinity of the rocks in question. Tuffaceous intercalations were also identified at many different stratigraphic heights throughout the study area. Due to the extreme range in composition of such material, it was not possible to include the tuffs in the geochemical classification scheme.

#### 2.6 Petrography of the Rietgat Formation.

#### Introductory Note on Alteration.

The primary mineralogy of the lavas (and to a certain extent the igneous textures) have undergone severe alteration as a result of metasomatism and metamorphism. A mineral assemblage comprising quartz + chlorite (ferroan clinochlore) + albite  $\pm$  epidote  $\pm$ actinolite  $\pm$  muscovite  $\pm$  biotite was identified by XRD and optical mineralogical studies. This assemblage is indicative of lower greenschist facies metamorphism (Winkler, 1974) and has also been identified by other studies of the Ventersdorp Supergroup (Cornell, 1978; Tyler, 1979; Schweitzer and Kröner, 1985; Crow and Condie, 1988; Grobler *et al.*, 1989; Meintjes, 1998). This paragenesis manifests itself principally as extensive silicification and chloritisation, in addition to varying degrees of epidotization.

Quartz veins and vugs, as well as amygdale fillings, attest to at least one fluid event: the results of thermometric analysis of inclusions contained therein are presented in section 3.7.1. Alteration of the Rietgat Formation in the study area may be clearly seen on a macroscopic scale in the form of bleached zones - particularly in close proximity to faults or other fissures. These zones (which should not be confused with weathering horizons) are characterised by higher facies alteration assemblages than adjacent rocks, typically displaying higher degrees of silicification and epidotisation. Figure 2.5 illustrates a mottled sample, which has undergone a moderate degree of fluid alteration: a more advanced degree of alteration may be seen in Figure 2.6, which depicts an epidotised horizon.

#### 2.6.1 Lithological and mineralogical observations.

The following paragraphs aim to provide a lithological and mineralogical overview of the Rietgat Formation according to the units described in the foregoing sections.

#### 2.6.1.1 Lower Sedimentary Horizon (LSH).

#### Distribution and disposition.

The LSH is restricted to relatively few borehole sections, principally S6, S4 and DKL6 (Figures 2.35, 2.37 and 2.38 respectively) in the south and section NVT1 in the north of the study area (Figure 2.26). As may be seen from Table 2.3, the LSH ranges between 5.9 and 14.5m in thickness - 11.73m on average, compared to nearly 35m for the USH.

The LSH comprises a series of shales and quartzwackes in association with occasional diamictites (Figure 2.7). Some very fine, layered material (Figure 2.8), possibly of pyroclastic origin was also recognised in this unit. Although grain-size ranges in diameter between 0.5 and 3.0cm in the LSH, rudaceous examples are comparatively rare in this unit. In terms of its colour, the horizon is characteristically grey, ranging from darker shades for the finer sediments, to lighter hues for the coarser material. Where identifiable, lithic clasts generally consist of detrital lava, the origin of which could not be constrained further than the Ventersdorp Supergroup. Otherwise, clasts comprise quartz (>70%), mica and occasional feldspars. Fining-upward sequences are common in the LSH and may be readily detected by the colour variation between their

fine and coarse components (Figure 3.2). Cross-bedding was also noted on a centimetre scale (Figure 2.9).

	Total Thickness of Entire Unit (metres)			Thickness of Individual Flows (metres)		
	Mean	Min.	Max.	Mean	Min.	Max.
Upper Sediment	34.76	14.91	49.10	-	-	-
Unit 5	41.03	63.00	105.00	5.77	0.03	79.88
Unit 4	28.44	6.00	78.00	3.12	0.15	23.22
Unit 3	132.30	9.80	348.00	8.39	0.43	64.95
Unit 2	49.53	14.90	116.70	21.57	9.95	53.39
Unit 1	66.08	9.80	134.00	13.78	0.10	46.12
Lower Sediment	11.73	5.90	14.50	-	-	-

**Table 2.3**Summary of the total unit and individual flow thicknesses for the KietgatFormation

A degree of silicification is evident in the LSH, as well as calcification and the concentration of secondary metallic sulphides. Alteration, although present, is less extreme than that seen in the overlying lavas: a greenschist facies assemblage is not immediately evident and little chloritisation may be seen. It is proposed that prior to alteration, the sediments were relatively mature with respect to their mineralogy, therefore the subsequent alteration product is relatively unchanged.



**Figure 2.5** Non-amygdaloidal example of Unit 3 lava, displaying mottled alteration. It is proposed that this 'mottled facies' is the product of varying degrees of fluid alteration (sample NVT1-41).



**Figure 2.6** Sparsely amygdaloidal example of Unit 3 lava, displaying elevated levels of epidotisation, as is indicated by the yellow-green coloration of the specimen (sample NVT1-31a).



**Figure 2.7** Clast-supported diamictite (USH), possibly generated as a result of fault scarp denudation, or as a flood deposit on a palaeolandsurface (sample S6-6).



**Figure 2.8** Very finely layered cryptocrystalline material of possible pyroclastic or exhalitive origin – sinter deposit? (sample ZTD1-49).

In the case of boreholes S6, NVT1 and S4 (Figures 2.35, 2.36 and 2.37), the LSH rests as a sub-conformable surficial deposit on the Makwassie Formation.

Where section DKL6 is concerned (Figure 2.38), the Makwassie and Goedgenoeg Formations (Figure 1.3) are absent from the succession. As a result, the LSH rests unconformably on the sediments of the Kameeldoorns Formation. The LSH, where present, is overlain by Unit 1 (section NVT1, Figure 2.26), Unit 3 (sections S4 and DKL6; Figures 2.37 and 2.38 respectively) and Unit 5 (section S6, Figure 2.35): in the former two cases a localised extrusive hiatus is indicated.

#### 2.6.1.2 Unit 1 (Lower Garfield Member)

#### Distribution and disposition.

Unit 1 was observed in all borehole sections north of KFN2 (Figures 1.3 2.28) and is thickest in borehole MAL1 (Figure 2.32). The total thickness of the unit ranges from 9.8 to 134m (Table 2.3), comprising individual flows of between 0.1 and 46.12m. Unit 1 is characteristically porphyritic, greenish-grey in colour, containing blebby chlorite and sub- to euhedral phenocrysts of plagioclase feldspar, principally of albitic composition (according to XRD, see Chapter 3). The aforementioned porphyries are at their coarsest towards flow centres containing plagioclase phenocrysts of up to 4mm length. It was also noted that Unit 1 coarsens considerably towards its base, where the plagioclase phenocrysts become progressively larger and more euhedral (Figure 2.10). Geochemistry aside, the porphyries of Unit 1 may be distinguished from those of Unit 2 on the grounds that they are consistently more porphyritic. Some aphanitic flow units were also seen, as were occasional amygdaloidal horizons.



**Figure 2.9** Small-scale cross-bedding in the LSH, indicating the migration of small-scale sedimentary bedforms. The intercalated quartz material (A) is possibly derived by means of secondary processes (sample ZTD1-17).



**Figure 2.10** Medium-grained porphyritic lava characteristic of Unit 1. Subhedral to euhedral albite phenocrysts are set in a quartz/chlorite groundmass (sample KFN2-24)
It is proposed for the purposes of this study that Units 1 and 2 are correlates of the Garfield Member as described by Winter (1976). Assuming that this is the case, Units 1 and 2 have been tentatively named the 'Lower' and 'Upper' Garfield Members respectively (the use of the distinction 'Member' being entirely informal in this case). Geochemical evidence to substantiate this suggestion will be given in Chapter 4.

#### Sedimentary intercalations.

Diamictite intercalations (section TNT2, Figure 2.29) and breccia horizons may also be seen on a very minor scale in Unit 1. No lateral correlation between boreholes was possible where this material was concerned due to the localised nature of its occurrence. The clastic component of these sediments is of local provenance (i.e. of Unit 1 porphyry), suggesting that a minimal degree of transport was involved. The textural immaturity of these sediments further supports the theory that very little transportation has taken place. A minor relocation of surficial detritus, itself the product of weathering, is envisaged as the mechanism of sedimentation.

The matrix of the breccias comprises grits and dark mud, which are presumed to have been derived from the same source as the clastic material. A high degree of calcification and to a lesser extent silicification and chloritisation may be seen, which are likely to be products of either diagenetic or greenschist metamorphic processes.

As far as inferences based on the presence of sedimentary intercalations are concerned, it is self-evident that some form of sub-aerial process must have prevailed. This could have been contemporaneous with lava extrusion, sedimentation having taken place on a palaeohigh, while extrusive activity continued in outlying areas. Alternatively a complete break in extrusion may have occurred, during which surface processes dominated. Whatever the case, the duration was sufficient to give rise to the denudation of source areas and the deposition of clastic sediments.

#### Inferred pseudotachylite in Unit 1.

Other notable features in Unit 1 include what has, with caution, been described as a pseudotachylite<sup>2</sup>. Killick *et al.* (1986) identified similar material at the VCR-Klipriviersberg interface, the origins of which they attributed to tectonism. Figure 2.11 illustrates a well-developed example of this material, which may be found in section NVT1 (Figure 2.24). Closer examination of the pseudotachylite revealed that the constituent clasts contain very fine-grained plagioclase phenocrysts. It is likely, therefore, that the clastic component of the pseudotachylite was derived from the finer-grained porphyries of Unit 2.

Another feature of the clasts is their relatively high metallic sulphide content, principally accounted for by pyrrhotite. The sulphides appear to be restricted to the clasts only and do not manifest themselves in the matrix. This may be a function of parent rock composition, or due to the fact that later fluid-bound sulphides were not compatible in matrix phases.

The pseudotachylite is clast-supported and bound by a relatively hard, dense, black aphyric matrix, which is featureless in hand specimen. Greater mention will be made

<sup>&</sup>lt;sup>2</sup> Due to the tentative nature of this description, the definition of a pseudotachylite, according to Bates and Jackson (1980) has been included: 'Pseudotachylite: a dense rock produced in the compression and shear associated with intense fault movement, involving extreme mylonitisation and/or partial melting. Similar rocks, such as the Sudbury breccias, contain shock-metamorphic effects and may be injection breccias in fractures formed during meteorite impact'.

of the petrography and optical characteristics of both the matrix and clastic materials in Chapter 3.

The precise juxtaposition of the pseudotachylite to the remainder of Unit 1 (and indeed the rest of the Rietgat Formation) is somewhat difficult to infer, since observations are based on one occurrence only. Assuming that this rock type is indeed a pseudotachylite and that it is fault-derived, geophysical and/or structural data for the area (unavailable at the time of writing) would facilitate a greater understanding of its disposition and mode of emplacement.

## Relationship to other units.

Wherever the LSH is absent from the stratigraphy, Unit 1 comes into contact with the underlying Makwassie Formation. No strong evidence to suggest that erosion has taken place prior to the emplacement of Unit 1 was detected. However, the presence of the LSH is probably indicative of a brief time lag between the extrusion of the Makwassie and Rietgat Formations. This is a contentious theory, since it is possible that the Makwassie Formation and lower flows of the Rietgat Formations are contemporaneous (Winter, 1976).

Unit 2, where present, overlies Unit 1 with conformity; it is possible that the former is a sub-facies of the latter. In the majority of sections, however, Unit 2 is absent; in such cases, Unit 3 overlies Unit 1 conformably - further evidence to support the theory that Unit 2 is indeed a sub-facies of Unit 1.

#### 2.6.1.3 Unit 2 (Upper Garfield Member).

## Distribution and disposition.

This unit is only present in the northernmost region of the study area and may be seen in boreholes NVT1, DKP1 and MA2 (Figures 2.26, 2.30 and 2.31 respectively). Although geochemically and visually discrete, Unit 2 only appears to occur in association with Unit 1 (and only then when the latter is at its most developed) and is never encountered in isolation.

Unit 2 may be recognised macroscopically by its very finely porphyritic appearance as well as the presence of blebby chlorite. Subhedral phenocrysts of quartz and feldspar may be identified in a heavily chloritised sub-morphous groundmass. In places the phenocrysts are small (<1mm), though due to the fact that they are still relatively large in comparison to the groundmass, the term 'porphyry' has nonetheless been deemed appropriate.

In terms of its total thickness, Unit 4 ranges between 14.9 and 116.7m (Table 2.3). Table 2.3 also illustrates how the individual flows comprising Unit 2 are of greater thickness than those of the remaining Units 1, 3, 4 and 5, ranging between 9.95 and 53.39m. This could be due to the fact that Unit 2 is only associated with the best developed volcanic sequences in the study area.

The degree to which Unit 2 has been altered is somewhat less than Units 3-5: no bleached or mottled horizons are identified in the unit, possibly due to a more

restricted fluid throughput or perhaps due to the fact that the porphyries are less susceptible to alteration.

#### Pillow lavas.

Pillow lavas were encountered towards the base of Unit 2 in borehole NVT1 (Figures 2.12, 2.13 and 2.26). The pillow structures themselves are intensely amygdaloidal and display severe alteration. The presence of shale and sulphide fillings between the pillows, as well as an overlying shaly sequence of over 40m in thickness, is indicative of a calm euxinic deep-water facies. There is no reason to presume that there was any break in sedimentation during the emplacement of the pillow lavas.

# Relationship to other units.

Allusion has been made to the possibility that Unit 2 is a sub-facies of Unit 1. Hence, where present, Unit 2 will, by virtue of this association, be underlain by or intercalated with Unit 1. It is argued in subsequent chapters that Unit 2 could represent a localised, contemporaneous geochemical variety of Unit 1. Alternatively, Unit 2 could be a late-stage derivative of the original Unit 1 composition, in which case the two units would not necessarily need to be contemporaneous. Regardless of which of the above models one subscribes to, Unit 2 rests upon Unit 1 with full conformity. Unit 2 is overlain conformably by the lavas of Unit 3: there is no evidence to suggest that any prolonged cessation of extrusion took place during the Unit 1-2 transition.



**Figure 2.11** Possible pseudotachylite: highly angular phaneritic lava clasts set in a dense melanocratic matrix. Relatively high metallic sulphide mineralisation throughout (sample NVT1-50).



**Figure 2.12** Amygdaloidal Unit 2 pillow lava. The pillows themselves exhibit intense bleaching and silicification. Fine-grained sedimentary intercalations divide the pillows (sample NVT1-46a).



**Figure 2.13** Amygdaloidal Unit 2 pillow lavas displaying varying degrees of bleaching, most notably at pillow margins. Sedimentary material fills interstices (sample NVT1-45).



**Figure 2.14** Typical example of monotonous Unit 3 lava. The lava is aphanitic, heavily chloritised and its amygdale population ranges from sporadic occurrences to dense discontinuous horizons (sample NVT1-23b).

## 2.6.1.4 Unit 3 (Central Rietgat Member).

# Distribution and disposition.

Unit 3 is in evidence in the majority of the borehole sections in the study area. It is generally well developed, with thicknesses for the entire member reaching nearly 350m. Individual flow thicknesses within Unit 3 are on average 8.39m, though they range from 0.43m to nearly 65m (see Table 2.3). The unit is visually characterised by its monotonous and sporadically amygdaloidal appearance (Figure 2.14). The amygdales appear to occur at random throughout the unit, showing no affinity to flow tops, rendering the identification of individual flow units a somewhat complex process and giving rise to both densely (Figure 2.15) and sparsely amygdaloidal horizons.

Unit 3 is extremely fine-grained and generally aphanitic with only the most developed flows featuring porphyritic flow centres (Figure 2.16). In many of the sections, Unit 3 contains quartz veining and vugs up to 2cm in diameter.

Unit 3 shares many common characteristics with Units 4 and 5. Such features include the widespread preponderance of chlorite and to a lesser extent chalcedony, as amygdale filling materials. Furthermore, the greenish-grey colouration of the lavas closely resembles that of the overlying units. Unit 3 also contains a restricted number of mottled (Figure 2.5), bleached and epidotised (Figure 2.6) horizons similar to those encountered Units 4 and 5. A limited quantity of layered material was observed close to the centre of Unit 3 in borehole NVT1. This horizon is geochemically and (with the exception of the lack of amygdales) petrographically identical to the adjacent lavas. It is proposed that the layered horizon represents what was originally a tuff of similar



**Figure 2.15** Densely amygdaloidal Unit 3. The lava itself is aphanitic and heavily chloritised/silicified and its amygdales contain zoned quartz/chlorite fillings (sample NVT1-23a).



**Figure 2.16** More thickly developed Unit 3 flows may exhibit a euhedral plagioclase-porphyritic affinity. Otherwise, the sample is sporadically amygdaloidal and displays chloritisation and silicification (sample NVT1-10a).

chemical composition to the lavas, which underwent the same alteration process as the rest of the sequence. The banding is merely a textural relic of the primary rock.

## Relationship to other units.

Unit 3 overlies Unit 2 with conformity, though where Unit 2 is absent from the series, it conformably overlies Unit 1 instead. This may be attributed to petrogenetic reasons, which are discussed in Chapter 5. The presence of bedded chert in section MA2 (Figure 2.31) is suggestive of a brief era during which warm, aqueous conditions prevailed, probably on a palaeo-landsurface, which were conducive to the precipitation of chert. The main importance of the cherts to this discussion is that their presence signifies a break in volcanic activity. This is why the term 'close conformity' has been used when describing the relationship between Units 2 and 3. This hiatus is non-tectonic, non-erosive and is apparently non-depositional in all sections other than MA2. In the opinion of the author, it is safer to assume that Units 1, 2 and 3 are contiguous. As has previously been discussed, Unit 3 is conformably overlain by Units 4 and 5.

## 2.6.1.5 Unit 4 (Upper Rietgat Member - Non-Amygdaloidal).

### Distribution, disposition and relationship to other units.

Considerable reference has been made to Unit 4 in the preceding paragraphs, due to its visual similarity to Unit 5, with which it is intercalated. In summary, Unit 4 comprises a near-identical mineral assemblage to Unit 5, this comprising clinochlore, quartz, muscovite and albite, as well as similar textures, colours, sedimentary intercalations and ash horizons. The only visual contrast between Units 4 and 5 is the virtual

absence of amygdaloidal flow tops in the latter (Figure 2.17). Other notable features in Unit 4 include epidotised and variolitic facies (sections S4 and DKL6; Figures 2.37 and 2.38 respectively) as well as occasional plagioclase porphyritic flow centres.

Unit 4 exhibits varying degrees of alteration, though overall to a moderate degree only, since it rarely comes into contact with the overlying sediments and their associated pervasive alluviation processes. This Unit occurs locally, being present in only half of the sections examined. The range in total thickness for Unit 4 is between 6 and 78m, comprising individual flows of between 0.1 and 23m in thickness (Table 2.3). Unit 4 only occurs in conjunction with Unit 5 and never as a discrete entity and overlies Unit 3 with conformity.

# 2.6.1.6 Unit 5 (Upper Rietgat Member - Amygdaloidal).

#### Distribution and disposition

Unit 5 is recognised in every borehole in the study area, ranging in total thickness from 65 to 105m. The unit comprises fine-grained greyish-green equigranular lavas, the average flow thickness of which is 5.77m (Table 2.3). Many flows less than 10 cm in thickness are seen, especially near the top of this unit. Interdigitation with Unit 4 from which it is geochemically distinct - is fairly common and may be seen in borehole sections MA1, KFN2, MAL1, S4 and DKL6 (Figures 2.27, 2.28, 2.32, 2.37 and 2.38). As has been outlined, the only visual means by which Unit 5 may be distinguished from Unit 4 is on the grounds of its amygdale content, the distribution of which varies from confined flow-top occurrences, through dense amygdale clusters to entirely amygdaloidal flow-units. The amygdales themselves range between 2 and 6mm in diameter, containing chlorite and/or chalcedony fillings, some of which display concentric zonation.

#### <u>Alteration.</u>

As is the case with the majority of the Rietgat Formation lavas, Unit 5 has undergone a high degree of fluid-related alteration. This has given rise to bleached horizons (Figure 2.18), veins (Figure 2.19), veinlets, mottled facies and chalcedony vugs; variolitic alteration may also be seen from place to place. Unit 5 displays the most intense and macroscopically visible alteration in the Rietgat Formation, particularly in its uppermost flows (Figure 2.20). Texturally, the unit is principally aphanitic, though some of the thicker flows do contain some porphyritic plagioclase, particularly towards their flow-centres. It therefore follows that relatively massive flows (most commonly found near the base of the unit) show the greatest porphyritic affinity.

## Sedimentary intercalations.

Besides its amygdaloidal lava component, Unit 5 also contains minor sedimentary intercalations and tuff layers. These include quartzwackes (section KFN2 - Figure 2.28) and shales (section S4 - Figure 2.37). Occasional coarse clastic horizons may also be seen which may represent brecciated flow-tops or alternatively in-situ degradation of the lavas resulting from sub-aerial exposure.

## <u>Relationship to other units.</u>

Earlier in this section, brief reference was made to the fact that Units 4 and 5 inderdigitate with one another in places. Where this is the case, no clear visible demarcation may be made between the two units, with the exception of amygdale



**Figure 2.17** Although technically defined by its dearth of amygdales, Unit 4 does in places exhibit sparse amygdaloidal tendencies. The amygdales typically contain quartz and/or chlorite fillings (sample NVT1-27a).



**Figure 2.18** Bleached, altered Unit 5 lava. Amygdales are abundant and contain concentrically zoned quartz/chlorite fillings (sample ZTD1-5).



**Figure 2.19** Extreme alteration and bleaching in Unit 5. Primary igneous features - such as amygdales - have been largely obliterated. Quartz veining is prominent (sample NVT1-3).



**Figure 2.20** Clear example of the intense alteration typical of the uppermost flow units of Unit 5. The white phase of speckled appearance is leucoxcene - an alteration product of sphene. Chlorite and quartz are also prominent alteration phases (sample S6-1).

preponderance in Unit 5. The contrast between Units 4 and 5 is more readily elucidated by geochemical means: it is probable that Units 4 and 5 are genetically related and that the distinction between the two is a function of minor source chemistry variation. This topic will be discussed in Chapter 5.

No erosional surfaces or other evidence for prolonged sub-aerial exposure (such as bleached or weathered horizons) were identified in the upper portions of Unit 3. It is therefore tentatively proposed that the lavas of Units 4 and 5 were extruded in relatively rapid succession, leaving little scope for surface processes to operate.

## 2.6.1.7 Upper Sedimentary Horizon (USH).

## Distribution and disposition.

The USH was encountered in the majority of the sections examined in the study area, where it ranges in thickness between 14.91 and 49.1m (see Table 2.3). The sediments are typically quartz-rich and clast-supported and are bound by a fine-grained matrix of calcite and opaque clay minerals. The clasts themselves consist of Ventersdorp lavas and are seldom greater that 5mm in terms of their long-axis length. The presence of occasional triple junctions between neighbouring quartz grains is attributed to either metamorphic or diagenetic processes. Since most of the quartz grains have undergone varying degrees of recrystallisation, it is extremely difficult to make inferences regarding primary sedimentary textures. However, the USH is texturally mature (particularly in comparison to the LSH), the constituent clasts displaying a high degree of rounding and sorting. Larger scale features such as fining upward sequences

(quartzwacke fining from grit up to sand), slump structures and cross-bedding are clearly identifiable.

In addition to the aforementioned arenaceous quartz-rich sediments, the USH contains a considerable amount of much darker argillaceous material in the form of mudstones, shales and silt. These argillites may occur as distinct intercalations within more either as discontinuous partings, intraclastic flasers, arenaceous horizons. conglomerates or rip-up clasts. Generally, such argillites are between ~0.5 and 10cm in thickness. Greater accumulations (>1m) of mudstones, shales and siltstones may also occur as distinct laterally extensive horizons, where they are more, display internal laminae and slumping and contain occasional sandy partings. The argillaceous horizons may either grade progressively into arenites or there may instead be a definite hiatus between these two facies. The precise mineralogy of the argillites is very difficult to determine by macroscopic means, due to the very fine-grained nature of the rocks. A degree of silicification and calcification was however noted.

## Veins and stringers.

Confined stringer and vein networks were also encountered in the sediments. These are almost invariably of quartz and are rarely developed beyond a few millimetres in section.

## <u>Sulphides.</u>

Low abundances of metallic sulphides (principally pyrite, pyrrhotite and chalcopyrite) were identified in the USH. Two principal modes of sulphide occurrence were noted, which are as follows:

- Granular detrital sulphides (Figure 2.21) occur in layers (2-5mm) which conform perfectly to the sedimentary laminae. Macroscopic examination of the metallic grains revealed a degree of rounding - suggestive of abrasion during sedimentary transport processes.
- Figure 2.22 illustrates an example of 'framboidal' metallic sulphide mineralisation. It is proposed that the pyrrhotite and pyrite in this style of mineralisation developed in-situ around a nucleus, which may itself have been a detrital sulphide grain. Further evidence to support this theory comes from the fact that the sedimentary laminae adjacent to the mineralisation have been displaced by the growth of such sulphides.

#### <u>Relationship to other units.</u>

In terms of its relationship to over- and underlying units, the USH overlies the lavas of the Rietgat Formation with conformity in places. Elsewhere however, the localised alteration of the uppermost flows of Unit 5 may be tenuously interpreted as being a product of sub-aerial weathering and exposure, possibly indicating a depositional hiatus. Nevertheless, it is just as likely that the permeation of waters from the overlying sediments were responsible for this feature and that the USH overlies the lavas with full conformity. Erosion appears to have been minimal during this period, as is suggested by the fact that all lava flows in direct contact with the sediments retain their amygdaloidal tops.



**Figure 2.21** Granular sulphide mineralisation in the USH showing conformity to sedimentary features, possibly as a result of detrital emplacement (sample ERO3-10).



**Figure 2.22** 'Framboidal' sulphide mineralisation within the argillaceous component of the USH. It is possible that this style of mineralisation occurred in-situ (sample NVT1-1).

The USH is overlain unconformably by the sediments of the Bothaville Formation (Figure 1.2), the plane of which is clearly identifiable by the presence of the coarse basal Bothaville conglomerate. The USH has sustained varying degrees of erosion prior to the deposition of the Bothaville Formation. In certain cases where the USH is omitted from the sequence, the Bothaville Formation is brought into direct contact with Unit 5.

#### 2.6.1.8 Intrusive Rocks

#### Distribution, disposition and relationships to other units.

Coarse-grained equigranular mafic sheeted intrusions were encountered in boreholes ERO2 and DKP1 (Figure 2.30). In the case of section DKP1, the intrusion is approximately 40m in thickness, displaying clear evidence of chilling near its margins, as well as the induration of adjacent country rocks. The intrusive body seen in the aforementioned section occurs along the contact between Unit 5 and the USH, which probably represents a weakness along which intrusion could take place. In the majority of instances, however, the principal lines of weakness giving host to intrusive bodies include structural features such as fault planes (Winter, 1995) and to a lesser extent jointing.

As is the case in the majority of the Rietgat Formation lavas, the intrusive material displays a high degree of alteration.

Ϋ́.

# 2.7 Structural Geology.

# Introductory note and previous work.

A dearth of publications pertaining to the structural geology of the Rietgat Formation exists at the time of writing. The only material remotely concerned with this topic includes Meintjes (1988, 1994) and Meintjes *et al.* (1989), which addresses the evolution of Ventersdorp-age structural sedimentary basins in the Welkom area. Stanistreet and McCarthy (1986) and Charlesworth *et al.* (1986) discussed the movements of the Rietfontein fault system of the Central Rand Group and its effects on Platberg sedimentation. Myers *et al.* (1990) described the dynamic relationship which existed between Platberg-age structures, sedimentation and volcanism northeast of Klerksdorp.

Broader studies of late Archaean to early Proterozoic tectonism on the Kaapvaal craton include a three-stage model by Clendenin *et al.* (1988a), which suggests that the Platberg Group and the Bothaville and Allanridge Formations were emplaced in a subsiding graben. Much work aimed at the clarification of regional tectonism during the deposition of the Witwatersrand Supergroup and Klipriviersberg Group has been undertaken. Such studies include Winter (1986, 1987, 1991), Roering (1986), McCarthy *et al.* (1986) and Barton *et al.* (1986).

# Implicit structure of the Rietgat Formation in the study area.

Figures 2.23a and 2.23b illustrate the structural geology of the study area and were extrapolated by Anglovaal geologists during gold reef exploration. These sections are therefore primarily concerned with the representation of the Upper Witwatersrand sediments and the VCR<sup>3</sup>. It is possible, however, to infer the structure of the overlying units with reference to the sections in Figures 2.23a and 2.23b. For instance, it may be seen that the general structural trend is dominated by near-vertical faults, in association with very occasional high-angle reverse faults and thrusts (Figure 2.23b). Moreover, it may be concluded from this fault array that extension was the foremost tectonic movement during the development of the region.

The faults shown in Figures 2.23a and 2.23b are primarily N-S trending and have given rise to the formation of a series of grabens and half-grabens. To be of relevance to the Rietgat Formation, the foregoing discussion does rely on certain fundamental presumptions. It is necessary to assume that the Rietgat Formation was subjected to the same epeirogenic movements as the Upper Witwatersrand sediments and the VCR and that tectonism did not predate the Rietgat. Where age relationships are concerned, it may be ascertained from Figures 2.23a and 2.23b that particular faults do indeed displace the Ventersdorp Supergroup, but do not transect the younger Karoo System.

Due to the fact that one of the main objectives of this study was to establish a geochemical stratigraphy for the region, the examination was restricted to untectonised borehole core. Hence only very minor faulting, recognisable by

<sup>&</sup>lt;sup>3</sup> The VCR (Ventersdorp Contact Reef) may be defined as the basal deposit of the Ventersdorp Supergroup. resting unconformably on the sediments of the underlying Witwatersrand Supergroup (Coetzee, 1960). Where the VCR is absent, the lavas of the Westonaria Formation (Figure 1.2) mark the base of the Ventersdorp Supergroup. The VCR is itself a component of the Venterspost Conglomerate Formation, which comprises a residual sedimentary accumulation (SACS, 1980).



Figure 2.23(a) Section (A)-(B) illustrating the sub-surface structure of the study area (see Figure 1.3 for location).



**Figure 2.23(b)** Section (C)-(D) illustrating the sub-surface structure of the study area. *(see Figure 1.3 for location).* 

Scale according to Target project local exploration grid





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Figure 2.25 Structure of the Witwatersrand Basin (after R. Myers *et al.*, 1990)

associated bleaching, chloritisation and occasional mylonitisation along its plane, were noted. It was not possible to determine the sense of movement of these faults in the absence of marker horizons. The presence of faults may instead be deduced by more implicit means. Since faulting is largely responsible for the creation of structural basins into which the lavas and sediments are emplaced, it is possible to infer the amount of fault movement based on the completeness of a succession. For example, sections MAL4, ERO4 and PDE1 (Figures2.33, 2.34 and 2.36, respectively) are relatively incomplete, therefore probably representing either a shallow or marginal basin environment, or indeed erosion. The nature and disposition of these palaeobasins is most readily elucidated by the construction of palaeotopographic diagrams. Figure 2.24 was plotted using all available borehole data for the study area

and represents the lowermost surface of the Rietgat Formation. the existence of a NW-SE basinal trend has been interpreted as being a northward extension of the De Bron Fault (R. Myers *et al.*, 1990; Figure 2.25)

A seismic study of the Allanridge-Bothaville area was undertaken by Anglovaal in 1997 the data from which were not available for inclusion in this study.

## 2.8 Summary of Stratigraphy and Discussion.

The foregoing paragraphs have demonstrated the fact that the Rietgat Formation may be sub-divided into distinct units. In summary, the development and stratigraphic relationships of the Rietgat Formation are as follows:

- The LSH rests with moderate conformity on the Makwassie Formation and is thought to represent a combination of detrital deposition on a palaeo land surface and the accumulation scree in the vicinity of fault scarps. It is probable that the sediments were deposited in topographic depressions during a period of volcanic quiescence. Alternatively, deposition may have been more widespread, the sediments having been removed by a subsequent erosive cycle. It is also possible that the LSH represents a deposit which accumulated on topographic highs which stood proud of the extruding lavas.
- Although visually and geochemically discrete, Unit 2 only occurs in conjunction with Unit 1, of which it is considered a sub-facies. The presence of pillow lavas in Unit 2 indicates that it was, at least in part, extruded under sub-aqueous conditions.

An overlying sedimentary facies, intercalations of which may also be seen between the pillow structures suggests that sedimentation and volcanism were contemporaneous.

- Unit 3 succeeds the aforementioned Unit 1-2 package with conformity. The presence of very well developed examples of the unit in the majority of sections in the study area is attributed to the rapid extrusion of very large quantities of lava. Should faulting have been active during this period, it would have had relatively little effect on the distribution of Unit 3, due to the fact that the rate of extrusion exceeded fault movement. The absence, furthermore, of sedimentary intercalations in Unit 3 may also attest to highly expedient extrusion, which could have been of sufficient magnitude as to eclipse sedimentary processes. Secondly, the volumes of lava extruded during this period were sufficiently great as to blanket the entire area irrespective of any palaeohighs.
- Units 4 and 5 are widespread in the study area and form a combined lava package in which the interdigitation of the two facies is common, the reasons for which will be explained in terms of petrogenesis later in this study. A widespread feature of Units 4 and 5 are their sedimentary intercalations, which comprise quartzwackes and shales. These sediments are in greatest abundance higher in the sequence, possibly due to waning of volcanism and the increased role of sedimentation during this period. Further evidence to support this theory may be gleaned from the fact that the lava flows higher in the sequence become successively thinner, pointing to a gradual cessation of volcanism.

- The Upper Sedimentary Horizon (USH) represents the complete dominance of sedimentary processes following the culmination of volcanism. This concurs with the gradual waning of volcanism that took place throughout the emplacement of Units 4 and 5.
- The lithologies of the USH suggest a period distinguished by very calm, widespread, low energy, deep-water conditions. The fact that diamictites and breccias are absent from this horizon, suggests that there was either no coarse clastic input to the basin or that the USH in this region merely represents a distal facies.
- The upper surface of the USH is unconformably truncated by the basal conglomerate of the overlying Bothaville Formation.
- Faulting is one of the most conceivable mechanisms governing the distribution of " the Rietgat Formation. It is highly probable that faulting played a role in the development of the structural sub-basins into which the lavas and sediments were emplaced. Lava distribution may also have been governed by the disposition of extrusive centres. The widespread distribution of the USH and Units 4 and 5 and presence of clastics therein has, with caution, been attributed to the abatement of fault movement later in Rietgat times. In explanation, fault movement can govern the development of structural basins, which in turn may restrict the distribution of sediments and volcaniclastics. Furthermore, faulting could be responsible for the development of scarps, from which coarse clastic wedges may be derived.

On a concluding note, it should be stated that the preceding discussion and concepts contained therein conform to lithostratigraphic<sup>4</sup> precedents. Given the fact that faulting appears to have been ongoing throughout the emplacement of much of the Rietgat Formation, extreme relative displacement of lithological units may occur. It is therefore very difficult to classify units on chronostratigraphic<sup>5</sup> grounds. Such movements may lead to the omission of certain units on a localised basis. Technically, such breaks may be termed unconformities, though since in this case they are contemporaneous with extrusion/sedimentation elsewhere, have not been considered thus. In short, a sequence stratigraphic approach has been adopted by this study; for further details, the reader is referred to Van Wagoner *et al.* (1988).

<sup>&</sup>lt;sup>4</sup> Lithostratigraphy, 'The elements of stratigraphy which deal with the lithology of strata and their organisation into units based on lithological character' Bates and Jackson (1980).

<sup>&</sup>lt;sup>5</sup> Chronostratigraphy, 'The branch of stratigraphy that deals with the age of strata and their time relations' Bates and Jackson (1980).

Geolog	y	Ni/Zr	P <sub>2</sub> (	D₅/Zr	
~		800	- 0.75	0.001	
	Highty altered lava, aphyric to porphyritic in places. Ash layer.				
	Altered grey lava, generally non-amygdaloidal. Porphyritic in places and containing occasional lapilli.				
	Amygdaloidal lava containing chlorite amygdales. Evidence of bleaching in places.				
	Densely amygdaloidal grey-green lava. Epidote facies.				
	Amygdaloidal lava with quartz and chlorite fillings. Epidote facies.				
1485	Altered lava; variably amygdaloidal (1-8mm Ø).				
L 1510				1	
1560	Sporadically amygdaloidal lava, green to grey in colour. Individual flow units are difficult to distinguish. Vuggy quartz in places.		I I I I	м.,	
	Sub-aphanitic layered unit. Possibly of volcanic				
	origin.		TTTT		
	Sporadically amygdaloidal lava, displaying a well developed plagioclase porphyry towards its base.		ΓΓΓΓ		
	Very fine-grained amygdaloidal lava.		TIT		
1710	Sporadicaity amygdaloidal lava.				

Figure 2.26 Lithological and geochemical stratigraphy for borehole NVT1.

	Geolog	У	-	Ni/Zr	P₂Q	₅/Zr	
			80 0 1	, , , , , , , , , , , , , , , , , , ,	0.003	0.0081	
1		Sporadically amygdaloidal lava, continued.	TTT				
ŀ		Very dense lava containing occasional plagioclase laths. Blebby chlorite throughout.		)			
		Altered horizon with mottled appearance.					
i (metres)		Sedimentary unit: shaly intercalations near base grading upwards into quartzwackes. Occasional metallic sulphides may be seen.	TITIT				
Depth	1835	Highly altered pillow lavas in a shale/massive sulphide matrix.		L			
	1885 – 1910 –	Aphanitic to porphyritic lavas containing breccia horizons. Possibly a pseudotachylite, clast size up to and including 6cm Ø.					
		Sulphide-rich shales and quartzwackes.					SEDIMENT
L							

Figure 2.26 (cont'd) Lithological and geochemical stratigraphy for borehole NVT1.

		<u>,</u>	G	eolog	Υ		Ni/Zr	P₂O₅/7r		
				Ū	• • •	0.06	0.75	. 20921 600.0		į
	830	hullin			Quartzwacke containing shale partings. Cross bedding and slump structures in places. Small quantities of buckshot pyrite may also be seen.			<b>_</b>	SEDIMENT	
	855 880	HIIILI		0000 0000	Highly altered amygdaloidal lava. Porphyritic lava. Monotonous amygdaloidal lava.				UNIT 5	
	905	111111			Grey lava flows, generally equigranular, with occasional chlorite-filled amygdales near flow tops only.			·	UNIT 4	
	930			000	Aphyric to sub-porphyritic lava	-	<u>↓</u> ]-		UNIT 5	-
	955		P	0.00		]-	\	.4		
etres)	980	111111			Monotonous, grey amygdaloidal lava, attered in_ places. Occasional quartz-filled vugs. Indistinct flow contacts.					
Depth (me	1005 1030	TITI		00000 00000 00000 00000	Very thin amygdaloidal lava flows.					
	1055	111111		9 9 9 9 9	Sporadically amygdaloidal lavas displaying variolitic alteration in places. Occasional quartz vugs (< 5cm Ø).				UNIT 3	
	1080	LILIL		2 2 0000 0000	Sporadically amygdaloidal inequigranular lava.					
	1130	4			Aphanitc in places.	1	_{	/ 	 	
	1155				Porphyritic lava, pale green in colour. Contains					
	1180				subhedral feldspar laths, which become coarser - lower down in flow unit.				UNIT 1	
	1205									  

Figure 2.27 Lithological and geochemical stratigraphy for borehole MA1.

Geol	ogy	Ni/Zr	P₂O₅/Zr	ſ
		8 0	- 0.75	0.000
655 - 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Quartzwacke, coarsening downwards from fine a sand to grit.			SEDIMENT
680	Veined, altered amygdaloidal lava.		- <b>-</b> <del>-</del>	
	Intensely attered lava with occasional amygdales; variolitic in places.			
730 000	Quartzwacke.			UNIT 5
755	Numerous lava flows, generally aphanitic, thin and non-amygdaloidal.			
	Thin lava flows, densely amygdaloidal in places.			
	Vuggy porphyritic lava. Amygdaloidal porphyry.			
	Aphyric to porphyritic lava.			
Depth (metres 000 000 000 000 000 000 000 0	Sporadically amygdaloidal lava flows, typically 3- 7m in thickness, containing vuggy quartz in places. Amygdales commonly contain chloritic fillings.			
905 - OCO 905 - OCO 930 - OCO 940 -	Banded mylonite. Sporadically amygdaloidal lava, aphanitic to fine- grained. Identifiable flow units with amygdaloidal tops and			
980	porphyritic centres. Lowermost flows commonly contain quartz velns and vugs.			
	Porphyritic lava, coarsest near flow centre.			
1030	Coarse grey quartz/teidspar porphyry, possibly a correlate of the Garfield Member (Winter, 1976).			

Figure 2.28 Lithological and geochemical stratigraphy for borehole KFN2.

...

			G	ieolog	IY		Ni/Zr		P₂O₅/Zr		
						800		- 0.75 - 0.0003		160010	
		=		0.0	Shale containing metallic sulphides.	-					SEDIMENT
	725 750				Numerous lava flows, mostly amygdaloidal and equigranular; also occasional aphanitic horizons, Bleached upper surface, - perhaps due to sub- aerial exposure.						UNIT 5
		TILL			Amygdaloidal porphyry.			TTTT			
. •	800	4		77777	Aphanitic lava displaying variolitic alteration.		1		1		
	825				Lava flows, amygdaloidal throughout.			T T T T			
res)	850	11111			Sporadically amygdaloidal lavas, the individual			11111			
Jepth (met	875 900	ILLI		QQQQ QQQQQ	units of which are extremely difficult to discern.			<u>i ti ti ti ti</u>			
L											
	925			0000	Sporadically amygdaloidal lava flows, as above. Amygdale fillings are typically of chlorite and or chalcedony.						
	950						(				
	975	LILL			Sporadically amygdaloidal grey lava flows, as above.						
	1000	-				]-					
	1025			8°40	Amygdaloidal porphyry.		l		<b>/</b>		
	1023				Porphyritic lava containing chlorite blebs		}	Ĩ			
	1050	LLLL			Moderately coarse porphyritic lava.						

Figure 2.29 Lithological and geochemical stratigraphy for borehole TNT2.



Figure 2.30 Lithological and geochemical stratigraphy for borehole DKP1.

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**Figure 2.31** Lithological and geochemical stratigraphy for borehole MA2.

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Figure 2.32 Lithological and geochemical stratigraphy for borehole MAL1.


Figure 2.33 Lithological and geochemical stratigraphy for borehole MAL4.



Figure 2.34 Lithological and geochemical stratigraphy for borehole ERO4.



Figure 2.35 Lithological and geochemical stratigraphy for borehole S6.

	Geolog	y		Ni/Zr		P₂O₅/Zr	
es)	760 - 0000 - 000	Attered lava flows, variolitic in places. Amygdales are generally restricted to the flow tops. Well developed flows may be vuggy and porphyritic in places. Possibly contains a pyroclastic/fuffaceous component.	0.08		0.75		
Depth (meti	785	Dark green siliceous diamictite.	1111111111				
	1 1224			<u> </u>		Ľ	<u>_</u> <u>_</u>

Figure 2.36 Lithological and geochemical stratigraphy for borehole PDE1.



Figure 2.37 Lithological and geochemical stratigraphy for borehole S4.



Figure 2.38 Lithological and geochemical stratigraphy for borehole DKL6

# CHAPTER 3: MINERALOGY AND PETROGRAPHY.

#### 3.1 Introduction.

A summary of the mineralogy and petrography of the Rietgat Formation is presented in the following chapter. Many of the observations contained herein are of relevance to the geochemistry and petrogenesis of the rocks in question. These issues will, however, be addressed in subsequent chapters. The aims and objectives of this chapter are as follows:

- To identify the mineral phases present in the rock and whether these are the product of primary igneous or secondary alteration processes.
- To delimit the metamorphic facies.
- To determine whether any mineralogical or textural variation exists between the units comprising the Rietgat Formation.

The following commentary is presented in terms of the geochemical stratigraphic units as described in the previous chapter. A summary of the principal textural and mineralogical characteristics of the Rietgat Formation is presented in Table 3.1. Where necessary, further subdivision of the units has been undertaken.

### 3.2 Brief note on previous work

T. B. Bowen (1984) discussed the petrography of the Rietgat and Goedgenoeg Formations in the broader context of the Witwatersrand triad: this study placed emphasis on the significance of petrography to geochemistry. Winter (1965) also commented briefly on the petrography of the Rietgat Formation, though this too was presented in the context of the entire Ventersdorp Supergroup. Similar studies specific to other Ventersdorp Supergroup Formations are instructive since they give an insight into the methods by which altered lavas may be examined and classified. Such material includes Winter (1995) who studied the Alberton Formation, Linton (1992), who investigated the Klipriviersberg Group and Meintjies (1998) who examined the Makwassie Formation.

#### 3.3 Techniques Employed

Mineralogical and petrographic examination of the Rietgat Formation was conducted primarily by optical means. Non-reflective opaque phases were identified at the University of the Free State using a CAMECA electron-microprobe. All samples were furthermore subjected to powder XRD<sup>6</sup> analysis to determine the mineral assemblage present. Given that the XRD technique employed was non-quantitative, it was not possible to derive modal mineralogical compositions for the samples

<sup>&</sup>lt;sup>6</sup> X-ray diffraction (XRD) is a non-destructive analytical technique for the identification of mineral phases present in powdered and solid samples. The Siemens D5000 diffractometer and associated DIFFRAC-AT (V 3.0) software at the University of the Free State automatically measure and record the sprectra produced by the individual mineralogical constituents in the powder sample. Identification is achieved by comparing the XRD spectra obtained from the unknown sample with a database containing reference patterns for a large number of standard phases.

# **Table 3.1**Summary mineralogy and petrography for the Rietgat Formation.

UNIT		MINERALOGY	TEXTURES	PLATE(S)
Upper Sediment		Almost entirely quartz with very occasional plagioclase grains and lithic fragments. Shaly material contains sulphide mineralisation in places.	Relatively mature; fining-upwards sequences.	3.13, 3.14, 3.15
5		Dominant plagioclase; interstitial calcite and chlorite, with minor clinozoisite and epidote. Occasional opaques.	Coarsely intersertal to hyalopilitic.	3.12
4		Twinned plagioclase, blebby chlorite, clinozoisite and occasional epidote.	Intersertal to hyalopilitic. Stellate clustering of plagioclase.	3.11
	facies I	Plagioclase (mostly saussuritised to clinozoisite), quartz and chlorite with very occasional opaque sphene and ilmenite.	Hyalopilitic to pilotaxitic. Amygdales contain quartz fillings (concentrically- zoned according to crystal size).	3.7
3	facies II	Acicular plagioclase, intersitial quartz and opaque material (sphene and ilmenite). Uncharacteristically devoid of chlorite.	The mass of the rock is pilotaxitic. Amygdales are concentrically-zoned and contain quartz, calcite and clinozoisite.	3.9, 3.10
	facies III	Containing plagioclase, chlorite, actinolite, epidote and disseminated opaques. Quartz manifests itself as silicification.	Crystalloblastic and aphanitic. The amygdale fillings are either of homogeneous quartz and/or calcite, bordered by clinozoisite rim.	3.8
2		Porphyritic plagioclase, altered to clinozoisite. Calcified and silicified.	Weakly porphyritic to aphyric, displaying relict hyalopilitic texture; glomeroporphyritic in places.	3.5, 3.6
1		Plagioclase, chlorite, quartz and opaques (sphene and ilmenite). Calcified and silicified.	The overall texture is porphyritic, with intersertal to crystalloblastic groundmass.	3.3, 3.4
Lower Sediment		Mineral grains principally of quartz and occasionally plagioclase. Lithic clasts of lava. Secondary calcite.	Clasts are angular and in generally inumature with respect to their texture and mineralogy.	3.1, 3.2
Intrusive Material		Clinopyroxene, which has undergone moderate chloritisation. Remnant biotite, plagioclase and actinolite.	Coarsely-crystalline and equigranular Sub-ophitic in places.	n/a
Pseudotachylite		Mineral grains predominantly of quartz and feldspar. Calcification and silicification common. Occasional blebs of clinozoisite and epidote.	Corrosion textures/reaction rims at clast margins. Matrix contains crystallization products and imbrication of constituent clasts.	3.16, 3.17

Furthermore, given the detection limits of XRD (~3% by weight, G. J. Beukes, pers. comm., 1999), some minor phases may escape identification. It is necessary therefore

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to use both optical and X-ray techniques in conjunction with one another in order to determine the mineralogical composition.

# 3.4 Unit by Unit petrographic appraisal of the Rietgat Formation.

### 3.4.1 Lower Sedimentary Horizon (LSH).

The sediments of the LSH are texturally and mineralogically immature as may be seen from Figures 3.1 and 3.2. Clasts are generally angular, ranging in size from <1mm, up to 10mm. Many of the larger clasts are of lithic origin, showing remnant intersertal<sup>7</sup> and hyalopilitic<sup>8</sup> igneous textures. Mineral grains - principally of quartz but occasionally of plagioclase may also been seen, some of which display undulose extinction. This is a metamorphic feature and has been interpreted as being a characteristic of the source from which the sediment was derived. In the case of sample DKL8-14, secondary calcite pervades the entire sample as vein material and interstitial fillings. Unlike the USH, the sediments of the LSH are matrix-supported. The matrix is almost entirely of very fine-grained quartz, which although difficult to examine appears to be highly crystalline, possibly as a result of secondary fluid processes. Secondary clinozoisite forms thin rims around some of the lava fragments.

<sup>&</sup>lt;sup>7</sup> An intersertal texture comprises an unorientated meshwork of feldspar laths in which the gaps are filled by glass or very fine crystals, the feldspar crystals forming a major part of the rock (decrease in feldspar content results in a variety of ophitic texture (Whitten & Brooks, 1973).

<sup>&</sup>lt;sup>8</sup> A hyalopilitic texture is a variety of pilotaxitic texture in which the felt of the crystals or crystallites is embedded in a glassy base (Whitten & Brooks, 1973).

# 3.4.2 Unit 1 (Lower Garfield Member).

Unit 1 is distinctively plagioclase porphyritic and in the case of sample DKP1-10, the groundmass is coarse, intersertal and in places crystalloblastic<sup>6</sup> (Figures 3.3 and 3.4).

Extensive and pervasive silicification are present as well as calcification (the latter being restricted to interstices only). Xenomorphic<sup>10</sup> opaques (possibly ilmenite or sphene) occupy many of the interstices and clinozoisite replaces plagioclase feldspars.

Elsewhere, the plagioclase is sufficiently fresh as to permit the identification of euhedral phenocrysts. In the case of MAL1-7, the host groundmass comprises smaller intersertal plagioclase crystals, the interstices of which are filled by opaques and highly pleochroic chlorite minerals. Patches of finely saccaroidal secondary quartz occur on a sporadic basis, containing variable quantities of calcite. In contrast to MAL1-7 and DKP1-10, MAL1-8 has not undergone such a degree of silicification or calcification. Instead, chloritisation appears to have been more prevalent, particularly at an interstitial level. The chlorite phases possibly owe their origin to alteration of primary biotite, remnants of which may be seen along primary cleavage planes.

<sup>&</sup>lt;sup>9</sup> Crystalloblastic is a term used to describe the texture produced by the simultaneous recrystallisation of several minerals as a result of metamorphic processes. A characteristic feature of the texture thus produced is that any of the minerals involved may be found as inclusions in any of the other minerals (Whitten & Brooks, 1973).

<sup>&</sup>lt;sup>10</sup> The term 'xenomorphic' may be applied to a mineral which displays no crystal shape (Whitten & Brooks, 1973).



**Figure 3.1** Lower Sedimentary Horizon, clastic component primarily of quartz. The range in clast size and angularity is suggestive of textural immaturity. The matrix is now heavily chloritised and the occasional euhedral opaques (A) are probably sphene (PPL).



**Figure 3.2** Lower Sedimentary Horizon, fining upwards from (A) to (B): the finer grained material typically has a darker colour-index than the coarser material. The rock is now heavily chloritised and also contains metal sulphides, both of which were probably derived by secondary processes. (Incident light).



**Figure 3.3** Unit 1 - non-pleochroic euhedral plagioclase laths dominate the sample and are set in a chloritised silicified groundmass. Plagioclase is commonly saussuritised to clinozoisite (present in this sample as a highly pleochroic brown mineral), most notably along twin planes (PPL).



**Figure 3.4** Unit 1 - highly altered example of the Lower Garfield Member exhibiting widespread chloritisation (greenish-yellow pleochroic mineral (A)) and saussuritisation. The parallel gashes are thought to be shock-related and are possibly derived from the nearby Vredefort impact structure (Colliston, *pers. comm.*, 1998) (PPL).



**Figure 3.5** A relatively fresh example of Unit 2. Secondary chlorite occurs as an interstitial groundmass phase (A) and as more prominent blebs throughout the sample (B). The plagioclase content of this unit is far less coarse than that seen in Unit 1 (PPL).



**Figure 3.6** Unit 2 - groundmass displays heavy alteration. Subhedral phenocrysts (A), originally of plagioclase feldspar are now fully altered to clinozoisite. Remnant plagioclase is also visible as a groundmass phase. Opaques are disseminated at random throughout the groundmass but are not present in the phenocrysts (PPL).

## 3.4.3 Unit 2 (Upper Garfield Member).

As Figures 3.5 and 3.6 illustrate, the rocks of Unit 2 are weakly porphyritic (NVT1-47) to aphyric<sup>11</sup> Many examples (such as NVT1-46b) display a relict hyalopilitic texture comprising a felted quartz/chloritic groundmass hosting intersertal plagioclase laths, clinozoisite and calcite. Isolated relict plagioclase phenocrysts are observed, which in most cases are now completely or almost completely altered to clinozoisite, visible as a distinct 'berlin blue' colour in XPL.

Local variations in texture and mineralogy within Unit 2 may occur, most probably in response to different levels of alteration. For example, NVT1-48 represents a finer grained crystalloblastic sample that has undergone severe alteration. Unit 2 may also be glomeroporphyritic<sup>12</sup> in places: where this is the case, the altered feldspar laths are more visible than those in the surrounding rock. Some feldspars have undergone such high degrees of saussuritisation that primary features such as twinning have been completely obliterated. Conversely, DKP1-9 is very fresh in comparison to the above, as is evident from its clear crystal morphology. The primary texture is sub-ophitic<sup>13</sup>, with secondary chlorite manifesting itself as both an interstitial groundmass phase, as well as more prominent blebs throughout the sample.

<sup>&</sup>lt;sup>11</sup> The term 'aphyric' may be applied to a phenocryst-poor volcanic rock (Whitelaw, *pers. com.*, 1998). <sup>12</sup> A glomeroporphyritic rock is one with a porphyritic texture in which groups of crystals (either of the

same mineral or of different minerals) are scattered through a finer-grained groundmass (Whitten & Brooks, 1973).

<sup>&</sup>lt;sup>13</sup> An ophitic/sub-ophitic texture is one in which augite encloses plagioclase (Whitten & Brooks, 1973).

## 3.4.4 Unit 3 (Central Rietgat Member).

Following a detailed optical examination of specimens taken from Unit 3 in a number of boreholes, it is concluded that three distinct facies exist. This subdivision is based on primary textural characteristics (summarised in Table 3.1) and is as follows:

#### <u>Facies I.</u>

The rocks comprising this facies are typically fine-grained, consisting of fine acicular plagioclase in a groundmass of xenomorphic quartz and chlorite (see Figure 3.7). The overall texture of the facies is hyalopilitic to pilotaxitic<sup>14</sup> with occasional calcite present as interstitial fillings only. Where clinozoisites are present, varying degrees of saussuritisation of the parent feldspar are identified, showing distinctive green pleochroism and high relief in PPL. An important characteristic of this facies is its zoned amygdales, 2-3mmØ, which contain quartz fillings concentrically zoned according to grain size. Anhedral opaques, determined by electron-microprobe analysis to be sphene and ilmenite, are disseminated throughout the entire facies, with the exception of its amygdaloidal component. It should be noted that due to the poor quality of the samples and consequent 'burning-out' of mineral phases during electron-microprobe analysis, this technique was not as widely employed as would have been desired.

<sup>&</sup>lt;sup>14</sup> A pilotaxitic texture comprises a felted mass of acicular or lath-like crystals, sometimes showing flow structures (Whitten & Brooks. 1973).



**Figure 3.7** Unit 3, Facies I - Amygdales contain quartz fillings concentrically zoned according to crystal size. This zonation is visible in high relief due to the presence of pleochroic chlorite at grain boundaries. The groundmass comprises microcrystalline quartz, chlorite and plagioclase, together with a high proportion of opaques (PPL).



**Figure 3.8** Unit 3, Facies III - Dense, fine-grained crystalloblastic groundmass comprising quartz, chlorite, plagioclase and opaque minerals (sphene or ilmenite). Amygdale fillings consist of concentrically zoned rims of quartz (A), chlorite (B) and calcite ( $\mathbb{C}$ ) (PPL).



**Figure 3.9** Unit 3, Facies II - Groundmass comprises a high proportion of opaque material (sphene and/or ilmenite), together with pilotaxitic plagioclase. The amygdales are concentrically zoned and contain fillings of calcite (A) and clinozoisite (B). The calcite is readily visible due to the high relief of its 120° cleavage (PPL).



**Figure 3.10** Unit 3, Facies II - Groundmass comprises a high proportion of opaques, in association with acicular plagioclase. Amygdales contain distinctive 'berlin-blue' clinozoisite core (A) and calcite rim (B) showing low-order birefringence colours (XPL).



**Figure 3.11** Unit 4 - Moderately equigranular intersertal plagioclase feldspar showing saussuritisation in places (A). Patchy silicification (B) tends to occur in association with chloritisation. Opaques are disseminated throughout the entire rock, though are commonly interstitial (PPL).



**Figure 3.12** Unit 5 - Coarsely intersertal euhedral plagioclase laths (A) in a fine matrix of green pleochroic chlorite and quartz. Opaques appear to occur on a very sporadic basis only and never appear to transect the plagioclase laths (PPL).

### <u>Facies II.</u>

This facies is exemplified by TNT2-11 (Figures 3.9 and 3.10) and is more or less fully pilotaxitic, comprising acicular plagioclase and fine interstitial quartz and opaque minerals. As is the case with facies I, the opaques are of sphene and/or ilmenite. TNT2-11, unlike most of the Rietgat Formation is more or less devoid of chlorite. The amygdale fillings of facies II comprise concentrically zoned rims of clinozoisite, quartz and calcite of low birefringence.

#### <u>Facies III.</u>

Facies III (typified by NVT1-23; Figure 3.8) comprises a completely crystalloblastic mass of aphanitic<sup>15</sup> plagioclase, clinochlore, epidote and occasional actinolite. Patchy silicification may be seen and as is the case with facies I and II, disseminated opaques are common. Amygdales are either of homogeneous calcite (displaying 102° cleavage throughout) or coarsely saccaroidal quartz, the latter becoming coarser towards the core of the amygdale. Both amygdale types generally posses a very thin rim of berlinblue clinozoisite and in the case of the quartz amygdales a rim of calcite.

## 3.4.5 Unit 4 (Upper Rietgat Member - Non-Amygdaloidal).

Twinned plagioclase crystals are prominent in Unit 4, where they typically display an intersertal/hyalopilitic texture (KFN2-8; Figure 3.11). Zoned and hollow plagioclase crystals were identified, which according to Lofgren (1972) are a product of cooling rates. Occasional glomeroporphyritic clusters of more finely grained plagioclase may

also be seen. Unit 4 contains occasional epidote (<1%) and more commonly blebby green pleochroic chlorite. Clinozoisite is recognised in Unit 4 where it manifests itself as a saussuritisation product of plagioclase. Two crystallographic orientations may be seen in the clinozoisite, one giving rise to a characteristic Berlin-blue colour in XPL and the other to a brown colour, following remnant twinning planes.

## 3.4.6 Unit 5 (Upper Rietgat Member - Amygdaloidal).

The rocks of Unit 5 are petrographically similar to those of Unit 4, save for the presence of amygdales in the former. Unit 5 is typically dominated by coarse intersertal, idomorphic<sup>16</sup> twinned plagioclase with hyalopilitic tendencies in places (see MA2-3; Figure 3.12). The interstices of Unit 5 may be filled by either a very fine greenish mineral (high relief in PPL) or by calcite. Calcite may in some cases also be present as fine stringers where it commonly associates with minor blue clinozoisite. Small quantities (~5%) of highly pleochroic brown material - completely opaque in certain cases are tentatively described as sphene. Unit 5 contains a submorphous groundmass of fine quartz and very occasional epidote (<1%), identifiable by its high birefringence in XPL.

#### 3.4.7 Upper Sedimentary Horizon (USH).

In all cases, the clast size of the USH ranges between 0.2 and 1.5 mm Ø. Furthermore, the clasts themselves are almost entirely of quartz composition (together with very

<sup>&</sup>lt;sup>15</sup> The term 'aphanitic' is a textural term used to describe igneous rocks having such fine grains that individual constituents are not visible to the naked eye, but are visible under suitable magnification

occasional plagioclase grains and lava fragments) indicating a reasonably high degree of mineralogical maturity (see Figures 3.13 and 3.14). In terms of their texture, the clasts are sub-angular to sub-rounded, indicating a moderate degree of textural maturity and therefore a high degree of sediment working. Fining-upward cycles may be seen, albeit on a small scale (the thickness of these laminae typically being in the order of 1cm).

Although in a broad sense, the USH is petrographically homogeneous, some minor localised variations are observed. For example, while secondary calcification is commonplace in ZTD1-1 (particularly in its coarsest layers), DKL8-7 is completely devoid of such mineralisation and is of virtually pure quartz composition. ZTD1-1 is clast-supported and since it contains virtually no matrix may be considered unimodal in terms of its grain-size distribution. Although in the case of DKL8-7, many of the constituent clasts are in contact with one another, a considerable number are separated by small amounts of highly silicified matrix. This sample therefore displays a strongly bimodal grain-size distribution. Hence it is debatable as to whether DKL8-7 is clastor matrix-supported. These inconsistencies have been attributed in part to localised facies variations as well as differing levels of secondary alteration.

Occasional epidote grains, readily identifiable by their high order birefringence colours, were dispersed throughout the USH regardless of facies variety. It is proposed that the epidote is an in-situ alteration product and that it was not derived in its present state from pre-existing rocks.

<sup>(</sup>Whitten & Brooks, 1973).

<sup>&</sup>lt;sup>16</sup> An idiomorphic rock is one which displays a fully developed crystal form (Whitten & Brooks, 1973).



**Figure 3.13** Upper Sedimentary Horizon - Comprises sub-rounded quartz grains (A), lithic fragments (B) and calcite (C) - possibly secondary and displaying cleavage planes in moderate relief. This sediment is texturally mature as is indicated by its unimodal size distribution (PPL).



Figure 3.14 Upper Sedimentary Horizon - Comprises sub-rounded quartz grains (A) and lithic fragments (B) which are possibly of lava. Calcite (C) displays low-order birefringence colours and probably arises from the calcification of pre-existing material (XPL).

Figure 3.15 illustrates the euhedral metallic sulphides (specifically pyrite, chalcopyrite and pyrrhotite) which occur in conjunction with the shale constituent of the USH. It is proposed that this association results from the fact that metallic sulphides form readily under the euxinic genetic conditions typical for many shale facies.

#### A brief note on the possible correlation of the USH with the sediments at T'Kuip.

As will be discussed in Section 4.5, an attempt was made to correlate the rocks of the Platberg and Pniel Groups in the Allanridge-Bothaville area with the exposed Sodium Group rocks at T'Kuip. It is possible that the sedimentary unit outcropping in association with the lavas of the Rietgat Formation at T'Kuip may represent a USH correlative. A dearth of surface exposure in the T'Kuip area rendered it impossible to discern the exact stratigraphic position of the outcrop. Correlation is complicated further by the fact that the sediments at T'Kuip are petrographically distinct from both the USH and the Bothaville Formation as seen in the Free State. It is proposed that this is the product of a facies variation.

#### 3.4.8 Intrusive Rocks.

The sheeted mafic intrusives encountered in the study area are typically coarsely crystalline and equigranular, containing a high proportion of clinopyroxene, which have undergone moderate chloritisation (ERO2-1). Relatively large plagioclase laths (4mm) are barely discernable due to the high degree of saussuritisation which they have undergone. An ophitic relationship between the plagioclase and clinopyroxene may be seen, though it is not widespread. Occasional amphiboles, principally



**Plate 3.15** Upper Sedimentary Horizon - Reflected light microscopy reveals the presence of euhedral pyrite grains (A). It is proposed that this mineralisation took place in-situ and took the form of nucleation around microscopic detrital sulphide grains (Reflected light).

actinolite, and hornblende were identified. No olivine remnants were recognised and saccaroidal quartz appears to be restricted to pervasive secondary occurrences

# 3.4.9 Pseudotachylites

Reference was made in Chapter 2 to isolated pseudotachylite occurrences in borehole NVT1. Although petrographically similar to ignimbrites and rheoignimbrites, pseudotachylites have been distinguished from tuffaceous material on the basis of the criteria (Colliston and Reimold, 1994) presented on page 88.



**Figure 3.16** Pseudotachylite - Banding of the matrix is readily discernable (A): this is possibly a flow-structure. The remainder of the sample comprises a range of mineral grains (B), which are predominantly of quartz and display a marked range in grain-size and angularity (PPL).



**Figure 3.17** Pseudotachylite - Lithic fragment (A) of feldspar porphyry shows slight corrosion at its outer rim. The matrix contains mineral grains, particularly of quartz (B) in addition to abundant opaque material. Chloritisation of the sample is moderate and imbrication of mineral grains - particularly quartz - is notable (PPL).

- Identification of crystallisation products in the matrix.
- Presence of vesicles.
- Corrosion textures/reaction rims at clast margins.
- Partial or complete assimilation of clasts into the matrix.
- Sintering textures within clasts.

Figures 3.16 and 3.17 depict the pseudotachylite as it is seen in the study area. Its mineral grains are predominantly of quartz with occasional plagioclase feldspar; lithic fragments are usually of porphyritic lava. The clastic component of the pseudotachylite is generally upwards of 1mm in diameter, sub- to well rounded and commonly annealed. In accordance with the above criteria for pseudotachylite recognition, the clasts frequently show reaction rims and display signs of corrosion at their margins - possibly a precursor to their assimilation of the clasts into the matrix. The matrix itself shows an advanced degree of crystallisation, which further substantiates the theory that this material is pseudotachylitic. Notable structures in the matrix include very fine banding, very high proportions of opaque material and imbrication of constituent clasts. Minor amounts of epidote and clinozoisite occur on a sporadic basis, particularly in the matrix and are assumed to be of secondary provenance.

# 3.5 Mineralogical Trends as Identified by XRD.

# 3.5.1 Introductory Note.

XRD analysis of 223 Rietgat Formation samples was undertaken, the purpose of which was to determine whether any mineralogical variation exists within or between units. A cross-section of samples from all lava units, sediments and tuffs were selected for this exercise. Regrettably however, not all of the T'Kuip samples were available at the time of analysis, hence the limited nature of the data from this location in Appendix 2. XRD was also used to assess the degree of lateral mineralogical homogeneity of the units in the study area.

It is necessary at this stage to explain the nature of the data referred to in this section. In the case of the present study, the XRD data is non-quantitative. As such it is only possible to affirm the presence of a mineral phase and not its specific abundance.

All of the XRD interpretations generated by this study are presented in Appendix 2, where they are arranged according to unit of origin. The following paragraphs aim to identify and interpret trends in this data and are organised in terms of mineralogy.

# Ferroan clinochlore.

This mineral is present in all of the samples, with the exception of MA1-11, which instead appears to be intensely epidotised. In virtually all cases, a very strong primary XRD peak is seen with respect to ferroan clinochlore, suggesting a relatively high abundance.

## <u>Quartz.</u>

All of the analysed samples were found to contain a quartz component. The intensity of the primary quartz peak was seen to vary markedly in proportion to the relative abundance of this mineral.

## <u>Albite/calcian albite.</u>

Where present, plagioclase feldspar manifests itself as either albite or calcian albite. This mineral was recognised throughout Units 1, 2 and 3 in the large majority of boreholes. Plagioclase feldspars are present in the lowermost portions of Units 4 and 5 but are absent in the upper horizons of these units. The tuffs are completely devoid of all plagioclase feldspars.

## <u>Muscovite.</u>

The main noteworthy muscovite occurrences in the Rietgat Formation may be found in the upper horizons of Units 4 and 5. Muscovite is also common in Unit 2, scarce in Unit 1 and almost completely absent in Unit 3. A strongly inverse relationship between muscovite and albite abundance appears to exist which may be explained in terms of metamorphism. Theoretical isograds (Figure 3.18) delineating this association were constructed using PTX, a computer program for DOS (Perkins *et al.*, 1986). Since PTX was unable to proffer a satisfactory relationship between albite and muscovite, anorthite was instead taken to represent the plagioclase content of the lavas. It is possible that anorthite may have undergone albitisation as a result of fluid processes subsequent to metamorphism.



Figure 3.18 P-T stability fields for a system containing muscovite and anorthite.



Figure 3.19 P-T stability fields for a system containing actinolite and calcite.

## <u>Epidote.</u>

Although widely identifiable by petrographic means at all stratigraphic levels, epidote was only very rarely observed in XRD patterns. A consequence of the relatively low abundance of epidote is that it often falls below the detection limits of XRD (~ 3%, G. J. Beukes, pers. comm., 1999). Accordingly, no clear mineralogical trends were elucidated by XRD with regard to epidote and stratigraphy. Epidote was only recognised in XRD samples obtained from the intensely altered zones as described in Chapter 2.

## <u>Biotite.</u>

This mineral was only encountered in its fresh state in certain intrusive samples. It is possible however that biotite also existed in the lavas and that this underwent alteration to chlorite. Biotite distribution may also attributed to primary minerlogical variations between the intrusive material and the lavas.

## <u>Calcite</u>

The distribution of calcite appears to be extremely sporadic, varying from hole to hole and from unit to unit. For example, calcite was observed throughout boreholes S4, ERO4, MAL1 and DKP1 in their entirety. Conversely, boreholes KFN2 and TNT2 are completely devoid of this mineral. Other boreholes (S6, DKL6, MAL4, MA1, MA2 and NVT1) show varying degrees of calcification, ranging from the advanced calcification of entire units, through moderate levels of calcification to a complete calcite absence.

# Actinolite/ferro-actinolite.

A moderately inverse relationship between ferro-actinolite and calcite abundancies is noted. Hence, actinolite distribution in the Rietgat Formation in the study area is roughly antipathetic to calcite distribution. Theoretical isograds depicting this relationship are again extrapolated using PTX and are shown in Figure 3.19.

# 3.6 Normative Mineralogical Classification of the Rietgat Formation.

### 3.6.1 Introduction.

The norm calculation is a means by which the mineralogy of a rock may be derived from the results of a geochemical analysis. The most widely used classification scheme is the CIPW-norm, the specifics of which may be found in Rollinson (1993). The normative mineralogical composition of a rock may differ substantially from the observed modal composition; this is due to the following simplifying assumptions.

- The calculations assume that the parent magma was anhydrous, therefore minerals such as hornblende and biotite are absent from the classification.
- No account is taken of solid solution between Ti and Al in ferromagnesian minerals.
- The Fe:Mg ratio in all ferromagnesian minerals is assumed to be the same.
- The CIPW-norm. is derived from geochemical data only and disregards the effects of crystal size.

Currie (1991) proposed that for altered mafic volcanic rocks, the CIPW-norm yields results that closely resemble the original modal composition. It therefore follows that CIPW-normative analyses are of particular use in estimating the primary mineral phases that have subsequently been replaced by metamorphic minerals.

CIPW norms were calculated for all 412 geochemical analyses undertaken in this study and are presented in Appendix 3. Mean CIPW-norm values for each unit of the Rietgat Formation (excluding tuffaceous and sedimentary units) are given in Table 3.2, an interpretation of which is presented in the following paragraphs.

# Quartz.

Normative quartz may be derived for all of the units of the Rietgat Formation (Table 3.2). Unit 3 contains a significantly lower quartz component (11.31%) relative to all of the other units (~20%). Since normative quartz is calculated from excess  $SiO_2$  (i.e. that already not held in bonds with other oxides), it follows that Unit 3 has, on average, a lower SiO<sub>2</sub> content (Table 3.2).

### Ilmenite, sphene & rutile.

The normative ilmenite, sphene and rutile values are a function of  $TiO_2$  content. If FeO <  $TiO_2$ , then an excess of  $TiO_2$  is allocated to sphene in proportion to the CaO content of the sample (only after CaO has been allocated to anorthite, see below). If there is still an excess of  $TiO_2$ , it is apportioned to rutile. With reference to the data in Table 3.2, it may be seen that Units 1 and 5 contain both normative sphene and rutile, suggesting a relatively high  $TiO_2$  excess. Conversely, Unit 3 and the intrusive material contain sphene only, which is indicative of a lower  $TiO_2$  excess. In the cases of Units

 $(\cdot, \cdot)$ 

. [	UNIT					
	1	2	3	4	5	Intrusives
Quartz	19.99	22.11	11.31	20.34	20.59	18.51
Corundum	-	0.14	-	3.47	-	-
Zircon	0.07	0.08	0.05	0.07	0.06	0.04
Orthoclase	9.67	14.97	3.93	8.04	7.80	8.06
Albite	23.39	23.07	27.47	21.48	19.34	17.63
Anorthite	22.52	20.58	25.55	21.00	27.34	22.86
Diopside	-	-	0.79	-	-	3.32
Hypersthene	10.10	7.45	13.30	10.89	10.80	11.12
Chromite	0.08	0.06	0.06	0.04	0.04	0.03
Haematite	9.84	8.98	11.72	11.33	10.37	14.53
Ilmenite	0.24	0.23	0.29	0.30	0.27	0.48
Sphene	2.97	-	3.74	-	0.81	3.15
Apatite	1.43	1.36	2.08	1.81	1.76	0.53
Rutile	0.03	1.29	-	1.48	1.06	-
n=	25	7	76	35	82	. 7
TOTAL	100.33	100.32	100.29	100.25	100.24	100.26

**Table 3.2**Mean CIPW-norm. compositions for the units of the Rietgat Formation.

2 and 4, the fact that normative rutile is present and sphene absent may be explained in terms of CaO stoichiometry. It is likely that the original CaO concentrations in these units were sufficiently low as to have been allocated in full to anorthite (see below). As a result, no excess CaO was available to buffer TiO<sub>2</sub> in sphene nucleation, hence excess TiO<sub>2</sub> contributes instead to the formation of rutile.

### <u>Feldspar minerals</u>

With regard to the feldspar minerals, orthoclase, albite and anorthite crystallise as a result of a buffering relationship between  $Al_2O_3$  and  $K_2O$ ,  $Na_2O$  and CaO, respectively. Any geochemical variations (with respect to  $K_2O$ ,  $Na_2O$  and CaO) within and between the units of the Rietgat Formation are reflected in their feldspar mineralogies. Cross-referencing of the  $K_2O$ ,  $Na_2O$  and CaO in Table 3.3 with the normative feldspar data in Table 3.2 serves to confirm this relationship.

#### <u>Corundum.</u>

Any  $Al_2O_3$  in excess of CaO following anorthite crystallisation goes to form normative corundum. Since Units 2 and 4 are corundum-normative (Table 3.2), one would expect their  $Al_2O_3$  content to be relatively high in accordance with the above rule. Although this principle may be applied in the case of Unit 4 (Table 3.3), Unit 2 to the contrary - contains a relatively low concentration of  $Al_2O_3$ . The allocation of  $Al_2O_3$  to corundum in the case of Unit 2 is probably a function of its low Na<sub>2</sub>O, CaO and K<sub>2</sub>O contents, resulting in a lower degree of buffering of  $Al_2O_3$  by the feldspars (possibly due to alteration).

#### <u>Pyroxenes.</u>

With reference to the pyroxene minerals, an excess of CaO over  $Al_2O_3$  is allocated with an equal amount of MgO + FeO to normative diopside. Any remaining MgO + FeO goes to form hypersthene. In the case of the present study, normative diopside was only encountered in Unit 3, suggesting that overall, this is the only unit in which a CaO excess comes about. In all of the units, an MgO + FeO excess occurs regardless of whether diopside is crystallised. As a result, normative hypersthene is present in all of the units.

			·			
	UNIT					
	1	2	3	4	5	Intrusives
SiO <sub>2</sub>	56.56	57.60	50.91	52.48	54.70	53.38
TiO2	1.30	1.34	1.54	1.55	1.45	1.53
$Al_2O_3$	13.90	14.05	14.43	15.81	14.45	13.18
Fe <sub>2</sub> O <sub>3</sub>	9.28	8.48	10.74	10.60	9.80	14.09
MnO	0.11	0.11	0.13	0.13	0.12	0.21
MgO	3.80	. 2.83	4.99	4.07	4.02	5.23
CaO	5.77	4.51	7.11	5.08	6.16	6.46
Na <sub>2</sub> O	2.62	2.57	3.04	2.09	2.30	2.21
K <sub>2</sub> O	1.59	2.40	0.72	1.51	1.20	1.17
$P_2O_5$	0.57	0.54	0.78	0.72	0.69	0.26
H <sub>2</sub> O-	0.07	0.06	0.07	0.07	0.07	0.14
LOI	3.57	4.16	4.06	5.36	5.24	2.34
n=	= 25	7	76	35	82	. 7
TOTAL	99.15	98.66	98.54	99.48	100.20	100.20

 Table 3.3
 Mean oxide compositions for the units of the Rietgat Formation.

## <u>Apatite.</u>

Finally, normative apatite (present in all of the units) crystallises in response to a  $P_2O_5$ presence, haematite to an Fe<sub>2</sub>O<sub>3</sub> excess and chromite and zircon to Cr and Zr excesses respectively. ۳.

# 3.7 Veins and Vuggy Quartz Occurrences.

Quartz veining may be observed throughout the Ventersdorp Supergroup in the study area. This material appears to show little or no conformity to any formation or lithological unit within the Supergroup and as such is somewhat sporadic in its distribution. The veins themselves range in size from hairline-size fillings, through veinlets (~ 1cm) to larger bodies of up to 25cm cross-section. Perhaps the most common mode of vein occurrence seen in the study area are the extensive stringer networks which pervade many metres of borehole core. These networks may possibly result from the movement of fluids along structurally-derived fissure planes. During their passage, these fluids gave rise to both wall rock alteration (up to 1cm from the fissure) as well as the precipitation of small quantities of vein quartz and/or chalcedony.

In the larger of the aforementioned vein systems, more diverse mineral assemblages may be seen, on both macro- and microscopic scales. These typically comprise coarse-grained quartz, in addition to variable quantities of calcite, chlorite and epidote. Texturally, the larger vein systems exhibit a saccaroidal texture, which is at its coarsest towards the centre of the body. The chlorite and epidote may have either been entrained from adjacent rocks by the circulating hydrothermal fluids, or instead have been derived during the greenschist facies metamorphism of the entire lava pile. Thermometric analyses of fluid inclusions (Section 3.7.1) have been used in an attempt to elucidate the nature of the fluid event responsible for the emplacement of the quartz veins.

Vuggy quartz is also extremely common throughout the entire Ventersdorp Supergroup. Vugs range in size from 10mm up to several centimetres in cross-section, usually associating with amygdales. The vug fillings are typically of quartz/chalcedony together with varying amounts of calcite and/or chlorite. In general, the larger the vug, the coarser its filling and the more diverse its mineralogical constituent. Zonation is quite common, this giving rise to agates. Vugs are at their most abundant in Units 3 and 5 of the Rietgat Formation, typically occurring nearer to the base of the lava flows rather than the top. Vugs do not appear to associate with the sedimentary or porphyritic facies of the Rietgat Formation and are extremely scarce in non-amygdaloidal units.

# 3.7.1 Thermometric Analysis - Introduction and Principles.

Thermometric analysis is concerned with the investigation of fluid inclusions trapped in their solid host. Further details concerning both the techniques and the principals of fluid inclusion analysis may be found in Shepherd *et al.* (1985), Chapters 4-6.

Analyses were undertaken at the University of the Free State using separate Chaixmeea heating and cooling stages, in conjunction with a Leitz biological microscope equipped with a UV filter. Heating was effected by an electrical resistance heater and cooling by the circulation of gaseous nitrogen in the presence of silica gel in order to prevent condensation. Rock wafers, polished on both sides, were prepared from vug material: such samples provide the best source of inclusions, since hydrothermal veins tend to yield poorer quality material (Shepherd *et. al.*, 1985). Sample selection was made on the basis of available material.

# <u>Freezing studies.</u>

Freezing studies were used to measure the salinity of the inclusions. Under aqueous conditions, the freezing point of water varies in proportion to the amount of salt in solution. Since a variety of chemical systems may manifest themselves in fluid inclusions (these being chlorides, sulphates and carbonates of Fe, Mg, Ca, Na and K in combination with water) it is first necessary to ascertain the precise nature of the brine. This may be deduced from the eutectic temperature of the system, this being the point at which first melting occurs in a fully frozen inclusion. In the case of the present study, the eutectic temperature was determined to be approximately -21°C. With reference to published data (Shepherd *et al.*, 1985), this corresponds closely to the eutectic temperature for the system  $H_2O + NaCl$ .

# Heating studies.

The ultimate aim of heating studies is to measure the homogenisation temperature, this being the temperature at which the inclusion becomes a one-phase system. By comparison with freezing studies, the phase changes observed at high temperatures are relatively uncomplicated. Homogenisation of the liquid and vapour  $H_2O$  + NaCl phases in the current study led to the solution of the vapour phase into the liquid state. The precise point at which the vapour bubble goes into exsolution is known as the homogenisation temperature: this was found to be between 56°C and 206°C for the observed populations.

## 3.7.2 Interpretation and synthesis of results.

The most effective means of representation of thermometric data are histograms and bivariate plots, since these provide an immediate appreciation of any groupings or
populations which may be present. When plotted, the data showed moderate bimodal distribution indicating the presence of more than one inclusion population, possibly resulting from the presence of  $CO_2$  in certain inclusions.

The object of this excercise has been to constrain the relationships - if any - between the veins and vugs and the greenschist metamorphic event. Although the temperature at which the veins and vugs were emplaced has already been elucidated, this alone is of little value in the clarification of a possible relationship to a metamorphic facies. It is also necessary to calculate the pressure at which trapping took place. Using the method of Shepherd *et. al.* (1985), the inclusions in wafers ERO2-5 and DKL5-19 were found to have been trapped at temperatures between 84.5° and 206.6°C at a pressure of between 0.59 and 18.69 bars Pressure conditions were found to be similar for all of the inclusion populations studied. With reference to Winkler (1974), these pressure conditions are clearly far outside the bounds of greenschist facies metamorphism. It has been concluded for the purposes of this study that the veins and vugs are the product of a later hydrothermal event.

#### 3.7.3 Discussion and Interpretation of Mineralogy.

The following section aims to summarise and interpret the mineralogical trends identified in this chapter.

One of the most noteworthy mineralogical features of the Rietgat Formation is its paragenesis. As has already been noted, the assemblage typically comprises chlorite, quartz, albite  $\pm$  actinolite  $\pm$  epidote, which according to Deer *et al.* (1993) is

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commonly representative of greenschist facies metamorphism. The P-T conditions for such a paragenesis are in the order of 400°C at a few kilobars (Deer *et al.*, 1993).

With regard to the minerals comprising the greenschist facies assemblage, it is important to note the following:

- Chlorite is a common hydrothermal alteration product of the of biotite, pyroxenes and amphiboles in igneous rocks (Deer *et al.*, 1993). Furthermore, the composition of the chlorite is often related to the composition of the original rock. In the case of the present study, the chlorite is principally Fe-rich (ferroan-clinochlore), reflecting its role in the replacement of an Fe-rich ferromagnesian phase. Chlorite is also a common amygdale filling in the lavas and is a product of intense hydrothermal alteration.
- Although occurring principally as a product of greenschist facies metamorphism (as described above), epidote and clinozoisite may also occur as a hydrothermal alteration product. This mode of epidotisation is generally confined to joints, fissures and amygdales.
- Albite may be a product of both greenschist facies metamorphism and primary magmatic processes (plagioclase feldspars being one of the most important constituents of basic and intermediate lavas). It is therefore contentious as to whether the albite component of the lavas was derived by primary or secondary processes. In the case of the present study however, it is probable that both of these processes have operated.

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In section 3.6, the presence of certain accessory phases were noted. One such mineral is ilmenite, some of which is a product of primary crystallisation, but much of which is derived from Ti-magnetite during cooling. Sphene is also a widespread accessory mineral in igneous rocks, where it is the dominant Ti-bearing mineral (Deer *et. al.*, 1993).

The metallic sulphide (pyrite, pyrrhotite and chalcopyrite) component of the Rietgat Formation is, as previously discussed, confined to the sedimentary portions of the Formation. It is possible that these sulphides formed by either sedimentary or diagenetic processes under reducing conditions.

The interpretations of the preceding paragraphs are based on the mineralogy of the Rietgat Formation as deduced by XRD analysis and petrography. A somewhat different mineral paragenesis was however elucidated by CIPW-normative calculation. Although some of the normative mineral constituents (such as the plagioclase feldspars, quartz, ilmenite and sphene) were identifiable by petrographic means, most were confined to the CIPW-norm only. This discrepancy may be accounted for at least in part by the simplifying assumptions of the norm calculation itself. It is also proposed that the results of the CIPW-norm reflect the primary mineralogical composition of the lavas prior to greenschist facies metamorphism. The presence of feldspars, quartz and pyroxenes in the norm are indeed characteristic components of basic to intermediate lavas. Minerals such as rutile, corundum, zircon, chromite and haematite are all common accessories in igneous rocks and serve no diagnostic purpose in this study. The fact that chlorite, epidote and clinozoisite are absent from the norm goes to substantiate the fact that they are indeed secondary

products. Vugs and quartz veining were found to have been trapped at temperatures between 84.5° and 206.6°C at a pressure of between 0.59 and 18.69 bars. Such temperatures and pressures conform to neither an extrusive igneous or a greenschist facies metamorphic event and are hence may be considered to be of subsequent origin.

## CHAPTER 4: GEOCHEMICAL STRATIGRAPHY.

### 4.1 Introduction.

The problem with lithological stratigraphic classifications is that they are prone to misinterpretation and are not always conducive to long-range correlation. In contrast, geochemical stratigraphic methods are easy to apply and in the case of the Ventersdorp Supergroup are laterally consistent over a wide area (Linton, 1992).

The main aim of the following chapter is therefore to elucidate the geochemical differences between the lavas of the Rietgat Formation. Parameters by which unknown samples may be classified into their respective units are also proposed. It should be emphasised that this chapter deals only with the more practical applications of geochemistry: petrogenetics and magmatic characterisation are discussed in Chapter 5.

The formulation of geochemical discrimination techniques arises out of the following needs. Firstly, it is desirable to estimate the depth to reef during exploration drilling, allowing decisions to be made regarding the continuation of boreholes. The fundamental assumption in this case is that the thickness of the Rietgat and underlying formations are known with certainty in the area. Secondly, geochemical stratigraphy may also be applied in the resolution of structural problems. Such issues include the loss of stratigraphic units due to normal faulting and the repetition of units due to reverse faulting and/or thrusting. The extrapolation of these structures to the

underlying reef may contribute towards the structural interpretation of the region and its ore bodies.

#### 4.2 Previous Work.

Perhaps the most comprehensive approach to the geochemical subdivision of lava units (in this case the Alberton Formation of the Klipriviersberg Group) is that of Winter (1995). In his study, Winter (*ibid.*) first examined chemical variations with stratigraphic height by means of univariate (element or oxide versus depth) plots. Since this exercise failed to highlight any geochemical variation between horizons, Winter instead sought to detect clustering or linear variation in the data by plotting paired variables on a series of scatter plots. Winter (*ibid.*) concluded that this method provided satisfactory discrimination between horizons. However, he also considered it desirable to involve all of the elemental variables simultaneously in the same classification scheme and employed multivariate statistical techniques to this end.

Having assessed the shortcomings of both element-element bivariate plots and ternary diagrams, Linton (1995) concluded that the only discrimination technique of value in the categorisation of lava suites is discriminant function analysis. This is due to the fact that the increased number of variables utilised by this technique provide a tighter constraint on the positioning of the fields.

## 4.3 The Geochemical Stratigraphy of the Rietgat Formation.

The following paragraphs aim to identify any geochemical characteristics and trends present in the lavas of the Rietgat Formation. A variety of graphical and statistical discrimination techniques have been used to this effect.

### 4.3.1 Univariate Analysis: Geochemical Variation with Stratigraphic Height.

Experimental geochemical profiles (element versus depth) were constructed for all boreholes with respect to all major oxides and trace elements. The aim of this exercise was to determine whether any vertical geochemical variation exists within the profile and if so whether such features can be correlated between holes. Given the fact that this exercise generated nearly 500 individual plots, only those identifying the clearest trends were selected for inclusion in this study, an explanation of which follows.

In the majority of cases, the morphology of the down-hole elemental profiles is somewhat irregular, rendering their interpretation a complex process. An approach similar to that of Myers *et al.* (1990) involving immobile trace elements (Zr, Ti/Zr and Cr) and their inter-relationships was also tested on the data set, though due to the disparate nature of the plots, no clear trends were evident. Consequently, reviews of only two principle ratios have been included in the present study, these being Ni/Zr and P<sub>2</sub>O<sub>5</sub>/Zr versus depth (Figures 2.26-2.38). The ratio of Ni to Zr was chosen since it is representative of fractionation (a relatively low Ni/Zr ratio is indicative of a relatively high degree of fractionation - see Chapter 5) and P<sub>2</sub>O<sub>5</sub> to Zr since these elements are fundamental to the sub-division of the Rietgat Formation (Figure 2.3). In contrast to most other trace element and major oxide variables, the ratios of Ni to Zr and of  $P_2O_5$  to Zr (Figures 2.26-2.38) were found to display relatively clear vertical zonation, which may be correlated laterally and which is applicable to all sections.

Units 1 and 2 show relatively low Ni/Zr values, though these are still higher than those displayed by Units 4 and 5. In most cases, the Unit 1 Ni/Zr value is very slightly elevated in relation to that of Unit 2. The Ni/Zr ratio of the intrusive material is far in excess of that of the lavas by which it is hosted. Unit 3 exhibits far higher Ni/Zr ratios than the rest of the Rietgat Formation, a trend which is most acute towards the centre of this unit. In comparison to Unit 3, Unit 4 displays a relatively low Ni/Zr ratio, as does Unit 5 in the majority of sections. In certain sections Unit 4 does, albeit on a minor scale, display Ni/Zr elevation relative to Unit 5.

With regard to the  $P_2O_5/Zr$  ratios, the observed trends are very similar to those displayed by Ni/Zr. Units 1 and 2 display consistently low values, Unit 3 displays an elevated  $P_2O_5/Zr$  ratio, which is consistent throughout the unit. Units 4 and 5 exhibit relatively low  $P_2O_5/Zr$  ratios; it is not possible on a linear plot to differentiate between the two units on this basis.

A large degree of scatter was observed in many of the profiles that were not included in this study. This may be attributed to alteration, particularly in the case of the more mobile variables such as Rb, Ba, Sr, Na<sub>2</sub>O and CaO. Conversely, it is also possible that a more limited scatter of data points is indicative of better geochemical preservation. Dispersal of the data may also be attributed to magmatic processes, such as contamination, mixing and fractionation. In summary, the lavas do - with the exception of a small number of anomalous samples - exhibit similar geochemical trends between boreholes, indicating that the lavas are laterally homogenous. Minor vertical geochemical variation do however exist, these being a function of lithological variation and/or alteration.

#### 4.3.2 Bivariate Analysis: Scatter Plots.

The previous exercise highlighted only subtle geochemical differences between the stratigraphic units. It has therefore been deemed necessary to employ an alternative discrimination technique with a view to establishing a more clear-cut geochemical constraint on stratigraphy. To this end a number of X-Y element-element scatter plots have been compiled. Such scatter plots are of use in that they may reveal both clustering and lineation, where present, in the data set. The propensity of variables to increase or decrease in proportion or inverse proportion to one another may also be observed from this type of diagram.

Initially this exercise involved the construction of 529 bivariate plots representing every combination of the 23 variables plotted against one another. Only the plots displaying the clearest and most representative data trends were however chosen for inclusion in this study, a summary of which follows.

It was first noted that the only scatter plots to show any clear data trends were those containing  $TiO_2$ ,  $P_2O_5$ , Zr, Cr and V (i.e. relatively immobile elements) as at least one of the variables. This is illustrated by Figures 4.4 to 4.6, which all exhibit varying scales of clustering of the data points. Plots including Zr as a variable do however

appear to reveal the tightest clustering and least amount of overlap of the data. A plot of Zr versus  $P_2O_5$  (Figure 2.3) was indeed used in Chapter 2 as a fundamental mechanism for the geochemical subdivision of the Rietgat Formation. Plots including V as a variable (Figures 4.1 - 4.16) also facilitate the recognition of individual units, though the clustering of the data is less dense. While Units 1 to 3 are clearly defined on V-plots, a certain amount of overlap between Units 4 and 5 does however occur. Plots which use  $P_2O_5$  as a variable tend towards a more dispersed appearance with more overlap between all units. Distinct fields may nonetheless be recognised, particularly in the case of Units 1 to 3 on a plot of  $P_2O_5$  versus Nb (Figure 4.12). Cr as a variable is also of use in the constraint of geochemical stratigraphic units, though it generally produces fields of data rather than the tight clusters characteristic of other diagrams. The level of overlap is however minimal.

As has been demonstrated (Figure 2.3), clustering of the data facilitates the identification of discrete geochemical units. The existence of such sharp geochemical discontinuities between the units may be a function of petrogenetic aspects - a topic which will be addressed in Chapter 5.

Certain plots (eg.  $TiO_2$  versus  $P_2O_5$ , Figure 4.7) do give an initial impression that lineation is present in the data. Although such trends can represent the petrogenetic development of a unit, closer examination of the data has revealed that no relationship exists between stratigraphic height and relative position in a geochemical lineation.

T. B. Bowen (1984) and Bowen *et al.* (1986a, 1986b) also applied element-element scatter plots to the discrimination of lavas. The aforementioned authors have proposed

that a plot of Ti/P versus P/Zr is the best means by which to characterise the volcanic rocks of the Witwatersrand Triad. Although this method provides accurate discrimination between the lavas of the Ventersdorp Supergroup as a whole, the elemental variations within the Rietgat Formation are, as Figures 4.17 and 4.18 suggest too small to facilitate the demarcation of individual units.







Figure 4.2 Scatter plot of Zr versus P<sub>2</sub>O<sub>5</sub> (this study).



Figure 4.3 Scatter plot of Zr versus Cr (this study).



Figure 4.4 Scatter plot of V versus Zr (this study).



Figure 4.5 Scatter plot of V versus Ni (this study).



Figure 4.6 Scatter plot of V versus Cr (this study).



Figure 4.7 Scatter plot of TiO<sub>2</sub> versus P<sub>2</sub>O<sub>5</sub> (this study).



Figure 4.8 Scatter plot of TiO<sub>2</sub> versus Ni (this study).



Figure 4.9 Scatter plot of P<sub>2</sub>O<sub>5</sub> versus Y (*this study*).



Figure 4.10 Scatter plot of P<sub>2</sub>O<sub>5</sub> versus Sc (this study).



Figure 4.11 Scatter plot of P<sub>2</sub>O<sub>5</sub> versus Ni (this study).



Figure 4.12 Scatter plot of P<sub>2</sub>O<sub>5</sub> versus Nb (this study).



Figure 4.13 Scatter plot of P<sub>2</sub>O<sub>5</sub> versus Cr (this study).



Figure 4.14 Scatter plot of Cr versus TiO<sub>2</sub> (this study).

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Figure 4.15 Scatter plot of Cr versus Ni (this study).



Figure 4.16 Scatter plot of Cr versus Nb (this study).



Figure 4.17 Ti/P versus Ti/Zr Ventersdorp Supergroup discrimination diagram (after T. B. Bowen, 1984)



**Figure 4.18** P/Ti versus Zr/P Ventersdorp Supergroup discrimination diagram (after T. B. Bowen, 1984)

### 4.3.3 Multivariate Statistics.

The preceding paragraphs have demonstrated that adequate geochemical discrimination between stratigraphic units may be derived by bivariate means. One may argue however that because rocks are multi-element systems it is desirable to employ more than two such variables simultaneously in a scheme of classification. It was to this end that Discriminant Function Analysis was utilised. A brief review of these techniques is included, though for further information specific to geological applications, the reader is referred to Davis (1973), Le Maitre (1982) and Pearce (1975).

#### 4.3.3.1 Discriminant Function Analysis (DFA).

DFA is a non-parametric statistical tool, which weights and combines variables into a linear equation, forcing the variable to be as different as possible. DFA requires an initial grouping of the data to be undertaken in order to define the functions, which in the case of the present study has been defined on the basis of a plot of  $P_2O_5$  versus Zr. The purpose of DFA is to perform the following functions:

- To discriminate between groups of observations on the basis of a number of variables.
- To classify observations and unknown samples into the correct groups on the basis of the variables used to define the discriminant function.

In the case of the present study, two principal DFA techniques were applied and may be defined as follows:

#### Stepwise Analysis:

A variable selection technique whereby a subset of the best-discriminating variables are selected from a larger pool of variables. The logic behind stepwise analysis is to select those elements from the data set which contribute most to discriminating the respective stratigraphic units.

### Canonical Discriminant Analysis:

A dimension reduction technique in which new variables, known as canonical functions, are derived from the original elemental variables. The purpose of this

exercise is to derive canonical functions which best discriminate between stratigraphic units. These canonical functions may then be plotted graphically, thus generating useful classification diagrams (it should be noted however that such diagrams are essentially a binary plot).

Table 4.1 St	tatistics and detai	ls of DFA of	Rietgat Forma	tion samples.
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Discriminant Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
_	· · · · · · · · · · · · · · · · · · ·	10.15	10.15	0.0.00000
1	12.77877	48.45	48.45	0.9630288
2	9.36881	35.35	83.97	0.9505561
3	2.65362	10.06	94.03	0.8522318
4	1.10705	4.2	98.23	0.7248475
5	0.30216	1.15	99.38	0.4817132
6	0.1664	0.62	100	0.3757498

After Function	Wilks-Lambda	Chi-square	Significance Level	DF
0	0.0005996	1379.9663	0.0000	138
1	0.0082624	892.0643	0.0000	110
2	0.0856708	457.04721	0.0000	84
3	0.3130088	216.04344	0.0000	60
4	0.6595268	77.41928	0.0002	38
5	0.8588121	28.31016	0.0575	18

## Ancillary Statistics:

It should also be noted that a number of ancillary statistics were generated as a result of DFA (see Table 4.1), the meanings of which are elucidated in the following paragraphs:

- *EIGENVALUE*: An eigenvalue is produced by DFA for each discriminant function and is a direct measure of the importance of each function in the discrimination of groups. The higher the eigenvalue, the more important the discriminant function. In general the eigenvalue is normalised and expressed in the form of a percentage.
- CANONICAL CORRELATION: the canonical correlation relates each discriminant function to the variables used to define the groups. As such, it is a direct measure of correlation between the data set and each discriminant function: the higher the value of the canonical correlation, the stronger this relationship is.
- WILKS' LAMBDA: This is a test of the statistical significance of each discriminant function. The Wilks' Lambda function is an inverse measure, so therefore a score of zero is the highest possible value (ie no discriminatory power has been removed by the discriminant functions). It follows that the value of lambda will increase as each successive function is calculated. Theoretically, lambda should equal 1 at the end of discriminant function analysis, this being due to the fact that all the discriminatory power of the variables has been removed by the discriminant functions.

- *CHI SQUARE* is used as a test of significance, ie whether the distribution of data differs from a predetermined theoretical 'normal' distribution. In the case of the present study, the Wilks' Lambda function for each discriminant function was converted into a chi-square value in order to test the statistical significance of each discriminant function. Because chi-square is a sample-based statistic, it will vary from sample to sample.
- *DF (DEGREES OF FREEDOM)* means the freedom to vary, and without recourse to detailed mathematics, is difficult to define. In general however, the degrees of freedom are the number of observations minus the number of estimates made from them (Till, 1974).

#### 4.4 Application of DFA to the Study Area

DFA was undertaken at the University of the Orange Free State on a Solaris 2.3 workstation using the SPSS<sup>17</sup> software package. Following the examination of a range of bivariate plots (as described in the previous section) it was decided that preliminary grouping of the data should be based on a plot of  $P_2O_5$  versus Zr (Figure 2.3). These elements have the advantage of being immobile under a range of geochemical conditions. The results of DFA are as follows:

#### Stepwise Analysis:

Table 4.2 illustrates the decreasing order of influence of elemental variables in the discrimination of the stratigraphic units of the Rietgat Formation. It should be noted

<sup>&</sup>lt;sup>17</sup> Statistical Package for Social Sciences.

that the Wilks' Lambda value decreases with each successive step further signifying the declining importance of each variable.

**Table 4.2**Results of Stepwise Discriminant Analysis.

Step	Variable Entered	Variable Removed	Variables Included	Wilks' Lambda
1	P <sub>2</sub> O <sub>5</sub>	none	1	0.15641
2	Zr	none	2	0.02042
3	TiO <sub>2</sub>	none	3	0.00777
4	Cr	none	4	0.00417
5	Al <sub>2</sub> O <sub>3</sub>	none	5	0.00287
6	Y	none	6	0.00218
7	Ba	none	7	0.00181
8	Na <sub>2</sub> O	none	8	0.00157
9	CaO	none	9	0.00136
	ļ			

## Canonical Discriminant Analysis:

With reference to Table 4.1, it may be seen that functions 1 and 2 are the most important of all the functions in terms of discriminating capacity since they have the highest eigenvalues and relative percentages. The low initial Wilks' Lambda value, as well as after Wilks' Lambda after the first function indicates that the variables used have a high discriminatory power. Table 4.3 indicates that only 9 of the 194 samples included in the analysis were misclassified - equal to ~4.6% of the total samples. This indicates that DFA is extremely accurate and can be used with confidence. Misclassified samples have been interpreted as having originated from near-unit contacts,

altered zones or as being representative of localised geochemical facies variations. A diagram representing the results of DFA is presented in Figure 4.19, on which groups (units) are represented as fields and group centroids as asterisks.

	Predicted Group Membership				
Number of Cases	Group 1	Group 2	Group 3	Group 4	Group 5
72	69 05 894	2	1	0	0
28	95.878 4 14 394	2.8% 24 85.7%	0	0.0%	0.0%
63	0	0 0	0.0% 63	0.0%	0.0%
7	0.0%	0.0%	100.0%	0.0%	0.0% 0
24	0.0%	0.0%	0.0% 1	100.0% 0	0.0% 22
	Number of Cases           72           28           63           7           24	Number of Cases         Group 1           72         69 95.8%           28         4 14.3%           63         0           7         0           0         0.0%           24         0	Number of Cases         Group 1         Group 2           72         69         2           95.8%         2.8%           28         4         24           14.3%         85.7%           63         0         0           7         0.0%         0.0%           24         0.0%         1	Number of Cases         Group 1         Group 2         Group 3           72         69         2         1           72         95.8%         2.8%         1.4%           28         4         24         0           63         0         0         63           7         0         0         0           7         0.0%         0.0%         0.0%           24         0         1         1	Number of Cases         Group 1         Group 2         Group 3         Group 4           72         69         2         1         0           95.8%         2.8%         1.4%         0.0%           28         4         24         0         0           63         0         0         63         0           7         0.0%         0.0%         100.0%         0.0%           24         0         1         1         0

Table 4.3Results of classification by DFA.

## 4.5 Application of DFA outside the Study Area

With reference to the canonical function coefficients in Table 4.4, it is possible to take unknown samples and classify them in the aforementioned scheme. In order to put this to the test, the Rietgat Formation data of T. B. Bowen (1984) was standardised, from which the canonical functions were then calculated. When plotted (Figure 4.20) it may be seen that only a weak relationship exists between the  $P_2O_5$ -Zr-constrained units (represented by numerals) and the fields derived by DFA of the Free State samples.





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	Standardized*		Standardized* Unstandardized*	
Discriminant Function	1	2	1	2
SiO <sub>2</sub>	0.86059	1.07068	0.24009	0 29870
TiO <sub>2</sub>	-0.89277	1.97147	-5.89768	3 13 02357
Al <sub>2</sub> O <sub>3</sub>	0.38393	-0.12659	0 39944	-0 13171
Fe <sub>2</sub> O <sub>3</sub>	0.2883	0.75708	0 14413	0.15171
MnO	0.03321	-0.24076	1 17100	-8 48042
MgO	0.23366	0.12842	0.22023	-0.40942
CaO	0.49629	0.85362	0.19769	0.12104
Na <sub>2</sub> O	0.43304	0.08018	0.39986	0.07403
K <sub>2</sub> O	0.19167	-0.09458	0 20993	-0.10350
$P_2O_5$	1.64842	-0.91922	25 64888	14 20269
Rb	0.18468	-0 00422	0.00582	-14.30208
Ba	-0.19209	0.50297	-0.000382	-0.00013
Sr	0.25243	-0.35154	0.00028	-0.00160
Zr	-0.63255	-1.14415	-0.02602	-0.00100
Nb	0.10123	-0.02394	0.02349	-0.00556
Ni	0.20831	0.18328	0.00914	0.00350
Zn	0.01316	-0.02789	0.00040	-0.00086
Cr	-0.23455	-0.32551	-0.00305	-0.00423
Cu	0.03599	-0.04856	0.00126	-0.00170
V	0.39743	-0.14698	0.01369	-0.00506
Ŷ	-0.42866	0.08678	-0.12156	0.02461
Co	0.09112	-0.14555	0.00904	-0.14445
CONSANT	0	0	-26.61031	-14.10960

# Table 4.4 Canonical Discriminant Function Coefficients

\*Canonical Discriminant Function Coefficient

A similar procedure was followed using 12 Ventersdorp Supergroup lava samples collected from the T'Kuip hills during the course of this study. These samples were first plotted in the style of T. B. Bowen (1984) to ascertain which samples were Rietgat Formation provenance, a summary of which is presented in Figure 4.21. The canonical functions were then calculated for these samples and are plotted on Figure 4.22. it may be seen from Figure 4.22 that although by no means conformable to the

current model, the data displays a somewhat greater degree of coherency in and clustering than is seen in the Bowen example.



Figure 4.20 Discriminant Function Analysis applied to the data of T. B.Bowen (1984).

The moderate to poor correlation of this model outside its type area could indicate either lateral geochemical heterogeneity, or perhaps localised geochemical variation in the lavas. For instance, a minor adjustment of the Unit 3-Unit 5 boundary in the T'Kuip example could lead to an almost perfect classification of these samples according to the type framework.



Rietgat & Goedgenoeg Formations	Dominion Group Porphyries	Klipriviersberg Group
CO	MPONENT SAMPL	ES:
TK1/1, TK1/3,	TK1/1A, TK1/1B,	TK2/1, TK2/1A,
TK1/4A, TK1/5,	TK2/2A, TK2/2B,	TK2/1B.
TK1/5A, TK1/5B,	TK2/2C, TK2/2D.	
TK1/6, TK2/2,		
TK2/2F, TK2/2G,		
TK2/2H, TK2/2I.		

**Figure 4.21** Above - Classification of Ventersdorp Supergroup lava samples from the T'Kuip Hills (After T. B. Bowen, 1984); Below - Summary of the aforementioned samples as per T. B. Bowen (1984) classification scheme.



**Figure 4.22** Discriminant Function Analysis applied to the data from T'Kuip (this study).

### 4.6 Discussion and Conclusions

This chapter has aimed to determine whether the lavas of the Rietgat Formation can be subdivided on the basis of their geochemistry. The application of univariate statistics to this problem failed to highlight any clear trends. Although bivariate analysis yielded sufficient between-unit clustering of data, it was considered desirable to employ multivariate statistical methods in order to analyse all of the elemental variables simultaneously. This technique proved to be of very great accuracy in the type area, though regrettably its application outside the type area failed to elucidate any unequivocal correlation. It is however possible to conclude that a degree of lateral geochemical homogeneity exists in the study area. The fact that only moderate to poor correlations may be made between the study area and outlying occurrences of the Rietgat Formation indicates a higher degree of lateral geochemical heterogeneity at a larger scale.

It is also pertinent and in a sense vindicating to note that, according to stepwise analysis that the most powerful discriminating variables are  $P_2O_5$  and Zr - ie the same variables upon which the pre-DFA grouping was originally based (Figure 2.3).

## CHAPTER 5: GEOCHEMICAL CLASSIFICATION, MAGMATIC AFFINITY TECTONIC SETTING AND PETROGENESIS.

#### 5.1 Introduction.

The main objective of the following chapter is to classify the lavas of the Rietgat Formation on the basis of their geochemistry. Conventional techniques and parameters have been used to constrain the magmatic affinity, tectonic setting, petrogenetic setting, petrogenesis and ultimately the source rocks of the Rietgat Formation. It is pertinent to note that in addition to geochemical criteria, any model aimed at explaining the geochemical evolution of the Rietgat Formation must also consider the lithological and petrographic characteristics described in earlier chapters. Other important considerations include the degree and scale of lateral geochemical homogeneity of the lavas and the virtual absence of sediments in much of the succession.

#### 5.2 Previous Work.

Many authors have identified the fact that igneous rocks may be classified in terms of their generic name, magmatic affinity and tectonic setting on the basis of their geochemical composition. Leading research and modelling to this end has, in recent decades, included studies by Irvine and Baragar (1971), Pearce and Cann (1973) Middlemost (1975), Cox *et al.* (1979) and Le Maitre (1989). In subsequent years, the models developed by the aforementioned authors have been applied to numerous igneous provinces throughout the world with the intention of elucidating the palaeotectonic setting, magmatism and petrogenetic aspects of these igneous suites.

A number of studies have attempted to constrain the geochemistry, mag'matic affinity, tectonic setting and petrogenesis of the lavas of the Ventersdorp Supergroup. M. P. Bowen (1984) examined the geochemistry of the Witwatersrand Triad volcanic rocks in the Klerksdorp area with a view to determining their petrogenesis. Marsh et al. (1992), Linton (1992) and Winter (1995) have investigated the geochemistry of the Klipriviersberg lavas in the vicinity of Klerksdorp. These studies have involved both the geochemical and magmatic characterisation of the Klipriviersberg Group as well as the clarification of the tectonic environment in which these lavas were extruded. Meintjes (1998) examined the geochemistry of the Makwassie and Goedgenoeg Formations between Klerksdorp and Allanridge. In his study, Meintjes sought to model the geochemical evolution of this lava series and to define the nature of the source from which it was derived. Schweitzer and Kröner (1985) and Crow and Condie (1988) have attempted to model the petrogenesis of the Ventersdorp Supergroup as a whole, using a variety of geochemical techiques. The work of these authors and others will be considered in a petrogenetic context at a later stage in this chapter. Very little investigation specific to the geochemistry and petrogenetics of the Rietgat Formation have been undertaken: it is therefore the purpose of this chapter to constrain the geochemical affinities of this lava series.

### 5.3 Geochemical Classification of the Rietgat Formation.

## 5.3.1 Application of Geochemical Discrimination Techniques

The previous section alluded to the fact that a number of discrimination procedures exist whereby igneous rocks may be geochemically classified according to their generic name, magmatic affinity and tectonic setting. Although a very wide range of discrimination diagrams are available to choose from, only those displaying the most explicit distribution of data are chosen for inclusion in this study. For a comprehensive review of such discriminatory procedures, the reader is referred to Rollinson (1993), Chapters 3-5.

## 5.3.1.1 Discrimination according to generic name

Winchester and Floyd (1976, 1977) have proposed a series of diagrams based on HFS (High Field Strength) elements which discriminate between basic and intermediate rocks. From a plot of Nb/Y versus Zr/TiO<sub>2</sub> (Figure 5.1) it may be seen that the lavas of the Rietgat Formation range from rhyodacite/dacite (Units 1 and 2) through andesite (Units 4 and 5<sup>18</sup>) to basaltic andesite (Unit 3) in terms of their composition. This system of classification was chosen in favour of the TAS (Total Alkalis versus Silica) diagram of Le Maitre (1989) since it is more appropriate to highly altered terranes: whereas alkaline metallic oxides are of high mobility in aqueous solutions, the HFS elements are of relatively low mobility and are probably therefore more representative of primary igneous processes.

## 5.3.1.2 Discrimination According to Magmatic Affinity

According to the ternary system  $Na_20$ - $K_2O$ - $FeO_{(total)}$  (or AFM diagram) of Irvine and Baragar (1971), the lavas of the Rietgat Formation display a tholeiitic to calc-alkaline affinity (Figure 5.2). This is applicable to all units, with the exception of Unit 2, which displays a calc-alkaline affinity. Although one of the more commonly used diagrams

<sup>&</sup>lt;sup>18</sup> It was found that Units 4 and 5 showed extremely close coherency with regard to the discrimination techniques used in this chapter and have, as such, been plotted as a single field.
in the discrimination between tholeiitic and calc-alkaline basalts, the so-called AFM diagram (Alkalis -  $Fe_{(tot)}$  - MgO) does have certain shortcomings. One such problem is that in most rocks the AFM parameters make up less than 50% of the oxide weight percentage, so it could be argued that the diagram is not truly representative of the whole rock (Wilson, 1989). The main use of the AFM diagram is however to highlight data trends which may ultimately lead to the identification of a rock series.

In contrast to Figure 5.2, all of the samples on Figure 5.3 (Irvine and Baragar, 1971) plot within the sub-alkaline (tholeiitic) field. The discrepancy between the two Irvine and Baragar diagrams is attributed to the effects of alteration processes, such as alkaline metasomatism. It should also be noted that in the ternary AFM system, the variables are normalised to 100%, which may also affect the accuracy of the technique.

# 5.3.1.3 Discrimination According to Tectonic Setting

Using the ternary system Zr/4 - Nbx2 - Y (Figure 5.4), Meschede (1986) was able to identify the tectonic environment in which basaltic rocks were emplaced. When applied to the present study, it may be seen from this diagram that the lavas of the Rietgat Formation are of within-plate origin and moreover range between alkaline and tholeiitic affinity, thus concurring with the system of Irvine and Baragar (1971) discussed in the previous section. One point of caution that should be considered with regard to this method is that it relies on the accurate measurement of Nb, which - according to Rollinson (1993) - is difficult to obtain for concentrations below 10ppm by means of XRF. Since the Nb concentrations observed in the study samples were in

the order of 10-20ppm, the discrimination technique of Meschede (1986) can therefore be applied with confidence.

Pearce and Norry (1979) investigated the reasons for variations in the ratio of Zr/Y and Ti/Y and concluded that they are probably a function of source heterogeneity. Using a plot of Zr versus Zr/Y (Figure 5.5) the authors were able to discriminate effectively between basalts from different tectonic settings. According to this technique, it may be seen that the study samples classify as within-plate basalts. It is also noted that Unit 3 plots as a distinct field on this diagram, possibly signifying source chemistry variation or a subsequent modification process such as fractional crystallisation or contamination.

Further evidence to support the classification of the Rietgat Formation lavas as calcalkaline basalts may be seen in Figures 5.6 and 5.7. These diagrams are, however, intended for use in conjunction with a composition in the range of 20% > CaO + MgO> 12% (Pearce and Cann, 1973). Since the study samples fall either within the lowermost portion of, or outside this range, this technique has been applied with extreme wariness. Additionally, Pearce and Cann (1973) indicate that the Y/Nb ratio for the samples should be < 1.0 in order to be applied to this model. Although varied, this ratio can reach elevations of up to 3 for the study samples, which may account for the data points which plot outside the given fields in Figures 5.6 and 5.7.



Figure 5.1 Classification scheme for rocks of basaltic to intermediate composition (after Winchester & Floyd, 1977, Figure 6).



**Figure 5.2** Discrimination diagram for basaltic rocks of Tholeiite/Calc-Alkaline affinity (after Irvine and Baragar, 1971, Figure 2).

UNITS 4 & 5 ------ UNIT 3 ----- UNIT 2 ------- UNIT 1 -------



**Figure 5.3** Discrimination diagram for basaltic rocks of Tholeiite/Calc-Alkaline affinity (after Irvine and Baragar, 1971, Figure 3).



**Figure 5.4** Discrimination diagram indicating the tectonic affinity of basaltic rocks (after Meschede, 1986, Figure 1).





**Figure 5.5** Discrimination diagram indicating the tectonic affinity of basaltic rocks (after Pearce & Norry, 1979, Figure 3).



**Figure 5.6** Discrimination diagram indicating the petrological and tectonic affinities of basaltic rocks (after Pearce & Cann, 1973).





**Figure 5.7** Discrimination diagram indicating the petrological and tectonic affinities of basaltic rocks (after Pearce & Cann, 1973).



**Figure 5.8** Discrimination diagram indicating the tectonic provenance of silicic igneous rocks (after Pearce *et al.*, 1977, Figure 1). *N.B. Unit 4 plots outside this diagram* 

UNITS 4&5	UNIT 3 — — —	UNIT 2	UNIT 1



**Figure 5.9** Discrimination diagram indicating the tectonic affinity of basaltic rocks (after Pearce, 1975).

Pearce *et al.* (1977) used the system MgO -  $FeO_{(total)}$  -  $Al_2O_3$  as a means by which to determine the tectonic setting in which sub-alkaline rocks were emplaced. It may be seen from Figure 5.8 that the study samples are centred on the field for continental origin. The usefulness of this diagram is restricted due to the mobile nature of the major oxides in basaltic rocks. Pearce (1976) has furthermore demonstrated that  $Al_2O_3$  and MgO are mobile during greenschist facies metamorphism - the paragenesis of which may be seen in the rocks of the Ventersdorp Supergroup. Another factor worthy of consideration is the extent to which basalts may transgress fields on the diagram as a result of crystal fractionation. The aforementioned processes may account for the incursion of the study sample data points into fields 1, 2, 3 and 4 on Figure 5.8.

A plot of Cr against Ti (after Pearce, 1975; Figure 5.9, this study) suggests that the study samples are of ocean floor composition, somewhat contradicting the evidence for continental derivation presented thus far in this section. This diagram has therefore been regarded with caution in view of the overwhelming evidence in favour of a continental origin for the lavas.

# 5.3.1.4 Notes of Caution with regard to Discrimination Diagrams.

It is considered pertinent to note that the following considerations should be made when interpreting discrimination diagrams:

- The effects of data 'straddling' field boundaries may be attributed to geological reasons - for example it is possible that a continental flood basalt may sample a wide variety of crustal contaminants en-route to the surface, thereby giving rise to a wide range of compositions.
- Discrimination diagrams should never be used uncritically, ie the effects of fractionation and element mobility should be borne in mind. Such an approach has been adopted in this study.
- Caution is required when discrimination diagrams are used in conjunction with ancient rocks. It is contendable that the composition of the mantle has changed with time and was less fractionated earlier in the history of the earth (Pearce *et al.*, 1984). Higher mantle temperatures in the Archaean may have given rise to higher degrees of melting, the consequence of which could be a movement of the field

boundaries on the discrimination diagrams. It is also important to consider the fact that at 2.7 Ga, plate tectonics of Phanerozoic affinity may not have been applicable.

#### 5.4 Petrogenesis.

This chapter has thus far endeavoured to classify the lavas of the Rietgat Formation according to published parameters. It has been established beyond doubt that compositional variations exist between the individual lava units of the Formation. The remainder of this chapter seeks to evaluate the geochemical processes responsible for these variations, as well as the possible nature of the source from which the Rietgat Formation was derived. Computer-based modelling was employed to this end and has been used to test large numbers of fractional crystallisation and mixing models. Given the wide array of discrimination and data-presentation techniques employed in this and foregoing chapters, it has been possible to propose a tectono-petrogeneticstratigraphic model for the Rietgat Formation, which is presented at the end of this chapter.

# 5.4.1 Process Identification.

An important factor in the understanding of the genesis of lavas is the identification of any samples which represent primary melts from the upper mantle. Such magmas should be unmodified by fractionation processes and in equilibrium with the composition of the mantle. Magnesium numbers have been used as an indicator of primary mantle characteristics and have been calculated for the lavas of the Rietgat Formation (Table 5.1). For an explanation regarding magnesium numbers, the reader is referred to Hughes and Hussey (1976, 1979). Given the fact that mantle magnesium numbers are in the range of 68-75 (Green and Ringwood, 1976) it is evident that the lavas of the Rietgat Formation are far removed from a primary mantle composition and that a high degree of geochemical evolution has taken place. The inferred nature of the process(es) responsible for the differentiation of the lavas of the Rietgat Formation are outlined in the following paragraphs.

Table 5.1Minimum, maximum and average magnesium-numbers for the lavas ofthe Rietgat Formation.

Unit	Value	Mg Number
	Average	29.25
5	Minimum	37.30
	Maximum	17.65
	Average	28.12
4	Minimum	13.67
	Maximum	35.48
	Average	31.71
3	Minimum	19.52
	Maximum	39.49
	Average	24.86
2	Minimum	20.76
	Maximum	27.96
	Average	29.01
1	Minimum	21.29
	Maximum	35.92

# 5.4.2 Identification of variation and trends in elemental data.

At first sight the geochemical data from the Rietgat Formation appear to show a nearincomprehensible variation in the concentration of individual elements. Given the assumption that these rocks are genetically related, it is necessary to apply a geochemical technique which rationalises the variables and facilitates the identification of any trends. The most commonly used means to this end is the variation diagram. Originally used by Harker (1909), this is a simple two-dimensional scatter plot on which two variables (one of which is usually SiO<sub>2</sub>) are plotted against one another and upon which linear trends may be observed in the data.

# 5.4.2.1 Bivariate plots of selected oxide variables.

A range of bivariate plots (Figures 4.1-4.16) were presented in Chapter 4, the purpose of which was to identify geochemical grouping of data with respect to stratigraphic units. Upon closer inspection, within-unit linear trends may be identified on the same diagrams: the reader is referred to Figures 4.1-4.4, which serve as examples.

Such trends on variation diagrams may occur as a result of the addition of crustal material to a melt, magma mixing or due to the incremental addition of new partial melt material to the existing magma. Fractional crystallisation is also an important process in the evolution of igneous rocks and may also be responsible, at least in part for the disjointed linear trends seen on the variation diagrams.

Although the procedure of Harker (1909) was followed, whereby al! of the major oxides were plotted against  $SiO_2$  and MgO, the variation in these two oxides is too

slight to highlight any clear trends in the data. Hence in this case, the application of major oxide data alone in the characterisation of the lavas is not possible. The subsequent sections illustrate the importance of trace element data to the understanding of the evolution of the Rietgat Formation.

## 5.4.2.2 Normalized multi-element diagrams.

Multi-element diagrams are of particular use in the depiction of basalt geochemistry. They display a wide range of elements and consequently show a greater number of peaks and troughs representing the relative enrichment and depletion of different groups of elements. The elemental data used in the construction of the so-called 'spidergram' (Figure 5.10) have been normalised to a chondritic meteorite reference standard. Chondrites were chosen for this purpose, since they are thought to represent unfractionated samples of the solar system dating from original nucleosynthesis. The normalisation values employed to this end are those of Taylor and McLennan (1985) and are presented in Table 5.2.

The remainder of this section aims to identify and explain the elemental trends present on the spidergram and to make inferences regarding the nature of the source region from which the lavas were derived. Regrettably, REE data for Units 2 and 3 were unavailable at the time of writing.

Table 5.2Chondrite Normalisation Values used in this study (after Taylor and<br/>McLennan, 1985).

Element	Chondrite Normalization Value	Element	Chondrite Normalization Value		
K	854	Ti	654		
Rb	3.45	Dy	0.381		
Ba	3.41	Y	2.25		
Nb	0.375	Но	0.0851		
La	0.367	Er	0.249		
Ce	0.957	Tm	0.0356		
Sr	11.9	Yb	0.248		
Pr	0.137	Lu	0.0381		
Nd	0.711	Sc	8.64		
Zr	5.54	v	85		
Sm	0.231	Zn	462		
Eu	0.087	Cu	168		
Gd	0.306	Ni	16500		
Tb	0.058	Cr	3975		

## Rare Earth Elements

The REE's<sup>19</sup> are of particular value in igneous petrology in that they are the least soluble of the trace elements, being relatively immobile during metamorphism, weathering and hydrothermal alteration. Hence, one may assert with a degree of confidence that REE patterns are representative of the unaltered rock.

It is observed (Figure 5.10) that Units 1, 4 and 5 are relatively enriched in LREE's (La, Ce, Pr and Nd).

<sup>&</sup>lt;sup>19</sup> All REE analyses were undertaken at the University of Cape Town. A summary of the analytical procedure involved to this end is presented in Appendix 1.

Eu anomalies are generally controlled by the feldspar minerals, this element being highly compatible in both plagioclase and potassic varieties of the mineral. Hence, the negative anomaly with respect to Eu (Figure 5.10) reflects the removal of feldspar from the melt. Although highly prevalent in felsic melts (Rollinson, 1993), this trend is less pronounced in the study samples due to their more basic to intermediate affinity. The very close conformity in elemental variation between Units1, 4 and 5 could be interpreted as being indicative of consanguinity.

	MA1-4	S4-10 S4-15		S4-3	MA1-8	MA1-20	MA1-1	
Unit	Unit 5 5 5		4	4	1	USH		
La	La 36.60 59.50		57.70	62.10	70.60	68.20	8.57	
Ce	Ce 80.00 120.00 1		117.00	128.00 142.0		139.00	18.50	
Pr	<b>Pr</b> 10.90		15.50	16.80	19.10	18.30	2.25	
Nd	Nd 45.50		62.00	66.40	77.00	71.50	9.21	
Sm	Sm 8.85 11.		11.10	11.20	13.60	12.70	1.96	
Eu	Eu 1.43 2.5		2.70 2.0		3.21	2.78	0.50	
Gd	7.97	9.22	9.01	6.12	10.60	9.97	1.94	
Ть	1.16	1.28	1.25	1.08	1.46	1.38	0.33	
Dy	6.99	7.44	7.25	6.18	8.39	8.00	2.24	
Ho	1.36	1.42	1.40	1.25	1.60	1.56	0.49	
Er	3.86	3.95	3.95	3.72	4.50	4.43	1.49	
Tm	0.53	0.54	0.54	0.53	0.61	0.61	0.22	
Yb	3.41	3.54	3.52	3.56	3.98	4.09	1.50	
Lu	Lu 0.51 0.52 0.52		0.52	0.54	0.59	0.60	0.22	

Table 5.3REE analytical data



Figure 5.10 Chondrite-Normalised Multi-Element variation diagram.

Depletion of the HREE's (Er, Tm, Yb and Lu) relative to the LREE's may be caused by the fractionation of olivine, garnet, hornblende, orthopyroxene and clinopyroxene into which the HREE's are highly compatible. In general, the more compatible elements to the right-hand side of the spidergram are less enriched due to the combined effects of fractional crystallisation and partial melting. This gives the spidergram its characteristic downward slope towards the right. It must therefore follow that the lavas of Units 1, 4 and 5 cannot have been derived from a source rich in olivine, garnet, hornblende, orthopyroxene or clinopyroxene.

In the case of the clastic sediments, the most important factor governing REE characteristics is provenance. Because the REE's are insoluble under aqueous conditions their presence in sedimentary rocks may instead be a function of the

particulate matter from which the rocks are derived. It follows therefore that REE characterstics of the sediment are representative of the geochemistry of their source. Furthermore, diagenetic processes have little influence on the REE characteristics of sedimentary rocks, since very large amounts of fluid would be required to effect this. The REE characteristics of the USH conform closely to those of the lavas, despite being an order of magnitude lower in terms of concentration. It is concluded that the sediments were derived locally - ie from the underlying lavas - thus explaining the coherent REE trend seen between the two lithologies. The lower concentrations of REE's in the sediments relative to the lavas has been attributed to the high quartz presence (as has been deduced petrographically in Chapter 3) which may have had a diluting effect on elemental abundancies (Wilson, 1989).

## <u>Trace Elements</u>

With respect to Figure 5.10 the LIL<sup>20</sup> elements (Rb, K, Ba and Sr) are relatively enriched in comparison to the HFS elements (Y, Zr, Nb and Ti). Since the LILE's are highly mobile at crustal levels under fluid conditions, it is realistic to assume that the LILE compositions of the Rietgat Formation are not representative of the original bulk composition of the series. This may be attributed to the fact that the lavas have undergone both metasomatic and greenschist facies alteration, which are fluidorientated and hence are ideally suited to the mobilisation of the LILE's. It is however possible to make certain inferences regarding petrogenesis of a rock based on its LILE characteristics. For instance, Sr may substitute for Ca in plagioclase, which may account for the negative anomaly seen (with respect to Sr) on the spidergram. Similarly Rb and Ba may substitute for K in feldspar, hornblende and biotite. The positive Ba and negative K anomalies may also be attributed to primary magmatic processes, though it is just as likely that they are the product of a secondary fluid event.

The abundance of certain elements may be strongly influenced by individual mineral phases. This is particularly common among HFS elements, where magmatic processes generally govern concentration. For example, a positive Zr anomaly may be attributed to the presence of zircon phenocrysts in the lavas. P is highly compatible in apatite, so it can be postulated that the negative P anomaly is a consequence of apatite fractionation. Since Nb is highly incompatible in continental crust, one could expect a strongly negative anomaly with respect to this element to result from crustal contamination. A weakly depleted trend is indeed visible from the spidergram (Figure 5.10) so it can-be inferred that crustal input was moderate during the petrogenesis of the lavas (Rollinson, 1993). This topic will however be addressed in the following section. The minor negative anomaly with respect to Ti is interpreted as signifying the fractionation of ilmenite and/or titanomagnetite (Wilson, 1989). Since Y is highly incompatible in basaltic melts but is readily accommodated by amphiboles, garnet, sphene and apatite, it is suggested that a positive anomaly with respect to this element could be indicative of an amphibole or sphene presence

<sup>&</sup>lt;sup>20</sup> Large Ion Lithophile (Elements)



Figure 5.11 Chondrite-Normalised variation diagram for the Transition Metals.

High concentrations of the transition metals (Zr, Figure 5.10; Ni and Co, Figure 5.11) serve as good indicators of the derivation of parent magmas from a peridotitic mantle source. Decreases in Ni and to a lesser extent Co through a rock series are suggestive of olivine, clinopyroxene or spinel fractionation. Both Ni and Co show depletion on the spidergram (Figure 5.11), corroborating the fact that some degree of fractionation

has taken place. An inconsistency does exist in that the Ni and Co abundancies do not decrease directly with stratigraphic height.

Cu and Zn have been omitted from the spidergram since they may have been extremely mobile during metamorphism, so therefore their concentrations probably do not represent igneous values (Wilson, 1989).

The analysis of trace element data in this section has made it possible to conclusively determine that both crystal fractionation and mixing/contamination processes have played a role in the genesis of the lavas of the Rietgat Formation. Proposals regarding the level of involvement of these processes are laid out in the following section.

#### 5.5 Genetic Modelling.

Having postulated that crystal-liquid fractionation and a degree of mixing were involved in the petrogenesis of the Rietgat Formation, it is desirable to clarify the role of these processes in greater detail. To this end a plot of Ni against Zr was constructed (Figure 5.12), upon which the linear trends of all Platberg-age lava series were superimposed.

It is the intention of the Ni-Zr plot to elucidate fractionation trends in igneous rock series. The elements Ni and Zr behave in inverse proportion to one another during crystal fractionation (Meintjes, 1998), the former becoming more depleted and the latter relatively enriched during this process. The main direction of the evolutionary trends (deduced by reference to the relative stratigraphic juxtapositions of individual samples in borehole sections) of the units of the Rietgat Formation are indicated by



Code	Description	Source of data		
(1)-(5)	Rietgat Formation - Units 1-5	This study		
Gm	Goedgenoeg - mafic			
Gi	Goedgenoeg - intermediate	Meintjes (1998)		
Gz	Goedgenoeg - zircon-rich			
Md-Mr	Makwassie Formation	This study		

Figure 5.12 Plot of Ni versus Zr as an indicator of fractionation processes.

the bold arrows on the Ni-Zr diagram. In the case of Unit 1, a degree of oscillation was evident in the down-profile Ni/Zr ratio. The overall trend is however that of reverse fractionation, which has been indicated by a bold arrow. At certain localities, the individual units display normal fractionation: a smaller arrow has been used to denote this 'secondary fractionation' trend on Figure 5.12.

Data from the Goedgenoeg and Makwassie Formations (Meintjes, 1998) and the Klipriviersberg Group and Allanridge Formation (data from the present study, Appendix 3) have also been included on the Ni-Zr diagram with a view to constraining the petrogenesis of the Rietgat Formation in the broader context of the Ventersdorp Supergroup.

Having first assumed that the lavas of the Rietgat Formation are derived by Raleigh fractionation, possible source materials were then modelled on the basis of their Ni-Zr content using the NEWPET software programme. Given the large number of uncertain variables and simplifying assumptions that are a feature of software packages such as NEWPET, any modelling derived by such means should be treated tenuously. A review of the  $K_D$ 's<sup>21</sup> applied by these calculations is presented in Table 5.4. A range of mantle compositions were subjected to up to 95% fractionation in an attempt to determine whether such a fractionation event could be responsible for the generation of the lavas of the Rietgat Formation. A garnet-bearing source was discounted due to

 $<sup>^{21}</sup>$  K<sub>D</sub>'s are distribution co-efficient, i.e. the rate at which any given elemental constituent will buffer into any given mineral phase during fractional crystallisation (this study).

	Olivine	Orthopyroxene	Clinopyroxene	Hornblende	Phlogopite	Plagioclase	Gamet	Quartz	Magnetite	Ilmenite	K-Feldspar	Sphene	Apatite	Rufile	Corundum
La	0.009	0.026	0.288	0.440	0.035	0.180	0.121	-	-	-	-	-	-		-
Ce	0.009	0.033	0.303	0.540	0.034	0.120	0.144	-	-	-	-	-	-	-	-
Pr	0.010	0.042	0.341	0.750	0.033	0.097	0.188	-	-	-	-	-	-	-	-
Nd	0.010	0.051	0.379	1.000	0.032	0.081	0.232	-	-	-	-	-	-	-	-
Sm	0.011	0.079	0.476	1.490	0.031	0.067	0.541	-	-	-	-	-	-	-	-
Eu	0.011	0.099	0.354	1.500	0.036	0.340	0.623	-	-	-	-	-	-	-	-
Gd	0.012	0.126	0.561	1.700	0.030	0.063	1.190	-	-	-	-	-	-	-	-
Dy	0.014	0.197	0.663	2.200	0.030	0.055	2.560	-	-	-	-	-	-	-	-
Er	0.019	0.355	0.706	2.100	0.034	0.063	4.240	-	-	-	-	-	-	-	-
Yb	0.023	0.470	0.719	1.400	0.042	0.067	5.730	-	-	-	-	-	-	-	-
Lu	0.027	0.590	0.719	1.300	0.046	0.060	6.300	-	-	-	-	-	-	-	•
K	0.006	0.006	0.027	0.860	2.700	0.360	0.150	-	-	-	-	-	-	-	-
Rb	0.004	0.003	0.030	0.400	3.100	0.200	0.200	-	-	-	0.500	-	-	-	-
. Sr	0.009	0.050	0.300	1.020	0.080	3.600	0.090	-	0.200	-	1.000	100.00	5.000	-	1.300
Ba	0.002	0.040	0.025	0.440	1.100	0.460	0.050	-	0.100	-	1.000	1.000	5.000	-	0.600
Cr	3.100	10.000	20.000	3.000	12.600	0.040	0.100	-	•	-	-	-	-	-	-
Ni	19.000	5.000	4.400	7.000	20.000	0.040	0.800	-	10.000	10.000	-	-	-	-	2.000
Ti	0.010	0.100	0.500	2.000	0.900	0.045	0.690	-	-	-	-	-	-	-	-
Sc	0.220	1.200	3.200	4.200	2.000	0.040	6.500	-	-	-	•	-	•	-	-
Yb	0.020	0.400	0.800	1.320	0.030	0.025	5.000	-	0.020	0.100	0.100	200.00	25.000	15.000	0.500
Nb	0.008	0.015	0.216	0.800	1.000	0.010	0.100	-	1.000	2.500	0.010	3.000	0.100	25.000	0.500
Zr	0.010	0.020	0.420	0.500	0.600	0.010	0.600	-	0.500	0.800	0.010	6.500	0.700	0.900	0.500
ivin .	1.800	1.400	1.300	0.940	6.000	0.050	5.000	-	-	-	-	-	-	-	-
	0.030	0.500	1.000	4.000	6.000	0.080	0.270	-	-	-	-	-	•	-	-
U TL	0.007		0.253	0.540	0.450			-	-	-	-	-	-	-	-
	0.007		0.138	0.540	0.310	1.000	12 000	-	-	-	-	-	-	-	-
Ga	0.040	0.700	0.580	0.800	4.000	1.000	12.000	-	-		-		-		-

 $|\mathbf{r}| \in$ 

Table 5.4  $K_D$ 's according to the NEWPET software programme.

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**Figure 5.13** Theoretical evolution by crystal fractionation of a range of mantle materials using NEWPET (<sup>1</sup>Irving, 1980; <sup>2</sup>O'Reilly & Griffin, 1987; <sup>3-7</sup>Boyd *et al.*, 1997).

the enriched nature of the study samples with respect to the HREE's (see Section 5.4.2.2). The results of this exercise are presented in Figure 5.13, which clearly indicates that even high degrees of fractionation of mantle material alone are insufficient to give rise to the basaltic-andesitic-rhyodacitic rocks of the Rietgat Formation. It is therefore likely that the only means by which the Zr concentrations may reach the elevated levels seen in the study data is if the source of the Rietgat Formation was enriched in Zr.

The existence of an enriched mantle source for the Platberg Group lavas has been documented by previous researchers (Schweitzer and Kröner, 1985; Crow and Condie, 1988): the enriched nature of the HFSE and REE in the Rietgat Formation are further evidence in support of this assertion. Crow and Condie (1988) have furthermore noted that such enrichments point to a separate source for the Platberg Group lavas, since such values are difficult to obtain from fractionated Klipriviersberg source. It should be noted that in the absence of isotopic and more detailed REE analytical data, the palaeo-tectonic environment and source rocks for the Rietgat Formation remain very contentious.

# 5.6 A tectono-stratigraphic-petrogenetic model for the evolution of the Rietgat Formation.

This section aims to combine and synthesise the findings of the foregoing chapters into a model explaining the tectonic, stratigraphic and petrogenetic evolution of the Rietgat Formation.

# 5.6.1 Tectonic Background

The prevalence of rifting during Platberg times has been extensively documented and is also easily evidenced by field relationships. Burke *et al.* (1986) and Stanistreet *et al.* (1986) observed that the lavas of the Ventersdorp Supergroup were extruded into a series of NE-SW trending grabens and half-grabens. Debate exists as to the mechanism responsible for the formation of the Ventersdorp basin and the emplacement of associated volcanic rocks. Schweitzer and Kröner (1985) have proposed that rifting may have taken place in response to an ascending mantle plume; Burke *et al.* (1986) and Winter (1976) have both suggested that rifting/volcanism occurred in response to the collision between the Kaapvaal and Zimbabwe Cratons  $\sim$ 2.6-2.7 Ga ago.

# 5.6.2 An 8-stage model for the development of the study area

In the light of the foregoing discussion, the following model has been proposed in the explanation of the geology of the Rietgat Formation:

# <u>Stage 1</u>

An extensional tectonic regime commencing in Kameeldoorns time gave rise to the development of a series of graben/half-graben basins (Figure 5.14). This phase of structural evolution is akin to stage 2 of the 3-stage rift system as proposed by Clendenin *et al.* (1988a). As has been mentioned, the regional tectonic framework responsible for driving this rifting has in the past been attributed to an asthenospheric upwelling or the collision of the Zimbabwe and Kaapvaal cratons. The continental



(Key to Figures 5.14 - 5.21; following pages)

signature of the lavas of the Rietgat Formation and the flood basalt affinity of the antecedant Klipriviersberg Group (Marsh *et al.*, 1992) is consistent with an asthenospheric upwelling. Associated lithospheric thinning and the regional elevation of geothermal gradients is proposed.



Figure 5.14 Stage 1 in the development of the study area: late Kameeldoorns time (key on page 162).



**Figure 5.15** Stage 2 in the development of the study area: late Makwassie to LSH times. (key on page 162)



**Figure 5.16** Stage 3 in the development of the study area: final Makwassie and Unit ... 1. (key on page 162)



**Figure 5.17** Stage 4 in the development of the study area: renewed structural extension. (key on page 162)



**Figure 5.18** Stage 5 in the development of the study area: extrusion of Units 1 and 2. (key on page 162)



**Figure 5.19** Stage 6 in the development of the study area: widespread extrusion of Unit 3 lavas. (key on page 162)



**Figure 5.20** Stage 7 in the development of the study area: contemporaneous extrusion of Units 4 and 5. *(key on page 162)* 



Figure 5.21 Stage 8 in the development of the study area: cessation of volcanism and the deposition of the USH. (key on page 162)

#### <u>Stage 2</u>

Extensional tectonism persisted into late Makwassie times (Minter *et al.*, 1986), during which basin development governed the distribution of the late-stage Makwassie porphyries (Figure 5.15). The newly uplifted fault scarps gave rise to the generation of large amounts of sediments in their vicinity, to form the LSH. Proximal and distal facies variations in these sediments are most easily recognised by their contrasting grain size: while the most proximal deposits comprise diamictites, the more distal deposits are of an argillaceous nature.

#### <u>Stage 3</u>

Figure 5.16 displays the final stages of extrusion of the Makwassie Formation, which is concomitant to the extrusion of Unit 1. Given the close proximity of Unit 1 to the Makwassie Formation on the Ni-Zr diagram - as well as its oscillatory to reverse fractionation trend - it has been proposed that the relatively evolved lavas of Unit 1may represent mixing between the remnant Makwassie residue and magma from a new shallow crustal reservoir. Following the complete cessation of Makwassie volcanism the new reservoir could have been periodically refluxed by pulses of partial melt from the mantle, which undergo fractionation and ultimately extrusion. This socalled RTF (Replenished, Tapped and Fractionated; O'Hara and Matthews, 1981) system can give rise to the reverse fractionation trends seen in Unit 1. It is also likely that AFC (Assimilation and Fractional Crystallisation; De Paolo, 1981) processes could be in operation which may be another factor contributing to the reverse fractionation trend.

#### <u>Stage 4</u>

The restricted distribution of Unit 2 in the study area may be due to a structural control on its emplacement (Figure 5.17). It is therefore proposed that a phase of reactivation of existing fault structures took place either prior to or during the earliest stages of its emplacement. Such tectonism may have been the product of either renewed extension or thermal subsidence triggered by fresh pulses of magma entering the shallow crustal reservoir.

#### <u>Stage 5</u>

It may be seen from the Ni-Zr plot (Figure 5.12) that Unit 2 is less evolved than Unit 1. It is proposed that the crustal reservoir in which the Unit 1 magma was ponded underwent refluxing by magma derived from a deeper level mantle reservoir (Figure 5.18). Also, the final cessation of activity on the former Makwassie reservoir could have reduced the potential input of more evolved material to the system. Unit 2 shows a coherent crystal fractionation trend (Figure 5.12) suggesting that the replenishment of the crustal reservoir did not take place in this period, thus allowing fractionation processes to operate undisrupted.

## <u>Stage 6</u>

Figure 5.19 shows the widespread extrusion of the lavas of Unit 3. It is once again envisaged that these lavas were derived by the refluxing of the same chamber from which Units 1 and 2 were derived. Further evidence to support this theory may be gleaned from the Ni-Zr diagram (Figure 5.12), which indicates that the starting composition of the Unit 3 series is of a less evolved composition than that of the preceding Unit 2.

#### <u>Stage 7</u>

It is proposed that Units 4 and 5 were emplaced concomitantly as is evidenced by their contemporaneous/interdigitating relationship and geochemical similarity in the study area (Figure 5.20). Figure 5.12 indicates that the composition of Unit 4 is more evolved than that of Units 3 and 5. It is postulated that volcanism had begun to wane by this stage in Rietgat times due to lower degrees of refluxing of the crustal reservoir. Indeed a greater sedimentary presence in these units attests to the decline of volcanism. It is possible that Units 4 and 5 evolved separately in the same chamber: a non-turbulent refluxing event at the base of the chamber could give rise to a density contrast, the result of which may be that the more evolved Unit 2 magmas rose buoyantly to the top of the chamber where they continued to differentiate. Units 1 and 2 were then extruded via different conduits.

#### <u>Stage 8</u>

Figure 5.21 depicts the complete cessation of volcanism and the absolute dominance of the sedimentary processes responsible for the deposition of the USH.

# 5.6 Discussion and Conclusion

The foregoing chapter has demonstrated that the lavas of the Rietgat Formation may be classified according to their geochemical composition. Elemental data have also been used to model and constrain magmatic differentiation processes and source regions.

. . . . ....

It can be concluded that the lavas of the Rietgat Formation are derived from the partial melting of an enriched mantle source. The resultant magma was then ponded at shallower crustal levels where it underwent a combination of AFC/RTF processes prior to extrusion, giving rise to the distinct geochemical units identified by this study.

# CHAPTER 6: SUMMARY AND PRESENTATION OF TYPE SECTION.

The following paragraphs aim to condense the findings of the foregoing chapters into a synopsis of the most salient features of the Rietgat Formation.

#### 6.1 General Characteristics and Lithology.

The rocks of the Rietgat Formation may be subdivided into a lower sedimentary horizon (LSH), which is overlain by 5 geochemically distinct lava units - accordingly named Units 1, 2, 3, 4 and 5. The uppermost unit of the Rietgat Formation is sedimentary and has been termed the upper sedimentary horizon (USH). This system of sub-division is an elaboration of the type stratigraphy for the Rietgat Formation as envisaged by Winter (1976).

The thickness of the Rietgat Formation in the study area varies widely and the succession is at its most developed in the deepest of the Platberg-age grabens, where it may attain a vertical thickness of more than 600m. The formation is laterally widespread in the area of the Free State Goldfields and may also be correlated to remote localities, such as the T'Kuip hills (Figure 2.2).

The lavas of the Rietgat Formation are typically fine-grained, greyish-green in colour and variably amygdaloidal, with individual flows ranging in thickness from 6m to over 300m. Flow tops are generally identifiable by their amygdaloidal affinity and in many cases their higher degree of alteration. Thicker flows, although not by necessity, tend to exhibit a porphyritic tendency towards their centre and a vuggy presence nearer their base.

#### 6.2 Mineralogy and Petrography.

The mineralogy and petrography of the lavas is very similar throughout the whole succession, varying only between rhyodacite, andesites and basaltic andesites. The primary composition of the lavas has been completely changed as a result of lower greenschist facies burial metamorphism, to which the entire Ventersdorp Supergroup was subjected. The resultant mineral assemblage in Units 1 to 5 comprise, in varying proportions, a paragenesis of quartz, albite, chlorite, actinolite, epidote and calcite. It is proposed that the chemical state of the lavas subsequent to metamorphism represents that of the original magma compositions, i.e. the introduction or extraction of elemental material was minimal.

The LSH and USH consist primarily of quartz and calcite, an assemblage which has been interpreted as being a function of protolith. A degree of chloritisation has however pervaded the sediments.

The alteration mineralogy manifests itself primarily as quartz and chlorite amygdale fillings and varying degrees of chloritisation and epidotisation of the groundmass of the lavas. Alteration also gives rise to bleached, silicified and epidotised zones, which occur principally in conjunction with flow tops and structural discontinuities, such as faults.
#### 6.3 Geochemical Stratigraphy.

Univariate, bivariate and multivariate data handling techniques have successfully demonstrated that it is possible to stratigraphically subdivide the lavas of the Rietgat Formation on the basis of their geochemistry. The application of a variety of such techniques has yielded consistent results (Figures 4.1-4.16). Adequate separation of the units may be facilitated by simple inter-element relationships, particularly with respect to immobile elements such as Ti, P, Zr, V and Nb. Multivariate statistical techniques provided tighter constraint on the geochemical groupings and facilitated the moderately positive correlation of sample data from T'Kuip with that of the study area (Figure 4.22).

### 6.4 Magmatic Classification and Tectonic Setting.

Using conventional geochemical nomenclature (Chapter 5), the lavas of the Rietgat Formation are classified as andesites, basaltic andesites and rhyodacites. Discrimination diagrams based on the variation of largely incompatible elements indicate that the lavas are of calc-alkaline to tholeiitic affinity and were erupted in a continental plate-tectonic setting. Both field and geochemical evidence support the theory that a rifting event took place during Platberg times.

Magnesium numbers indicate that the lavas of the Rietgat Formation do not represent unmodified primary mantle melts. The modification of such magmas is reflected in the REE and trace element characteristics of the lavas, which suggest that a degree of crustal contamination and fractional crystallisation have taken place.

## 6.5 Petrogenesis.

It is proposed that the primary magmas of the Rietgat Formation were derived by the melting of an enriched peridotitic mantle source. Upon ascent, these magmas may have ponded in the lower crust where they underwent AFC processes, thus affording the magmas their continental signature. Further contamination may be attributed to assimilation of wall-rock material from conduits during their ascent. Moreover, an elevated geothermal gradient in the region resulting from lithospheric thinning could also have resulted in the melting of crustal material and the subsequent contamination of the magmas.

Field and geochemical evidence are consistent with the consanguinous development of the Rietgat Formation, to which end it is proposed that the ponded magmas may have undergone a periodic RTF process.

#### 6.6 Proposed Reference Section.

The stratigraphy of the Rietgat Formation is summarised in Figure 6.1. Since the original type section RG1 (Winter, 1976; Figure 2.1, this study) for the Rietgat Formation was unavailable at the time of writing, a composite reference section involving boreholes NVT1 and KFN2 is proposed. These sections have been chosen on the grounds that they are the most geochemically and lithologically representative profiles in the study area. An explanation of Figure 6.1 has not been included since it is believed that this would amount to repetition of the annotated explanations contained therein.

		· · · · · · · · · · · · · · · · · · ·			
	LITHOLOGY	DESCRIPTION	RANGE IN THICKNESS	UNIT	TYPE BORE HOLE
terms only		Quartzwacke, coarsening down from fine sand to grit. Dark grey shaly intercalations commonly containing buckshot or blebby metallic sulphides (1). In some places quartz veins and stringers may be seen in this horizon. Away from the type section, a higher ratio of shale to arenites may be seen; in some cases the USH is almost entirely of shale.	15-50m	USH	
in relative		The lowermost lavas of Unit5 are amygdaloidal and grey in colour (5). Individual flows are thin and identifiable by their amygdaloidal flow tops. Thicker flows exhibit a porphyritic affinity. The uppermost flows display intense alteration and contain vuggy quartz (4). Higher in succession, sediments	10.2-105m	DF SERIES	
esented		(comprising quartzwackes (3) with shaly partings (2))         become increasingly dominant over lavas.         Altered grey lava series - generally non-amygdaloidal and equigranular (6), displaying varying degrees of alteration.	CONCOMM EXTRUS OF UNITS	TANT ZOLLI ON 4&5	5
are pi	(6) 	Sporadic clusters of amygdales. Thicker flows plagioclase porphyritic. Sedimentary Intercalations are very rare.	6-78m		KFN.
tted: unit thicknesses are representative and a		The unit is characterised by large volumes of sporadically amygdaloidal lava (8), the individual flows of which are often difficult to discern. Some flow top do however display a greater amygdaloidal affinity, which can facilitate the recognition of individual flows from place to place. Extremely dense clustering of amygdales was also noted, albeit on an irregular basis. In terms of their appearance, the lavas are greenish-grey in colour, largely due to the presence of chlorite as both an amygdale filling and as a groundmass alteration phase. Although the lavas are generally equigranular, occasional porphyries (11) do exist. Less prevalent features of Unit 3 include restricted epidote horizons (10), which are greenish-yellow in colour and do not appear to bear any relationship to stratigraphy. Elsewhere, the lavas contain layered material (9) which has been interpreted as being of tuffaceous origin. The lowermost flows of the unit frequently contain quartz or chalcedony vugs and vein networks (12).	9.8-348m	UNIT 3	BOREHOLE
ale omit		Featureless quartz-feldspar porphyries (13). Type locality contains pillow lavas (15), which grade upwards into pyritiferous shales and subsequently quartzwackes (14).	4.9-110m	UNIT 2	Γ1
Vertical sc		The unit comprises massive quartz-feldspar porphyries (16) which are coarser and more developed than those of the overlying Unit 2. Its phenocryst content is largely euhedral, associating with blebby chlorite. The type section contains a vein breccia (17) which has been interpreted as being a pseudotachylite.	9.8-134m	UNIT 1	REHOLE NV
	0	The lower portion of this unit is dominated by diamictite (19), of lava clasts in a carbonate matrix, which in the type area grades upwards into sandy and shaly material (18): in other sections only diamictites are present.	5.9-16.1m	LSH	BC

Figure 6.1 Composite stratigraphic type section for the Rietgat Formation

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## 6.7 Scope for future study.

- It is suggested that the geographical area of the current study is too small. A wider area would have facilitated a more comprehensive geochemical, stratigraphic and tectonic appraisal of the Rietgat Formation.
- A problem that faced the current study was the lack of suitable geochemical data. The inclusion of isotopic and more detailed REE data would have assisted in the formulation of a more accurate petrogenetic model for the Rietgat Formation, particularly in the context of the Ventersdorp Supergroup or even the Kaapvaal craton as a whole.
- It has been noted that very little study of the Allanridge Formation has been undertaken: such a study could surely contribute to our understanding of the geology of the Ventersdorp Supergroup as a whole.

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- Armstrong, R. A., Compston, W., Retief, E. A., and Welke, H. J. (1986). Ages and isotopic evolution of the Ventersdorp volcanics. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 89-92.
- Armstrong, R. A., Compston, W., Retief, E. A, Williams, I. S. and Welke H. J.(1991). Zircon ion microprobe studies bearing on the age and evolution of the Witwatersrand triad. *Precambrian Research*, 53, 243-266.
- Barton, J. M., Roering, C., Barton, E. S., van Reenen, D. D. and Smit, C. A. (1986). The Late Archaean-Early Proterozoic evolution of the Kaapvaal Craton and its possible relationships to the Witwatersrand basin. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 15-17.
- Bates, R. L. and Jackson, J. A. (1980). *Glossary of Geology*. American Geolgical Institute, Virginia, 751 pp.
- Beetz, P. F. W. (1936). Contributions to the geology of the Klerksdorp district from the results of the drilling activities by the Western Reefs Exploration and Development Company, Limited. Trans. Geol. Soc. S. Afr., 39, 223-261.
- Bickle, M. J. and Erikson, K. A. (1982). Evolution and subsidence of early Precambrian sedimentary basins. *Phil. Trans. R. Soc. Lond.*, A305, 225-247.
- Buck, S. G. (1980). Stromatolite and ooid deposits within the fluvial and lacustrine sediments of the Precambrian Ventersdorp Supergroup of South Africa. *Precambrian Research*, 12, 311-330.
- Burke, K., Kidd, W. S. F and Kusky, T. (1985). Is the Ventersdorp rift system of Southern Africa related to the collision between the Kaapvaal and Zimbabwe cratons 2.64 Ga ago? *Tectonophysics*, **115**, 1-24.

7.77

- Burke, K., Kidd, W. S. F and Kusky, T. (1986). Archaean foreland basin tectonics in the Witwatersrand, South Africa. *Tectonics*, **5**, 439-456.
- Booth, J. M. (1987). Acid volcanism in the Platberg Group around Klerksdorp: examples of ash-flow and air-type pyroclastic deposits. *Workshop on pyroclastic volcanism and associated deposits. Abstr. Univ. Natal, Pietermaritzburg*, 22-23.
- Bowen, M. P. (1984). The petrogenesis of the volcanic rocks of the Witwatersrand Triad in the Klerksdorp area, Transvaal. MSc. Thesis (unpubl.), Rhodes Univ., Grahamstown, 223 pp.
- Bowen, T. B. (1984). The geochemical stratigraphy of the volcanic rocks of the Witwatersrand Triad in the Klerksdorp area, Transvaal. MSc. Thesis (unpubl.), Rhodes Univ., Grahamstown, 224 pp.
- Bowen, T. B., Marsh, J. S., Bowen, M. P. and Eales, H. (1986a) Volcanic rocks of the Witwatersrand Triad, South Africa: Description, classification and geochemical stratigraphy. *Precambrian Res.*, 31, 297-324.
- Bowen, M. P., Bowen, T. B., Marsh, J. S. and Eales, H. V. (1986b). Geochemical stratigraphy of the volcanic rocks of the Witwatersrand triad. Abstr. Geocongress '86 Geol. Soc. South Africa, 99-102.
- Buck, S. G. (1980). Stromatolite and ooid deposits within the fluvial and lacustrine sediments of the Ventersdorp Supergroup of South Africa. *Precambrian Res.*, 12, 311-330.
- Burger, A. J. and Coertze, F. J. (1973). Radiometric age measurements on rocks from Southern Africa to the end of 1971. Bull. *Geol. Surv. S. Afr.*, **58**, 58pp
- Charlesworth, E. G., McCarthy, T. S., Stanistreet, I. G., and Cadle, A. B. (1986). Structural geology of the Rietfontein fault system of the Central Rand. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 23-26.

- Clendenin, C. W., Charlesworth, E. G. and Maske, S. (1988a). An early Proterozoic threestage rift system, Kaapvaal Craton, South Africa. *Tectonophysics*, 145, 73-86.
- Clendenin, C. W., Charlesworth, E. G. and Maske, S. (1988b). Tectonic style and mechanism of early Proterozoic basin development, southern Africa. *Tectonophysics*, 158, 275-291.
- Clendenin, C. W., (1989). Tectonic influence on the evolution of the early Proterozoic Transvaal sea, southern Africa. Ph. D. Thesis (unpubl.). Univ. Witwatersrand, Johannesburg, 276 pp.
- Coetzee, C. B. (1960). The geology of the Orange Free State Gold-Field. Mem. Geol. Surv. S. Afr., 49, 197 pp.
- Cornell, D. H. (1977). Alteration of volcanic formations beneath the Transvaal volcanosedimentary pile. *Abstr. Geocongress '77 Geol. Soc. S. Afr.*, 25-28.
- Cornell, D. H. (1978). Petrologic studies at T'kuip: evidence for metamorphism and metasomatic alteration of volcanic formations beneath the Transvaal volcanosedimentary pile. *Trans. Geol. Soc. S. Afr.*, **81**, 261-270.
- Corstorphine, G. S. (1903). The volcanic series underlying the Black Reef. Trans. Geol. Soc. S. Afr., 6, 99-100.
- Corstorphine, G. S. (1904). The history of startigraphical investigation in South Africa. S. Afr. Assoc. for the advancement of Science, President's Address, 145-191.
- Corstorphine, G. S. (1906). Discussion on a paper by A. L Hall and W. A Humphrey: 'The Black Reef Series'. Proc. Geol. Soc. S. Afr., 9, 40 pp.
- Cox, K. G., Bell, J. D. and Pankhurst, R. J. (1979) The interpretation of igneous rocks, George Allen and Unwin Ltd., London.

- Crockett, R. N. (1971). The rocks of the Ventersdorp system of the Lobatse and Ramotswa areas, Republic of Botswana; their possible origins and regional correlations. *Trans. Geol. Soc. S. Afr.*, **74**, 1-24.
- Crow, C. and Condie, K. C. (1988). Geochemistry and origin of Late Archaean volcanics from the Ventersdorp Supergroup, South Africa. *Precambrian Research*, 42, 19-37.

Currie, K. L. (1991). Genorm: A generalized norm calculation. Comp. Geosc., 17 (1), 77-89.

Davis, J. C. (1973). Statistics and data analysis in geology. John Wiley, Toronto, 550 pp.

- Deer, W. A., Howie, R. A. and Zussman, J. (1993). An introduction to the Rock Forming Minerals, 2nd edition, Longman, England, 696 pp.
- De Paolo, D. J. (1981). Trace element and isotopic effects of combined wall-rock assimilation and fractional crystallisation. *Earth Planetary Sci. Lett.*, **53**, 189-202.
- Green, D. H. and Ringwood, A. E. (1976). The genesis of basaltic magmas. Cont. Min. Pet., 15, 103-190.
- Grobler, N. J., De Bruiyn, H., Van der Westhuizen, W. A. and Schoch, A. E. (1986). Komatiitic affinities at the bottom and top of the late Archaean-Early Proterozoic intracratonic Ventersdorp volcanic pile. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 89-92.
- Grobler, N. J. and Emslie, D. P. (1975-1976). A re-examination of the Zoetlief-Ventersdorp relationship at the T'kuip Hills, Britstown district. *Ann. Geol. Surv. S. Afr.*, 11, 99-113
- Grobler, N. J. and Emslie, D. P. (1976). Stromatolitic limestone and chert in the Ventersdorp Supergroup at the T'kuip hills area and surroundings, Britstown district, South Africa. Trans. Geol. Soc. S. Afr., 79, 49-52.

- Grobler, N. J., Kleynhans, E. P. J., Botha, P. J., De Bruiyn, H. (1982). Distinction between lavas of the Allanridge andesite and Rietgat Formations in the Northern Cape and Western Transvaal. *Trans. Geol. Soc. S. Afr.*, 85, 117-126.
- Grobler, N. J., Van der Westhuizen, W. A. and Tordiffe, E. A. W. (1989). The Sodium group, South Africa: reference section for Late Archaean-Early Proterozoic cratonic cover sequences. *Aust. J. Earth Sci.*, **36**, 41-64.

Harker, A. (1909). The natural history of igneous rocks. Macmillan, New York.

- Haughton, S. H. (1969). Geological history of Southern Africa. Geol. Soc. S. Afr., Johannesburg, 535 pp.
- Hughes, C. J. and Hussey, E. M. (1976). M and Mg values in igneous rocks: proposed useage and comment on currently employed Fe<sub>2</sub>O<sub>3</sub> corrections. *Geochim. Cosmochim. Acta*, 40, 485-486.
- Hughes, C. J. and Hussey, E. M. (1979). Standardised procedure for presenting corrected Fe<sub>2</sub>O<sub>3</sub>/FeO ratios in analyses of fine-grained mafic rocks. *N. Jb. Miner. Mh.*, H12, 570-572.
- Hutchison, C. S. (1974). Laboratory handbook of analytical techniques. John Wiley and Sons, New York.
- Irvine, T. N. and Baragar, W. R. A. (1971). A guide to the chemical classification of the common volcanic rocks. *Canadian Journal of Earth Sciences*, **8**, 523-548.
- Jacobson, W. (1940). Vulkanologische und tektonische Beobachtungen an der jungalgonkischen Ventersdorp-Formation Sudafikas. Geol. Rndsch., 31, 255-284.
- Karpeta, W. P. (1989). Bedded cherts in the Rietgat Formation, Hartbeesfontein, South Africa: a late Archaean to early Proterozoic magadiitic alkaline playa lake deposit? S. Afr. J. Geol., 92, 29-36.

- Killick, A. M., Thwaites, A. M., Schoch, A. E. and Germs, G. J. B. (1986) A Preliminary account of the tectonites near the interface between the Ventersdorp and Witwatersrand Supergroups, South Africa. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 35-38.
- Labuschagne, A. N. (1974). The petrology of the lower Ventersdorp lavas in the East Driefontein Gold Mine. MSc. Thesis (unpubl.), Univ. Potchefstroom, Potchefstroom, 117 pp.
- Le Maitre, R. W. (1982). Numerical petrology. Developments in Petrology, 8, Elsevier Sci. Publ. Co., Amsterdam.
- Le Maitre, R. W. (1989). A classification of igneous rocks and glossary of terms, recommendations of the international union of geological sciences subcommission on the systematics of igneous rocks. Blackwell Scientific Publications, Oxford.
- Linton, P. L. (1992). The geochemical stratigraphy of the Klipriviersberg along the western margin of the Wiwatersrand Basin. MSc. Thesis (unpubl.). Univ. of the "" Witwatersrand, Johannesburg, 276 pp.
- Linton, P. L. and McCarthy, T. S. (1993). A method for the stratigraphic classification of the Klipriviersberg Group and Allanridge Formation volcanic rocks. S. Afr. J. Geol., 96, 49-56.
- Linton, P. L., McCarthy, T. S. and Myers, R. E. (1990). A geochemical reappraisal of the stratigraphy of the Klipriviersberg Group in the type borehole LL1 in the Bothaville area. S. Afr. J. Geol., 93, 239-244.
- Lofgren, G. E. (1972). Plagioclase crystal morphology as determined by growth temperature. *Abstr. 5.3 in program for advanced study institute on feldspars, July 1972, Manchester.*

- Marsh, J. S., Bowen, M. P., Rogers, N. W. and Bowen, T. B. (1992). Petrogenesis of the Late Archaean Flood-Type Basic Lavas from the Klipriviersberg Group, Ventersdorp Supergroup, South Africa. *Journal of Petrology*, 33, 817-847.
- Matthyssen, J. L. (1953) 'n Nuwe stratigrafiese indeling van die Ventersdorp-sisteem. MSc. Thesis (unpubl.) Univ. Pretoria.
- McCarthy, T. S., Charlesworth, E. G. and Stanistreet, I. G. (1986). Post-Transvaal structures across the northern margin of the Witwatersrand Basin. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 43-46.
- McCarthy, T. S., McCallum, K., Myers, R. E. & Linton, P. (1990a). Stress states along the northern margin of the Witwatersrand basin during Klipriviersberg volcanism. S. Afr. J. Geol., 93, 245-260.
- McCarthy, T. S., Stanistreet, I. G., Cadle, A. B. & Durrheim, R. (1990b). The geology of the Ventersdorp Supergroup (Bezuidenhout Valley) outlier to the east of Johannesburg and its relevance to the tectonics of the Witwatersrand Basin margin. S. Afr. J. Geol., 93, 289-309.
- McCarthy, T. S., Stanistreet, I. G. and Robb, L. J. (1990c). Geological studies related to the origin of the Witwatersrand Basin and its mineralization an introduction and a strategy for research and exploration. S. Afr. J. Geol., 93, 1-4.
- McIver, J. R., Cawthorn, R. G. and Wyatt, B. A. (1982). The Ventersdorp Supergroup the youngest komatiitic sequence in Southern Africa. In Komatiites, Eds. Arndt & Nisbet; George Allen & Unwin, London, 526 pp.
- Meschede, M. (1986). A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. *Chem. Geol.*, 56, 207-218.

Meintjes, P. G. (1988). The evolution of volcanic sedimentary basins of the Ventersdorp

Supergroup near Welkom. MSc. Thesis (unpubl.), Univ. of the Free State, Bloemfontein, 211pp

- ... Meintjes, P. G. (1994). The Platberg Group in the Bothaville area, Tectonics division, Geol. Soc. South Africa 10<sup>th</sup> anniversary conference.
  - Meintjes, P. G. (1998). Stratigraphy, petrochemisytry and genesis of the Makwassie Formation, Ventersdorp Supergroup. Ph. D. Thesis (unpubl.), Univ. of the Free State, Bloemfontein, 336 pp.
  - Meintjes, P. G., Visser, J. N. J. and Grobler, N. J. (1989). Evolution of the late Archaean volcano-sedimentary basins of the Platberg Group near Welkom, Orange Free State. S. Afr. J. Geol., 92, 235-249.

Middlemost, E. A. K. (1975) The basalt clan. Earth Sci. Rev., 11, 337-364.

- Minter, W. E. L., Hill, W. C. N., Kidger, R. J., Kingsley, C. S. and Snowden P. A. (1986). The Welkom Goldfield. In: Anhausser, C. R. and Maske, S. (eds.), *Mineral deposits* of Southern Africa, Vol I.Geol. Soc. S. Afr., 1020pp.
- Myers, J. M. (1990) The geology of the Gondwana Basin, Eastern Transvaal, PhD. Thesis (unpubl.), Univ. Witwatersrand, Johannesburg.
- Myers, J. M., McCarthy, T. S. and Stanistreet (1990). Platberg-age structures, sedimentation and volcanism in the Buffelsdoorn Graben northeast of Klerksdorp. S. Afr. J. Geol., 93, 261-271.
- Myers, J. M., Myers, R. E. and McCarthy, T. S. (1988). Geology and geochemistry of the Makwassie Formation, Ventersdorp Supergroup, in the Klerksdorp area. *Abstr. Geocongress '88 Geol. Soc. South Africa*, 449-452.
- Myers, R. E., Cawthorn, R. G., McCarthy, T. S. and Anhaeusser, C. R. (1987). Geochemistry and Mineralization of Proterozoic volcanic suites. Geol. Soc. S. Afr.

Spec Publ., 33, 315-325.

- Myers, R. E., McCarthy, T. S., Bunyard, M., Cawthorn, R. G., Falatsa, T. M., Hewitt, T., Linton, P., Myers, J.M., Palmer, K. J. and Spencer, R. (1990). Geochemical stratigraphy of the Klipriviersberg Group volcanic rocks. S. Afr. J. Geol, 90, 224-238.
- Nel, L. T. (1927). The Geology of the country around Vredefort. An explanation of the geological map. *Geol Surv. S. Afr.*, 130 pp.
- Nel, L. T. (1935). The geology of the Klerksdorp Ventersdorp area. An explanation of the geological map. *Geol. Surv. S.Afr.*, 159 pp.
- Nel, L. T., Frommurze, H. F., Willemse, J. and Haughton, S. H. (1935) the Geology of Ventersdorp and adjoining country. An explanation of sheet 53 (Ventersdorp). *Geol. Surv.S. Afr.*, 94 pp.
- Nel, L. T., Truter, F.C., Willemse, J. and Mellor, E. T. (1939). The geology of the country around Potchefstroom and Klerksdorp. An explanation of sheet 61 (Potchefstroom). *Geol. Surv. S. Afr.*, 156 pp.
- Nelson, D. R., Trendall, A. F., De Laeter, J. R., Grobler, N. J. and Fletcher, I. R. (1992). A comparitive study of the geochemical and isotopic systematics of late Archaean flood basalts from the Pilbara and Kaapvaal cratons. *Precambrian Research*, 54, 231-256.
- O'Hara, M. J and Matthews, R. E. (1981). Geochemical evolution of an advancing, periodically replenished, periodically tapped and continuously fractionating magma chamber. *Jour. Geol. Soc. London*, **138**, 237-277.
- Palmer, K. J., Spencer, R. M., Hewitt, T. and McCarthy, T. S. (1986). Geochemistry of the Klipriviersberg lavas as a stratigraphic guide in the Witwatersrand basin. Abstr. Geocongress '86 Geol. Soc. South Africa, 171-175.

Pearce, J. A. (1975). Basalt geochemistry used to investigate past tectonic environments on

Cyprus. Tectonophysics, 25, 41-67.

- Pearce, J. A. (1976). Statistical analysis of major element patterns in basalts. J. Petrol, (17) 1, 15-43
- Pearce, J. A. and Cann, J. R. (1973). Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth and Planetary Science Letters*, **19**, 290-300.
- Pearce, J. A. and Norry, M. J. (1979). Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks. *Contributions to Mineralogy and Petrography*, 69, 34-67.
- Pearce, T. H., Gorman, B. E. and Birkett, T. C. (1977). The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks, *Earth and Planetary Science Letters*, 36, 121-132.
- Pienaar, P. J. (1956). Stratigraphy and petrography of the Ventersdorp system in the Orange Free State Goldfields, South Africa. MSc. Thesis (unpubl.), Queen's Univ., Kingston, Ontario, 190 pp.
- Potgieter, C. D. and Visser, J. N. J. (1976). Precambrian ignimbrites and associated volcaniclastics from the Herbert district, Northern Cape Province. *Trans. Geol. Soc.* S. Afr. 79, 27-30.
- Robb, L. J., Davis, D. W. and Kamo, S. L. (1991). Chronological framework for the Witwatersran Basin and environs: towards a time constrained depositional model, S. Afr. J. Geol., 94 (1), 86-95.
- Roedder, E. (1984). Fluid Inclusions. *Reviews in Mineralogy*, **12.** Mineralogical Society of America.
- Roering, C. (1986). Aspects of thrust faulting on the northern margin of the Wiwatersrand basin. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 59-64.

- Rollinson, H. R. (1993). Using geochemical data evaluation, interpretation, presentation. Longman, New York, 352 pp.
- S.A.C.S., South African Committee for Stratigraphy, (1980). Stratigraphy of South Africa. Part 1: Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia and the Republics of Bophutatswana, Transkei and Venda. Handb. Geol. Surv. S. Afr.
- Schweitzer, J. and Kröner, A. (1985). Geochemistry and petrogenesis of early Proterozoic intracratonic volcanic rocks of the Ventersdorp Supergroup, South Africa. Chem. Geol., 51, 265-288.
- Shepherd, T., Rankin, A. H. and Alderton, D. H. M. (1985) A practical guide to fluid inclusion studies. Blackie, New York, 239pp.
- Spencer, R. M. (1986). A model for the tectonic evolution of the South Rand basin. Abstr. Geocongress '86 Geol. Soc. South Africa, 63-66.
- Stanistreet, I. G. and McCarthy, T. S. (1986). The control of the Rietfontein fault system on the sedimentation of the Ventersdorp and Witwatersrand Supergroups. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 67-70.
- Stanistreet, I. G., McCarthy, T. S., Charlesworth, E. G., Myers, R. E. and Armstrong, R. A. (1986). Pre-Transvaal wrench tectonics along the northern margin of the Witwatersrand basin, South Africa. *Tectonophysics*, 131, 53-74.
- Stanistreet, I. G. and McCarthy, T. S. (1990). Middle Ventersdorp graben development north of the Carletonville goldfield and its relevance to the evolution of the Witwatersrand basin. S. Afr. J. Geol., 93, 272-288.
- Taylor, S.R. and McLennan, S. M. (1985). The continental crust: its composition and evolution. Blackwell, Oxford, 312 pp.

- Till, R. (1974) Statistical methods for the earth scientist, an introduction. Macmillan, London, 154pp.
- Tyler, N. (1979). Stratigraphy, geochemistry and correlation of the Ventersdorp Supergroup in the Derdepoort area, West-Central Transvaal. *Trans. Geol. Soc. S. Afr.*, **82**, 133-147.
- Van der Westhuizen, W. A., De Bruiyn, H. and Meinjtes, P. G. (1991). The Ventersdorp Supergroup: an overview. *Journal of African Earth Science*, **13**, 83-105.
- Van der Westhuizen, W. A. and Grobler, N. J. (1987). Ignimbrites from the Sodium Group in the Britstown area. *Abstr. Workshop on pyroclastic volcanism and associated deposits, University of Natal, Pietermaritzburg.*
- Van der Westhuizen, W. A., Grobler, N. J., Loock, J. C. and Tordiffe, E. A. W. (1989). Raindrop imprints in the Late Archaean-Early Proterozoic Ventersdorp Supergroup, South Africa. Sedimentary Geology, 61, 303-309.
- Van Niekerk, C. B. (1968). The suitability of extrusive rocks for U-Pb radiometric dating. PhD thesis (unpubl.), Univ. of Cape Town.
- Van Niekerk, C. B. and Burger, A. J. (1964). The age of the Ventersdorp System. Ann. Geol. Surv. S. Afr., 3, 75-86.
- Van Niekerk, C. B. and Burger, A. J. (1968). Pb-isotope dating of the Zoetlief System, South Africa. *Earth Plan. Sci. Lett.*, 4, 211-218.
- Van Wagoner, J. C., Pasamentier, H. W., Mitchum, R. M., Vail, P. R., Sarg J. F., Loutit, T. S. and Hardenbol, J. (1988). An overview of the fundamentals of sequence stratigraphy and key definitions, in Wilgus, C. K., Hasting, B. J., Rosamentier, H., Van Wagoner, J. C., Ros, C. A. and Kendall, C. G. St. C. (Eds.), Sea Level Change: an integrated approach. Soc. Econ. Paleontol. Mineral. Spec. Publ., (42), 39-46, 407 pp.

- Visser, D. J. L. (1957). The structural evolution of the Union (Anniversary address by the President). Proc. Geol. Soc. S. Afr., 60, 13-50.
- Visser, J. N. J. and Grobler, N. J. (1985). Syndepositonal volcanism in the Rietgat and arenaceous Bothaville formations, Ventersdorp Supergroup (late Archaean-early Proterozoic), in South Africa. *Precam. Res.*, **30**, 153-174.
- Visser, J. N. J., Grobler, N. J., Joubert, C. W., Potgieter, C. D., Potgieter, G. J. A., McLaren,
  C. H. and Liebenberg, J. (1975). The Ventersdorp Group between Taung and
  Britstown, Northern Cape Province. Annual Geological Survey of South Africa, 11, 15-28.
- Walraven, F., Burger, A. J. and Allsopp, H. L. (1983). Summary of age determinations carried out during the period April 1981 to March 1982. Ann. Geol. Surv. S. Afr., 17, 87-93.
- Walraven, F., Smith, C. B. and Kruger, F. J. (1991). Age determinations of the Zoetlief Group – a Ventersdorp Supergroup correlative. S. Afr. J. Geol, 94, 220-227.
- Whitten, D. G. A. and Brooks, J. R. V. (1973). Dictionary of Geology. Penguin, London.
- Wilson, M. (1989). Igneous Petrogenesis, A Global Tectonic Approach, Unwin Hyman, London, 466 pp.
- Winchester, J. A. and Floyd, P. A. (1977). Geochemical discrimination of different magma series and their differentiation products using immobile elements, *Chem. Geol.*, 20, 325-343.
- Winkler, H. G. F. (1974). Petrogenesis of Metamorphic Rocks. 3<sup>rd</sup> Edition, Springer-Verlag, New York. 320 pp.
- Winter, F. (1995). The Stratigraphy and Geochemistry of the Alberton Formation, Ventersdorp Supergroup, southwest of Klerksdorp. MSc. Thesis (unpubl.), Univ. of

the Free State, Bloemfontein 267 pp.

- Winter, H. (1961). Results of research work on the Ventersdorp project. Third Ann. Rep. Econ. Geol. Res. Unit, Univ. of Witwatersrand, Johannesburg, 17 pp.
- Winter, H. (1962). Results of research work on the Ventersdorp project. Fourth Ann. Rep. Econ. Geol. Res. Unit, Univ. of Witwatersrand, Johannesburg, 31 pp.
- Winter, H. (1963). Results of research work on the Ventersdorp project. Fifth Ann. Rep. Econ. Geol. Res. Unit, Univ. of Witwatersrand, Johannesburg, 49 pp.
- Winter, H. (1964). Results of research work on the Ventersdorp project. Sixth Ann. Rep. Econ. Geol. Res. Unit, Univ. of Witwatersrand, Johannesburg, 33 pp.
- Winter, H. (1965). Results of research work on the Ventersdorp project. Seventh Ann. Rep. Econ. Geol. Res. Unit, Univ. of Witwatersrand, Johannesburg, 41 pp.
- Winter, H. (1965b). The stratigraphy of the Ventersdorp System in he Bothaville district and adjoining areas. *Ph.D. Thesis (unpublished), Univ. of Witwatersrand, Johannesburg,* 130 pp.
- Winter, H. (1976). A Lithostratigraphic classification of the Ventersdorp succession. Trans. Geol. Soc. S. Afr., 79, 31-48.
- Winter, H. (1986) Cratonic foreland model for Witwatersrand Basin development in a continental back-arc, plate tectonic setting. *Abstr. Geocongress '86 Geol. Soc. South Africa*, 75-80.
- Winter, H. (1987) A cratonic foreland model for Witwatersrand Basin development in a continental back-arc, plate tectonic setting. S. Afr. J. Geol, 90, 409-427.
- Winter, H. (1991). Ventersdorp History as deduced from a partially preserved succession of depobasins dominated by volcanism. Conf. Precamb. Basins of South Africa,

Sedimentary Division of the Geological Society of South Africa.

Wyley, A. (1859) Notes on a journey in two directions across the Colony, made in the years 1857-8, with a view to determine the character and order of the various geological formations. *Appendix to C. G. H.Parl. Rep.* **G 57-59**, 25, 27, 29, 30, 33, 34, 62.

### **APPENDIX 1: ANALYTICAL PROCEDURES.**

#### A1.1 Rare Earth Element Analysis.

The analytical procedure used by the University of Cape Town to determine the REE content of the sample material is summarised below:

Approximately 50 mg of sample powder was dissolved using standard, multi-stage HF/HNO3 digestion apparatus. The solution was then diluted to 1‰ of its original concentration using a 2% HNO3 solution containing 10 ppb of In and Re, which were employed as internal standards. Only high-purity, bottle-distilled acids and Millipore water were used.

The dissolved and diluted samples were subsequently analysed for REE using a Perkin Elmer/Sciex Elan 6000 ICP-MS. The ICP-MS instrument parameters used were as follows:

Nebuliser gas flow = 0.94 l per min.

Main gas flow = 15 l per min.

Auxillary gas flow = 0.75 l per min.

ICP RF forward power = 1100 W

Pressure in the quadrupole chamber =  $2.03*10^{-5}$  torr.

Nickel sampler and skimmer cones were used. The Elan 6000 was operated in its peak hopping mode, using the autolens option, dwell times of 50 ms per amu and total

integration times of 3 s per analyte peak. Before analysis, the instrument was optimised to minimise interferences by oxide species and doubly charged ions (CeO/Ce < 3 %; Ba++/Ba+ < 3 %). In addition, the data were corrected for Ba and REE oxide interferences. Calibration was achieved by external standardisation with one blank and two synthetic, multielement REE standards. In and Re were used as internal standards to correct for any instrumental drift during the analysis period. Blank subtraction was carried out after internal standardisation for both standards and samples.

All of the samples were analysed twice and the data set out in this study represent average values of those repeat analyses. The relative standard deviation (RSD) for these repeat analyses was mostly better than 1 % and always better than 3 % for all samples and elements. The same deviations apply to repeat analyses of both in-house and international reference standards, (ALR-33G and JB-2 respectively). Based on repeat analyses of ALR-33G and JB-2relative to tabulated values for these two materials, the accuracy was mostly better than 5 % and always better than 9 %.

#### A1.2 XRF Analytical Procedure.

All of the XRF spectrometry undertaken during the course of this project was conducted at the University of the Orange Free State on a Philips PW-1404 spectrometer. American, Canadian, Japanese, Norwegian, South African and French standards were used in the calibration of this apparatus, in conjunction with Philips X40 analytical software.

The 412 samples collected while core-logging were split in two, crushed and then milled to -300 mesh. Approximately 10g of powder from each sample was then pressed into a briquette, using boric acid as a base. These pellets were used in the determination of both the trace element abundancies and the Na<sub>2</sub>0 %. A further 3g of sample powder was accurately weighed into a silica crucible and heated to 110°C for a period of 12 hours, after which it was again weighed. The weight difference was used in the calculation of the H<sub>2</sub>O<sup>-</sup> presence in the sample. The powder was then ignited in a kiln at 1000°C for 6 hours, following which it was re-weighed. This weight loss was used to calculate the loss on ignition (known as the LOI) and represents the loss of volatile contents, such as H<sub>2</sub>O<sup>+</sup> and CO<sub>2</sub>. Following ignition, approximately 0.3g of the remaining sample was mixed with a fluxing agent, melted at 980°C and then pressed into fusion beads. The beads were used in the determination (with the exception of Na<sub>2</sub>O) of the major oxide composition of the samples.

## APPENDIX 2: ANALYTICAL DATA - X-RAY DIFFRACTION.

	······································	·····		T	r					<u> </u>
SAMPLE	UNIT	DEPTH (metres)	Fe Clinochlore	Albite	Quartz	Muscovite	Biotite	Epidote	Calcite	Actinolite
DKL6-10	2	718.80	X	X	X	X				
DKL6-11	1	730.00	x	x	x	х				
DKL6-11A	2	734.19	x		x	x			x	
DKL6-11B	2	737.34	x	x	x				x	] ]
DKL6-12	2	742.00	x	x	x				x	
DKL6-13	1	753.32	x	x	x				x	
DKL6-13A	1	759.98	x	x	x				x	
DKL6-13B	1 1	772.20	x	x	x				x	
DKL6-14	1	773.15	x	x	x				x	
DKL6-15A	3	782.96	x	x	x				x	
DKL6-16	3	790.15	x	x	x			ļ	x	
DKL6-16A	Tuff	800.12	x		x	x				
DKL6-17	Tuff	802.00	x		l x	x				
DKL6-8A	1	703.51	x	x	x	x			l x	
DKL8-10	2	779.50	x		x	x	1			{ }
DKL8-11		798 75	x	x		x			x	1
DKL8-12	2	806.00	x	x	x	x			x	
DKL8-13	3	831.29	x	x	x	x			x	
DKL8-8	2	755.60	x		x	x		1	~	
DKL8-9	2	774 80	x			x				
DKP1-1	Intrusive	827.51	x	x	x					x
DKP1-10	5	1.063.09	x	x	x				x	
DKP1-11	5	1,005.05	x	x						
DKP1-12	5	1,077.52			x					
DKP1-2	Intrusive	868 21	x	X	x					x
DKP1-3	Intrusive	907.00	x	x						
DKP1-4	Intrusive	925.00	x	x			1		X	N N State
DKP1-5	Intrusive	978.89	x		x					
DKP1-6	Intrusive	980.72					1	ľ		
DKP1.7		995 36	x							
DKP1-8		1 023 36								Ŷ
DKP1-9		1,029.50				ļ				
ERO2-1	Intrusive	240 50					v			
ERO2-2	Intrusive	322.05	x							
ERO4-0	1	637.00			x x				v	
ERO4-1	1	640.00					1	1	Ŷ	
ER04-10		726 70		x x	x		1			
ERO4-11	2	732.40					1	}		
ERO4-2		642.40	X		Ŷ	v			v	
ERO4-3		645 10	x		Ŷ	Ŷ				
ERO4-4		648.20	Ŷ	v	Ŷ					1
ERO4-5		650 40	Ŷ	Ŷ					Ŷ	
ERO4-6	1	651 10	v		Ŷ	[		1		1
ER04-7	1	654.00	Ŷ	Ŷ	Ŷ					
ERO4-8		689.00	Ŷ	Î	Ŷ				Ŷ	
ERO4-9		724.01	x x	Ŷ	Ŷ		ł			
KFN2_1	1 1	682.05	v v			v				^
KFN2-10		701 50	Ŷ	Ŷ	l û	^				
KEN2-11		808.27				1		1		
KEN2-12	2	000.21					· ·			
KEN2 12	2	020.73								
KEN2 14	د د	042.00 921.77								
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SAMPLE	UNIT	DEPTH (metres)	Fe Clinochlore	Albite	Quartz	Muscovite	Biotite	Epidote	Calcite	Actinolite
KEN2-16	3	885.09	x	x	x			<u> </u>		x
KFN2-17	3	903.11	x	x	x					-x
KFN2-18	3	921.32	x	x	x	1				x
KFN2-19	3	935.96	x	x	x					
KFN2-2	2	692.86	x	x	x	X	ļ			
KFN2-20	3	946.22	x	x	x					
KFN2-21	3	958.97	x	x	x					
KFN2-22	5	994.26	x	x	x					x
KFN2-24	5	1,015.82	x	x	x	ļ.				x
KFN2-25	5	1,027.68	x	x	x		]			x
KFN2-26	5	1,037.91	x	x	x				[	x
KFN2-3	2	712.97	x	x	x	x	1		ļ	
KFN2-4	1	728.87	x	x	x	x	ł			
KFN2-5	2	739.60	x	x	x					
KFN2-6	2	748.20	x	x	x	ļ				
KFN2-7	2	758.62	x	x	x	ſ		ĺ	í	
KFN2-8	2	774.51	x	x	x	ļ				
KFN2-9	1	781.21	x	x	x	1		ļ	ļ	
MA1-1	Tuff	853.20	x		x	ļ			x	
MA1-10	3	971.65	x		x				x	
MA1-11	3	972.92	1	Í X	X	ľ		x		
MA1-12	3	987.00	x	X	X				X	
MA1-13	3	1,005.50	x	х	x	}	ļ		x	
MA1-14	3	1,029.70	x	X	X	1			X	1
MA1-15	3	1,053.17	x	X	X				X	
MA1-16	3	1,100.00	l X	X	X	ł			X	
MA1-17	Intrusive	1,125.14	x	l	X		2		A S H	
MA1-18	5	1,142.18	X	X	X				j .	X
MA1-19	5	1,162.98	X	X	X					
MA1-2	1	858.30	X		X	X			X	
MA1-20	5	1,177.00	x	X	X			ł		X
MA1-21	5	1,210.00	X	X	X					X
MA1-3	1	870.98	X	X	X	X			X	
MA1-4	1	882.78	X	X	X	X			X	[ [
MA1-5	I	893.18	X	X	X	X			X	
MA1-6	2	905.00	X	X	X	X			X	
MAI-7		935.11	X	X .	X				X	
MAI-8	2	946.12		X	X				X	
IVIAI-9	3	965.32				l	]			
11VIA2-1		919.51		v						
MA2-10	3	1,085.87				1	1			
MAD 12		1,097.22								
MA2-12		1,122.85						ł		
MA2 14		1,137.19						[	1	
MA2 15	د د ا	1,100.80								
MA2-15	5 Tuff	1,103.12					1			
MA2-17		1,1/7.50		v						
MA2-18	<del>4</del> <	1,187.00				1		1		
MA2-10	2 1	1,204.21						1		
MA2-3		938.77						ł		
MA2-4	2	940.21 954 17	Ŷ		Ŷ		]	]	Ŷ	
	<u> </u>	<u></u>		1		I ^		1	1 ^	1 1

SAMPLE	UNIT	DEPTH (metres)	Fe Clinochlore	Albite	Quartz	Muscovite	Biotite	Epidote	Calcite	Actinolite	
MA2-5	1	962.65	x		x	x	<u> </u>		x		
MA2-6	1	988.39	x	·Χ	x				x		
MA2-7	3	1,015.92	x	x	x				x		
MA2-8	1	1,044.47	X	x	x i		]		x		
MA2-9	3	1,067.35	x	x	x				x		
MAL1-1	1	702.35	x		x	x			x		
MAL1-10	5	860.75	X	<b>X</b> -	x				x	x	
MAL1-11	5	895.36	X	X	X				x	X	
MAL1-2	1	706.85	x	X	x				X		
MAL1-3	1	713.65	x	X	<sup>-</sup> X			ļ	· X		
MAL1-4	2	721.20	x	X	x				x		
MAL1-5	1	731.26	X	X	X				X		
MAL1-6	1	760.42	X	x	x			}	x	}	ł
MAL1-8	5	818.96	x	X	x				x		
MAL1-9	5	834.75	x	x	x				x	x	ŀ
MAL4-1	2	759.61	x	X	x	X			x		
MAL4-2	1	778.80	X	x	x	x	1		x		
MAL4-3	1	809.12	X	x	x			}		]	1
MAL4-4	1	830.37	X	X	x	l .				x	1
MAL4-5	3	840.71	x	X	x					X	
MAL4-6	3	858.21	X	x	x					x	
MAL4-7	3	869.42		x	X X						
MAL4-8	3	889.91	X	X	x		1			x	ļ
NVT1-10	2	1,347.31	x	x	x	x					
NVTI-11	2	1,354.95	. <b>X</b>	X	<b>X</b> .	x					
NVT1-12	2	1,367.13	x	X	x	X			1		
NVT1-13	2	1,379.49	X	X	x		1			₩.e*4	
NVT1-14	2	1,387.18	X	X	X.			ļ		<i>i.</i>	l
NVT1-15	I	1,397.89	X	<b>X</b>	[ X	(	1		[	ĺ	Ĺ
NVT1-16	1	1,411.07	X	X	x						
NVT1-17	3	1,420.27	x	X	x						
NVT1-18	3	1,430.37	X	X	X						
NVT1-19	3	1,440.06	x	X	x						
NVT1-2	2	1,313.00	X		X	X			x		
NVT1-20	3	1,442.10	X	X	X						
NVT1-20A	3	1,454.17	X	X	X	1				X	
NVT1-21	3	1,472.82	x	X	X					X	
NVT1-22	3	1,485.83	X	X	X						
NVT1-22A	3	1,499.63	X	X	x	1				X	
NVT1-23	3	1,518.75	X	X	X					X	ŀ
NVT1-24	3	1,533.50	X	X	x					X	
NVT1-25	3	1,548.20	X	X	x					X	
NVT1-26	3	1,556.61	X	X	x					X	
NVT1-27	3	1,567.19	X	X	x	ł			1	x	
NVT1-28	3	1,579.46	X	. X	x					X	
NVT1-29	-3	1,590.89	X	X	x				1	X	
NVT1-30	3	1,599.23	X	X	X		1		ŀ	X	
NVT1-32	3	1,625.27	X	X	х		}			X	
NVT1-33	3	1,,638.55	X	X	х	<b>.</b>				X	1
NVT1-34	3	1,657.24	X	X	X	ł	1		X		
NVT1-35	3	1,665.50	X	X	X	ł				X	L
NVT1-36	3	1.677.24	I X	I X	IX	1	1	1	1	I X	L

					·					
SAMPLE	UNIT	DEPTH (metres)	Fe Clinochlore	Albite	Quartz	Muscovite	Biotite	Epidote	Calcite	Actinolite
NVT1-37	3	1.714.10	x	X	X		<u> </u>		··	X
NVT1-38	3	1.726.17	x	x	x					х
NVT1-39	3	1.132.13	x	x	x					x
NVT1-4	2	1,316.86	x	1	x	l x			x	
NVT1-40	3	1,750.26	x	x	x		[		1	x
NVT1-44	4	1,800.67	x		x	x			x	
NVT1-46	4	1,818.27	x		x	x			x	
NVT1-47	4	1,847.12	x	x	l x	x	1		i i	
NVT1-48	4	1,859.75	x	x	x	x	1			
NVT1-49	4	1,874.10	x	x	x	X				
NVT1-5	2	1,318.62	x		x	X			x	
NVT1-51	5	1,890.87	x	x	x	x				
NVT1-52	5	1,910.00	x	x	x	x	l			
NVT1-53	5	1,940.82	X	x	X	x		-		
NVT1-6	2	1,322.89	X	(	X	X	i –	1	x	i i
NVT1-7	2	1,326.68	X	X	X	x			· ·	· · ·
NVT1-8	2	1,337.00	X	X	X	X				
NVT1-9	2	1,341.09	X	X	X	X			}	
PDE1-1	1	749.95	X	X	X	X			X	
PDE1-2	1	765.29	X	X	X	X		ļ	X	
PDE1-3	1	778.20	X	X	X			Ì	X	X
PDE1-4	1	799.10	X		( X	ĺ	[	1	X	x
PDE1-5	1	818.68	X	X	X			ļ	X	x
PDE1-6	Sediment	848.21	X		X			1		
PDE1-7	Sediment	849.69	X	1	X			}		
S4-1	1	736.18	X	1	X	X			X	
\$4-10	1	809.00	X	X	X	X		1	X	104 B
S4-11	1 <u>.</u>	811.76	X	X	X	X		ļ		•
S4-12	1	821.07	X	X	X	X			X	
S4-13	· .1 ·	831.11	X		X				X	X
S4-14	1	843.87	X	X	X				X	X
S4-15		855.70	X	X		ł			X	X
S4-16	1	867.10		X					X	X
54-17	3	838.20				l		1	X	
54-2	1	744.17		1				ļ		1
54-5	2	/50./2		1						
54-4		/55.13								
54-0	2 1	194.28		v				]		
S6-1	ו ר	000.00 728.25								
S6-1R	ے 1	742.00								
S6-2	L T	742.00	$\cdot$	1				1		
S6-3	1 1	800.70		v	Ŷ	^	1			
S6-3A	1	833.80		Ŷ					Ŷ	
S6-3B	1	750 62	x	x	x	ł				
S6-3C		773.61	x	x	x	}		1	1	1
S6-3D	1	790.15	x		x	1	1			
S6-3E		823.00	x	x			l I			x
S6-3F		836.65	x	x	x x	l				x
S6-5		841.75	x	x	x		[	[	[	x
S6-6	1	854.00	x	x	x		1		x	
ТК1/1В	(outcrop)	outcrop	x	x	x	x	1			

SAMPLE	UNIT	DEPTH (metres)	Fe Clinochlore	Albite	Quartz	Muscovite	Biotite	Epidote	Calcite	Actinolite
ТК1/3	(outcrop)	outcrop	X	X	X	x				
TK2/2F	(outcrop)	outcrop	X	Х	Х					
TK2/21	(outcrop)	outcrop	X	X	Х					Х
TNT2-1	1	725.87	X		Х	Х				
TNT2-10	3	946.05	X		X			X		
TNT2-13	3	986.06	X	X	X					
TNT2-14	5	1,021.62	X	x	x					X
TNT2-15	5	1,036.28	X	X	x					X
TNT2-16	5	1,055.69	X		X					X
TNT2-3	1	747.65	X	X	· X			2 Ma		
TNT2-4	1	762.49	X	X	Х			•		
TNT2-5	1	778.86	X	X						
TNT2-6	3	835.84	X	X	x					X
TNT2-7	3	897.65	X	X	X		1	1		х
TNT2-9	3	933.97	X	X	X				X	

# APPENDIX 3: ANALYTICAL DATA - X-RAY FLUORESCENCE

						·		<u></u>	<b>}</b>			· · · · · · · · · · · · · · · · · · ·			·
	DKL6-10.	DKL6-11	DKL6-11A	DKL6-11B	DKL6-12	DKL6-13	DKL6-13A	DKL6-13B	DKL6-14	DKL6-15A	DKL6-16	DKL6-16A	DKL6-17	DKL6-6	DKL6-8A
Depth (metres)	718.80	730.00	734.19	737.34	742.00	753.32	759.98	772.20	773.15	782.96	790.15	800.12	802.00	444.15	703.51
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	4	5	4	· 4	4	5	5.	5	5	3	3	Tuff	Tuff	Tuff	5
wt.%															
SiO <sub>2</sub>	58.44	59.09	50.84	56.32	55.04	55.14	56.89	56.10	58.16	47.66	49.66	84.66	64.82	53.71	55.20
TIO,	- 1.57	1.51	1.56	1.58	1.62	1.44	1.60	1.26	1.58	1.67	1.50	0.36	2.24	1.20	1.49
Al <sub>2</sub> O <sub>3</sub>	14.81	14.50	15.06	15.11	15.71	14.71	15.26	12.17	15.14	15.16	14.92	5.69	12.99	13.36	14.55
Fe <sub>2</sub> O <sub>3</sub>	11.00	8.00	6.13	10.95	13.79	7,89	10.11	9.95	8,41	14.22	10.96	6.55	10.13	11.15	9.31
MnO	0.11	0.10	0.20	0.13	0.14	0.11	0.09	0.15	0.08	0.14	0.10	0.06	0.07	0.14	0.11
MgO	4.86	2.73	2.18	3.81	5.31	2.80	4.17	4.22	3.63	8.71	6.44	1.57	2.73	3,90	4.08
CaO	2.30	4.96	10.02	4.49	2.62	8 39	4.85	7.70	4.89	3.88	6.44	1.09	2.49	7,51	6.13
Na-O	2.06	2.84	0.04	2.79	1.56	2.73	3.08	1.88	3.86	1.61	2.79	0.09	0.01	1.53	0.78
K.0	0.96	1 16	4 20	0.49	0.81	1 51	0.55	0.22	0.30	0.45	0.03	0.97	3.18	1.59.	2.32
P.O.	0.75	0.70	0.80	0.76	0 77	0.72	0.76	0.63	0.76	0.87	0.79	80.0	0.36	0.27	0.72
H.O.	-0.11	0.04	0.00	0.05	0.07	0.05	0.08	0.05	0.00	0.10	0.07	0.06	0.10	0.05	0.07
	3 42	4 49	8 89	4 28	4 01	5 85	4 20	6.58	3 56	5 43	6.50	1.66	2.86	5.68	6.63
тот	100 39	100.12	100.01	100.76	101.45	101 34	101 64	100.96	100.46	99.90	100.20	102.84	101.98	100.09	101 39
nnm	100.55	100.12		100.70	101.15		101.01	100.20	100.10			102.01		100.07	
Rb	31.80	40.20	154.00	17.10	32.40	42 50	12.00	1.40	4.40	7.30	0.01	32.00	164.60	21.70	78.90
Ba	345.80	428.30	1.354.20	227,20	351,50	816 80	333.00	249.90	291.90	643.30	55,10	529.70	850.80	450.40	589.50
Sr	128,10	253.70	66.60	271.00	176.80	549.20	492.80	406.60	706.60	247.30	227.10	43.30	62.10	533.90	85.30
Zr	349.90	329.20	366.80	346.00	350.30	315.10	333.00	275.70	333.60	239.20	219.70	92.80	253.60	179.30	337.50
Nb	15.00	14.40	18.00	16.40	16.60	15.50	15.60	13.20	15.20	13.00	11.70	3.20	13.60	10.30	15.90
Ni	82.40	55.60	52.20	76.40	82.90	73.00	72.70	69.10	77.00	124.40	118.10	52.90	160.60	149.40	77.10
Zn	104.40	80.80	114.60	123.30	142.50	93.40	<sup>•</sup> 93.80	102.80	111.20	141.50	95.70	44.20	75.10	104.70	83.20
Cr	218.40	215.40	186.80	229.70	246.50	212 50	238.30	173.10	228.80	379.90	324.70	190.00	139.90	53.20	207.60
Cu	32.80	13.30	16.20	17.80	19.20	25.40	18.20	11.50	17.90	106.10	10.30	28.60	170.50	116.20	7.30
V	242.80	213.50	201.70	194.50	272.90	197.50	241.20	197.30	214.00	274.60	249.70	70.60	300.90	173.90	228.20
Y	38.20	37.00	51.20	45.50	43.60	38.70	39.40	29.40	38.20	36.10	33.20	8.60	46.00	21.60	37.00
Sc	20.40	17.50	21.20	12.10	26.80	18 00	19.70	15.30	21.40	20.40	19.20	6.70	22.10	15.80	24.10
Co	45.30	34.70	17.20	41.30	48.00	38.00	45.80	45.90	40.40	72,00	54.10	27.30	104.30	64.40	35.50
CIPW Norms. (%)	22.71	26.42	16.02	26.01	22.22	16 66	22.60	26.06	21.26	10 60	12.02	75.07	44.51	20.00	75.07
Quartz	33.71	20.47	10.93	23.91	32.32	10.05	22.07	20.95	1 34	7.40	12.92	263	5 85	20.99	135
Zimon	0.21	0.07	-	0.07	9.09	0.06	2.59	0.06	0.07	0.05	0.48	0.02	0.05	0.04	0.07
Orthoolese	5.87	7 19	27 33	3.01	4 99	9.37	3 34	1 38	1.83	2 82	0.04	5.68	19.04	9.97	14 51
Alhite	18.00	25.14	0.37	24.48	13.17	24 20	26.77	16.87	33.73	14.43	25.21	0.75	0.08	13.72	6.97
Anorthite	6.85	21.16	31.35	18 11	8.08	24 59	19.88	25.61	20.26	14.62	28.71	4.99	10.34	26.42	27.34
Dionside		-	9.94	-	-	7.55		5.24	•		-	-		6.03	•
Wollastonite	-	-	•	.	-	-	- ·	•		-	-	-	、 <b>-</b>	-	-
Hypersthene	12.50	7.11	1.36	9.84	14.05	3.81	10.67	8.72	9.34	22.99	17.13	3.87	5.87	7.50	10.73
Chromite	0.05	0.05	0.04	-0.05	0.05	0.05	0.05	0.04	0.05	0.08	0.07	0.04	0.03	0.01	0.04
Haematite	11.36	8.37	6.73	11.35	14.05	8.27	10.38	10.55	8.69	15.07	11.71	6.48	10.23	11.82	9.83
Ilmenite	0.24	0.22	0.46	0.28	0.32	· 0.24	0.19	0.34	0.17	0.31	0.23	0.12	0.20	0.36	0.25
Sphene	-	-	3.62	0.28	-	3.40	-	2.84	-	-	-	-	-	2.66	•
Apatite	1.85	1.74	2.09	1.87	1.92	1.80	1.86	1.59	1.87	2.20	2.00	0.19	0.87	0.68	1.81
Rutile	1.49	1.47	·	1.49	1.48		1.54	· ·	1.54	1.61	1.48	0.29	2.16		1.44

	DKL8-10	DKL8-11	DKL8-12	DKL8-13	DKL8-8	DKL8-9	DKP1-10	DKP1-11	DKP1-12	DKP1-2	DKP1-3	DKP1-4	DKP1-5	DKP1-7	DKP1-8
Depth (metres)	779.50	798.75	806.00	831.29	755.60	774.80	1,063.09	1,079.32	1,122.68	868.21	907.00	925.00	978.89	995.36	1,023.36
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	4	5	. 4	4	4	4	1	1	1	Intrusive	Intrusive	Intrusive	Intrusive	5	3
wt.%										·					
SiO <sub>2</sub>	53.91	55.83	47.33	48.06	57.77	56.64	56.61	59.25	56.36	48.60	47.23	50.00	48.59	56.35	53.63
TIO2	1.40	-1.45	1.70	1.53	1.28	1.56	1.29	1.42	1,33	1.66	1.72	1.79	1.77	1.61	1.50
Al <sub>2</sub> O <sub>3</sub>	13.74	14.00	15.42	13.98	13.44	14.31	13.36	15.40	14.08	13.90	14.12	13.83	14.51	15.27	14.49
Fe <sub>2</sub> O <sub>3</sub>	9.81	9.45	12.81	10.40	10.97	11.00	11.47	7.46	9.69	16.06	16.30	15.70	16.28	7.92	10.62
MnO	0.12	0.14	0.16	0.13	0.12	0.11	0.15	0.09	0.11	0.21	0.27	0.27	0.27	0.17	0.19
MgO	3.04	4.09	4.23	4.74	3.19	4.40	4.61	2.30	3.08	5.66	5.75	6.44	5.91	3.82	6.93
CaO	6.96	5.53	6.38	8.12	4.23	3.40	4.23	4.08	5.92	9.80	8.22	6.08	7.19	5.70	5.23
Na <sub>2</sub> O	1.36	3.02	2.14	2.39	0.06	0.20	1.97	2.84	2.70	2.34	2.60	2.56	2.70	5.45	3.06
K <sub>2</sub> O	1.70	0.23	0.72	0.38	2.21	2.09	0,30	2.75	1.06	0.11	0.57	0.62	0.96	0.03	0.08
P <sub>2</sub> O <sub>5</sub>	0.65	0.67	0.76	0.81	0.57	0.71	0.53	0.62	0.57	0.22	0.23	0.24	0.25	0.82	0.77
H <sub>2</sub> O-	0.06	0.06	0.11	0.09	0.08	0.14	0.08	0.10	0.05	0.14	0.10	0.08	0.06	0.08	0.09
LOI	6.69	4.47	6.34	7.43	5.49	4.97	4.67	3.39	5.07	2.11	2.97	2.93	2.27	2.10.	2.93
тот	99.44	98.94	98.10	98.06	99.41	99.53	99,27	99.70	100.02	100.81	100.08	100.54	100.76	99.32	99.52
ppm pr	68.20	0.00	20.50	17.10	87 50	75 70	4.60	65 70	21.90	4 20	11.70	11.50	21.80	0.01	0.01
RD	465 20	9.90	558.00	17.10	673.80	808 50	182.20	1 689 90	584.60	262.90	556.90	500.10	1 370 00	30.50	116.00
Da Sr	330.30	972 20	266 70	404 80	71.80	56 10	352.10	480 70	600 10	693 50	346 90	240.50	409.20	220.90	517.70
7r	319.50	306.30	369.50	228.70	313.30	351.50	318.90	353.20	342.80	169.40	187.90	190.90	185.60	326.10	226.00
Nb	16.30	15.80	19.20	12.70	13.60	16.80	15.20	16.00	16.20	13.00	13.80	12.20	13.80	15.20	12.90
Ni	18.30	18.90	24.50	27.60	20.90	· 23.60	91.00	73.30	78.50	127.10	104.70	85.00	109.20	63.70	109.10
Zn .	72.10	78.30	93.70	112.90	46.20	73.60	108.70	68.60	122.70	121.50	136.10	121.20	138.30	49.00	108.30
Cr	106.30	115.60	127.90	110.30	128.80	111.60	341.40	382.30	352.10	125.90	157.80	150.90	154.20	192.40	291.90
Cú	24.60	16.50	13.00	7.00	25.20	6 90	12.40	35.90	23.80.	186.70	161.50	152.80	176.70	7.00	30.80
V	44.20	43.30	52.80	39.60	35.90	41.70	215.40	193.50	197.20	250.80	311.20	338.70	323.80	206.30	237.50
Y S-	181.80	210.00	223.50	311.90	120.10	224.90	37.30	35.60	40.70	30.30	38.30	30,70	36.20	41.00	20.40
80 Ca	192.70	207.20	290.40	244.10	33.70	36.60	57 30	37.00	45 30	76 40	79.00	74 90	82 30	33.80	55 00
CIPW Norms (%)	51.00	55.50	+0.30			50.00	51.50	57.00	45.50	70.10		71.20	02.50		
Ouartz	24.52	22.59	15.60	13,70	39.16	37 74	31.19	22.39	22.52	10.16	7.60	11.93	7.75	10.46	16.65
Corundum	-	0.35	1.46	-	4.93	7.66	3.52	1.70	-	· -	-	-	-	-	1.70
Zircon	-		-	-	-	-	0.06	0.07	0.07	0.03	0.04	0.04	0.04	0.07	0.05
Orthoclase	10.84	. 1.44	4.64	2.48	13.92	13.08	1.88	16.92	6.61	0.66	3.48	3.76	5.77	0.18	0.49
Albite	12.41	27.06	19.76	22.33	0.54	1.79	17.63	24.98	24.07	20.09	22.68	22.21	23.21	47.47	26.83
Anorthite	28.45	24.42	29.12	29.05	18 <u>.</u> 40	12.95	18.71	17.45	24.47	27.53	25.99	25.07	25.11	17.64	21.89
Diopside	· ·	•	-	وو و	•	-	-	•	-	12.23	7.58	-	3.11	0.75	
Wollastonite		10.70	-	-	8.47		12.15	5 95	8.08	8 64	11.25	16 44	13.21	9.45	17.88
Chromito	8.17	10.79	11.49	-	0.47	11.01	0.07	0.08	0.08	0.04	0.03	0.03	0.03	0.04	0.06
Haematite	10.58	10.01	13.98	11.49	11.69	11.65	12.14	7.75	10.21	16.30	16.80	16.10	16.54	8.15	11.01
Ilmenite	0.28	0.32	0.37	0.31	0.27	0.25	0.33	0.17	0.23	0.49	0.62	0.61	0.61	0.37	0.42
Sphene	2.98		-	3.75	•	-	•	•	2.06	3.51	3.56	3.15	3.64	3.59	-
Apatite	1.66	1.68	1.96	2.12	1.44	1.78	1,33	1.55	1.43	0.53	0.56	0.59	0.61	2.00	1.90
Rutile	0.15	1.37	1.66	-	1.22	1.52	1.19	1.38	0.44	-	·•	0.23	·	-	1.33
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	DKP1-9	ERO2-1	ERO2-2	ERO4-11	ERO4-2	ERO4-3	ERO4-4	ERO4-5	ERO4-6	ERO4-7	ERO4-8	ERO4-9	KFN2-1	KFN2-10	KFN2-11
Depth (metres)	1,049.16	240.50	322:05	732.40	642.06	645.19	648.29	650.40	651.10	654.00	689.00	724.01	682.95	791.50	808.27
Formation	Rietgat	Rictgat	Rictgat	Rictgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	2	Intrusive	Intrusive	3	5	• • 5	5	5	· 5	5	5	5	5	5	5
wt.%															
SiO <sub>2</sub>	57.78	50.75	53.23	50.43	50.52	55.69	48.53	59.28	47.85	53.04	57.81	53.90	54.12	56.80	48.18
TIO1	· 1.64	2.04	1.15	1.53	1.53	1.33	1.37	1.32	1.46	1.44	1.55	1.46	1.37	1.46	1.81
Al <sub>2</sub> O <sub>3</sub>	. 16.21	14.07	13.36	13.69	14.97	12.81	14.51	12.40	14.99	13.95	15.38	13.96	15.17	14.48	16.79
Fe <sub>2</sub> O <sub>3</sub>	9.48	15.99	1.1.55	12.38	11.02	8.51	11.12	10.45	9.38	7.81	9.67	10.05	9.80	9.77	13.70
MnO	0.12	0.19	0.24	0,14	0.10	0.11	0.11	0.10	0.11	0.10	0.10	0.11	0.11	0.11	0.12
MgO	3.68	3.80	7.91	5.45	6.10	4.61	5.93	5.89	5.58	3.88	3.83	3.97	5.17	3.91	6.26
CaO	2.49	8.04	5.05	6.86	6.12	7.54	.7.83	3.90	8.84	6.75	3.62	5.98	5.44	6.37	3.97
Na <sub>2</sub> O	2.00	2.14	3:13	2.82	0.45	0.43	1.51	1.45	1.82	1.80	2.84	2.88	1.29	2.86	· 1.91
K <sub>2</sub> O	4.40	1.37	0.15	0.27	2.08	1.97	0.80	0.43	1.11	1.72	1.42	1.58	1.64	1.03	2.40
P <sub>2</sub> O <sub>5</sub>	0.72 :	0.30	0.46	0.80	0.74	0.71	0.68	0.63	0.73	0.69	0.75	0.71	0.68	0.70	0.91
H <sub>2</sub> O-	0.08	0.34	0.25	0.13	0.14	0.09	0.09	0.07	0.11	0.06	0.07	0.07	0.12	0.04	0.06
LOI	2.52	2.09	2.75	3.16	7.26	7.70	8.15	4.80	8.63	6.75	3.25	3.38	6.26	2.97	4.21
ТОТ	101.12	101.13	99.23	97.66	101.03	101,50	100.63	100.72	100.61	97.99	100.29	98.05	101.17	100.50	100.32
ppm															
Rb	99.70	43.70	0.30	6.30	78.40	75.80	29.70	15.30	42.00	75.20	33.50	40.60	65.40	222.90	57.70
Ba	3,404.40	481.60	59.60	336.90	657.40	629.80	242.20	191.50	295.90	799.30	1,460.40	718.40	605.80	957.60	3,670.70
Sr	221.00	685.40	182.20	420.20	73.10	76.00	136.40	111.20	174.10 228.60	189.00	421.70	613.60	130.60	602.40	328.30
Zr	425.40	232.30	235.80	249.70	346.70	305.40	310.70	293.80	328.50	331.30	337.00 16 30	324.80	14 50	15.90	18 70
N D Ni	19.20	15.90	12.80	14.50	78.50	52.20	86.40	62.00	76.50	68.90	80.30	72 20	51.00	74.90	91.20
7n	60.70	124 70	109.80	129.80	104 Å0	69 30	92 20	104 60	97.80	87.20	115 70	103.40	67.10	89.10	150.80
Cr.	429.20	54 80	534 20	267 70	224.00	176.50	211.60	202.20	229.00	195.60	227.10	210.10	133.30	212.60	218.30
Cu	18.90	201.50	22.40	24.50	32.00	11.80	12.80	27.10	6.70	20.70	11.50	19.90	12.90	17.80	28.30
v	274.00	272.50	218.0Ò	233.90	241.70	197.50	218.60	217.60	218.90	218.70	249.40	215.30	234.20	201.40	257.60
Y	42.50	45.60	35.20	38.10	43.70	39.20	36.30	35.10	40.60	37.60	37.00	41.30	46.20	39.30	49.20
Sc	26.10	25.30	24.30	20.90	21.60	22.40	23.10	17.50	22.40	21.60	16.70	17.20	20.40	18.90	22.10
Co	52.90	63.00	61.70	54.70	51.40	<u>34,80</u>	44.50	55.30	41.50	35.40	50.10	44.00	43.60	48.90	56.70
CIPW Norms. (%)				14.00	21.06	27.40	14.02		10.72	14.95	25.06	16.12	24.05	10.80	12 72
Quartz	20.23	13.95	13.64	14.23	21.00	27.49	14.93	35.25	10.72	14.65	25.00	10.15	24.03	19.60	5 94
Corundum	0.10	0.05	-	- 0.05	2.74	0.06	0.06	9.11	0.07	0.07	9.50	0.07	0.07	0.06	0.07
Carcon Orthoclase	26.17	8 22	0.03	1.69	13.16	12.45	5 13	2.66	7 16	8.37	8 67	9.89	10.25	6.33	14.79
Alhite	17.01	18 34	27.52	25.28	4 07	3 88	13.83	12.80	16.76	12.14	24.78	25.75	11.52	24.82	16.83
Anorthite	8.61	25.11	22.84	25.36	27.46	29.06	32.98	15.98	32.08	23.75	13.99	21.73	23.99	24.28	15.36
Diopside		5.68	- 1	0.27	-	1,25		-	4.34	-	-	0.16	-	- 1	
Wollastonite	-		-	- 1	•	-	-	-	-	-	-	-	-	-	-
Hypersthene	9.21	6.96	20.47	14.26	16.26	11.67	15.98	15.30	13.13	8.26	9.84	10.38	13.58	9,99	16.23
Chromite	0.09	0.01	0.11	0.06	0.05	0.04	0.05	0.04	0.05	0.04	0.05	0.05	0.03	0.05	0.05
Haematite	9.53	16.20	12.00	13.12	11.77	9 08	12.04	10.90	10.21	6.36	9.97	10.62	10.34	10.02	14.26
Ilmenite	0.24	0.43	0.52	0.32	0.23	0.25	0.26	0.22	0.25	0.17	0.22	0.25	0.25	0.24	0.27
Sphene		.4.52	0.11	3.58	-	3 17	3.08		3.57		-	<i>3.48</i>	- 1.71	2.//	-
Apatite	1.80	0.72	1.13	2.02	1.88	1 80	1.75	1.36	1.89	1.57	1.86	1.79	1./1	1./1	2.32
Rutile	1.52	<u>ل</u>	0.88		<u> </u>	्रिंग् हे. रूकर	0.09	1.20	•	·	1.48		1.31	0.23	1.74

	MA1-1	MA1-2	MA1-3	МА1-4	MA1-5	MA1-6	MA1-7	MA1-8	MA1-9	MA1-10	MA1-11	MA1-12	MA1-13	MA1-14	MA1-15
Depth (metres)	853.20	858.30	870.98	882.78	893.18	905.00	935.11	946.12	965.32	971.65	972.92	987.00	1,005.50	1,029.70	1,053.17
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rictgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit (New)	Sediment	1	1	1	1	2	1	2	3	3	?3	3	3	3	3
wt.%															
SiO <sub>2</sub>	76.51	58.15	57.67	53.07	56.79	53.37	56,46	54.99	54.68	44.01	55.85	51.00	51.14	49.87	52.66
TiO,	1.07	1.44	1.31	1.37	1.43	1.42	1.50	1.72	1.71	1.74	1.34	1.49	1.52	1.51	1.44
A1.0.	5.53	14.00	14.31	14.34	15.01	14.85	14.96	15.83	14.75	15.91	13.71	13.32	13.99	14.07	13.83
Fe.O.	10.20	14.37	. 9.19	10.24	10,91	11.67	10.62	11.35	9.79	11.10	8.60	10.51	11.29	11.51	9.68
MnO	0.12	0.13	0.12	0.13	0,12	0.14	0.11	0.10	0.09	0.12	0.06	0.12	0,13	0.13	0.12
MgQ	1.85	3.08	2,97	4.19	3.93	4.18	3.63	4.49	4.76	5,86	0.37	4.82	5.60	5.67	4.92
CaO	3,11	2,50	6.63	7.17	4.20	5.87	4.67	3.65	5.96	7.23	15.30	7.36	6.64	7.03	8,30
Na <sub>2</sub> O	0.01	· 0.03	2.34	1.06	0.89	2.43	3,30	3.39	3.12	3.45	0.01	2.95	3.28	3.12	2.93
K.0	0.02	1.84	0.69	1.66	2.14	0.72	0.33	0.06	0.04	0.02	0.05	0.04	0.04	0.18	0.81
1.0	0.14	0.65	0.62	0.67	0 67	0.67	0.70	0,87	0.89	0.91	0.77	0.79	0.82	0.81	0.78
1203	0.01	0.02	0.02	0.05	0.07	0.04	0.05	0.05	0.06	0.04.	0.01	0,10	0.07	0.07	0.03
1.01	3.56	5.17	5.02	7 39	5 21	5 83	4.42	3.57	4.69	6.76	1.64	4.83	2.52	2.45	2.14
TOT	102.13	101 38	101.04	101.34	101.37	101.19	100,75	100.07	100.54	.97.15	97.71	97.33	97.04	96.42	97.64
nom	102.15								~						
Rh	0.01	58,40	21,10	59.50	79.00	26.70	6.80	0.01	0.01	0.01	9.30	0.01	0.01	2.00	17.60
Ba	14,90	604.00	193.20	643.70	877.60	323.70	153.40	60.50	65.40	46.60	89.20	59.20	87.30	351.50	1,306.90
Sr	35.70	41.10	414.00	88.20	73.40	151.00	303.40	264.80	579.10	274.10	5,482.60	433.50	490.80	526.90	468.80
Zr	133.20	324.00	296.70	318.70	318.70	317.10	321.30	346.50	268.30	261.60	86.80	225.20	228.90	221.50	225.70
Nb	13.00	15.80	13.30	15.70	14.10	15.00	14.20	16.90	14.50	13.30	15.00	12.20	13.20	12.70	13.10
Ni	320.70	53.10	50.50	60.70	65.90	56.10	72.40	82.20	103.50	120.90	28.80	99,60	114.20	118.20	100.70
Zn	64.70	83.30	97.80	87.90	85.70	96.60	129.20	97.50	92.00	97.70	9.90	109.50	92.80	81.60	78.00
Cr	1,098.60	148.90	130.20	147.50	153.20	161.90	206.80	207.60	275.40	321.70	209.50	286,50	318.00	299.10	251.50
Cu	129.60	12.10	24.20	10.30	6.20	5.80	7.10	5.40	6.00	10.40	30.00	49.50	21.80	16.60	24.30
v	130.80	230.50	207.10	226.80	249.90	229.50	234.70	253.90	255.70	227.90	190.20	235.60	229.50	227.40	207.60
Y	12.50	32.60	35.80	39.00	33.00	36.10	38.90	44.20	42.50	37.10	44.00	38.00	37.10	36.30	35.20
Sc	19.70	21.60	16.50	18.90	18.90	21.60	18.50	18.90	20.40	20.90	26.60	22.40	21.60	21.90	19,40
Co	103.00	64.60	37.80	45.70	53.90	56.20	47.70	53.70	48,40	59.50	17.40	52.30	55.20	57.10	50,40
CIPW Norms. (%)						00.45	22.24	03.77	10.76	2.45	22 (2	16.02	12.25	11.60	12.00
Quartz	68.32	44.42	26.06	22.51	31.57	20.45	23.35	23.11	19.76	2.45	32.02	10.02	15.25	11.09	15.05
Corundum	0,17	9.27	-	-	5.33	1.01	2.40	3.81	0.84	-	0.02	-	0.05	0.04	0.05
Zircon	0.03	0.07	0.06	0.06	0.06	0.00	2.03	0.07	0.03	0.03	0.02	0.05	0.05	1 14	5.02
Orthoclase	0.12	11.33	4.20	10.47	13.19	4.47	2.05	20.27	27.56	12 57	0.08	27.14	29.38	28.12	25.97
Albite	0.08	0.26	20.05	9.33	7.83	21.37	10.46	12 00	25.03	31.08	38.89	24.84	24.73	25.44	23.31
Anorthite	14.74	8.04	27.08	51.42	17.39	20.10	19.40	12.77	25.05	51.00	2.08	2 70	-	1.00	7.97
Diopside	-		. •	_	-	-			_		-	-	-	-	-
wollastonite	-	7.07	1 77		10.19	10.92	0.30	11.59	12.38	16.65	-	11.96	14.77	14.57	9,15
Hyperstuene	4.07	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.06	0.07	0.04	0.06	0.07	0.06	0.05
Lasmatita	10.24	14 04	0.03	10.00	1135	12.05	11.03	11.77	10.22	12.00	8.95	11.34	11.95	12.26	10.14
Inacinatite	0.33	0.10	0.27	0.10	0.28	0.32	0.24	0 23	0.20	0.29	0.11	0.25	0.29	0.30	0.27
Salvana	0.21	0.30	1.84	1 41	0.20	0,52		-	-	1.33	3.29	3.60	3.30	3.57	3.37
Anatite	034	1.62	1.54	1.70	1 66	1.67	1,73	2,14	2.21	2.40	1.92	2.04	2.06	2.05	1.97
Rutile	0.98	1.34	0.48	0.73	1.34	1.32	1.43	1.66	1.68	1.23	-	-	0.11		<u> </u>

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	KFN2-4	KFN2-5	KFN2-6	KFN2-7	KFN2-8	KFN2-9	MA1-1	MA1-10	MA1-11	MA1-12	MA1-13	MA1-14	MA1-15	MA1-16	MA1-17
Depth (metres)	728.87	739.60	748.20	758.62	774.51	781 21	853.20	971.65	972.92	987.00	1,005.50	1,029.70	1,053.17	1,100.00	1,125.14
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat						
Unit	5	4	4	4	. 4	5	Sediment	3		3	3	3	3	3	Intrusive
wt.%			:									•			
SiO <sub>2</sub>	56.63	54.11	52.14	49.61	50.96	54 48	76.51	44.01	55.85	51.00	51.14	49.87	52.66	49.44	75.27
TIO <sub>2</sub>	· 1.46	1.62	1.45	1.66	1.73	1.51	1.07	1.74	1.34	1.49	1.52	1.51	1.44	1.55	0.56
A1203	15.89	16.23	15.61	18.00	16.78	15.05	5.53	15.91	13.71	13.32	13.99	14.07	13.83	14.81	8.47
Fe,O	10.00	10.03	10.15	12.52	11.27	10.44	10.20	11.10	8.60	10.51	11.29	11.51	9.68	10.93	6.73
MnO	0.10	0.12	0.12	0.12	0.11	0.12	0.12	0.12	0.06	0.12	0.13	0.13	0.12	0.15	0.05
MgO	4.24	4,18	3.83	4.92	4.72	4.11	1.85	5.86	0.37	4.82	5.60	5.67	4.92	5.51	1.11
CaO	3.46	4.44	7.14	3.24	5.11	7.20	3.11	7.23	15.30	7.36	6.64	7.03	8.30	7.73	0.82
Na-O	3.48	3.86	3,59	3.62	3,53	2.75	0.01	3.45	0.01	2.95	3.28	3.12	2.93	3,13	0.01
K.0	0 31	0.19	0.28	0.29	0.11	0.67	0.02	0.02	0.05	0.04	0.04	0.18	0.81	0.69	4 38
P.O.	0.67	0 74	0.67	0.72	0.81	0.74	0.14	0.91	0.77	0.79	0.87	0.81	0.78	0.81	0.15
H O.	0.07	0.74	0.06	0.02	0.01	0.04	0.14	0.01	0.01	0.10	0.02	0.01	0.03	0.01	0.13
1.01	2.55	0.07	6 3 4	2.63	3.62	2.00	2.56	6.76	1.64	0.10 1 93	2.07	2.45	2.14	2.52	1.25
тот	99.87	00 73	101 38	98.41	98.86	100.05	102 13	97 15	97.71	97.33	97.04	96.42	97.64	07.33	98.83
nnm			101.50	20,41	,0.00		102.13				27.01	50.12		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	70.05
Rb	6 90	3 00	6 60	10.90	1.50	14 40	0.01	0.01	9 30	0.01	0.01	2.00	17.60	14 90	100.80
Ba	203.00	204.10	218.50	338.90	136.30	968.20	14.90	46.60	89.20	59.20	87.30	351.50	1,306.90	753.90	4.311.30
Sr ·	432 80	462.60	428.30	477 80	587.00	684.70	35.70	274.10	5.482.60	433.50	490.80	526.90	468.80	467.80	114.40
Zr	328,40	366.00	336.30	370.60	363.90	335.10	133.20	261.60	86,80	225.20	228.90	221.50	225.70	248.70	188.70
Nb	14.60	16.30	15.40	17.30	16.90	17.30	13.00	13.30	15.00	12.20	13.20	12.70	13.10	14.10	10.00
Ni	53.00	52.40	50.90	61.90	87.80	74.40	320.70	120.90	28.80	99.60	114.20	· 118.20	100.70	97.10	53.30
Zn.	96.20	88.00	70.80	104.50	110.50	89.20	64.70	97.70	9.90	109.50	92.80	81.60	78.00	112.10	43.20
Cr	152.30	155.60	136.70	174.00	246.60	191.90	1,098.60	321.70	209.50	286.50	318.00	299.10	251.50	226.10	162.80
Cu	7.60	21.10	7.40	11.10	11.50	22.00	129.60	10.40	30.00	49.50	21.80	16.60	24.30	34.40	12.60
v	226.70	225.10	229.40	276.60	242.70	205.90	130.80	227.90	190.20	235.60	229.50	227.40	207.60	218.20	73.50
Y	38.00	43.20	41.60	41.80	46.10	42.60	12.50	37.10	44.00	38.00	37.10	36.30	35.20	38.10	22.50
Sc	21.20	16.70	19.40	16.50	19.70	19.20	19.70	20.90	26.60	22.40	21.60	21.90	19.40	22.40	7.90
Co	40.00	46.00	37.80	57.50	58.30	43.60	103.00	59.50	17.40	52.30	55.20	57.10	50.40	47.90	24.50
CIPW Norms. (%)		12.00	10.00		14.02	12.20	(0.22)	2.46	22.62	16.02	12.26	11.00	12.00	0.76	66.42
Quartz	24.17	17.98	1.2.82	15.93	14.92	17.70	08.32	2.45	32.02	10.02	15.25	11.09	13.09	دد.ه	30.42
Ziroon	5.20	-0.07	0.07	. 7.91	3.00	0.07	0.17	0.05	0.02	0.05	0.05	0.04	0.05	0.05	0.04
Orthoglass	1.07	1.18	1.75	1.81	0.07	4.08	0.03	0.05	0.02	0.05	0.05	1 14	5.02	4 31	26.58
Albite	30.59	34 19	31.98	32.35	31.40	23.97	0.08	32.52	0.08	27.14	29.38	28.12	25.97	27.95	0.08
Anorthite	13.50	18.22	27.04	12.25	21.34	27.63	14.74	31.08	38.89	24.84	24.73	25.44	23.31	25.73	4.33
Diopside	-	-	0.81	-	-	-	•	-	2.08	2.70	-	1.00	7.97	3.47	-
Wollastonite			• .	-	-	-	-	-	-	-		-	-	-	-
Hypersthene	10.97	10.90	9.67	12.94	12.36	10.54	4.67	16.65	-	11.96	14.77	14.57	9.15	12.88	2.83
Chromite	0.03	0.03	0,03	0.04	0.05	0.04	0.24	0.07	0.04	0.06	0.07	0.06	0.05	0.05	0.03
Haematite	10.39	10.50	10.69	13.22	11.85	10.76	10.35	12.00	8.95	11.34	11.95	12.26	10.14	11.54	6.90
Ilmenite	0.22	0.27	0.27	0.28	0.25	0.27	0.21	0.29	0.11	0.25	0.29	0.30	0.27	0.34	0.11
Sphene	-	. •	· 3.40	-	•	2:31		1.33	3.29	3.60	3.30	3.57	3.37	3.58	-
Apatite	1.66	1.84	1.67	1.81	2.02	1.82	0.34	2.40	1.92	2.04	2.06	2,05	1.97	2.04	0.43
Rutile	1.40	1.55	-	1.61	1.69	0.07	0.98	1.23	-		0.11	-	•	•	0.52

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Depth (metres)         1,14           Formation         Rie           Unit         SiO1           wt.%         SiO2           SiO2         SiO3           TIO3         SiO3           Al2O3         SiO3           Fe3O3         SiO3           MaO         SiO3           MgO         SiO3           CaO         SiO3           Na2O         SiO3           K2O         SiO3           P2O5         SiO3           H2O-         SiO3           LOI         SiO3           TOT         99           Ppm         Rb           Zr         312           Nb         100           Zn         99           Cr         37           Cu         33           V         16           Y         44           Sc         11           Co         44	12.18       1,16         ietgat       Rid         1	.98         858.30           lgat         Rictga           1         .5           .92         58.14           .26         .1.44           .75         14.00           .42         14.37           .12         0.12           .55         3.08           .64         2.50           .51         0.02           .36         5.17           .30         101.38           .70         58.44           .30         604.00           .60         41.10           .60         324.00           .70         158.40           .30         603.24.00           .60         324.00           .70         15.80           .60         321.10	1,177.00 Rietgat 1 53.56 1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	1,210.00 Rietgai 1 53.98 1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	870.98 Riet3at 5 57.67 1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	882.78 Rietgat 5 53.07 1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	893.18 Rietgat 5 56.79 1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	905.00 Rietgat 4 53.37 1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	935.11 Rietgat 5 56.46 1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	946.12 Rietgat 4 54.99 1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	965.32 Rietgat 3 54.68 1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	919.51 Rietgat 5 58.00 1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	1,085.87 Rietgat 3 49.77 1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	1,097.22 Rietga 3 49.78 1.55 14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.88 226.33	
Formation         Ris           Unit         wt.%           SIO <sub>2</sub> 5           SIO <sub>2</sub> 5           TIO <sub>3</sub> 11           Fe <sub>2</sub> O <sub>3</sub> 12           MnO         0           MgO         0           CaO         0           Na <sub>2</sub> O         12           LOI         9           PpO <sub>3</sub> 14           TOT         9           ppm         76           Sr         61           Zr         31           Nb         14           Ni         100           Zn         99           Cr         37           Cu         33           V         16           Y         44           Sc         11	ietgat         Rid           1	tgat         Rietga           1         -2           .92         58.15           .26         .1.44           .75         14.00           .42         14.37           .12         0.12           .55         3.06           .64         2.56           .51         0.02           .16         1.88           .55         0.64           .038         5.17           .30         101.38           .70         58.44           .30         604.00           .60         41.10           .60         324.00           .70         15.86           .60         324.00           .70         15.86           .60         324.00           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70         15.86           .70	Rietgat 1 53.56 1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	Rietgai I 53.98 1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67 90	Rietgat 5 57.67 1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	Rietgat 5 53.07 1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	Rietgat 5 56.79 1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14 10	Rietgat 4 53.37 1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	Rietgat 5 56.46 1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	Rietgat 4 54.99 1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	Rietgat 3 54.68 1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	Rietgat 5 58.00 1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	Rietgat 3 49.77 1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	Rietga 49.74 1.55 14.51 10.96 0.11 5.30 7.44 3.30 0.04 0.82 0.00 2.55 96.35 0.00 130.76 775.86 226,33	
Unit	1           14.97           5.119           3.08           9.61           0.13           4.19           6.13           1.51           2.92           0.52           0.03           0.766           9.20           4.60           2.70           3.38           9.20           4.60           1.55           9.20           4.60           1.55           9.20           4.60           1.15           3.38           9.20           4.60           2.70           33.60           8.99.10           99.20           2.70	1	1 53.56 1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	1 53.98 1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	57.67 1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	53.07 1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	5 56.79 1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	4 53.37 1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	5 56.46 1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	4 54.99 1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	3 54.68 1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	58.00 1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	3 49.77 1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	3 49.78 1.55 14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.82 226.30	
wt.%     5001     5001       SIO1     5001     5001       Al1001     1001     1001       Fe2O3     1000     1000       MBQO     1000     1000       CaO     1000     1000       Ma2O     1000     1000       Ford     1000     1000       FOT     9000     1000       Ford     1000     1000       Ford     3000     1000       Zr     3000     3000       V     1600     1000       Y     4400     4400       Se     11000     1000       Y     1600     1400       Y     11000     1000       Zr     3000     1000 <t< td=""><td>i4.97       5.         1.19       3.08         9.61       9.61         0.13       0         4.19       6.13         1.51       1         2.92       0         0.52       0         0.33       9.61         9.60       1.51         2.92       0.03         0.52       0         0.60       1.15         9.20       46         2.70       33         6.60       14         3.60       8         99.10       99         90.20       24</td><td>.92         58.15           .26         .1.44           .75         14.00           .42         14.33           .12         0.11           .55         3.08           .64         2.50           .51         0.02           .16         1.84           .55         0.64           .03         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .60         323.10</td><td>53.56 1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50</td><td>53.98 1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90</td><td>57.67 1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30</td><td>53.07 1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70</td><td>56.79 1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10</td><td>53.37 1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10</td><td>56.46 1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30</td><td>54.99 1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50</td><td>54.68 1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30</td><td>58.00 1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00</td><td>49.77 1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10</td><td>49.78 1.55 14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.39 0.01 130.70 775.82 226.33 1.207 1.</td></t<>	i4.97       5.         1.19       3.08         9.61       9.61         0.13       0         4.19       6.13         1.51       1         2.92       0         0.52       0         0.33       9.61         9.60       1.51         2.92       0.03         0.52       0         0.60       1.15         9.20       46         2.70       33         6.60       14         3.60       8         99.10       99         90.20       24	.92         58.15           .26         .1.44           .75         14.00           .42         14.33           .12         0.11           .55         3.08           .64         2.50           .51         0.02           .16         1.84           .55         0.64           .03         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .60         323.10	53.56 1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	53.98 1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	57.67 1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	53.07 1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	56.79 1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	53.37 1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	56.46 1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	54.99 1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	54.68 1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	58.00 1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	49.77 1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	49.78 1.55 14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.39 0.01 130.70 775.82 226.33 1.207 1.	
SiO <sub>2</sub> 50         SiO <sub>2</sub> 50         VIO <sub>3</sub> 11         Fe <sub>2</sub> O <sub>3</sub> 11         Fe <sub>2</sub> O <sub>3</sub> 11         CaO       10         Na <sub>2</sub> O       11         CaO       11 $P_2O_3$ 11 $P_2O_3$ 11         CaO       12         FOT       90         OP       11         FOT       90         Sr       610         Zr       311         Nb       11         Ni       100         Zr       312         V       16         Y       44         Sc       11         Co       44	i4.97       5.         i.19       3.08         9.61       0.13         9.61       6.         6.13       1.         1.51       1.         2.92       0.03         0.52       0.03         0.766       9:         70.80       5:         9.20       46         2.70       33         6.60       14         103.60       8         99.10       99         90.20       24	.92         58.15           .26         .1.44           .75         14.00           .42         14.37           .12         0.11           .55         3.06           .64         2.50           .51         0.02           .16         1.84           .55         0.64           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .00         53.10           .10         83.30	53.56 1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	53.98 1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	57.67 1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	53.07 1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	56.79 1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	53.37 1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	56.46 1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	54.99 1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	54.68 1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	58.00 1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	49.77 1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	49.78 1.55 14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.88 226.33 1.20	
$I'IO_1$ II $AI_2O_3$ II $Fe_2O_3$ II $MnO$ II $MgO$ II $CaO$ II $CaO$ II $CaO$ II $CaO$ II $P_2O_3$ II $f_2O_2$ II $f_2O_2$ II $fOT$ 9 $Opm$ II $Rb$ 7 $Sa$ 1,45 $Sr$ 61 $Zr$ 31         Nb       10 $Zn$ 9 $Cr$ 37 $Cu$ 3 $V$ 16 $Y$ 44 $Sc$ II $Co$ 4	1.19         3.08       1.         9.61       9         0.13       4.19         6.13       1.         1.51       2.92         0.52       0.03         0.03       9         7.66       91         9.20       4.66         2.70       33         6.60       1.15         9.20       4.66         2.70       33         6.60       1.15         92.00       4.66         99.10       99         99.10       99         99.20       2.6	.26         .1.44           .75         14.00           .42         14.37           .12         0.11           .55         3.00           .64         2.50           .51         0.02           .16         1.84           .55         0.62           .04         0.02           .38         5.11           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .00         53.10           .10         83.30	1.33 13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	1.35 13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	1.31 14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	1.37 14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	1.43 15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	1.42 14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	1.50 14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	1.72 15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	1.71 14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	1.36 14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	1.67 14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	1.55 14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.39 0.01 130.70 775.82 226.30	
M2O3     1       Fe2O3     1       Fe2O3     1       MnO     1       MgO     1       CaO     1       CaO     1       Va2O     1       S2O3     1       J2O3     1       J2O4     1       LOI     1       FOT     9       Opm     1       Rb     7       Ba     1,459       Sr     619       Zr     312       Nb     11       Ni     100       Zn     99       Cr     37       Cu     3       V     16       Y     44       Sc     1       Co     4	3.08       1.         9.61       9.         0.13       4.         4.19       9.         6.13       1.         1.51       1.         2.92       0.         0.52       0.         0.03       0.         9.66       1.15         9.060       1.15         9.060       1.15         9.20       4.6         2.70       33         6.60       1.         10.60       8.         99.10       99.         90.20       2.6	.75         14.00           .42         14.37           .12         0.13           .55         3.00           .64         2.50           .51         0.02           .16         1.84           .55         0.69           .38         5.11           .30         101.33           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .00         53.10	13.97 8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	13.53 7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	14.31 9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	14.34 10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	15.01 10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	14.85 11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	14.96 10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	15.83 11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	14.75 9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	14.22 7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	14.59 10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	14.51 10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.39 0.01 130.70 775.82 226.30	
Fe <sub>2</sub> O <sub>3</sub> MnO       MnO     MgO       CaO     GaO       Va <sub>2</sub> O     GaO       V <sub>3</sub> O     GaO       V <sub>3</sub> O     GaO       V <sub>3</sub> O     GaO       V     GaO	9.61         0.13         4.19         6.13         1.51         2.92         0.52         0.03         0.66         9.766         9.080         50.60         1.51         9.20         4.60         1.51         9.20         4.60         1.51         9.20         4.60         1.53         9.20         4.60         2.70         33.60         8.99.10         99.20         90.20	.42         14.37           .12         0.13           .55         3.00           .64         2.50           .51         0.02           .16         1.84           .55         0.62           .04         0.02           .30         101.33           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .00         53.10	8.82 0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	7.21 0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	9.19 0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	10.24 0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	10.91 0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	11.67 0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	10.62 0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	11.35 0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	9.79 0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	7.99 0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	10.62 0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	10.96 0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.88 226.33	
MnO     MgO       CaO     GaO       CaO     GaO       Va2O     GaO       CaO     GaO       CaO     GaO       CaO     GaO       CaO     GaO       CaO     GaO       CaO     GaO       CoI     GaO       CoI     GaO       CoI     GaO       CoI     GaO       CaO     GaO       CaO     GaO       Ca     GaO       Ca     GaO       V     16       Y     44       Se     11       Co     44	0.13 4.19 6.13 1.51 2.92 0.52 0.03 0.33 0.52 0.03 0.60 1.15 9.20 4.6 9.7 0.60 1.15 9.20 4.6 2.70 3.38 6.60 1.15 9.20 4.6 2.70 3.38 9.20 4.6 2.70 3.38 9.20 4.6 2.70 3.38 9.20 4.6 9.20 9.20 9.20 4.6 9.20	.12         0.13           .55         3.00           .64         2.50           .51         0.02           .16         1.84           .55         0.62           .04         0.02           .30         101.33           .30         604.00           .60         41.16           .60         324.00           .70         58.40           .30         604.00           .60         324.00           .70         15.86           .00         53.10           .10         83.30	0.11 4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	0.10 3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	0.12 2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	0.13 4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	0.12 3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	0.14 4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	0.11 3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	0.10 4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	0.09 4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	0.10 2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	0.11 5.62 7.44 2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	0.11 5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.88 226.33	
MgO	4.19	.55         3.08           .64         2.50           .51         0.00           .16         1.84           .55         0.62           .04         0.02           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.86           .00         53.10	4.03 6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	3.08 7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67 90	2.97 6.63 2.34 0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	4.19 7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	3.93 4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	4.18 5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	3.63 4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	4.49 3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	4.76 5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	2.78 4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	5.62 7.44 2.96 0.08 0.08 3.40 97.20 0.40 103.20 526.50 247.10	5.30 7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.88 226.33	
CaO     CaO       Na2O     Size       Size     Size       P2O3     Size       P2O3     Size       P2O4     Size       COI     Size       COI     Size       Size     Size       Size     Size       V     Size       V     Size       Size     Size       Size     Size       Size     Size	6.13         1.51         2.92         0.52         0.03         3.38         97.66         99.00         0.60         1.15         92.0         46         2.70         33.60         8.99.10         99.10         99.20         2.70         33.60         8.99.10         99.20         2.70         3.360         8.99.10         99.20         2.70         3.60         8.99.10	.64         2.50           .51         0.02           .16         1.84           .55         0.62           .04         0.02           .38         5.17           .30         101.38           .70         58.40           .60         41.10           .60         324.00           .70         15.88           .60         53.10           .70         15.83	6.05 2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	7.43 2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	6.63 2.34 0.69 0.62 5.17 101.04 21.10 193.20 414.00 296.70 13.30	7.17 1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	4.20 0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	5.87 2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	4.67 3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	3.65 3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	5.96 3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	4.92 0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	7.44 2.96 0.06 0.88 3.40 97.20 0.40 103.20 526.50 247.10	7.46 3.30 0.08 0.82 0.01 2.51 96.35 0.01 130.70 775.88 226.33	
Na2O       K2O       P2O3       H2O-       LOI       TOT       99       70m       Rb       70       Ba       1.450       Sr       611       Zr       311       Nb       141       Ni       101       Zn       99       Cr       37       Cu       34       V       16       Y       44       Sc       11       Co       4	1.51         2.92         0.52         0.03         3.38         97.66         9.0         0.60         1.15         9.20         46         2.70         33.60         99.10         99.10         99.20         2.70         3.60         89.10         99.20         2.70         3.60         8.99.10         99.20         2.70         3.60         8.99.10         99.20         2.70         3.60         8.99.10         99.20         3.60         8.99.10         99.20         2.70         3.60         8.99.10         9.910         9.920         2.910         9.920         9.920         9.920         9.920         9.920         9.920         9.920         9.920         9.920         9.920      9	.51         0.03           .16         1.84           .55         0.69           .04         0.02           .38         5.17           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.8           .60         53.10           .10         83.30	2.80 2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	2.74 2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	2.34 0.69 0.62 5.17 101.04 21.10 193.20 414.00 296.70 13.30	1.06 1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	0.89 2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	2.43 0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	3.30 0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	3.39 0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	3.12 0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	0.69 2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	2.96 0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	3.30 0.08 0.82 0.01 2.51 96.39 0.01 130.70 775.80 226.30	
$\chi_2 O$ $\chi_2 O$ $P_1 O_3$ $q_1 Q_2$ LOI $q_2 Q_2$ $r OT$ $g_2 Q_2$ ppm $q_1 q_2 Q_2$ Rb $7q_1 q_2 Q_2$ Sr $(1, 45)$ Sr $(1, 65)$ Sr $(1, 65)$ Sc $(1, 65)$ Co $(4, 75)$	2.92	.16         1.84           .55         0.69           .04         0.02           .38         5.17           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.8           .60         53.10           .10         83.30	2.38 0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	2.55 0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	0.69 0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	1.66 0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	2.14 0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	0.72 0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	0.33 0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	0.06 0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	0.04 0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	2.65 0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	0.06 0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	0.08 0.82 0.01 2.51 96.39 0.01 130.70 775.80 226.30	
PaOs     4       H2O-     6       LOI     9       ppm     9       Rb     70       Ba     1.450       Sr     611       Zr     312       Nb     14       Ni     100       Zn     99       Cr     377       Cu     34       V     16       Y     44       Sc     11       Co     44	0.52 0.03 3.38 7.66 9.7 70.80 5: 0.60 1,15 9.20 46 2.70 33 6.60 14 3.60 8 99 10 99 20 2.70 33 6.60 14 15 10 2.70 33 6.60 14 15 10 2.70 33 6.60 10 10 10 10 10 10 10 10 10 1	.55         0.61           .04         0.02           .38         5.17           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.8           .60         53.10           .10         83.30	0.59 0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	0.60 0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	0.62 0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	0.67 0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	0.67 0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	0.67 0.04 5.83 101.19 26.70 323.70 151.00 317.10	0.70 0.05 4.42 100.75 6.80 153.40 303.40 321.30	0.87 0.05 3.57 100.07 0.01 60.50 264.80 346.50	0.89 0.06 4.69 100.54 0.01 65.40 579.10 268.30	0.63 0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	0.88 0.08 3.40 97.20 0.40 103.20 526.50 247.10	0.82 0.01 2.51 96.39 0.01 130.70 775.80 226.30	
H <sub>2</sub> O-     1       LOI     9       Dpm     9       Rb     70       Ba     1,450       Sr     611       LT     312       Nb     10       Zn     99       Cr     37       Cu     34       V     16       Y     44       Sc     11       Co     44	0.03 3.38 7.66 9.080 5.060 1,15 9.20 4.66 1.15 9.20 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 4.66 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.15 9.20 1.25	.04 0.02 .38 5.17 .30 101.38 .70 58.40 .30 604.00 .60 41.10 .60 324.00 .70 15.88 .00 53.10 .10 83.30	0.07 3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	0.05 5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	0.02 5.17 101.04 21.10 193.20 414.00 296.70 13.30	0.05 7.39 101.34 59.50 643.70 88.20 318.70 15.70	0.07 5.21 101.37 79.00 877.60 73.40 318.70 14.10	0.04 5.83 101.19 26.70 323.70 151.00 317.10	0.05 4.42 100.75 6.80 153.40 303.40 321.30	0.05 3.57 100.07 0.01 60.50 264.80 346.50	0.06 4.69 100.54 0.01 65.40 579.10 268.30	0.08 5.64 99.06 91.60 1,006.10 81.50 318.00	0.08 3.40 97.20 0.40 103.20 526.50 247.10	0.01 2.51 96.39 0.01 130.70 775.80 226.30	
LOI 99 FOT 99 Ppm 76 Ba 1,459 Sr 611 Sr 311 Nb 110 Zr 317 Nb 110 Zn 99 Cr 377 Cu 34 V 16 Y 44 Sc 11 Co 44	3.38         9           17.66         9           17.66         9           17.66         9           17.66         9           17.66         9           17.66         9           17.66         9           17.66         1           15.9         2.0           46         1           17.60         8           19.10         9           10.20         2.0	.38         5.17           .30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .70         15.88           .71         15.88           .72         .73           .73         .74           .74         .75           .75         .76           .76         .77           .77         .77           .78	3.18 96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	5.41 98.03 58.40 892.30 416.20 340.30 16.10 67.90	5.17 101.04 21.10 193.20 414.00 296.70 13.30	7.39 101.34 59.50 - 643.70 88.20 318.70 15.70	5.21 101.37 79.00 877.60 73.40 318.70 14.10	5.83 101.19 26.70 323.70 151.00 317.10 317.10	4.42 100.75 6.80 153.40 303.40 321.30	3.57 100.07 0.01 60.50 264.80 346.50	4.69 100.54 0.01 65.40 579.10 268.30	5.64 99.06 91.60 1,006.10 81.50 318.00	3.40 97.20 0.40 103.20 526.50 247.10	2.51 96.39 0.01 130.70 775.80 226.30	
FOT         9'           ppm         7           Rb         7           Ba         1,450           Sr         61'           Zr         31'           Nb         10'           Zn         9'           Cr         37'           Cu         3'           V         16'           Y         4'           Sc         1'           Co         4'	17.66         94           70.80         5:           50.60         1,15           9.20         46           2.70         33           6.60         11           13.60         8           99.10         9	.30         101.38           .70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.86           .00         53.10           .10         83.30	96.89 55.20 1,114.60 455.50 352.30 17.40 96.50	98.03 58.40 892.30 416.20 340.30 16.10 67.90	101.04 21.10 193.20 414.00 296.70 13.30	101.34 59.50 643.70 88.20 318.70 15.70	101.37 79.00 877.60 73.40 318.70 14.10	101.19 26.70 323.70 151.00 317.10	6.80 153.40 303.40 321.30	0.01 60.50 264.80 346.50	0.01 65.40 579.10 268.30	99.06 91.60 1,006.10 81.50 318.00	97.20 0.40 103.20 526.50 247.10	96.39 0.01 130.70 775.80 226.30	
ppm         7/           Rb         7/           Ba         1,450           Sr         611           Zr         312           Nb         110           Zn         99           Cr         37'           Cu         33'           V         16'           Y         44'           Sc         1'           Co         4'	70.80         5:           50.60         1,15           9.20         46           2.70         33           6.60         11           93.60         8           99.10         9           9.20         2.4	.70 58.40 .30 604.00 .60 41.10 .60 324.00 .70 15.80 .00 53.10 .10 83.30	55.20 1,114.60 455.50 352.30 17.40 96.50	58.40 892.30 416.20 340.30 16.10 67.90	21.10 193.20 414.00 296.70 13.30	59.50 - 643.70 88.20 318.70 15.70	79.00 877.60 73.40 318.70 14.10	26.70 323.70 151.00 317.10	6.80 153.40 303.40 321.30	0.01 60.50 264.80 346.50	0.01 65.40 579.10 268.30	91.60 1,006.10 81.50 318.00	0.40 103.20 526.50 247.10	0.01 130.70 775.80 226.30	
Rb     7       Ba     1,450       Sr     619       Zr     311       Nb     10       Zn     99       Cr     37       Cu     33       V     16       Y     44       Sc     11       Co     44	20.80     5:       20.60     1,15:       39.20     46:       2.70     33:       6.60     1:       10.60     8:       29.10     9:       20.20     2:	.70         58.40           .30         604.00           .60         41.10           .60         324.00           .70         15.80           .00         53.10           .10         83.30	55.20 1,114.60 455.50 352.30 17.40 96.50	58.40 892.30 416.20 340.30 16.10 67.90	21.10 193.20 414.00 296.70 13.30	59.50 643.70 88.20 318.70 15.70	79.00 877.60 73.40 318.70 14.10	26.70 323.70 151.00 317.10	6.80 153.40 303.40 321.30	0.01 60.50 264.80 346.50	0.01 65.40 579.10 268.30	91.60 1,006.10 81.50 318.00	0.40 103.20 526.50 247.10	130.70 775.80 226.30	
3a     1,450       Sr     611       Zr     311       Nb     10       Ni     100       Zn     99       Cr     37       Cu     3.       V     16       Y     44       Sc     1       Co     4	0.60     1,15       19.20     46       12.70     33       16.60     10       13.60     8       19.10     9       10.20     24	.30         604.00           .60         41.10           .60         324.00           .70         15.80           .00         53.10           .10         83.30	1,114.60 455.50 352.30 17.40 96.50	892.30 416.20 340.30 16.10 67.90	193.20 414.00 296.70 13.30	643.70 88.20 318.70 15.70	877.60 73.40 318.70 14.10	323.70 151.00 317.10	303.40 321.30	264.80 346.50	65.40 579.10 268.30	81.50 318.00	526.50 247.10	775.80	
Sr     61       Zr     31       Nb     14       Ni     10       Zn     9       Cr     37       Cu     3.       V     16       Y     44       Sc     1       Co     4	19,20         46           12,70         33           16,60         11           13,60         8           19,10         9           10,20         34	.60         41.10           .60         324.00           .70         15.80           .00         53.10           .10         83.30	455.50 352.30 17.40 96.50	416.20 340.30 16.10 67 90	414.00 296.70 13.30	88.20 318.70 15.70	73.40 318.70 14.10	317.10	303.40	264.80 346.50	268.30	318.00	247.10	226.30	
Zr     31.       Nb     14       Ni     10.       Zn     99       Cr     37       Cu     34       V     16       Y     44       Sc     11       Co     44	12,70         33           16,60         10           13,60         8           19,10         9           10,20         34	.70 15.80 .00 53.10 .10 83.30	352.30 17.40 96.50	340.30 16.10 67.90	13.30	15.70	14.10	517.10	521.50	540.50	200.30	516.00	247.10	220.30	
Ni 10 Zn 99 Cr 37 Cu 34 V 16 Y 44 Sc 11 Co 4	03.60 8 99.10 9	.00 53.10 .10 83.30	96.50	67.90	15.50	15.70	1.4.10.1	15 00 1	14 20	16.00	14 50	13.60	13.70		
Zn 9 Cr 37 Cu 3 V 16 Y 44 Sc 1 Co 4	99,10 9	.10 83.30	0.50		50 50 1	60 70 l	65.90	56 10	72 40	82 20	103.50	49.30	120.90	127.60	
Cr 37' Cu 37' V 16 Y 44 Sc 11 Co 4	20 20 24		II 9X00	86 50	97.80	87.90	85.70	96.60	129.20	97.50	92.00	65.40	89.80	104.20	
Cu 3 V 16 Y 44 Se 1 Co 4	7 31/1 34	70 148.90	373.20	228.50	130.20	147.50	153.20	161.90	206.80	207.60	275.40	127.50	328.30	313.60	
V 16 Y 44 Se 1 Co 4	4.50 2	.60 12.10	27.20	27.10	24.20	10.30	6.20	5.80	7.10	5.40	6.00	14.80	· 8.50	24.20	
Y 4 Sc 1 Co 4	6.20 19	.30 230.50	180.00	181.40	207.10	226.80	249.90	229.50	234.70	253.90	255.70	221.30	255.80	229.30	
Sc 1 Co 4	10.80 4	.50 32.60	42.40	44.70	35.80	39.00	33.00	36.10	38.90	44.20	42.50	32.00	40.80	40.70	
Co 4	7.20	.70 21.60	17.70	19.40	16.50	18.90	18.90	21.60	18.50	18.90	20.40	21.90	25.10	19.20	
	7.20 4	.10 64.60	40.00	35.70	37.80	45.70	53.90	56.20	47.70	53.70	48.40	39.50	53.10	54.10	
CIPW Norms. (%)												22.00	12.24	10.04	
Quartz 1	9.54 1	.07 44.42	13.24	13.82	26.06	22.51	31.57	20.45	23.35	23.77	19.70	33.00	12.24	10.84	
Corundum	-	- 9.27	-	-		-	5.33	1.01	2.40	5.81	0.84	2.89	- 0.05	- 0.05	
Lircon	0.06	49 11 2	15.05	16 31	0.06	10.00	13.10	4 47	2 03	0.07	0.05	16.81	0.38	0.50	
Albito 1	3 3 5 7	38 0.26	25.30	25.04	20.65	9.55	7.83	21.57	29.00	29 74	27.56	6.25	26.72	29.75	
A northite 2	2.55 2.	02 864	19 84	18.49	27.68	31.42	17.39	26.10	19.46	12.99	25.03	22.03	28.15	26.18	
Dionside	2.93	.77 -	3.14	9.98		•	-		-	•	•	•	-	1.99	
Wollastonite	-			•	-	-					-	-		-	
Hypersthene	9.72	.97 7.93	9.27	3.67	7.72	11.11	10.19	10.92	9.39	11.59	12.38	7.42	14.94	13.14	
Chromite	0.08	.07 0.03	0.08	0.05	0.03	0.03	0.03	0.03	0.04	0.04	0.06	0.03	0.07	0.07	
Haematite 1	10.20	.93 14.94	9.42	7.79	9.59	10.90	11.35	12.24	11.03	11.77	10.22	8.56	11.33	11.68	
lmenite	0.28	.25 0.30	0.23	0.22	0.27	0.30	0.28	0.32	0.24	0.23	0.20	0.23	0.25	0.25	
Sphene	2.76	.95 0.30	3.20	3.30	1.84	1.41	-	-	-	-	-	-	3.75	3.73	
Apatite	1.32	.39 1.62	1.51	1,54	1.54	1.70	1.66	1.67	1.73	2.14	2.21	1.01	2.23	2.08	
Kutile	- ·	- 1.34	·	<u>ا ب ا</u>	0.48	0.73	1.54	1.32	1.43	1.00	1.08	1.33	L0.12	•	
× .	MA2-12	MA2-13	MA2-14	MA2-15	MA2-16	MA2-17	MA2-18	MA2-2	MA2-3	MA2-4	MA2-5	MA2-6	MA2-7	MA2-8	MA2-9
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Depth (metres)	1,122.85	1,137.19	1,156.85	1,165.12	1,177.50	1,187.65	1,204.21	938.77	948.21	954.47	962.65	988.39	1,015.92	1,044.47	1,067.35
Formation .	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat						
Unit	3	3	3	3	Tuff	2	1	5	5	4	5	5	3	5	3
wt.%											-——				
SiO <sub>2</sub>	42.64	47.67	50.50	51.11	43.97	56.56	54.17	58.33	54.61	46.68	53.46	51.54	52.11	54.49	49.76
TIO <sub>2</sub>	1.63	1.42	1.46	1.49	0.20	1.26	1.28	1.40	1.35	1.84	1,40	1.60	1.68	1.24	1.67
Al <sub>2</sub> O <sub>1</sub>	16.23	13.90	14.72	14.79	2.94	13.43	13.67	14.54	14.20	20.68	14.89	14.51	14.83	13.74	14.67
Fe <sub>2</sub> O <sub>2</sub>	11 84	10.74	11 17	10.28	6.08	8 58	9.75	7 94	9.23	8 58	8 71	11 19	11.17	9.59	12.10
MnO	0.13	0.11	0.13	0.15	0.12	0.12	0.12	0.10	0.12	0.14	0.10	0.11	0.11	0.11	0.13
MaO	5.95	5 42	5 56	5 59	1.69	3 14	3 70	3.01	3 40	3 14	2 79	4 4 8	4 62	3 81	5 97
CaO	7 89	7 17	7 44	841	23.42	5 15	6.04	4 62	5 57	6 50	6 10	4 98	4 20	5 97	4 59
Na O	1.05	3.65	4 27	3.68	0.01	2 20	2 52	2.62	2.55	0.30	2.64	2.66	2 07	2.65	2.77
K 0	1.70	0.07	0.06	0.10	0.01	2.20	2.52	1.47	0.83	5 18	2.04	0.20	2.57	2.05	0.23
N <sub>2</sub> U	1.39	0.07	0,06	0.10	0.03	207	2.29	0.47	0.83	5.18	1.19	0.29	0.04	2.17	0.23
P <sub>2</sub> O <sub>3</sub>	0.83	0.72	0.73	0.77	0.07	0.52	0.55	0.65	0.04	0.93	0.07	0.79	0.85	0.54	0.80
H <sub>2</sub> O-	0.05	0.10	0.10	0.10	0.04	0.01	0.05	0.06	0.07	0.09	0.03	0.06	0.07	0.06	0.03
LOI	6.37	2.58	2.58	2.34	19.02	3.30	3.63	4.79	5.69	7.00	5.73	4.96	4.14	5.29	4.73
101	96.93	93.35		98.81	97.59	97.14	97.77	99.53	98.26	100.90	97.71	97.17	96.79	99.66	
ppm	17.00	0.10	0.60	0.20	0.01	(0.40	61.00	62.40	27.40	202.50	47.10	10.70	0.01	1 70	2.10
KD D-	37.00	0.10	0.50	127.10	26.20	1 708 20	51.90	52.40	27.40	203.50	47.10	10.70	0.01	1.70	5.10
D8	2,884.20	104.20	140.50	137.10	30.20	1,798.20	1,313.00	040.00	412.10	2,340.80	010.00	184.10	00.10	551.10	527.90
5r 7.	328,30	434.90	411.00	220.90	193.50	243.90	014.30	139.70	100.70	420.20	288.40	340.00	265.70	255.10	271.70
	243,90	12 70	228.00	230.80	5 80	367.30	310.40	327.30	300.10	420,30	15.00	16.20	203.70	233.20	235,30
ND Ni	112.40	111 20	101.90	100 70	14.80	61.10	02.00	51.30	61.00	19.00	59.70	10.30	108.60	106.50	14.00
7n	113.00	76.00	83.00	82 20	42.00	86.80	92.90	84.40	01.00	212 70	04 20	118 20	123.80	115.80	122.10
Cr.	395 50	289.00	250 70	231.90	62 10	276 70	311 40	135 30	153.00	176 30	158 10	199.00	295.80	271.90	334 10
Cn Cn	12 30	289.00	21 70	231.50	13 20	270 70	28 90	9 70	7 30	97 30	5 60	8 30	15.00	271.50	15.80
v	229 30	210.10	210.40	206.10	21.90	164 60	192 40	235 50	232.60	280 10	232 30	245 20	272 30	254 30	236.20
v	37.40	35 40	34 80	35 70	12 20	39 60	40.60	33.40	36 00	57 70	38.40	42.60	36.50	40.30	37.00
Sc.	20.90	20.90	16 20	22.60	18.00	18 20	21 20	21.90	19 70	26.80	22 10	22 10	20 70	18 90	18 50
Co	50 80	56 40	48 10	44 60	12.50	37 10	48.70	38.70	43.90	36.50	43.20	55.00	56.00	56.20	61.00
CIPW Norms, (%)															
Ouartz	4.06	7.45	10.02	8.22	18.54	20 48	16.22	26.20	23.05	9.49	19.87	21.67	22.83	16.18	17.76
Corundum	-	-	-	-	•		-	1.83	0.50	4.88	-	2.72	4.61		3.68
Zircon	0.05	0.05	0.05	0.05	0.01	0 08	0.06	0.07	0.06	0.08	0.06	0.06	\0.05	0.05	0.05
Orthoclase	10.21	C.46	0.56	0.61	0.22	18 11	14.41	9.20	5.31	33.26	7.67	1.87	0.25	13.60	1.54
Albite	16.66	33.99	34.17	32.31	0.11	19.84	22.66	23.41	23.33	1.32	24.29	24.40	27.14	· · 23.78	25.48
Anorthite	34.84	23.51	22.87	24.45	10.05	19.60	20.51	19.94	25.52	29.08	27.52	21.31	16.63	20.37	18.67
Diopside	-	4.42	6.24	7.08	11.56	0.36	2.98	- ·	-	- ·	-	-	-	2.65	-
Wollastonite	-	-	-		-			-	-	-	- 1	-		-	-
Hypersthene	16.42	12.81	10.64	11.17	-	8.17	8.42	7.92	9.15	8.54	7.56	12.30	12.43	8.84	16.11
Chromite	0.08	0.06	0.05	0.05	0.01	0.06	0.07	0.03	0.03	0.04	0.03	0.04	0.06	0.06	0.07
Haematite	13.00	11.82	10.02	10.67	7.74	9.14	10.36	8.39	9.98	9.22	9.47	11.91	12.06	10.17	12.72
Ilmenite	0.27	0.26	0.29	0.34	0.32	0.26	0.26	0.23	0.28	0.36	0.24	0.29	0.25	0.25	0.30
Sphene	1.89	3.50	3.38	3.36	0.21	2.99	3.01	-	-	-	0.63	]	I	2.91	•
Apatite	2.23	1.88	1.89	1.90	0.21	1.33	1.40	1.64	1.64	2.40	1.74	2.07	2.18	1.36	2.23
Rutile	0.84	-	-	-			-	1.36	1.31	1.76	1.14	1.55	1.68		1.62
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	MAL1-1	MAL1-10	MAL1-11	MAL1-2	MAL1-3	MAL1-4	MAL1-5	MAL1-6	MAL1-7	MAL1-8	MAL1-9	MAL4-1	MAL4-2	MAL4-3	MAL4-4
Depth (metres)	702.35	860.75	895.36	706.85	713.65	721.20	731.26	760.42	799.50	818.96	834.75	759.61	778.80	809.12	830.37
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	5	1	1	5	5	4	5	5	1	1	1	4	5	5	5
wt.%															
SiO <sub>2</sub>	53.03	57.86	57.30	51.03	55.37	46.94	54.62	51.80	54.24	62.21	61.28	49.71	54.47	57.29	56.83
TIO <sub>2</sub>	+ 1.45	1.35	1.20	1.57	1.55	1.55	1.43	1.61	1.30	1.32	1.30	1.38	1.33	1.47	1.49
AbO	14.78	14.63	13.57	14.99	14.88	16.53	14.61	14.89	14.08	13.65	12.97	14.26	14.32	13.97	13.45
Fe <sub>2</sub> O <sub>2</sub>	10 72	9 3 9	9 78	9 64	9 4 9	11.23	10.09	11 16	8 90	7 66	7 46	10.21	842	9 3 9	9 12
MnO	0.11	0.10	0.12	0.14	0.11	0.15	0.13	0.10	0.12	0.09	0.10	0.13	0.12	0.10	0.10
MeO	3 71	3 16	4 97	4 13	4 47	5 23	3 44	6 42	3 16	4.01	3 34	5.58	3.25	3 37	4 27
C.O.	6 71	6.62	6.84	7 29	5 22	7 20	6 47	4 84	5.84	3 52	6.67	6 14	5.60	3 78	5 01
Na.O	0.71	2.88	1 91	3.04	3.01	2 45	2 57	2.58	3 44	3 40	2 73	0.78	2.53	3 11	3 15
K O	2.16	0.11	1.71	0.23	0.21	0.21	0.84	0.05	0.12	0.17	0.17	1.68	1 11	0.40	0.24
R <sub>2</sub> O	0.70	0.11	0.53	0.23	0.21	0.21	0.04	0.05	0.12	0.17	0.57	0.63		0.40	0.24
r <sub>2</sub> O <sub>5</sub>	0.70	0.39	0.55	0.75	0.75	0.78	0.72	0.80	0.57	0.57	0.57	0.05	0.01	0.05	0.71
H <sub>2</sub> O-	0.08	0.06	0.03	0.10	0.13	0.00	0.03	0.12	0.09	0.07	0.08	2 0 10	0.00	0.03	2.07
LUI	0.93	3.33	3.42	0.32	3.00	0.97	2,87	5.00	4.97	3.38	4.20	07.91	1 3.43 1 07.27	3.27	3.27
101		100.70	101.10	99.41	100.23	99.30	100.82	99.43	90.83	100.03	100.87	97.81	97.27	90.89	97.71
քբա	78 80	0.01	21.00	3.80	1 30	3 50	30.40	0.01	0.01	0.01	0.01	56.10	37.10	8 30	2 20
Ra	1 480 00	214 90	1 739 90	166.50	141.00	· 162.20	678 10	87 70	139.80	245.90	301.00	693.60	687.00	542.80	352.80
Sr .	126.60	656.20	1,759.90	255.90	228.20	303 20	460.80	356.20	410.30	506.40	504 20	109.50	303.00	627 10	597 40
7.	330.30	337.80	284 10	337.00	336.00	348 70	319.00	234 60	323.90	338.00	323.10	337.60	321 70	318.90	327.00
Nb	16 60	15 50	14 30	15.90	14.80	15.90	14.90	11.90	14.90	14 40	14.50	15.70	14.20	14.40	16.00
Ni	71.10	81.80	103.70	72.00	73.70	88.90	70.80	127.50	81.20	97.40	70.20	53.60	50.80	80.30	71.90
Zn	74.40	87.50	110.10	111.60	79.20	90.30	122.30	97.00	102.70	88.20	52.80	79.70	98.70	115.40	98.30
Cr	190.20	378,60	423.50	224.40	222.00	232.10	200,40	364.20	190.90	355.00	382.20	134.10	129.70	248.50	220.80
Cu	13.50	29.30	28.60	291.10	18.80	5.80	30.80	15.50	32.80	16.20	10.20	41.70	7.20	17.10	12.60
v	222.10	188.10	173.30	223.30	239.50	267.90	225.70	266.00	211.90	194.00	156.60	218.00	211.20	213.90	211.00
Y	40.40	38.90	39.70	41.20	38.80	43.90	39.30	38.00	42.60	36.20	33.00	36.40	37.00	37.70	39.00
Sc	22.40	16.70	17.00	21.20	21.40	25.30	18.00	22.60	21.60	19.40	18.50	19.70	18.20	19.40	23.90
Co	39.10	42.10	43.00	43.30	47.30	49 60	48.60	56.60	44.10	52.20	35.30	40.10	36.90	48.10	46.70
CIPW Norms. (%)		• • •													
Quartz	23.94	23.99	21.82	14.81	22.32	11 67	20.80	20.17	20.34	30.81	24.98	20.93	22.08	28.16	23.70
Corundum	0.67	•	-		2.03	1 20	•	4.04	•	2.86	-	-	0.17	3.31	0.54
Zircon	0.07	0.07	0.06	0.07	0.07	0 07	0.06	0.05	0.07	0.07	0.07	0.07	0.06	0.06	0.07
Orthoclase	13.60	0.67	8.66	1.47	1.31	1.34	5.24	0.31	0.77	1.04	1.04	10.99	7.17	2.53	1.50
Albite	6.39	25.09	16.55	27.72	26.80	22.42	22.91	23.15	31.72	29.78	23.91	7.29	23.33	28.12	28.24
Anorthite	30.09	27.51	24.95	28.07	22.33	33.27	21.29	19.03	24.08	14.47	23.47	29.34	20.23	15.39	21.75
Diopside	-	-	2.39		-	·	-	-		•	2.23	-	-		
Wollastonite		013	11.48	11.09	11 71	14.09	9.03	16.95	8.57	10.34	7 58	15 36	8.82	8.97	11.27
Chromite	0.04	0.08	0.09	0.05	0.05	0.05	0.04	0.08	0.04	0.08	0.08	0.03	0.03	0.05	0.05
Haematite	11 40	9.67	10.02	10.39	9,99	12.14	10.63	11.83	9,70	7.93	7,72	11.28	9,18	10.04	9.66
Ilmenite	0.25	0.20	0.24	0,32	0.25	0.35	0.29	0.22	0.28	0,19	0.19	0.31	0.28	0.23	0.22
Sphene	-	1.86	2,73	3,74			1.35	•	2.13	-	3.06			-	
Apatite	1.78	1.45	1.31	1.87	1.82	2.00	1.81	2.17	1.47	1.41	1.40	1.66	1.58	1.76	1.79
Rutile	1.41	0.53	-	-	1.50	1 <sup>\$</sup> 60	0.80	1.59	· 0.40	1.27		1.36	1.30	1.45	1.46

	MAL4-5	MAL4-6	MAL4-7	MAL4-8	NVT1-10	NVT1-11	NVT1-12	NVT1-13	NVT1-14	NVT1-15	NVT1-16	NVT1-17	NVT1-18	NVT1-19	NVT1-2
Depth (metres)	840.71	858.21	869.42	889.91	1,347:31	1,354.95	1,367.13	1,379.49	1,387.18	1,397.89	1,411.07	1,420.27	1,430.37	1,440.06	1,313.00
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	3	. 3	3	3	. 4	4	. 4	4	4	5.	5	3	3	3	4
wt.%															
SIO <sub>2</sub>	50.77	50.42	49.64	57.54	49.97	52.51	52.49	51.53	52.68	53,18	47.43	46.98	51.09	49.78	48.39
TiO <sub>2</sub>	<i>*</i> 1.58	1.54	1.47	1.48	1.55	1.59	1.46	1.58	1.51	1.41	1.75	1.94	1.78	1.82	1.54
Al <sub>2</sub> O <sub>3</sub>	14.04	13.63	15.18	14.27	15.22	15.79	15.75	16.54	15.54	14.54	15.97	17.34	15.97	15.77	18.46
Fe <sub>2</sub> O <sub>2</sub>	11.50	11.80	10.07	9.56	9.62	10.52	7.86	11.22	9.53	7.94	11.56	11.30	12.00	12.08	10.03
MnO	0.12	0.12	0.09	0.11	0.15	0.14	0.10	0.15	0.13	0.08	0.11	0.11	0.11	0.12	0.24
MeO	6 33	5 90	5 53	3 36	4 83	4.51	1 70	3.94	3.19	2.25	4.36	4.23	4.81	5.04	4.06
CaO	5 73	7 45	6.96	3.83	4.91	2.93	6.35	3.26	4.84	7.10	6.19	6.03	4.13	3.89	6.88
Na-O	3.00	3.05	2 94	3 33	3 83	4 40	5.02	3.48	4 37	3 81	3 86	4.39	3.18	3.94	0.02
K.0	0.03	0.04	0.05	0.40.	0.65	0.27	1 32	1 94	0.92	2.01	0.13	0.27	0.91	0.73	2.55
P.O.	0.05	0.83	0.74	0.40	0.69	0.69	0.68	0.72	0.72	0.67	0.15	0.27	0.89	0.90	0.75
1 103	0.01	0.00	0.04	0.05	0.03	0.07	0.00	0.72	0.70	0.07	0.08	0.50	0.07	0.00	0.75
1.01	2.10	0.0 <del>9</del>	.00	0.00	5.03	0.07	4 70	3.43	4.22	5.40	0.04	2.73	2.63	2 91	7.60
TOT	3.30 07.30	06.01	4.07	3.10	96.48	96 73	97.62	97.86	9.22	08.68	4.00	07 37	98.57	07 03	100.53
Innti	, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		90.00	<u> </u>	20.48	30.15	97.02	97.00		98.08		91.51	70.57	71.75	100.55
RP	0.01	0.80	0.01	0.01	20.00	10.10	32 60	56 40	30.10	59.60	6 30	7 70	29.60	22.00	110 30
Ba	80.10	130 70	261.60	89.70	917.30	243.90	1 466 00	4.461.30	1.032.50	1.688.10	194.50	314.50	1.712.20	1.211.30	813.10
Sr	569 10	768 90	695 50	884 90	264.00	240.90	312.80	336.20	371.10	395.00	698.10	1.093.90	471.30	284.60	57.60
Zr	253.60	221.00	235.70	208.70	359.70	362.00	345.10	373.00	360.50	328.50	337.70	361.60	319.30	322.90	372.20
Nb	14.00	14.30	13.30	11.40	17.00	17.00	16.20	18:90	17.90	16.00	18.80	19.10	18.60	17.90	19.90
Ni	107.00	119,70	112.00	129.70	49.60	66.70	34.20	58.70	51.70	21.80	94.50	87.40	107.10	104.30	70.50
Zn	100.60	100.00	100.10	83.80	205.70	439.00	50.20	132.90	88.20	58.30	135.60	98.80	112.50	121.00	146.00
Cr	271.40	305.10	381.10	376.00	148.30	159.60 <sup>.</sup>	. 133.10	149.40	147.90	124.00	217.20	229.40	273.20	280.90	129.50
Cu	19.70	25.50	27.80	20.10	21.80	42.40	31.40	48.60	13.60	13.10	6.40	6.10	9.50	4.50	25.20
V	242.00	225.40	247.20	233.70	231.60	279.00	235.50	256.60	244.40	217.90	257.00	305.80	286.60	299.20	247.10
Y	39.70	38.20	36.30	34.40	41.10	41.40	37.80	42.80	39,30	36,20	46.40	52.90	44.10	39.00	35.50
Sc	21.60	20.90	17.20	18.20	13.30	24.30	19.10	15.70	16.30	16.10	15.80	22.90	18.30	15.80	26.60
Co	57.60	57.70	54.30	51.30	40.80	62.30	39.50	46.60	57.10	25.40	46.60	51.60	55.70	51.90	56.30
CIPW Norms. (%)					10.10			12.24		0.60			16.21		21.22
Quartz	14.57	12.45	15.97	· 10.60	10.18	15.81	0.00	13.34	11.17	9.50	7.67	4.01	10.21	11.27	21.22
Corundum	0.56	0.04	2.74	-	0.93	4.87	-	. 4.41	0.13	0.07	0.27	1.14	4.43	3.09	3.20
Lircon	0.03	0.04	0.05	0.04	0.07	0.37	9.07	12.17	0.07	14.23	0.07	0.07	5.68	4 59	16.26
Albias	0.19	0.23	26.06	20.18	7.21	1.71	0.42 45 81	31.20	30.58	34.58	35 41	39.70	28.36	35.43	0.10
Anorthite	27.03	27.23	20.30	28.10	22.05	10.89	17.90	13.41	21.21	17 18	27 37	25.61	16.07	14 67	31.70
Dioneide	24.00	29.71	24.75	20.10	22.05	10.05	5 22	13.41	21.21	8 99	27.57	25:01	10.07	-	-
Wollestonite		2.07			_	_	5.22	_	_		_	-	-	-	- 1
Hypersthene	16 79	14 16	13 17	15.07	13.16	12 03	7.15	10.40	8.50	1.86	11:77	11.26	12.63	13.34	10.88
Chromite	0.06	0.07	0.08	0.08	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.05	0.06	0.06	0.03
Haematite	12.25	12.45	11.80	10.67	10.52	11.27	8.48	11.89	10.20	8.52	12,53	12.08	12.65	12.84	10.79
Ilmenite	0.28	0.27	0.24	0.20	0.35	0.33	0.23	0.34	0.30	0.18	0.26	0.25	0.25	0.27	0.56
Sphene	-	3.64	-	2.69	-		3.58	-	-	3.50	-	-	-	-	-
Apatite	2.05	2.08	2.27	1.94	1.80	1,76	1.75	1.90	1.79	1.72 ·	2.27	2.50	¥.26	2.30	1.92
Rutile	1.54	-	1.68	0.39	1.51	1.53	<b>.</b>	1.49	1.46		1.76	1.94	1.74	1.79	1.36

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	NVT1-20	NVT1-20A	NVT1-21	NVT1-22	NVT1-22A	NVT1-23	NVT1-24	NVT1-25	NVT1-26.	NVT1-27	NVT1-28	NVT1-29	NVT1-30	NVT1-32	NVT1-33
Depth (metres)	1,442.10	1,454,17	1,472.82	1,485.83	1,499.63	1,518.75	1,533.50	1,548.20	1,556.61	1,567.19	1,579.46	1,590.89	1,599.23	1,625.27	1,638.55
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	3	3	3	3	3	3	3	3	. 3		3	3	3	3	3
wt.%															
SIO <sub>2</sub>	49.93	47.21	46.25	48.27	53.51	53.66	52.13	51.92	50.64	50.27	52.27	49.31	50.55	47.79	57.12
TiO <sub>2</sub>	1.80	1,76	1.72	1.74	1.66	1.68	1.54	1.52	1.55	1.49	1.52	1.50	1.48	1.58	1.67
Al <sub>2</sub> O <sub>3</sub>	15.70	15.55	15.68	15.14	14.03	14.00	13.66	14.23	14.07	13.65	14.23	14.27	13.85	14.89	14.25
Fe <sub>2</sub> O <sub>3</sub>	11.70	12.64	11. <b>92</b>	11.71	11.28	9.92	. 10.79	10.07	11.16	10.67	10.65	11.84	9.32	11.62	7.65
MnO	0,11	0.12	0.12	0.11	0.11	0, 10	0.15	0.12	0.14	0.14	0,12	0.16	0.16	0.17	0.09
MgO	4.77	5.32	4.97	5.17	5,11.	4.:i3	5.18	3.68	5.56	5.35	6.66	5.92	4.36	5.81	3.55
CaO	4.39	5.58	7.63	6.40	3.64	6.66	7.77	8.89	7.35	8.79	7.64	7.27	10.85	7.37	5.54
Na <sub>2</sub> O	3.85	3.20	3.38	3.03	2.06	3,38	3.87	3.19	3.06	3.38	3.10	3.22	4.57	3.62	5.12
K2O	0.67	0.12	0.08	0.60	1.83	0.89	0.20	1.27	0.84	0.57	0.78	0.76	0.39	0.98	0.83
P <sub>2</sub> O <sub>5</sub>	0.89	0.88	0.87	0.89	.0.84	0.39	0.80	0.78	0.81	0.79	0.79	0.79	0.78	0.79	0.83
H <sub>2</sub> O-	0.06	0.15	0.12	0.05	0.08	0.05	0.05	. 0.04	0.06	0.05	0.03	0.12	0.10	0.13	0.06
LOI	3.72	4.21	5.34	4.88	3.65	2.08	2.80	2.89	2.47	2.52	2.45	2.83	2.55	2.71	1.79
TOT	97.59	96.74	98.08	97.99	97.80	98.34	98.94	98.60	97.71	97.67	100.24	97.99	98.96	97.46	98.50
ppm									<b>a</b> r 60				10.70	20.00	22.40
Rb	21.50	5.60	3.90	18.40	55.90	27.10	8.00	42.50	26.00	18.70	24.90	24.80	12.70	29.60	22.40
Ba	1,202.50	169.60	147.50	993.40	2,904.10	769.60	343.20	1,320.30	1,103.90	693.40	1,239.90	950.40	357.90	800.00	497.20
Sr 7-	4/7.00	585.70	011.40	466.00	257.00	202.00	241.30	1,153.90	220 10	222.80	723.00	438.30	221.00	449.80	271 70
Lr Nb	17.00	298.10	285.00	289.00	16.00	15 90	15 30	15 80	14 30	14 40	15 30	14.50	13.90	15.40	13.60
NI	101 20	119 50	112.00	117 30	10.00	102 10	112.00	113.20	123.70	127.00	124.90	134.10	113.50	113.00	109.80
Zn	114.50	111.80	108.20	125.10	128.40	100.20	95.90	89.50	106.80	101.50	124.00	116.30	77.60	108.60	86.40
Cr	254.90	256.20	254.60	283.40	265.10	292,70	255.00	261.00	295.70	293.10	292.30	323.00	269.40	274.10	234.10
Cu	7.40	19.70	18.40	11.20	16.00	47.90	16.40	25.20	16.30	38.70	93.10	19.50	41.20	18.30	194.80
v	294.90	273.50	280.10	266.10	260.20	250.50	241.10	212.10	257.50	224.80	242.40	264.70	235.60	231.90	211.50
Y	. 38.40	39.60	40.40	41.50	35.70	36.20	37.60	37.70	36.80	35.70	38.30	35.30	35.10	36.60	30.60
Sc	16.90	15.00	17.80	17.40	19.90	20.90	20.10	22.20	30.20	24.10	21.90	24.50	21.00	27.60	22.10
Co	51.90	60.80	53.90	55.00	52.40	39.50	48.70	44.10	53.40	48.20	50.30	54.60	37.30	54.30	46.70
CIPW Norms. (%)	11.60	11.60	( in	10.04	22 61		10.10	10.41	10.20	8.06	0.46	7 66	1.06	2.07	11.62
Quartz	11.50	11.50	0.43	10.04	22.31	11.40	10.10	10.41	10.20	0.05	9.40	7.00	1.90	2.91	11.52
Zimon	2.83	2.21	0.06	0.06	4.00	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.04	0.05	0.05
Orthoclese	4 23	0.00	0.00	3 82	11.52	5 48	1 23	7.86	5.23	3.55	4.73	4.74	2.40	6.13	5.09
Albite	34.72	29.31	30.87	27.55	18.53	34.12	34.07	28.21	27.20	30.70	26.83	28.67	40.15	32.37	44.82
Anorthite	17.50	23.99	29.60	27.95	14.19	18.92	20.13	21.77	23.37	21.48	23.20	23.46	16.77	22.76	13.95
Diopside	-	-	-	-	-	3.17	7.68	11.47	3.75	11.28	4.63	3.61	22.96	-4.44	2.73
Wollastonite	-	- '	-	-	•	-	•.	-	-	•	-	•	-	•	-
Hypersthene	12.66	14.34	13.36	13.84	13.53	10.26	9.87	4.29	12.82	8.79	14.83	13.84	0.64	13.24	7.89
Chromite	0.05	0.06	0.05	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.05
Haematite	12.47	13:68	12.87	12.58	11.99	10.31	11.23	10.53	11.73	11.22	10.89	12.46	9.68	12.28	/.91
Ilmenite	0.25	0.29	0.28	0.26	0.25	0 22	0.34	0.27	0.32	. 0.32	0.27	0.30	0.35	2.39	200
Spnene	-	2.27	18.6	0.25		4 02	1.00	3.3/-	00,cU 2 02	5.44 1.09	1.49	1 08	3.32	100	2.55
Apatite	2.28	2.27	2.23	2.28	1.10	2721	1.90	1.95	2.05	1.70	1.95	1.50	1.92		2.05
INALLE	1,79	1.73	0.10	1.04	1.03				L			L		مسيرين فاستستعب ال	· · · · · · · · · · · · · · · · · · ·

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	NVT1-34	NVT1-35	NVT1-36	NVT1-37	NVT1-38	NVT1-39	NVT1-4	NVT1-40	NVT1-44	NVT1-46	NVT1-47	NVT1-48	NVT1-49	NVT1-5	NVT1-51
Depth (metres)	1,657.24	1,665.50	1,677.24	1,714.10	1,726.17	1,132.13	1,316.86	1,750.26	1,800.67	1,818.27	1,847.12	1,859.75	1,874.10	1,318.62	1,890.87
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat									
Unit	3	3	3	3	3	3	4	. 3	. 2	2	2	2	\ 2	4	1
wt.%												N			
SIO2	52.20	51.10	49.99	49.46	48.12	50.46	57.20	51.17	60.90	54.69	58.47	58.90	. 55.93	55.90	56.77
TIO <sub>2</sub>	1.49	1.54	1.56	1.68	2.02	1.79	1.38	1.61	1.16	1.31	1.38	1.30	1.32	1.28	1.44
A1,0,	13.70	13.87	14.45	13.25	14.61	13.79	15.09	13.66	13 00	13.99	14.22	13.82	13 70	14 13	15.08
Fe-O.	9.85	10.99	11.67	11 74	13.63	12.75	7 7	12 34	8 59	8 14	8 43	8 11	8.06	6.83	0 10
MnO	0.12	0.15	0.13	0.13	0.17	0.19	0.12	0.16	0.12	· 0.14	0.45	0.00	0.00	0.05	0.11
MaO	3 33	3.90	3 84	3.54	5 74	4 90	2 28	4 38	2.25	2 60	2.95	2 07	2 22	2 14	2 70
CaO	7.95	7.63	7 82	935	6.27	7.18	6 37	7.85	4 46	6.41	3 10	4.06	5.92	7 22	6.02
Na-O	2.76	2.95	3 23	2.68	2.87	3.29	0.07	2 43	0.70	3 20	3 16	3 23	3.50	0.03	3 20
K.O	1.46	1 08	0.97	1 19	0.10	0.50	3 41	1.75	2.46	1.27	2 10	1.82	1 91	3 34	2 34
8.0	0.77	0.70	0.87	1.17	1.02	0.33	0.63	0.84	2,40.	0.52	2.19	0.61	1.61	5.54	2.34
r <sub>2</sub> 0 <sub>5</sub>	0.77	0.78	0.78	0.80	1.02	0.71	0.03	0.84	0.45	0.32	0.52	0.31	0.53	0.00	0.01
H <sub>2</sub> U-	0.06	0.01	0.06	0.07	0.04	0.09	0.04	0.03	0.09	0.02	0.08	0.05	0.11	0.02	0.06
TOT	4.74	2.05	4.43	4.37	2.91	2.57	0.52	2.78	4.99	5.79	3.33	3.88	5.32	/.30	0.41
101	96.43	97.35	98.83	98.32	97.30	98.51	100.85	98.50	99.17	98.04	97,92	98.74	98.32	98.92	97.93
Ppul Ph	43.80	56.10	24.00	33 30	4 80	17 10	137.00	31.50	112.50	57.00	54 70	52.60	48.20	140.60	53.10
Ra	1 571 40	1 721 60	703 70	952.90	111 50	712.20	997.20	916.40	559.90	624.00	1 234 70	1 019 70	842 20	1 025 20	830.30
Sr	689 90	578 60	620.10	533.20	248 70	553 40	58.60	496 30	72 50	282.40	308.60	348 80	298.20	70 70	211 50
Zr	237.90	242 10	239 10	272 50	325 60	281 10	340.50	262.80	384 90	421.10	425.80	415.40	397.90	335.40	349.80
Nb	14.60	15.30	13.30	71.10	18.90	16.80	15.40	15.90	16.50	18.50	19.00	18.50	18,80	15.90	16.70
NI	97.80	95.20	94.10	64.60	75,70	74.60	42.20	72.30	39,10	43.80	48.80	52.50	61.10	40.40	99.40
Zn	93.90	110.20	115.90	149.40	104.80	132.00	49.60	119.70	86.10	92.00	111.10	96.70	84.50	42.20	87.50
Cr	196.60	195.60	207.00	128.40	145.30	122.20	117.90	137.40	198.70	234.50	276.50	239.70	270.00	111.10	427.50
Cu .	50.90	26.30	30.50	35.80	21.00	31.40	7.40	29.80	16.60	13.90	17.00	19.00	19.70	18.00	17.70
v	202.50	222.70	249.00	240.80	282.10	287.70	235.20	246.40	163.20	175.70	204.00	186.50	197.70	206.20	224.40
Y	33.30	35.30	35.30	39.80	43.20	39.00	32.10	37.50	31.00	37.20	41.60	37.80	39.80	35.60	38.80
Sc	22.00	23.30	20.10	26.50	27.00	22.20	13.40	24.00	11.20	14.30	13.30	15.00	13.90	16.90	13.80
Co	44.10	47.50	52.60	47.10	59.00	51.00	22.10	52.00	36.40	28.80	36.60	37.60	34.60	26.80	37.40
CIPW Norms. (%)															
Quartz	14.49	9.79	10.55	11.38	12.56	11.17.	30.05	14.11	37.91	18.21	23.23	22.45	17.32	29.04	15.61
Corundum			-		0.84		1.20	-	2.23	-	2.26	0.28	-	-	-
Zircon	0.05	-0.05	0.05	0.05	0.07	0.06	0.07	0.05	0.08	0.08	0.09	0.08	0.08	0.07	0.07
Orthoclase	9.23	12.30	-5.46	/,51-	0.63	3.65	21.43	7.73	15.50	8.10	13.72	11.37	11.51	21.00	14.21
Albite	24.94	26.30	28.97	24.10	25.08	29.04	20.03	21.49	0.29	29.30	28.29	28.83	31.81	0.28	27.78
Anorthite	22.10	20.30	23.73	21.99	25.97	22.08	29.44	23.75	20.57	21.78	15.11	18.12	17.38	\$1.21	20.43
Wellestenite	7.90	8.04	5.58	12.02	-	2.77	•	5.01		5.08	•	-	4.70		1.29
Hypersthene	5 10	6 52	7 55	3 56	15.12	11 45	6.02	9 N 9	5.95	5 32	7 77	7 80	3 77	5 87	630
Chromite	0.04	0.03	0.04	0.03	0.03	0.03	0.02	0.03	0.04	0.05	0.06	0.05	0.06	0.02	0.09
Haematite	10.52	11 58	12 37	12.51	14.42	13 30	8.19	12.90	9,13	8.83	8.92	8.55	8,66	7,46	9,43
Ilmenite	0.28	0.35	0.30	0,30	0.40	0.44	0.27	0.36	0.26	0.21	0.18	0.19	0.21	0.30	0.21
Sphene	3,56	3,55	3.68	4.01	-	4.03	-	3.68	-	3.21	-	•	3.21	2.76	3.36
Apatite	1.97	1.97	1.97	2.18	2.56	2:26	1.59	2.09	1.14	1.34	1.33	1.29	1.36	1.56	1.49
Rutile	<u> </u>	-	•	-	1.93	-	1.32	•	1.09	<b>-</b> .	1.36	1.27	-	0.12	· ·

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·. ·	NVT1-52	NVT1-53	NVT1-6	NVT1-7	NVT1-8	NVT1-9	PDE1-1	PDE1-2	PDE1-3	PDE1-4	PDE1-5	PDE1-6	S4-1	S4-10	S4-11
Depth (metres)	1,910.00	1,940.82	1,322.89	1,326.68	1,337.00	1,341.09	749.95	765.29	778.20	799.10	818.68	848.21	736.18	809.00	811.76
Formation	Rietgat	Rietgat	· Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat.	Rietgat
Unit	1	1	4	4	4	4	5	5	5	5.	5	Tuff	5	5	5
wt.%	- ·														
SiO <sub>2</sub>	57.33	60.87	55.05	54.94	53.75	52.84	56.08	52.97	55.77	56,41	56.04	68.88	50.33	51.73	52.50
TiO <sub>2</sub>	1.31	1.29	1.28	1.38	1.61	1.58	1.46	1.50	1.41	1.44	1.44	1.62	1.45	1.39	1.42
Al <sub>2</sub> O <sub>3</sub>	13.87	13:86	14.13	15.09	16.34	16.76	14:45	14.33	14.04	14,72	14.08	10.13	14.25	14.21	14.11
Fe-O1	10.46	6.36	7.86	9.33	10.12	9.72	10.61	11.02	9,79	10.10	. 9.34	8,19	12.18	12.03	9.25
MnO	0.12	0.10	0.11	0.11	0.14	0 13	0.13	0.15	0.12	0.11	0.12	0.09	0 11	· 014	0.12
MoO	2.83	2.04	2 84	3.28	5.28	5.07	5:16	5.48	3.94	4.16	3.88	3.44	6.35	5.21	2.57
CaO	3.77	4.52	6.73	4.99	2.58	3.55	5.11	5.41	7.67	5.57	6.57	2.43	6,49	6.30	8,70
Na-O	2 86	2.16	0.60	3.18	3.98	4.32	1.37	2.14	2.01	1.96	2.77	0.01	0.01	0.91	1.58
K.0	1.68	2 34	2.95	0.98	0.39	0.24	1 38	0.49	1 40	1 76	2 11	3 98	1.55	1 29	1 74
P O.	0.55	0.48	0.59	0.62	0.69	0.71	0.70	0.72	0.71	0.70	0.71	0.25	0.72	0.69	0.70
u O.	0.02	0.13	0.02	0.02	0.05	0.06	0.00	0.11	0.09	0.11	0.05	0.08	0.11	0.05 0.06	0.05
101	3 77	4 38	6.98	4 99	3 38	4.60	5.88	5 79	3 88	3 79	2.96	2.68	813	6.00	7 71
TOT	98.57	98.53	99.14	98.92	98 31	98.98	102.42	100.11	100.83	100.83	100.07	101.78	101.68	100.93	100.45
pom .															
Rb	43.50	140.30	143.80	47.60	17.50	9.30	60.50	19.30	29.00	38.30	49.40	101.80	47.70	47.60	49.80
Ba	717.00	652.60	1,223.10	521.90	270.70	172.80	501.80	181.00	927.40	871.00	1,050.80	2,909.60	442.70	409,50	347.50
Sr	144.00	273.50	80.90	169.00	207.20	210.10	122.40	245.60	655.80	540.90	664.90	92.60	91.70	141.80	190.20
Zr	341.30	616.90	331.40	337.50	367.10	369.70	319.90	329.10	310.90	309.90	306.70	188.10	326.50	314.90	325.70
Nb	15.20	25.50	16.40	15.60	16.30	17.00	15.40	15.90	16.30	15.40	15.90	. 10.80	15.40	15.70	16.00
NI	82.50	20.30	44.30	52.10	56.90	53.50	78.00	74.00	66.70	68.40	73.00	54.40	74.20	71.60	71.70
Zn	111.90	67.20	71.10	75.80	90.30	75.20	103.40	123.50	101.60	100.90	94.70	. 55.20	104.50	122.60	96.90
Cr	409.80	59.30	121.10	135.90	154.40	153.30	218.50	190.70	161.40	230.00	205.60	118.40	185.50	209.90	190.30
Cu	25.90	10.00	16.30	32.60	25.50	19,10	26.20	23.40	31,70	20,20	23.00	58.20	26.20	20.20	5.90
V	237.90	141.50	211.70	245.60	283.50	275.90	226.80	223.50	191.80	206.00	194.50	210.40	225.30	228.90	213.60
Y	33.30	52.50	36.40	35,70	40.20	40.20	37.60	40.70	41.60	38.20	40.20	34.10	34.10	38.10	38.90
Se	19.20	8.80	16.30	14.10	19.90	20.60	20.70	10.00	20.40	16.20	12.80	17.70	17.20	10.00	20.40
	42.10	23.20	33.00		37.40		48.00	55.80	41.00	44.00	43.90	54.30	52.10	52.00	43.00
CIPW Norms. (76)	24.60	25.50	25.71	10.08	18 53	14.70	27.03	22 12	20.74	22.63	16 12	44 09	24.53	. 23.54	20.23
Corundum	1.83	0.67	25.71	1 23	6 63	4 85	3 15	2 26	20.74	1.05	-	1 77	2 61	1.56	-
Zircon	0.07	0.07	0.07	0.07	0.05	0.07	0.06	0.07	0.06	0.06	0.06	0.04	0.07	0.06	0.07
Orthoclase	10.50	14.76	18.98	6.19	2.44	1.50	8.48	3.08	8.55	10.75	12.87	23,79	9.82	8.14	11.11
Albite	25.53	19.43	5.51	28.66	35.49	38.51	12,01	19.22	12.56	17.11	24.15	0.08	0.09	8.20	14.43
Anorthite	16.18	20.78	29.52	22.25	8.88	13 79	21.72	23.63	26.03	24.21	20.41	11.33	29.57	28.64	28.36
Diopside	-				-		· -	-	3.04	-	3.28	-	-	<u>.</u> .	6.70
Wollastonite	-		· •	- '	· -	-	•	- ·	-		· -	•	•	-	-
Hypersthene	7.44	5.40	7.68	8.70	13.86	13.30	13.32	14.49	8.56	10.69	8.44	8.65	16.93	13.82	3.80
Chromite	0.09	0.01	0.03	0.03	0.03	0.03	0.05	0.04	0.03	0.05	0.04	0.03	0.04	0.05	0.04
Haematite	11.04	6.76	8.53	9.94	10.67	10.24	11.00	11.70	10.11	10.42	9.62	8.27	13.03	12.81	9.98
Ilmenite	0.24	0.23	0.26	0.25	0.32	0.29	0.29	0.34	0.27	0.24	0.26	0.20	0.26	0.32	0.28
Sphene	1 .	-	2.04	• •			•	•	3.24		3.31	-	-	-	3.40
Apatite	1.38	1.22	1.53	1.57	1.73	1.78	1.73	1.81	1.75	1.72	1.75	0.62	1.83	1.75	1.79
Rutile	1.25	1.25	0.42	1.34	1.53	1.51	1.36	1.41	-	1.36	-	-	1.42	1.31	•

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	S4-12	S4-13	S4-14	S4-15	S4-16	S4-17	S4-2	S4-3	S4-4	S4-8	S4-9	S5-12	S5-13	S6-1	S6-1B
Depth (metres)	821.07	831.11	843.87	855.70	867.10	838.20	744.17	750.72	755.13	794.28	800.85	822.85	869.55	738.25	742.00
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	5	5	5	5	5		5	4	5	4	5	<u> </u>	3	4	<u> </u>
wt.%															
SiO <sup>3</sup>	55.42	55.95	54.52	55.98	56.03	50.85	51.53	55.44	53.99	36.53	50.36	53.77	48.04	50.65	44.91
TIO <sub>2</sub>	* 1.41	1.44	1.41	1.40	1.44	1.61	1.38	1.54	1.41	1.81	1.39	1.44	1.55	1.94	1.39
Al <sub>2</sub> O <sub>3</sub>	15.38	14.32	13.69	14.45	14.23	14.60	14.24	15.20	13.72	17.61	13.99	13.69	14.21	18.63	14.75
Fe203	9.21	9.51	9.93	9.94	10.14	10.37	8.68	11.02	9.79	29.18	9.98	9.81	11.45	7.65	8.15
MnO	0.11	0.13	0.12	0.14	0.14	0.11	0.10	0.09	0.11	0.22	0.11	0.13	0.11	0.08	0.12
MgO	2.78	3.60	3.80	3.94	3.94	57	4.45	6.06	3.22	4.62	3.51	3.98	5.09	4.64	4.69
CaO	8,71	7.86	7.50	8.36	6.56	6.75	8.68	3.43	7.07	3.52	9.25	7.16	6.83	. 5.48	12.00
Na-O	1.92	2.68	1.92	2.02	2.87	3.28	0.02	0.02	1.72	0.01	0.84	2.38	2.54	0.05	0.01
K.0	1 71	0 47	1 16	1.37	1.83	0.11	2.41	2.09	0.96	0.85	2.10	1.22	0.21	4,55	3.01
P.O.	0.74	0.70	0.68	0.70	0.72	0.85	0.71	0.73	0.68	0.82	0.70	0.69	0.78	0.95	0.73
1 203	0.74	0.05	0.00	0.70	0.72	0.04	0.07	0.11	0.00	0.02	0.06	0.02	0.08	0.05	0.17
H <sub>2</sub> O-	0.03	0.05	0.04	0.03	2 80	5.20	0.07	U.I.I £ 00	6.00	0.10	0.00	2 0.13	0.08	6.00	11.42
LOI	1.33	4.30	3.38	3,46	100.84	3.39	9.20	5.00 101.61	0.12	101.02	0.04	J.04	4.70	100.87	101.35
101	104.79	101.27	98.33	101.01	100.04	99.15	101.55	101.01	90.05	101.02	101.13	70.24	95.19	100.87	101.55
ppm pp	60.70	p 70	25 70	20 00	41 70	0.01	75 80	65 20	33.60	32.20	84 70	23.80	5 90	155.10	96.20
RU Do	490.50	479.10	701.30	690.20	778.20	120.30	502.40	617.50	190.40	273 40	467.40	1 077 90	360.50	1 077 70	577.90
Da S-	242.70	792.60	646.80	762 20	722 30	400.10	123 70	63.80	412.40	47 70	206.90	717.00	688 30	42 70	88.60
7-	316.50	307.80	313.60	300.60	315 30	257.10	325.60	342.60	313 50	391 30	318 10	309.00	218.80	457.00	330.80
Nh .	14 70	16 20	16.60	15.60	16 30	13 50	15 70	16 50	14.60	23.80	15.90	15 50	13.00	19 40	16 10
Ni	62 10	71.80	73 50	75.60	76.00	106 90	70.20	69.60	70.80	98.60	69.40	18 30	20.00	66 00	64 20
7.0	109 30	99.20	100.20	102 10	105.80	94.10	71.80	90.20	105.30	195.50	101.00	73.60	117.70	50.60	49.40
C.	183.10	203 60	206 70	200.30	207.30	283.00	172.30	212.80	185.50	277.20	175.40	107.90	115.40	248.90	182.80
Cu ·	23.10	31.20	27.60	30.00	32.50	23.50	23.20	27.50	26.30	19.00	23.50	28.80	42.40	36.10	12.60
v	207.80	200,80	194.00	189.80	199.50	247,50	214.80	242.40	212.20	319.20	200.90	44.40	40.20	291.60	203.20
Y	39.90	40.90	41.60	41.60	43.00	39.80	38.70	32.90	38.90	36.60	40.60	186.20	316.20	55.10	39.90
Se	19.70	19.90	19.40	21.90	18.70	21.40	22.90	19.40	18.50	18.50	19.70	192.20	188.80	24.60	19.20
Co	40.00	40:60	45.50	48.00	43.80	52.90	37.90	46.30	46.40	96.50	39.80	38.50	45.70	34.70	31.50
CIPW Norms. (%)	· · ·														
Quartz	19.61	20.82	22.03	19.69	16.24	13.03	22.08	34.41	24.85	22.11	18.56	18.72	14.18	17.76	8.56
Corundum	- 1		- '	· -	· .	-	•	8.74	-	12.83	•	-	-	6.18	-
Zircon	0.06	Q.06	0.06	0.06	0.06	0.05.	0.07	0.07	0.06	0.08	0.06	-	-	0.09	0.07
Orthoclase	10.40	2.88	7.43	8.25.	11.06	0.69	15.48	12.95	6.14	5.29	13.49	7.65	1.37	24.48	19.85
Albite	16.68	23.46	16.58	17.39	24.81	29.62	0.19	0.18	15.70	0.09	7.71	21.36	23.67	· 0.45	0.09
Anorthite	29.08	26.60	26.97	26.82	21.04	26.48	34.35	12.99	29.03	12.81	30.59	24.47	29.46	22.47	34.90
Diopside	4.62	3.71	2.31	5.28	2.57		2.12	•.	-	- '	7.50	2.84	-	-	16.69
Wollastonite	· -	-		-	-	-	-		-	•	-	•	-	-	•.
Hypersthene	4.97	7.56	9.10	7.54	8.84	13.74	11.04	15.78	8.65	12.09	6.01	9.20	13.96	12.21	5.28
Chromite	0.04	0.04	0.04	0.04	0.04	0.06	0.04	0.05	0.04	0.06	0.04	-	•	0.05	0.04
Haematite	9.46	9.84	10.49	10.11	10.36	11.07	9.41	11.52	10.56	30.66	10.82	10.41	12.61	8.09	9.08
Ilmenite	0.24	0.28	0.28	0.31	0.31	0.25	0.23	0.20	0.26	0.50	0.26	0.29	0.26	0.17	0.28
Sphene	3.25	3.30	3.25	3.11	3.23	2.47	3.38	•	2.98	-	3.37	3.37	1.58	-	3.44
Apatite	1.81	1.72	1.73	1.70	1.75	2.15	1.83	1.82	1.74	2.05	1.80	1.73	2.03	2.40	1.93
Rutile	·	-	- '	-	-	0.58	-	1.51	0.17	1.64	-	-	0.93	1.96	-

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· .	<b>S6-2</b>	S6-3	S6-3A	S6-3B	S6-3C	S6-3D	S6-3E	S6-3F	S6-5	S6-7	S6-8	TK1/1	ΤΚΙ/ΙΑ	ТК1/1В	ТК1/2
Depth (metres)	747.10	800.70	833.89	759.62	773.61	790.15	823.00	836.65	841.75	863.90	890.00	Outcrop	Outcrop	Outcrop	Outcrop
Formation	Rictgat	Rictgat	Rictgat	Rietgat	Rietgat	· Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Sodium Gp.	Sodium Gp.	Sodium Gp.	Sodium Gp.
Unit	5	5	5	5	5	5	· 5	5	5	5	1	?	?	<u>?1</u>	?
wt.%				: 1				:						1	
\$101	\$5.76	55.65	56,38	54,44	57.01	\$6.19	56.51	60.47	57.65	54.71	56.69	49.17	87.65	72.40	53.06
TiO <sub>2</sub>	1.40	1.42	1.53	1.60	1.45	1.49	1.43	1.34	1.26	1.50	1.22	0.90	0.26	0.42	1.08
Al <sub>2</sub> O <sub>3</sub>	14.08	14.36	14.60	14.50	14.40	14.21	14.22	13.42	13.99	13.65	13.29	13.30	6.27	11.23	14.79
Fe <sub>2</sub> O <sub>3</sub>	9.78	9.92	10.39	10.72	. 9.38	10.11	10.49	9.32	10.02	10.61	9.45	8.76	1.25	4.62	9.08
MnO	0.12	0.14	0.11	0,14	0.12	0.13	0.12	0.12	0.12	0.14	0.11	0.16	0.01	0.04	0,11
MgO	3.26	4.10	4,45	5.69	3.63	3.64	4.27	3.66	4.37	6.06	3.99	5.31	0.54	2.51	3.65
CaO	7.52	7.13	4.90	4.66	7.15	6.50	7.11	5.42	5.76	6.31	. 6.18	8.19	0.13	0.86	4.44
Na <sub>2</sub> O	1.87	2.44	2.89	2,35	2.33	2.12	2.19	2.74	2.87	2.43	2.15	1.77	0.69	0.74	4.42
K-0	1.03	1.20	1.61	0.32	1.47	1.22	1.53	1.13	1.87	0.97	2.17	0.86	1.71	2.69	0.69
P.O.	0.69	0.69	0.74	0.75	0.71	0,72	0.71	0.66	0.55	0.80	0.54	0.36	0.04	0.07	0.41
н.о.	0.04	0.09	0.12	0.07	0.04	0(7	0.09	0.07	0.06	0.07	0.06	-	0.09	0.02	0.03
	6.28	3.56	2 73	5 20	3.93	4 (9	2 82	3 29	2.32	2.96	3.35	8.26	1.07	2.60	4.60
тот	101.83	100.70	100.45	100.44	101.62	100,49	101.49	101.64	100.84	100.21	99.20	97.04	99.71	98.20	96.36
nm								· · ·							
Rb	34.60	24.00	37.70	9.70	28.80	23.00	34.00	23.50	23.00	45.10	57.20	25.30	55.70	93.50	10.80
Ba	545.00	548.20	936.80	149.80	1,242.90	620.80	625.50	556.50	1,349.70	758.90	1,003.10	209.20	614.10	805.60	909.10
Sr	372.00	547.90	469.30	271.50	691.40	445 (10	496.60	567.10	410.90	685.60	987.10	235.90	11.90	30.70	315.20
Zr	309.20	305.60	334:00	334.00	316.30	316.60	315.70	289.20	244.20	304.40	314.50	134.50	229.30	321.10	228.20
Nb	15.50	15.30	16.90	15.10	. 16.40	15.80	17.20	14.50	14.20	15.70	15.80	7.40	5.40	12.60	10.10
Ni	68.10	. 74.00	74.30	73.50	66.00	63.80	72.10	70.00	102.40	101.20	93.10	150.00	4.40	10.50	97.60
Zn	102.40	108.30	87.40	129.70	103.60	104.00	113.00	80.40	106.50	132.60	102.00	133.90	12.10	41.80	122.20
Cr	176.10	224.10	218.60	194.70	177.90	205.50	192.80	183.50	236.60	360.40	345.80	382.30	13.60	13.90	238.90
Cu	24:60	24.20	17.80	8.40	30,50	21.00	26.10	10.00	25.90	23.00	25.50	39.40	0.90	4.00	106.60
v	195.50	196.50	218.60	248.10	195.80	199.10	190.70	172.50	222.80	190,10	164.80	202.40	12.40	24.10	229.30
Y	39.10	40.40	42.70	42.00	40.40	36.20	39.20	38.00	39.00	38.30	41.00	20.80	12.00	21.80	20.00
Sc	17.00	16.70	17.70	22.90	17.70	14.30	17.70	14.80	22.00	18.50	17.70	20.90	2.80	14.00	47.80
CIPW/Norms (%)	42.90	40.00	40.80	51.20	40.00	43.70	48.00	41.10		49.00	45.90	45.20	2.00	14.00	47.00
CIP W NOTES. (70)	24.18	-19.24	18 64	24 30	20.40	23.04	19 84	25 70	17 79	17.51	20.43	14.87	76.38	54.28	12.37
Corondum	24.10	17.24	0.86	3.75	-	-	-	-		-	-	-	3.05	5.68	-
Zircon	0.06	0.06	0.07	0.07	0.06	0,06	0.06	0.06	0.05	0.06	0.06	0.03	0.05	0.06	0.05
Orthoclase	6.38	7.31	9.77	1.99	8.91	7.49	9.19	6.81	11.23	5.92	13.41	6.19	11.16	17.41	4.71
Albite	16.57	21.27	25.05	20.89	20.19	18.62	18.80	23.59	24.66	21.16	18.99	16.15	5.67	6.26	39.26
Anorthite	28:29	25.49	20.37	19.28	25.17	26.69	24.85	21.40	20.16	24.22	21.17	28.88	0.56	4.42	20.79
Diopside	1.34	1.65	-	-	1.78	-	1.55	-	1.35	•	2.93	10.85	-	-	-
Wollastonite		· -	-	-	-	-		-		•	-	-	\	-	-
Hypersthene	7.88	7.46	11.35	14.89	8.43	9.41	10.07	9.27 <sup>.*</sup>	10.43	15.53 <sup>-</sup>	9.02	10.02	1.52	6.60	10.12
Chromite	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.08	0.07	0.08		· · · · · · · · · · · · · · · · · · ·	0.05
Haematite	10.24	10.22	10.65	11,26	9.61	10.49	10.64	9.48	10.18	10.92	9.86	9.64	1.30	4.75	9.72
Ilmenite	0.27	0.31	0.24	0.32	0.27	0.29	0.26	0.26	0.26	0.29	0.23	0.34	0.04	0.11	0.25
Sphene	3.25	·3.20	-		3.32	1.58	3.23	1.35	2.81	2.16	2.84	2.18		0.70	1.29
Apatite	1.72	1.69	1.81	1.87	1.74	1.78	1.71	1.60	1.34	1.96	1.35	0.95	0.13	0.20	1.08
Rutile .	· ·		<u> </u>	1.51	•	0.75	•	0.67	·	0.51	·	L	<u> </u>	0.39	0.30

	ТК1/3	TK1/4	TK1/4A	TK1/5	TK1/5A	TK1/5B	TK1/6	TK2/1	TK2/1A	TK2/1B	TK2/2A	TK2/2B	ТК2/2С	TK2/2D	TK2/2E
Depth (metres)	Outcrop	Outcrop	Outcrop	Outcrop	Outcrop	Outerc p	Outcrop	Outcrop	Outcrop	Outcrop	Outcrop	Outcrop	Outcrop	Outcrop	Outcrop
Formation	Sodium Gp.	Sodium Gp.	Sodium Gp.	Sodium Gp.	Sodium Gp.	Sodium Gp.	Sodium Gp.								
Unit	?	?	5	5	3	3	3	?	?	?	?2	?	?1	?	?1
wt.%.												1			
SiO,	53,15	74,20	50.95	52.00	51.63	51.52	52.49	45.33	45.68	50.57	65.80	65.36	58.59	74.3	61.50
TIO <sub>2</sub>	1.41	0.34	1.65	1.63	1.58	1.54	1.53	1.64	1.75	1.56	0.71	0.56	0.99	0.6	0.94
Al <sub>2</sub> O <sub>3</sub>	13.07	11.87	13.12	13.00	12.10	12.22	12.19	11.54	12.52	14.02	12.44	8.29	10.69	6.36	8.87
Fe <sub>2</sub> O <sub>2</sub>	9.92	3.19	10.77	11.22	11.69	11.02	11.02	14.12	. 16.44	10.77	5.06	16.62	17.47	13.09	17.82
MnO	0.10	0.04	0.15	0.23	0.17	0.20	0.16	0.20	0.19	0.12	0.09	0.16	0.18	0.13	0.17
MaO	4.42	7.29	4.27	4.28	4.99	4.64	5.14	5.41	5.63	4.97	0.86	2.96	3.26	2.27	3,38
CaO	5 26	2 03	5.93	5.97	5.39	5.97	7.36	9.01	5.85	5.36	3.12	0.51	0.95	0.48	0.79
N <sub>B-</sub> O	2 27	0.13	2 90	2.00	1.74	1.89	1.91	0.76	0.36	2.50	3.52	0.01	0.01	0.01	0.01
K O	0.76	3 51	0.23	1.22	0.61	1.22	0.83	0.13	0.59	0.54	3 22	0.24	1 33	0.04	0.10
	0.70	0.04	0.25	0.72	0.64	0.67	0.65	0.13	0.23	0.25	0.19	0.07	0.11	0.04	0.07
r <sub>2</sub> 05	0.57	0.04	0.71	0.72	0.07	0.07	0.00	0.23	0.25	0.25	0.13	0.07	0.11	0.04	0.07
H <sub>1</sub> O-	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.11	2.05	0.07	0.00	2.27
LOI	5.72	3.08	5.82	. 4.80	0.01	07.05	4.30	7.99	7.08 '06.06	0.10	3.18	2.95	3.37	2.30	3.37
101	90.07	100.33	90.31	97.08	90.57	97.05	97.02	90.39	90.90	90.80	90.30	97.04	97.02	<u> </u>	97.09
ррш	20.70	202.20	6 30	25.00	17.00	24.60	10.50	7.40	27.50	13.80	64 40	5 00	35.80	2 00	5 30
RU Ro	463.60	420.20	400.20	1 232 30	555 50	1 514 20	640.60	94.90	295 70	181 70	1 387 70	131.90	593.90	77 10	92.80
Da .	224.00	420.90	200.20	1,252.50	167.10	240.20	401.80	72.80	52.00	78 70	91.00	11.00	17.60	7.00	8 90
5r 7.	349 50	683.50	200.30	249.80	241 50	236.40	237.20	150.80	167.30	206.40	380.50	201.00	331.20	209 30	279.50
N.h.	15.80	33.20	13.80	14 30	13.00	13 40	14.80	10.00	11 60	9 10	11 10	11.70	18 70	11.80	16 90
Ni	72 30	6 70	135.60	100.20	141.10	131.00	158.30	90.20	106.80	81.10	12.80	28.70	33.80	24.40	26.10
7n	191.70	29.20	365.00	128 60	151 10	. 130 80	160.50	144.30	165 40	132.80	49.60	181.60	194.20	142.50	201.80
Cr	191.80	4 50	446 30	277 10	450.80	464 50	488.70	114.20	133.70	171.70	16.20	16.60	9.70	28.20	21.50
Cu .	22.80	13.20	35.70	36.90	37.60	36.20	38.70	116.80	188.10	192.70	46.10	8,60	18.70	7.20	23.90
v	235.00	21.60	347.20	299,70	313.30	281.80	278.40	305.10	334.70	272.20	50.10	109.90	147.20	84.10	123.80
Y .	38.50	79.70	43.60	40.70	38.50	38.20	41.00	35.40	33.30	29.60	21.30	13.30	28.40	12.50	27.40
Sc	16,70	2.10	25.60	25.00	28.30	21.70	24.60	30,50	27.50	25.80	2.90	0.10	10.30	2.10	12.00
Co	45.10	9.00	56.60	51.20	57.30	55.20	60.50	60.60	75.60	51.30	14.50	59.60	60.20	47.40	61.30
C1PW Norms. (%)															
Quartz	22.51	36.67	18.35	20.14	23.75	20.09	19.41	18.91	22.61	17.12	27.89	62.01	49.34	71.52	58.19
Corundum	- 1	3.57	-	•	-	•	-	•	0.47	•	-	7.63	7.78	5.60	7.97
Zircon	0.07	0.14	0.05	0.05	0.05	0,05	0.05	0.03	0.03	0.04	0.08	0.04	0.07	0.04	0.06
Orthoclase	5.18	20.52	1.70	8.42	4.20	8.48	5.71	0.78	4.02	3.71	21.40	1.62	9.00	0.29	0.63
Albite	20.24	. 0.97	26.13	17.57	15.67	17.36	16.58	7.00	3.27	22.51	29.92	0.08	0.35	0.08	0.09
Anorthite	25.47	9.64	24.82	24.82	26.05	23.48	23.89	31.02	32.67	28.38	8.82	2.29	4.77	2.41	3.73
Diopside	-	-	-	-	-	0.96	5.94	11.49	•	•	3.99	-	-	-	-
Wollastonite					-	-	-	-	15.04	12 70	-		-		
Hypersthene	12.34	25.24	11.81	11.62	13.94.	12.45	11.18	10.05	15.94	13.78	0.56	1.91	8.85	0.01	0.77
Chromite	0.04	201	0.10	11.00	12 40	0.10	11 70	15 67	18 22	11 71	5.74	17.52	18.44	13.26	19.03
riaemante	10.75	2.94	0.22	0.52	0.30	00.11	034	0.40	0.40	0.30	0.24	0.30	0.47	0 31	0 41
Sabana	0.27	0.12	0.32	202	0.39	2.55	3 62	3 00		0.30	1 66	-	-	-	
Anotite	1.50		1 87	1.96	1.66	1 73	1 68	0.63	0.61	0.45	0.48	0.17	0.27	0.09	0.79
Rutile	1.15	0.27	0.61	0.30	1.43		-	-	1,75	1.47	-	0.39	0.86	0.49	0.18

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	TK2/2F	TK2/2G	ТК2/2Н	TK2/21	TNT2-1	TNT2-10	TNT2-13	TNT2-14	TNT2-15	TNT2-16	TNT2-17	TNT2-3	<b>TNT2-4</b>	TNT2-5
Depth (metres)	Outcrop	Outcrop	Outcrop	Outcrop	725.87	946.05	986.06	1,021.62	1,036.28	1,055.69	1,071.00	747.65	762.49	778.86
Formation	Sodium Gp.	Sodium Gp.	Sodium Gp.	Sodium Gp.	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Řietgat	Rietgat	Rietgat
Unit	3	3	3	3	5	3	3	1	1	1	· 1	. 5	5	5
wt.%	_													
SiO <sub>2</sub>	48.75	49.91	50.51	52.22	52.42 ·	46.81	51.81	57.78	52.02	56.85	50.81	53.97	48.89	53.51
TIO	· 1.07	1,07	1.17	0,94	1.27	1.35	1.49	1.29	1.30	1.26	1.52	1.42	1.35	1.38
Al <sub>2</sub> O <sub>3</sub>	14.72	14.62	15.62	12.40	14.04	16.01	14.19	13.58	14.45	12.86	14.42	14.12	13.62	13.81
Fe <sub>2</sub> O <sub>1</sub>	5.17	5.18	4.02	10.70	8.60	11.09	11.28	8.96	11.47	8.84	11.40	9.64	8.82	9,90
MnO	0.10	0.11	0.09	0.17	0.10	0.12	0.15	0 10	0 14	0.11	0.16	0.12	0.18	0.13
MgO	2.05	2.23	0.94	6.90	3,93	2.69	4.57	3.76	6.43	4.45	4.49	4.18	3.95	3 43
CaO	10.84	10,19	9.82	6.79	7.62	17.03	7.19	5.39	4.80	5.40	7.61	4.78	8.78	6.87
Na-O	4.69	4.86	6.16	1.96	0.17	0.21	2.98	2.85	3.26	2.47	3.02	3.60	3.40	2.51
K.0	0.51	0.67	1 27	1 93	2 80	0.96	2.04	1.58	0.41	2.08	2.26	0.27	0.15	1 34
P.O.	0.42	0.42	0.47	0.36	0.61	0.77	0.79	0.55	0.56	0.55	0.78	0.66	0.65	0.67
н.о.	0.12	0.08	0.05	0.08	0.05	0.05	0.04	0.55	0.50	0.55	0.75	0.08	0.05	0.07
1,01	8 43	8.05	7.24	3 30	8.01	1.83	2 75	2.68	3.08	1 28	2 2 2	4.75	7.91	4.61
TOT	96.80	97 39	97.36	97.84	99.62	98.92	99.28	98 71	98.03	98.33	98.85	97 59	97.66	98.20
nnm	20.00	57.55	57.50					70.71	78.05	76,55	30.05		77.00	
Rb	12.50	12.30	21.40	40.90	128.30	25.70	48.70	37.60	6.80	48 90	55 20	7.90	4.70	29.60
Ba	396,90	602,10	1.237.60	2,233,40	945.70	506.20	1,729,10	794.10	316.30	867.30	1.984.00	147.80	144.50	1.762.20
Sr	422.00	323.10	365.60	424.60	74.80	1,810.60	564.70	534.50	538.50	472.20	588.50	250.50	308.30	769.40
Zr	185.20	185.50	205.20	160.70	304.50	198.10	236.50	331.20	337.00	325.80	246.40	318.70	306.80	305.80
Nb	10.20	8.20	10.20	10.20	14.50	16.30	13.80	16.20	16.90	15.50	15,10	14.10	13.60	15.40
Ni	119.40	112.70	39.10	235.10	52.10	70.00	. 89.90	97.30	111.80	99.80	91.60	54.60	49.30	69.80
Zņ	69.60	65.40	33.50	127.00	121.50	51.20	114.00	94.40	111.30	95.90	111.10	123.60	99.80	107.60
Cr	355.70	380.40	198.60	697.30	123.30	173.10	205.00	347.70	355.50	406.60	195.90	170.40	140.00	200.60
Cu	10.70	5.70	10.30	39.90	21.00	51.00	33.90	24.80	16.90	28.80	32.50	7.20	9.10	28.70
V	210.50	180.80	197.00	205.00	198.10	252.70	212.90	174.70	202.90	173.80	211.70	234.00	184.10	200.30
Y ·	30.80	24.50	34.70	25.50	36.00	48.80	39.40	39.10	42.60	40.80	40.10	39.20	38.20	41.10
Sc	20.80	19.00	15.30	23.10	23.60	22.10	20.40	17.50	18.70	22.90	18.90	22.60	· 22.10	17.70
Co	23.50	27.60	15.80	57.50	36.90	27.20	48.40	46.80	57.00	42.70	49.30	47.40	36.60	43.40
CIPW Norms. (%)									10 -0					
Quartz	1.78	2.11	-	12.78	23.09	12.33	. 9.29	21.10	13.79	19.95	6.81	18.68	10.56	18.45
Corundum	-	-	-	-	-	0.04	0.05	0.07	1.24		-	0.82	-	-
Zircon Omtheologic	0.04	0.04	0.03	0.03	19.10	5.94	12.51	0.07	0.07	12.07	12.07	1.73	0.00	0.00
Albito	3.42	4.44	57.43	12.10	10.12	3.80	26.13	5.70 25.16	2.30	22.97	15.07	32.84	32.04	22.07
Andre	10.06	18.06	12.49	20.59	32.01	1.65	20.13	20.10	29.08	18.88	10.49	21.04	23.04	22.07
Dionside	12.48	13.00	5.62	8.25	0.63	14 92	5 77	20:50	21.55	1 36	7.68	-	12.12	2 94
Wollastonite	7 64	6 20	11 44	-		-		_	•.	-	·	-	-	-
Hypersthene	-	-	-	14.41	10,40	-	9.13	9.77	16.89	11.05	8.05	11.22	5,34	7.77
Chromite	0.09	0.09	0.05	0.16	0.03	0.04	0.04	0.07	Ó.08	0.09	0.04	0.04	0.03	0.04
Haematite	5.85	5.80	4.46	11.34	9.39	11.43	11.69	9.35	12.09	9.32	11.82	10.39	9.82	10.58
Ilmenite	0.22	0.24	0.20	0.36	0.24	<u>.</u> 0.26	0.34 .	0.21	0.31	0.23	0.36	0.28	0.43	0.30
Sphene	2.69	2.63	-	2.00	3.10	3.08	3.37	2.86		2.98	3.42	-	3.14	3.26
Apatite	- 1	-	-	-	1.58	1.89	1.96	1.37	1.41	1.39	1.94	1.69	1.72	1.72
Rutile	1.13	1.12	1.24	0.92		<b></b> .	-	0.08	1.21		-	1. <u>3</u> 8	-	

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	TNT2-6	TNT2-7	TNT2-9	ZTD1-10	ŻTD1-11	ZTD1-12	ZTD1-13	ZTD1-14	ZTD1-4	ZTD1-5	ZTD1-6	ZTD1-7	ZTD1-8	ZTD1-9
Depth (metres)	835.84	897.65	933.97	345.20	346.80	362.00	370.00	370.90	282:40	290.30	294.20	304.80	323.30	330.80
Formation	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat	Rietgat
Unit	3	3	3	3	3	3	. 3	3	5	5	5	5	5	5
wt.%								-						
SiO <sub>2</sub>	50,81	50.21	48.53	57.09	54.84	48.16	57.66	58.02	67.33	53.57	64.49	57.18	57.18	47.37
TIO	1.61	1.42	1.27	1.27	1.37	1.25	1.34	. 1,32	1.35	1.20	1.38	1.46	1.56	1.59
A1.0.	14.88	15.01	14.19	13.62	14.13	12.73	14.01	13.51	14.89	14.73	14.82	15.29	16.53	17.72
F. O	11.68	0.83	9.75	0.27	8 80	8 5 2	8.75	10.32	6.61	11.58	7 20	8 10	9.07	11.69
M-0	0.12	0.13	0.12	0.20	0.05	0.32	0.15	0.16	0.05	0.17	0.08	0.13	1 0.10	0.15
MaQ	5.54	4 92	4.78	4.08	4 90	4.28	2.48	2 80	1.69	3.18	2.02	2 36	3 52	4 04
mg0	5.91	12.60	7.50	4.98	5.03	6.04	6 76	6.23	1.69	6.07	2.02	6 14	3 56	6 67
No O	3.01	2.51	1.30	2.16	1.09	1.07	2 00	2 43	3 4 5	3 18	3.56	4 19	4 13	3 21
NH20	3.71	2.51	1.54	2.10	1.28	1.92	2.33	1.45	1.96	0.21	5.50	9.15	9.15	0.34
K <sub>2</sub> O	0.09	0.09	3.82	1.70	2.10	1.01	1.51	1.05	1.60	0.31	1.60	0.05	0.70	0.54
P205	. 0.84	0.79	0.77	0.53	0.36	0.48	0.33	0.33	0.33	0.33	0.38	0.01	0.03	0.00
H <sub>2</sub> O-	0.09	0.09	0.11	0.04	0.02	0.05	0.07	0.06	0.08	0.07	0.06	0.08	0.09	0,17
LOI	2.82	2.97	6.13	8.15	8.38	17.25	6.83	6.66	2.97	6.55	3.78	5.69	4.75	7.49
101	98.00	100.57	98.31	103.90	102.41	102.71	102.90	103.18	102,51	101.16	102.76	101.97	101.82	101.10
ppm	1.20	0.70	84 70	00.60	110.00	101.40	62.00	\$2.60	107.10	10.40	07.60	34.20	. 27 20	21.10
KD D-	. 1,30	0.70	84.70	90.50	760.30	101.40	360.80	32.00	660.20	19.40	97.30 634.50	34.20	37.50	21.10
Ba IS-	138.00	69.90 522.50	1,220.70	023.20	709.30	276.00	216.80	209.40	154.10	206.90	182.80	318.90	260.80	311.80
5r 7-	483.80	232.30	140.10	283.30	238.00	278.00	210.00	234 70	268.00	200.90	273.60	279.40	263.30	284.00
ZT.	278.70	13.60	12 210.40	11.00	10.50	13.60	11.50	12 50	11 10	12 20	11 90	12.90	11.90	14 40
NU	105.60	106.00	101.80	61.50	67.60		51.00	56 20	39.10	66.60	46 30	54 20	82 20	88 50
7n	110.80	84.90	118 10	113.70	107.30	117.80	99.50	114.00	77 50	132.00	88 50	108.50	135.90	171.10
	243.20	241.20	231.50	236.10	247.50	214 60	216.20	209.00	263.70	222 40	270.50	261.40	274.50	288.80
Cu	19.70	18.50	11.70	11.90	14.80	18.60	68.60	43.30	54.00	8.70	69.90	30.40	38.10	9.90
v	256.10	209.60	172.40	265.20	271.20	277.70	254.10	245.30	240.50	228.10	253.00	244.60	324.10	317.60
Ŷ	39.30	36,80	35.60	32.20	31.40	36.20	29,30	. 33,70	29.00	30.60	28.40	35.40	30.30	38.40
Sc	19.90	22,60	22,90	21.20	17.90	25.60	20.60	22.70	12.20	16.50	18.80	21.10	17.70	23.50
Co	60.20	39.20	49.90	38.30	40.30	37.90	36.30	39.50	24.80	<sup>-</sup> 48.70	33.00	37.90	48.50	52.60
CIPW Norms. (%)														
Quartz	10.99	9.37	7.96	22.45	19.82	·15.60·	21.36	25.55	35.65	19.02	29.31	17.14	19.89	9.48
Corundum	0.07	- ·	•	0.54	0.74	-		- '	5.42	-	2.93	• .	• 4.08	1.57
Zircon	0.06	0.04	0.04	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.06 (
Orthoclase	. 0.56	0.54	24.55	10.53	13.25	12.57	8.09	6.45	11.09	1.95	10.79	4.01	4.28	2.16
Albite	33.01	21.78	. 12.31	19.09	17.82	19.02	26.35	21.31	29.35	28.46	30.45	36.85	36.03	29.07
Anorthite	24.76	30.20	23.31	22.01	22.99	24.35	21.83	23.71	4.99	26.47	11.40	21.85	14.15	30.99
Diopside	-	18.91	6.02	-	-	2.55	4.11	0.59	-	-	-	0.85	-	-
Wollastonite	-	-	-			-		•	-		-	-	-	10 77
Hypersthene	14,51.	3.81	10.15	12.96	12.98	11.30	4.53	7.19	4.23	8.38	5.09	5.72	9.04	10.77
Chromite	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.00	12 51
Haematite	12.28	10.08	10.59	9.69	9.46	9.98	9.11	10.70	0.00	1.2.23	/.28	8.31 0.37	9.35	12.51
limenite	0.28	0.29	0.28	. 0.44	0.47	0.54	0.32	0.35	0.09	0.38	0.15	0.27	0.21	0.54
Sphene		3.20	3.03		1 42	2,90	3.01	2.91	1 22	1.21	-	5.58 1.51	1 55	1.60
Apante	2.10	1.92	1.99.	1.32	1.42	1.34	1.30	1.30	1.33	0.58	1.40	1.51	1.55	1.52
Ruine	1.33	•		1.10	1 1.21		l	51	1	0.50				

	ERO3-1	ERO3-2	ERO3-3	ERO3-14	ERO3-15	ERO3-17	ERO3-18	ERO3-19	ERO3-20	ERO3-21	ERO3-22	ERO3-23	ERO3-24	ERO3-25	ERO3-26
Depth (metres)	269.90	288.85	319.21	621.80	686.40	801.50	857.90	919.40	968.85	1,021.75	1,083.42	1,144.60	1,204.55	1,259.17	1,402.18
Formation	Allanridge	Allanridge	Allanridge	Kameel.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.
wt.%															
sio.	53.11	54.41	51.16	51.05	52,50	52.92	52.60	48.85	52.03	52.70	55.11	52.61	50.48	51.42	54.56
τιο.	1.12	1.21	1 40	2.54	0.54	0.55	0.62	0.42	0.40	0.48	0.66	0.57	0.57	0.63	0.82
	13.60	13.51	14 94	10.21	12 75	13.62	14 39	9.98	9.62	11.20	14 34	12 74	13.12	13.89	13 54
F: 0	10.15	10.02	10.74	11.20	10.35	10.05	10.10	11.00	10.11	0.79	10.10	10.23	11.31	10.34	10.80
re <sub>2</sub> O <sub>3</sub>	10.15	0.13	0.00	0.10	0.55	0.05	10.19	0.24	0.11	9.76	0.10	0.17	0.17	0.17	0.12
MnO MaO	2.1.0	0.12	0.09	0.10	0.10	0.13	\$ 07	13.02	14.18	10.18	6.05	6.02	8.03	7 37	6.49
MgO A.A	3,03	3.02	3.11 e uu	10,54	7.73	7.12	5,57	10.02	7 28	9 54	0.05	12.03	8.54	. ,,,,,,	5 87
CaU	6.76	7.15	5.88	0.09	7,74	8.09	9.00	10.13	1.20	8.34	7.22	12.03	0.54	7.07	J.07
Na <sub>2</sub> O	4.06	3.27	3.72	0.02	2.73	3:4	3.20	1.53	0.63	2.32	3.89	2.10	3.21	2.72	2.37
K <sub>2</sub> O	1.11	2.45	0.25	0.05	0.99	1.00	0.91	0.64	1.10	0.96	1.08	0.24	0.55	0.61	2.00
P <sub>2</sub> O <sub>5</sub>	Q.24	0.26	0.27	0.44	0.08	0.08	0.10	0.06	0.05	0.07	0.09	0.08	0.08	0,08	0.11
H <sub>2</sub> O-	0.40	0.07	0.13	0.12	0.01	0.09	0.10	0.12	0.10	0.17	0.03	0.09	0.06	0.09	0.09
LOI	3.35	2.41	5.58	7.27	2.73	2.28	2.25	3.54	4.01	2.96	2.11	2.11	2.38	3.06	2.39
TOT	97.75	99.41	97.27	99.62	99.53	99.79	99.53	99.62	99.66	99.57	100.83	99.99	98.50	100.25	99.36
ppm			•												
Rb	29.00	47.60	3.50	2.20	28.00	32.60	31.90	20.50	43.50	30.50	36.50	10.00	21.10	18.00	69.80
Ba	431.70	1,292.10	143.30	75.40	708.20	449.30	454.50	336.20	601.60	616.90	542.50	133.00	215.80	222.70	814.00
Sr	529.60	890.20	204.40	57.60	406.40	468.30	549.10	127.70	107.70	282.40	396.40	437,30	295.20	151.00	205.00
Zr <sub>.</sub>	172.10	184.00	234.20	313,70	61.90	64.70	74.90	53.90	45.70	59.90	77.00	63.30	67.30	73.70	100.30
Nb	9.10	10.70	11.00	16.40	3.20	3.00	4.30	3.30	0.50	3.50	2.70	4.60	3.70	4.00	4.80
Ni	154.00	118.90	112.70	80.40	202.30	163.20	138.40	381.60	391.70	286.00	130.40	196.00	203.20	199.70	166.60
Zn	97.00	97.50	92.20	87.60	74.30	75.40	80.20	73.20	70.40	65.40	72.10	74.90	80.40	/6.00	83.40
Cr	56.80	36.80	28,30.	113.00	671.00	505.40	242.00	1,858.10	2,246.80	1,473.00	155.00	4/1.00	450.50	403.70	274.40
Cu	82.50	112.50	82.20	176.30	43.50	/3.90	88.90	27.60	44.90	48.00	35.00	70.20	34.90	200.00	210.60
V	171.40	165.60	182.20	273.00	192.10	187.30	177.50	179.60	107.30	137.10	177.00	183.00	190.30	209.90	10.00
Υ.	25.10	27.90	25.10	54.30	15.60	10.70	10.90	13.60	10.80	14.60	10.30	17.00	18.20	35.00	23.00
Sc	14.20	20.00	12.80	20.40	50.90	34.00	29.80	61.20	56.00	\$0.30	47.00	50.40	53.40	48 80	50.20
	42.00	47.30	30.30	55.20	50.20	44.50	40.10	01.20	50.90	50.50	47.00	50.40	55.40	10.00	50.20
CIPW Norms. (%)	10.04	10.27	14 13	25.46	7 24	6.39	7 15	3 44	11 39	7 74	7 77	11.27	4 57	6.83	12.25
Quartz	10.04	10.27	14.15	0.10	7.24	0.27	7.15	5.44		-	-	-	-		
Zimon	0.04	0.04	0.05	0.07	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02
Orthoclase	6 99	14.96	1.62	0.32	6 06	6 08	5.55	3.95	6.82	5,90	6.48 -	1.45	3.39	3.72	12.23
Albite	36.54	28.54	34 38	0.18	23.86	28.14	28.38	13.49	5.58	20.35	33.35	18.17	28.27	23.70	22.44
Anorthite	16.89	15.48	25.50	29.69	20.30	20.21	22.61	19.26	21.13	17.97	18.75	25.20	20.59	24.62	20.17
Dionside	10.84	12.67			13.89	17.45	16.64	24.92	11.91	19.10	12.11	26.58	16.95	18.54	5.47
Wollastonite			-		-	-		-	-	-	-	-	-	-	-
Hynersthene	4.60	3,46	8,46	27.92	16.61	10.13	7.60	22.25	31.45	17.53	9.66	5.31	12.97	10.31	14.16
Olivine			-	-		-		-		•	-	-	-	-	-
Chromite	0.01	0.01	0.01	0.03	0.15	0.11	0.05	0.42	0.51	0.33	0.03	0.10	0.10	0.10	0.06
Haematite	10.80	11.28	11.73	12.35	10.69	10.32	10.49	11.56	10.58	10.14	10.23	10.56	11.77	10.65	11.15
Ilmenite	0.34	0.30	0.25	0.25	0.32	0.31	0.32	0.37	0.11	0.27	0.35	0.37	0.38	0.37	0.28
Sphene	2.49	2.69	3.21	-	0.96	0.99	1.15	0.59	0.88	0.88	1.19	0.96	0.97	1.11	1.72
Apatite	0.61	0.64	0.70	1.13	0.20	0.20	0.24	0,15	0.12	0.17	0.22	0.19	0.20	0.20	0.27
Rutile	-		0.09	2.62	-	<u> </u>	•	-		-		-	<u> </u>	-	

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	ER03-27	ERO3-28	ERO3-29	ERO3-30	ER03-31	ERO3-32	ERO3-33	S3-1	\$3-2	S3-3	\$3-4	S3-5	S3-6	\$3-7	\$3-13
Depth (metres)	1,456.32	1,556.90	1,597.85	1,675.00	1,717.18	1,753.40	1,823.00	274.85	317.05	351.90	382.90	429.60	472.90	500.50	765.10
Formation	Klip.	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Klip.	Klip.	Klip.						
wt.%															
SiO,	54.84	54.53	53.75	50.47	50.92	53.04	53.21	47.93	51.77	51.31	53.14	53.32	55.14	55.00	52.64
TIO,	0.88	0.91	0.93	1.10	1.08	1.96	1.01	1.16	1.15	1.14	1.06	1.16	1.18	1.26	1.53
ALO,	14 44	14.29	14.09	15.06	14.85	13.73	14.07	14.18	13.52	13.37	13.24	13.53	13.49	13.79	14.46
Fe.O.	11.45	11 50	10.86	12 79	11.65	13 27	11 75	11 17	11.58	11 13	9.09	10 90	10.61	11.28	9 34
MnO	0.14	0.14	0 14	0.15	0.13	0 14	0.14	0.12	0.14	0.13	0.13	0.14	0.14	0.15	0.10
MgO	4 30	5 14	5 10	5.87	5 60	5 79	4.31	3.72	4.37	3.62	3.38	4.89	3.60	4.85	5.01
CaO	6.96	6.37	6.62	4.97	6.14	5.54	8.38	7.75	7.31	8.19	10.03	6.47	6.95	4.77	6.17
Na.O	2.69	3.11	3.90	2.97	3.12	3 30	2.13	2.87	3.84	3.80	5.06	4.19	3.35	3.27	0.18
KO	2.07	1.62	2.05	1.96	1.92	0.19	1.96	1 32	1.59	1.58	0.22	1.86	2.09	2 33	2 38
R <sub>2</sub> O	0.12	0.12	0.12	0.14	0.14	0.12	0.13	0.25	0.24	0.24	0.24	0.25	0.25	0.26	0.73
P <sub>2</sub> O <sub>5</sub>	0.12	0.12	0.12	0.14	0.02	0.12	0.03	0.14	0.24	0.15	0.12	0.14	0.12	0.00	0.07
H <sub>2</sub> O-	1.01	0.02	1.52	2.69	2.99	2.72	2.48	6.02	2.07	2.05	2.75	1.75	2.45	2.10	7.02
TOT	00 01	00 00	00 12	08 10	00 45	00 21	09.60	0.55	08 76	97 71	98.46	98.60	99 37	99.15	99.63
nnm	33.51	11.11	77.12	50.17	77.45	77.61	11.00	71.54	70.70	21.11	70.10	70.00	77.07		11.05
2P	84 50	62 20	70 60	71 50	66.00	16.50	62.10	25.70	32.30	32.50	5.80	35.80	38.10	42.70	79.30
Ba	607.90	546.70	418.00	682.40	352.30	291.70	963.00	569.60	659.60	777.30	68,90	783.70	898.60	1,907.20	786.30
Sr	305.90	251.80	143.10	184.20	182.60	199.10	519.70	254.50	664.80	692.30	734.30	403.50	826.80	426.50	77.10
Zr	109.90	107.20	111.90	121.80	117.90	116.20	104.20	192.70	173.40	175.90	161.90	185.80	183.90	206.70	355.40
Nb	6.40	6.50	5.90	6.40	5.80	7.80	7.60	8.60	9.60	9.50	8.90	9.60	10.00	10.70	15.70
Ni	105.20	124.70	120.00	145.20	135.60	138.70	133.60	176.50	168.70	157.60	118.10	163.20	113.50	107.60	78.90
Zn	96.10	89.40	82.20	108.70	91.90	104.80	90.20	108.30	106.40	109.00	60.40	99.90	102.00	106.20	83.10
Cr	18.30	44.60	27.60	60.80	53.60	86.70	67.00	51.40	52.20	45.60	41.60	52.10	39.90	26.80	194.30
Cu	123.10	79.80	85.80	133.40	108.30	92.80	108.10	76.60	90.00	78.60	63.50	103.50	108.90	119.90	8.80
V	207.90	206.40	217.40	240.70	231.40	244.20	196.90	197.60	188.10	172.20	187.70	189.80	163.70	173.80	220.30
Y	21.70	20.10	21.10	23.10	23.10	23.20	22.30	26.50	27.30	27.00	32.80	25.90	26.90	27.60	39.10
Sc	25.30	28.90	23.10	27.00	26.70	22.00	19.50	20.00	20.90	14.70	18.30	19.20	15.00	15.50	18.90
Co	52.00	51.60	49.90	64.70	52.00	65.80	58.00	50.60	55.50	51.70	35.60	51.00	46.40	40.00	29.50
CIPW Norms. (%)	12.00	11.70		7.24	(12)	12.42	12.42	0 72	6.20	6 20	4.01	5 22	12.10	11.94	25.65
Quartz	12.80	11.70	5.57	1.34	0.43	13.43	13.42	0.73	0.30	0.39	4.01	5.55	12.10	11.04	23.03
Corundum	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.08
Orthoclase	13.12	9.82	12 45	12.16	11.90	3.01	11.96	8.63	9.85	9.89	1.36	11.38	12.78	14.22	15.23
Albite	23.23	26.92	33.82	26.32	27.63	28.94	18.56	26.84	34.02	34.02	44.79	36.66	29.28	28.53	1.65
Anorthite	21 37	20.75	15.27	23.06	21.83	22.00	23.78	24.25	15.70	15.65	13.37	13.08	16.16	16.68	28.18
Dionside	8.45	6.56	11.74		4.62	2.06	12.19	10.03	13.67	17.61	19.02	11.90	11.47	2.18	
Wollastonite									-	.	4.04				
Hypersthene	7.02	10.06	7.58	15.31	12.46	13.99	5.42	5.60	5.08	1.40		7.09	3.97	11.46	13.48
Olivine						-			-		-	•	6		•
Chromite		0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05
Haematite	11.68	11.77	11.13	13.40	12.19	13.75	12.10	12.35	12.12	11.78	9.51	11.27	10.96	11.63	10.09
Ilmenite	0.34	0.35	0.35	0.38	0.33	0.35	0.35	0.34	0.37	0.34	0.33	0.36	0.35	0.37	0.23
Sphene	1.76	1.84	1.89	1.46	2.35	2.24	2.11	2.71	2.49	2.52	2.30	2.49	2.56	2.74	
Apatite	0.29	0.29	0.29	0.35	0.35	. 0.30	0.32	0.66	0.60	0.61	0.60	0.62	0.62	0.65	1.88
Rutile				0.36										-	1.53

	\$3-14	\$3-15	\$3-16	\$3-17	S3-18	\$3-19	\$3-20	\$3-21	S3-22	\$3-23	\$3-25	\$3-26	\$3-27	\$3-28	\$3-29
Depth (metres)	780.70	799:80	881.90	897.90	1.081.70	1.183.60	1,266,30	1,320,30	1.450.00	1.512.23	1.649.40	1.681.10	1.746.90	1.792.60	1.861.25
Formation	Klip.	Klip.	Makwassie	Makwassie	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	, Klip.	Klip.	Klip.	Klip.	Klip.
wt.%											·····				
SiO	50.02	53.58	56.67	54.27	52.42	50.40	53.70	53.84	52.20	53,31	52.39	52.07	53.00	53.90	53.89
TIO.	1.43	1.52	1.36	1 29	0.55	0.38	0.66	0.52	0.57	0.55	0.65	0.81	1.00	0.92	0.92
ALO,	13.62	14.28	14 13	13.93	11.94	9.36	13.98	11.89	12 42	11.96	13.07	13.26	14.51	14 31	14.07
Fe.O	7.82	7 77	8.60	8 63	10.06	10.54	10.06	10.13	10.27	10.36	11.10	10.81	11.97	11.31	11.60
MnO	0.10	0.10	0.11	0.05	0.16	0.15	0.00	0.15	0.15	0.16	0.16	10.81	0.18	0.15	0.14
MeO	3 54	3 88	3 56	· 242	9.55	13.10	5 57	6.92	6.56	7.80	633	6.69	4 74	3.05	4 18
CaO	9.75	6 71	5.00	7 41	7.61	7 18	7 94	8.27	9 14	9.36	9.91	7.66	5 74	831	7 82
Ná O	0.79	2.26	3 75	3 34	2 60	1.07	3 84	3 13	2 47	3 14	2.04	3 38	3 30	3 50	2.96
K-0	2.36	1 54	0.19	1 27	1.03	0.64	0.91	0.55	1.50	0.82	1.57	1 30	2.11	0.87	1.03
R10	0.68	0.70	0.15	0.55	0.08	0.04	0.21	0.03	0.07	0.02	0.09	0.11	0.13	0.07	0.12
1,0j	0.08	0.70	0.05	0.00	0.03	0.05	0.10	0.07	0.07	0.00	0.03	0.11	0.13	0.12	0.12
1.01	0.08	6.42	4.40	0.02	0.14	2.97	0.00	2.04	0.03	0.02	0.02	2.10	0.04	0.00	1.07
TOT	9.23	98.76	9.40	98.12	08.03	97.51	00.43	97.81	97.41	00.65	90.14	98.80	08.84	00 20	08.71
nom	<u> </u>			<u> </u>						77.05	<u></u>	90.00	58.64	77.25	
Rb	86.60	56.80	5.40	30,90	23.80	28.30	25.40	18.60	60.10	26.80	55,40	43.00	73.00	34.90	41.40
Ba	811.50	631.70	206,40	1,507.40	475.90	278.10	243.40	293.60	425.50	211.60	657.90	377.10	949.20	342.20	391.20
Sr	151.10	212.90	704.40	766.50	175.40	118.50	399.30	303.00	275.00	105.00	379.20	161.60	182.90	400.80	449.90
Zr	333.00	342.60	345.70	329.40	70.40	52.30	83.90	61.20	67.20	63.00	68.90	98.80	117.00	105.30	102.80
Nb	17.20	16.40	16.40	17.20	2.70	1.70 *	3.90	2.50	3.20	2.80	4.70	4.70	6.50	6.40	7.60
Ni	67.70	72.50	97.90	82.00	243.30	362.10	126.20	198.50	203.70	217.00	177.70	189.60	110.70	105.20	120.20
Zn	106.70	101.20	100.50	103.80	68.40	69.50	66.60	70.40	72.00	74.60	82.60	88.60	74.20	89.10	91.60
Cr	168.40	202.70	363.90	325.70	997.60	2,054.00	151.70	526.10	496.80	500.80	388.80	346.30	22.80	25.60	33.40
Cu ·	30.00	13.60	11.60	36.50	32.90	51.50	96.90	48.70	73.70	71.90	86.60	87.10	44.80	108.90	88.40
V .	195.20	217.10	194.20	176.90	188.40	174.10	160.40	186.60	191.60	205.00	202.40	193.70	217.60	207.40	215.50
Y.	44.90	43.30	40.70	41.40	15.00	12.10	17.10	14.60	15.30	13.90	17.60	19.20	21.20	21.40	21.70
Sc :	24.50	18.60	19.50	19.50	28,70	27.60	31.70	27.30	32.30	28.90	32.90	27.30	25.60	23.90	29.80
	24.90	24.30	29.40		49.90	38.30	44.70	40.70	50.10		51.40	53.50		52.00	32.30
CIP W Norms. (76)	17.52	18 67	20.86	15.00	7 4 8	10.38	7.46	11 30	9 02	7.00	10.06	5.88	8.91	10.88	13.02
Comindum	17.52	18.07	20.00		-	10.50	-	11.50	-		10:00	5.00	-	-	15.52
Zircon	0.07	0.07	0.07	0.07	0.01	0.01	0.02	0.01	. 0.01	0.01	0.01	0.02	0.02	0.02	0.02
Orthoclase	15.52	9.88	1.20.	8.07	6.35	4.05	5.56	3.41	9.32	4.98	9.55	8.00	12.93	5.28	6.31
Albite	7.42	20.71·	33.78	30.32	22.91	9.65	33.53	27.74	21.92	27.24	17.72	29.71	28.88	31.14	25.89
Anorthite	29.60	···· 26:32	22.58	20.75	18.64	21.57	18.82	17.58	19.28	16.53	22.48	17.85	19.23	20.90	22.84
Diopside	11.18		-	8.66	14.68	11.71	15.27	18.57	20.67	22.93	20.29	14.64	5.36	14.17	10.96
Wollastonite	-	-	¦ ; .	-	.	-		•	-	-	-		-	-	-
Hypersthene	4.61	10.46	9.44	2.47	17.98	30.16	7.24	9.45	7.56	9.29	6.80	10.53	9.73	3.52	5.69
Olivine		•			•	•	-	-	-	•	-	+		-	-
Chromite	0.04	0.05	0.08	0.08	0.22	0.47	0.03	0.12	0.11	0.11	0.09	0.08	0.01	0.01	0.01
Haematite	8.68	8.41	9.16	9.26	10.48	11.35	10.38	10.01	10.77	10.62	11.49	11.23	12.38	11.72	11.99
limenite	0.24	0.23	0.23	0,21	0.28	0,14	1.33	0.34	1.04	0.33	1 19	1.50	1.00	1.94	199
Spnene	3.00	3.55	0.24	3.14	0.21	0.82	0.25	0.69	0.17	0.94	0.22	0.37	0.30	0.20	0.00
Putto	1.79	1.80	1.40	1.41	0.21	0.45	0.25	9.17	0.17	0.15	0.22	0.27	0.52	0.29	0.29
Kutte		0.08	1.23	<u>_</u>			L	L				L	L		ليستسبب

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	\$3-30	\$3-31	\$3-32	\$3-33	\$5-1	S5-2	S5-3	S5-4	\$5-15	S5-17	\$5-19	\$5-20	\$5-21	· · · \$5-22	\$5-23
Depth (metres)	1,921.25	1,981.60	2,021.90	2,078.85	331.00	361.75	386.89	414.60	952.70	980.40	1,046.15	1,124.78	1,183.85	1,233.85	1,289.90
Formation	Klip.	Klip.	K lip.	Klip.	Allanridge	Allanridge	Allanridge	Allanridge	Makwassie	Makwassie	Klip.	Klip.	Klip.	Klip.	Klip.
wt.%						· · ·			•						
SiO <sub>2</sub>	54.56	52.92	. 52.80	53.63	54.68	53.70	52.38	53.21	54.96	59.64	56.01	53.36	57.79	49.67	52.92
TIO,	0,91	0,97	1.01	1.00	1.15	1.20	0.98	1.21	1.24	1.28	0.57	0.63	0.48	0.39	0.49
Al <sub>2</sub> O <sub>3</sub>	13.91	14.18	14.10	14.12	13.81	13.97	13.74	14.22	13.52	13.99	12.19	14.05	9.12	9.33	11.79
Fe,O,	11.50	12.08	11.86	12.35	10.57	11.03	11.89	11.40	10.79	7.96	10.18	10.59	9.26	10.48	9,93
MnO	0.16	0.15	0.15	0.14	0.13	0.13	0.16	0.13	0.14	0.08	0.17	0.13	0.18	0.16	0.16
MgO	4.15	4.72	4.45	4.51	3.85	4.55	4.60	4.65	3.53	4.08	6,60	6.33	9.74	15.81	9.80
CaO	8.76	7.83	7.84	7.56	6.43	6.81	6.63	6.83	6.33	3.75	6.61	6.48	7.17	6.97	7.65
Na-O	3.36	3.05	3.14	2.62	4.08	3.98	4.63	3.75	2,36	3.19	3.79 -	2.71	1.75	0.86	2.84
к.0	0.42	1.26	1.00	0.87	0.47	1.43	0.28	1.49	1.76	0,80	0.75	1:06	0.41	0.52	0,30
P.G.	0.12	0.13	0.13	0.13	0.24	0.26	0.22	0.26	0.26	0.46	0.08	0.10	0.05	0.06	0.07
1.0-	0 11	0.15	0.09	0.04	0.10	0.08	0.22	0.09	0.07	0.08	0.12	0.17	0.14	0 20	0.18
1.01	1.87	2.03	2.27	2.29	3.20	2.00	1.99	1.95	3.22	3.75	1.79	2.81	2.94	4.70	2.55
тот	99.83	99.47	98.84	99.26	98.71	99.14	97.72	99.19	98.18	99.06	98.86	98.42	99.03	99.15	98.68
ppm											-				
Rb	16.70	51.50	37.70	30.80	9.50	25.20	3.40	26.30	30.80	36.10	. 22.10	35.90	8.70	17.60	9.00
Ba	155.40	475.20	367.80	467.70	199.10	491.70	99.10	571.40	695.40	391.00	330.90	477.70	84.50	196.40	124.50
Sr	351.60	402.00	412.10	307.00	599.00	476.70	307.80	570.40	737.00	384.50	306.10	381.20	54.80	117.30	343.40
Zr	101.00	104.90	106.50	109.60	169.10	189.20	170.80	183.00	306.10	518.80	71.90	79.30	63.20	48.50	58.70
NB	5.20	7.90	7.70	7.00	7.50	9.40	8,10	8.00	17.10	22.90	4.20	3.80	1.30	1.80	2.50
Ni	122.00	139.10	135.10	131.20	146.80	162.50	170.90	164.40	100.90	53.90	165.20	151.00	282.20	470.60	276.90
<u></u>	84.00	90.90	91.70	91.80	90.20	103.70	90,10	100.30	97.00	92.30	64.20	220.00	1 672 10	75.20	1 381 60
Cr Cr	32.00	30.00	01.90	79.40	43.80	101 20	90.80	114 20	397.70	229.80 6.40	27.10	56.50	1,373.10	2,700.00	76 10
v	202.20	216.50	222.00	219.80	188 10	185.60	174.80	185.00	173.80	142.80	195.20	194 50	166 60	168.90	158.90
v	18.40	22 50	21.40	22 10	26.20	26.30	21.50	26 50	43 30	51.00	15 40	17 20	10.80	11 40	14 10
Sc	26.20	25.30	32.60	27.60	20.90	20.60	15.00	20.30	22.80	11.10	29.20	25.30	29.80	34.30	32,30
Co	53.70	57.30	57.00	57.80	47.60	53.80	61.70	53.00	35.20	23.20	44.40	48.40	46.50	65.30	52.80
CIPW Norms. (%)															
Quartz	13.58	10.74	11.58	15.62	13.53	8.07	7.60	8.17	19.13	26.33	11.56	12.85	21.35	7.82	8.87
Corundum	-	-	-		• •	· • ·	• .	-	•	2.19	-	•	•	-	•
Zircon	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.06	0.11 <sup>.</sup>	0.01	0.02	0.01	0.01	0.01
Orthoclase	2.54	7.67	6.14	5.32	2.92	8.72	1.73	9.08	10.98	4.98	4.58	6.58	2.53	3.27	1.85
Albite	29.05	26.52	27.54	22.87	36.18	34.69	41.02	32.66	21.04	28.34	33.08	24.02	15.43	7.72	25.04
Anorthite	22.13	21.90	22.23	25.00	18.88	16.55	16.65	18.12	22.30	16.64	14.49	24.18	16.49	21.30	19.34
Diopside	14.91	11.41	11.29	/.8/	7.49	10.23	10.60	9.08	4.20	·	13.09	5.72	14.79	10.74	14.45
Wollastonite	2.66.		6.26	7 04	6.58	6.94	7.08	- יד ד	7 30	10.67	-	- 13.87	18.42	36.80	18 74
Olivine	3.00	0.80	0.20	7,34		0.94	,.08	-	,.50	10.07	-	15.67	-		10.74
Chromite	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.09	0.05	0.13	0.07	0.35	0.63	0.31
Haematite	11.75	12.42	12.29	12,74	11.08	11,36	12,45	11.73	11.37	8.36	10.50	11.10	9.65	11.12	10.35
Ilmenite	0.39	0.37	0.37	0.35	0.34	0.33	0.41	0.33	0.29	0.16	0.34	0.30	0.25	0.08	0.24
Sphene	1.78	1.97	2.09	2.09	2.53	2.61	1.99	2.63	2.84	-	. 1.00	1.24	0.90	0.91	0.95
Apatite	0.29	0.32	0.32	0.32	0.60	0.64	0.55	0.64	0.65	1.15	0.20	0.25	0.12	0.15	0.17
Rutile	. <u>.</u>	<u>.</u>	-	<u> </u>	<u> </u>	•		-	-	1.26		-	•	-	<u> </u>

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·····	S5-24	<b>\$5-25</b>	S5-26	\$5-27	S5-28	\$5-29	<b>\$5-30</b>	<b>S5-3</b> 1	\$5-32	<b>\$5-33</b>	DKL6-1	DKL6-2	DKL6-3	DKL6-4	DKL6-5
Denth (metres)	1,351.90	1,421.07	1,471,55	1,498.30	1,575.95	1,630,80	1,709.70	1,870.40	1,919.95	1,976.80	282.70	325.00	350.30	391.00	416.65
Formation	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge
wt.%															
SiO	52.72	52,87	52.91	51,77	52.56	50.76	52.04	54.70	55.75	53.88	53.50	52.40	53.35	53.52	55.81
TiO	0.49 '	0.58	0.75	0.63	0.68	0 51	0.54	0.93	0.89	0.91	1.22	1.15	1.16	1.18	1.21
ALO	(11.72	13.03	14.22	12 74	13 30	12 57	11.06	14 21	13.95	13 78	14 09	14 21	14 20	13 94	13.61
Fa.O.	0.05	10.78	11.07	11.06	10.81	10.50	10.88	11 77	11 20	11 71	10.22	11.58	11.96	11.53	10.35
MnO	0.15	0.15	0.14	0.16	0.16	0.15	0.16	0.16	0.12	0.15	0.11	0 14	0 14	0.14	0.14
MrO	10.14	7 36	5 54	7 43	7 24	7 92	9 14	4 10	4.48	4 81	3 80	4 77	5 34	4 50	4 31
CaO	8 4 4	9.78	7.57	8.78	8.01	9.53	9.96	7.59	5.56	6.57	7.17	6.88	4.96	6.81	6.86
Na-O	1 18	2 28	3.03	3 31	3.00	2 79	1 70	3.33	3.41	2.61	4.06	4.61	3.41	3.68	3.16
K 0	1.10	0.85	1.63	0.78	0.90	0.39	1.03	0.75	1 32	2 03	1 17	0.16	1 35	1 73	2 42
R <sub>2</sub> O	1.65	0.05	0.00	0.78	0.90	0.07	0.07	0.12	0.12	0.12	0.26	0.24	0.24	0.25	0.26
r <sub>1</sub> 0 <sub>5</sub>	0.07	0.08	0.09	0.07	0.08	0.07	0.07	0.12	0.12	0.12	0.20	0.24	0.24	0.25	0.20
H <sub>2</sub> U-	0.04	0.12	0.03	0.10	0.12	0.14	0.09	0.13 i 91	0.14	0.07	0.40	0.11	0.10	0.10	0.22
	2.77	2.29	2.03	2.14	08.07	2.00	02 82	00 62	00 32	00 10	99.35	98.62	98.87	99.40	100.99
101	99.50	100.17	33.05	30.37	76.75	78.05	90.02		<u> </u>		77.55	98.02	70.02	77.40	100.77
PPW Rh	120.20	29.50	59 20	30.80	34 90	13.70	46.70	29.60	47.30	76.20	27.60	3.90	22.90	34.20	46.90
Ra	345.10	345.30	656.70	307.50	394.70	98.20	347.70	87.50	525.00	582.90	510.20	69.80	650,40	1.016.20	1,495,70
Sr	125.50	338.10	364.20	284.00	298.90	126.70	261.10	536.30	249.80	223.10	864.60	307.90	398.70	769.70	834.70
Zr	71.30	67.60	86.00	71.70	74.20	60.90	58.10	99.70	105.20	107.00	177.40	182.50	175.40	180.80	194.60
Nb	3.80	5.10	4.70	5.10	4.60	3.60	4.90	6.40	4.90	6.50	9.30	8.70	8.00	11.00	10.90
NI	276.70	207.40	149.60	209.20	194.50	241.00	294.00	105.30	108.10	113.30	155.30	164.70	180.00	167.80	106.40
Zn	71:10	81.40	85.90	81.50	82.40	77.30	81.30	88.00	84.40	93.40	81.70	106.20	126.70	113.00	97.40
Cr ·	1,257.60	527.60	243.40	481.10	444.30	610.20	893.00	21.70	29.60	36.80	54,60	57.00	74.60	62.40	30.20
Cu	58.80	59.40	98.10	61.50	76.30	64.00	62.30	102.20	60.70	73.10	40.10	221.70	88.20	118.40	125.00
V ·	157.60	185.60	184.80	198.10	205.80	194.10	190.20	213.80	197.00	204.10	187.40	167.40	190.70	184.10	159.40
Y	14.70	18.30	20.10	18.50	17.20	15.10	17.10	21.30	19.50	20.40	27.60	23.20	24.50	29.60	29.50
Sc	26.70	27.80	20.60	34.30	33.40	41.50	31.20	26.70	27.60	22.00	21.70	15.30	23.10	18.90	13.90
Co	51.30	53.00	55.50	52.40	53.70	55.10	57.40	52.00	48.20	52.20	. 40.30	64.10		52,40	43.50
CIPW Norms. (%)	10.40	10.27	9.60	<b>6 10</b>	0 22	6.01	10.10	12.00	14.74	12.08	0.11	7 77	11.50	8 41	11.41
Quartz	10.49	10.27	8.39	5,46	0.27	0.91	10.10	13.99	14.74	12.90	9.11	1.27		0.41	11.41
Corundum	0.01	-	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.04
Orthoclase	11.23	5 15	9.96	4 78	5 51	2 42	6 32	4 55	8.08	12.45	7.24	0.99	8.31	10.52	14.59
Alhite	10.33	19 73	26.44	28.95	26.24	24.77	14.89	28.85	29.81	22.87	35.93	40.57	30.02	32.01	27.25
Anorthite	22.00	23.35	21.06	18.21	20.87	21.94	20.21	22.15	19.51	20.62	17.58	18.33	20.30	16.92	16.17
Diopside	15.28	19.07	11.92	19.40	14.09	20.25	22.82	10.29	4.49	7.76	11.23	9.48	0.35	10.22	10.77
Wollastonite		-	•	-	-	.	-	-	· -	-	-	-	-	-	-
Hypersthene	19.04	9.92	8.72	10.14	12.12	11.32	13.00	5.69	9.45	8.81	4.71	7.96	13.68	6.80	5.97
Olivine	-	- 1	·-	-	• ·	· .	-	-	- '	•	-	•	-	-	•
Chromite	0.28	0.12	0.05	0.11	0.10	0.14	0.20	-	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Haematite	10.29	11.03	11.42	11.43	11.17	11.02	11.27	12.05	11.57	12.13	10.69	12.04	12.44	11.85	10,55
Ilmenite	0.23	0.32	0.33	0.35	0.35	0.32	0.31	0.38	0.30	0.37	0.29	0.36	0.36	0.36	0.34
Sphene	0.95	1.05	1.48	1.15	1.27	·0;90	0.97	1.85	1.87	1.84	2.76	2.47	2.50	2.53	2.60
Apatite	0.17	0.19	0.22	0.17	0.20	0.17	0.17	0.29	0.30	0.30	0.05	0.59	0.00	0.01	0.04
Rufile	L	-	<b>-</b> .		I	-		-	-			-	•	-	-
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	DH1-1	DH1-2	DH1-3	DH1-4	DH1-5	DH1-6	DH1-7	DH1-8	DH1-9	DH1-10	DH1-11	DH1-12	DH1-13	DH1-14	DH1-15
Depth (metres)	56.50	65.10	75.00	83.80	125.50	141.30	160.40	164.70	167.20	169.20	175.30	189.00	212.00	223.70	248.30
Formation	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge
wt.%									·						
SiO	56.83	52.00	55.58	53.41	56.94	55.87	55.01	58.17	53.67	60.13	56.92	58.29	56.97	54.36	51.21
TIO,	0.76	0.94	0.78	0,80	0.87	0.76	0.72	0,73	0.73	0,75	0.72	0.76	0.66	0.89	1.01
A1.O.	12.99	15.77	13.17	13.57	13 44	13.12	13 77	13.03	15.89	13 43	13.56	13.58	12.67	12 72	13.22
E.O.	9.11	0.13	9.55	0.08	0.80	0.05	0.00	7.68	8 01	6.61	7 80	8.41	7.85	0.08	10.43
MnO	0.11	9.15	0.12	9.98	0.12	0.12	9.09	0.11	0.91	0.01	0.13	0.41	0.10	0.14	0.13
MinO	0.08	4.19	0.12	0.14	4.27	0.12	5 22	0.11	2 70	0.08	4 93	0.09	2 97	. 0.14	2 22
ingo	3.21	4.20	. 4.24	6.71	4.27	4,15 6,49	4 80	4.77	5.78	4.51	5.03	5.00	5.87	. 4.00	7.05
	4.93	0.50	0.09	0.21	2.47	0.02	3.00	4.50	0.25	4.21	3.33	2.40	2.02	. 3.24	2.35
Na <sub>1</sub> O	2.48	3.01	3.98	3.04	3.47	3.33	3.79	4,31	4.17	4.79	4.03	3.00	3.03	5.54	3.31
K <sub>2</sub> O	2.54	0.23	0.64	0.95	1.45	1.90	1.20	0.67	0.19	1.11	0.42	1.70	1.05	1.04	0.84
P <sub>2</sub> O <sub>5</sub>	0.15	0.17	0.15	0.15	0.16	0.16	0.15	0.15	0.16	0,16	0.15	0.13	0.14	0.20	0.20
H <sub>2</sub> O-	0.14	0.31	0.56	Q.34	0.14	0.12	0.32	0.34	0.18	0.15	0.20	0.24	0.23	0.13	0.34
LOI	4.34	5.18	2.57	2.98	2.68	2.23	2.61	2.26	3.29	2.35	. 2.11	2.59	4.10	2.67	5.15
тот	96.58	98.33	. 97.33	97.11	100.14	98.46	96.91	96.98	97.31	98.08	97.50	99.35	97.63	97.61	97.11
ppm															
Rb	59.50	8.00	15.40	21.30	38.50	60,30	28.70	17.30	5.80	25.60	11.10	45.10	41.00	46.60	23.90
Ba	517.30	88.70	203.40	277.00	345.80	401.40	363.80	258.70	91.20	369.00	127.60	637.00	672.10	503.80	316.50
Sr	339.20	604.50	404.90	176.60	299.70	343.70	161.30	218.70	867.70	171.90	411.20	270.80	348.10	294.10	487.10
Zr	134.10	142.10	135.00	144.20	146.90	139.80	160.30	155.60	133.20	163.00	148.60	154.60	139.60	164.10	175.30
Nb	5.50	6.60	6.10	08.6	0.00	7.00	4.70	3.00	4.20	3.201	4.10	4.50	4.40	/.00	8.00
N1 7-	79.50	92.90	90.60	104.30	94.60	92.50	129.00	114.00	108.30	62.20	107.00	114.50	68.00	121.50	99.80
Zn	08.20	/0.30	68.90	/0./0	90.20	84.00	82.10	104 50	177.40	105 80	107.00	102.00	104.70	262.10	87.40
lor Ion	170.10	133.40	100.00	147.40	80.10	86.20	196.00	112.60	20 70	23.10	52.90	56 30	57.20	94 30	79.60
	165.00	212.50	203.90	182 70	169.00	167 30	160.80	151.60	203.60	128 80	177.60	149.20	145.80	180.70	171.80
v.	15.00	212.50	203.90	18 70	21 10	20.30	17 30	15 30	17 10	12 60	17.00	16.90	15.00	22.00	25 20
Sa	13.50	23.60	28.10	10.70	21.10	16 40	18 60	17.50	21.40	16 90	18 10	20.00	18 60	18 10	10.00
Co	29.70	38.20	34.30	47.10	44.50	42.90	42.90	31.30	33.00	28.80	33.00	37.80	29.30	44.50	46.60
CIPW Norms, (%)															
Ouartz	20,75	12.09	13.50	11.62	14.58	13.06	12.53	15.54	12.05	15.38	12.27	15.75	18.33	11.97	12.49
Corundum	-	-	-	-	- '		-	-		-	-		-	-	•
Zircon	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
Orthoclase	16.32	1.47	4.02	6.00	8.82	12.08	7.56	4.20	1.20	. 6.87	2.61	10.80	10.47	10.24	5.43
Albite	22.78	32.90	35.75	32.84	30.17	29 32	34.12	40.43	37.60	42.40	41.33	31.56	27.48	29.81	30.57
Anorthite	18.29	28.20	17.20	19.09	17.30	15 69	18.13	14.15	25.71	12.44	15.66	16.29	17.29	15.71	20.47
Diopside	3.95	2.40	11.56	8.19	10.47	12 28	3.26	5.24	3.33	4.75	9.60	9.99	10.79	12.84	14.18
Wollastonite	-	-	-		- `	-	-	•			-	-	•	-	-
Hypersthene	6.85	10.37	6.65	9,33	6.08	5 07	12.61	10.16	8.49	9.03	8.17	4.82	5.34	6.30	2.46
Olivine	-	- ·	•	-	-		•	•	-	•	•			-	-
Chromite	0.04	0.03	0.04	0.03	0.03	0.03	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.06	0.02
Haematite	8.81	9.83	9.08	10.64	10.16	10.35	9.67	8.14	9.49.	6.92	. 8.29	8.71	8.41	10.53	11.38
Ilmenite	0.19	0.31	0.28	0.34	0.28	0,28	0.29	0.26	0.22	0.19	0.30	0.21	0.24	0.32	0.33
Sphene	1.79	2.08	1.67	1.66	1.83	1.58	1.51	1.57	.1.63	1.69	1.47	1.66	1.43	1.89	2.28
Apatite	0.39	0.44	0.38	0.38	0.39	0.40	0.38	0.38	0,41	0.40	0.37	0.32	0.36	0.50	0.52
Rutile	1 <u>-</u>	-	-	· ·	•			<u>·</u>	-	·		· ·	<u> </u>	<u> </u>	<u> </u>

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	DH1-16	DH1-17	DH1-18	DH1-19	DH1-20	DH1-21	DH1-22	DH1-23	DH1-24	DH1-25	DH1-26	DH1-28	DH1-29	DH1-30	DH1-31
Depth (metres)	262.90	285.00	309.60	340.00	367.20	382.00	399.80	411.40	420.80	431.40	441.70	475.70	496.00	513.50	525.10
Formation	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge	Allanridge
wt.%								•					1		
SiO <sub>2</sub>	52.68	53.92	54.50	53.83	55.00	54.91	54.04	50.20	52.89	52.00	52.47	53,56	49.54	51.21	51.34
TIO,	0.99	1.03	0.95	0.96	0.92	1.04	1.01	1.13	1.03	0.97	1.01	0.95	1.03	1.08	1.03
ALO	12,98	13.05	13.19	12.79	12.47	12.94	12.92	13.63	13.33	13.15	13.28	12.75	12.78	13.21	12.61
Fe O.	10.66	10.82	10.56	11.24	10.84	11 33	10.89	10.28	10 73	10.35	10 44	10.35	11.63	11.27	6:39
MnO	0.00	0.13	0.13	0.15	0.14	0.15	0.13	0.14	0.15	0.14	0.13	0.13	0.13	0.13	0.11
Ma()	3 40	2 93	3.62	4 00	4 27	4.08	3.62	4 85	3.67	4 57	4 20	4 54	3.61	4.00	2.88
C	6 38	6 76	6 66	6 64	6.92	6.02	6.71	6.02	7.09	7.88	8 19	7.50	7.95	7 71	10.13
No O	2 91	3.41	3.44	3 73	3 50	3 21	3 31	2.54	3 41	4 11	3.49	3 38	2 97	3 73	3 97
Najo	2.91	1.16	1.45	0.70	1.70	1.45	2.12	0.96	1.21	9,11	0.77	1.60	2.27	3.75	1.40
K <sub>2</sub> O	2.48	1,10	1.43	0.79	1.72	1,43	2.13	0.60	1.51	0.15	0.77	1.39	2.38	1.74	0.000
P <sub>2</sub> O <sub>5</sub>	0.21	0.23	0.21	0.21	0.21	0.23	0.23	0.23	0.24	0.23	0.23	0.23	0.23	0.24	0.23
H <sub>2</sub> O-	0.24	0.17	0.15	0.17	0.18	0.22	0.13	0.14	0.08	0.15	0.14	0.05	0.20	0.17	0.16
LOI	4.12	3.80	3.03	.2.91	2.14	2.91	2,95	6.39	3.36	4.10	4.68	2.89	4.70	3.64	6.84
TOT	97.17	97.41	97.89	97.42	98.31	98.29	98.07	96.41	97.29	97.80	99.03	97.92	97.15	98.13	
ppm	(0.10	20.00	26.00	10.10	20.70	22.10	40.70	10.70	20 10	4.60	14 60	21.00	62.00	27.00	20.00
RO	035.10	444.20	270.20	278.50	510.80	33.10	45.70	995 10	570.60	4.30	14.30	402.20	1 200 70	1 000 50	460 10
D8	302.00	\$70.00	200.20	368.50	418 20	475.10	422.30	367.50	423.70	506.00	400.30	453.50	613 70	635.20	478.00
3r 7-	188.00	108.10	183.30	177.00	169.40	190.70	188 10	195.90	184.90	176.00	160 00	183 00	173.70	177 50	176.00
Nh	10.40	9 80	9.50	8 30	7.60	9 90	10.60	8 20	8 40	7.80	. 6.00	9.00	970	9.80	8 10
Ni	99.80	100.50	109.60	135.00	144 50	124 70	123 70	131.80	125 60	161.90	167.20	177.10	164.00	150.80	146 50
7.0	97.00	90.30	98.50	91 70	97.00	94 00	100 30	120.90	82.10	89 20	83.20	100 40	111.70	103.50	76.00
Cr	73 90	30.30	33 60	74 00	86 80	45.90	33 50	32.40	30.40	148 50	188 40	191 20	62.50	53.90	68 40
Cu	107.10	140.90	94.00	103.00	87.10	66.30	106.40	19.70	102.10	43.00	184.50	93.10	108,80	113.50	45.20
v	164,90	178,50	177.70	175.50	175.10	183.80	173.00	196.90	178.00	162.60	173.10	161.20	167.20	185.20	160.90
Y '	25.60	27,70	25.30	23.50	23.30	24.90	12.50	26.70 ·	24.50	25.30	23.90	27.30	26.50	26.80	24.70
Sc	14.40	13.60	16.70	19.20	19.20	23.40	16.90	20.30	16.90	15.00	20.00	16.90	18.30	16.10	25.30
Co	47.00	46.90	47.40	54.60	51.00	50.80	48.70	48.90	48.00	45.00	49.30	44.80	51.90	<u>52.7</u> 0	29.20
CIPW Norms. (%)				:											
Quartz	12.20	15.66	13.86	13.63	12.13	11.90	11.83	15.22	12.28	9.48	11.14	10.57	6.86	6.15	5.57
Corundum	· ·	-	-	-		• .	-	-	• -	-	•	-	-	-	-
Zircon	0.04	0.04	0.04	0.04	0.04	0.04	Q.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Orthoclase	15.82	7.35	-9.06	4.96	10.61	8.93	13.27	5.66	8.26	0.95	4.84	9.91	15.27	10.92	9.78
Albite	26.53	30.88	30.73	33.45	30.85	34.44	29.48	23.91	30.74	37.17	31.34	30.11	27.24	33.46	37.25
Anorthite	16.23	18.09	17.20	16.80	13.81	14.05	14.88	25.94	18.36	18.18	19.45	15.73	15.77	15.06	13.53
Diopside	10.62	10.37	10.60	10.96	14.12	9.89	12,40	1.83	11.42	14.99	14.99	15.02	17.69	16.38	17.18
Wollastonite	-			-	-		-	-		-	-	-	-	-	6.43
Hypersthene	4.22	3,01	4.61	.5.49	4.54	601	3.76	12.60	4.46	5.22	4.16	4.96	1.58	2.99	•
Olivine				-	-		-	-	-	-	-	-	-	-	-
Unromite	0.02			0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.04	0.04	0.01	U.U]	0.02
Haematite	11.49	11.58	11.15	0.20	11.29	13,79	11,40	0.29	0.20	11.00	0.22	10.90	12.01	11.93	7.09
limedite Sabano	0.30	2.00	2.33	2.01	1.00	219	2 10	2 60	2 20	2 00 1	2 21	2.04	2 20	0.34 2.39	2 42
Anatito	2.23	2.28	2.04	2.01	0.50	2,10 0.57	2.17 0.59	2.00	0.61	0.59	0.59	2.04 0.52	2.29	0.61	0.61
Apaine .		0,59	0.55	0.55	0.52	0.57	0.08	0.01	0.01	0.58	0.08	0.58	0.00	0.01	0.01
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	DH1-32	DH1-33	DH1-34	DH1-35	DH1-36	DH1-37	DH1-38	DH1-39	DH1-40	LRP3-3	LRP3-4	LRP3-7	LRP3-8	LRP3-9	LRP3-10
Depth (metres)	532.00	537.60	542.50	551.30	560.40	575.0	583.20	598.30	632.50	535.54	541.12	554.62	567.65	575.40	579.60
Formation	Allanridge	Allanridge	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.							
wt.%															
SiO <sub>2</sub>	44.25	56.03	48.38	48.87	52.89	52.53	· 51.77	52.51	52.99	58.35	43.79	57.26	57.14	51.18	51.81
TIO,	1.06	1.01	1.04	1.17	1.05	1.09	1.07	1.06	1.08	1.50	1.35	1.56	0.50	0.45	0.46
A1.0.	13.60	12.30	13.13	12.88	13.20	13.38	13.48	13.37	13.50	14.40	13.96	14.84	11.63	12.03	11.19
Fe.O.	4.51	8 29	11.96	8 27	11.62	10.52	9.51	11.01	11 17	9 4 4	11.61	11.70	946	9.40	10.66
MnO	0.15	0.13	0.16	0.14	0.12	0.3	0.13	0.13	0.14	0.09	0.11	0.10	0.13	0.16	0.10
MaO	1.86	4 45	4 18	3.49	3 94	3.85	3.87	4 21	4 27	4 27	5 55	5.84	10.98	11 77	12 20
C 0	13.51	6.83	. 6.93	10.15	5 70	6.95	7 34	6.93	7.09	4.27	10.88	2.86	3 48	5.80	6.55
No O	3.90	4 31	2.50	3.06	3.62	4.07	3.85	3 13	4.05	0.12	0.35	0.55	0.85	1 33	1.28
Na <sub>2</sub> O	5.80	4.51	2.50	5.00	1.01	4.07	1.02	1.80	0.03	0.12	1.80	1.05	0.05	0.01	1.20
<b>N</b> <sub>2</sub> <b>O</b>	2.40	0.90	0.24	0.04	1.01	10	1.02	1.07	0.64	2.73	1.60	1.95	0.01	0.01	0.01
P <sub>1</sub> O <sub>5</sub>	0.24	0.23	0.21	0.24	0.22	04	0.24	0:24	0.24	0.71	0.67	0.74	0.07	0.07	0.07
H <sub>2</sub> O-	0.13	0.19	0.07	0.13	0.16	0.15	0.16	0.17	0.17	0.12	0.08	0.11	0.10	0.32	0.16
LOI	10.99	3.40	7.25	8.57	3.30	2.60	5.15	2.51	2.03	5.33	10.91	4.68	7.04	7.86	6.33
101	96.50	98.07	96.05	97.61	96.83.	96.67	97.59	97.16	97.57	101.33	101.06	102.19	101.39	100.38	101.00
ippm n.	41.60	17.00	6 70	12.50	16.00		179 00	22 50	17.60	107 50		84.00	0.01	0.01	0.01
RD	41.00	17.00	0.70	12.50	10.90	22,00	18.80	33.3U 970.60	504.70	107.50	73.30	64.90	0.01	26.20	20.70
D8	090.00	419.00	147.00	373.20	440.00	721.20	419,40	670.30	594.70 706.80	318.00	207.90	453.10	102.70	20.30	126 70
Sr 7-	180.00	172.20	330.40	375.00	176.20	121.20	177.80	191 70	160.00	47.00	119.40	243.10	58 50	63.30 56.40	56.80
Zr ·	7 10	6.00	8 30	7.60	8 10	177.00	8 10	0.00	9.50	16.00	15 50	16.60	1.50	270	3 30
N	52.30	163.90	175 30	150.00	186 20	162.10	167.10	164.80	170.00	58.00	83.50	82 70	270.00	267.60	318.80
7n	50.60	84 40	175.50	89.90	120.70	92 50	97 70	105.60	105 70	61.90	114 60	104 20	120.40	66 50	67.80
Cr	64.20	69.00	62.10	74 20	80.20	53.20	56.80	56.60	60.30	214.40	179.10	218.20	1.869.60	1.501.50	1.756.20
Cu	13.00	36.20	122.50	111.50	54.40	111.50	81.90	116.60	114.80	10.30	9.70	6.30	18.10	39.00	56.50
v	128.80	166.90	198.70	168.20	201.50	178.50	184.40	177.50	172.20	244.20	197.40	234.80	239.10	225.60	212.30
Y	27.40	23.10	26.10	26.70	23.00	26.50	25.40	27.40	27.40	35.50	38.90	34.50	9.30	8.80	8.80
Sc	21.10	18.60	21.40	22.80	19.20	16.10	18.30	20.90	20.00	21.60	17.70	21.60	34.70	31.50	23.60
Co	15.70	41.20	59.50	35.80	55.90	48.30	46.20	49.60	52.50	40.80	53.60	57.00	72.00	71.00	80.20
CIPW Norms. (%)		· · · ·						-							
Quartz	-	12.00	16.18	9.68	13.51	8.81:	9.26	10.56	9.44	35.04	10.09	34.67	30.25	15.12	14.52
Corundum		-* -*	-	-	-	-	-	-	-	5.35	-	8.58	4.29	•	-
Zircon	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.07	0.07	0.01	0.01	0.01
Orthoclase	16.63	5.64	1.60	4.26	6.40	7.31	6.54	11.84	5.21	16.87	11.84	11.87	0.06	0.06	0.06
Albite	35.01	38.60	23.84	29.12	32.80	36.67	35.30	28.03	35.93	1.06	3.29	4.78	7.63	12.20	11.46
Anorthite	15.19	12.25	26.96	21.98	18.01	15.81	17.90	1.7.88	17.00	17.41	34.65	9.74	17.88	29.11	26.21
Diopside	11.72	14.93	5.57	21.11	5.98	12.70	13.09	10.93	12.02	• '	12.32	-	-	0.29	5.10
Wollastonite	18.03		-	0.91	-	-		-	5.00	11.00	-	-		21.66	20.02
Hyperstnene	-	4.82	9.15	•	7.74	.4.54	4.39	0.05	5.00	11.09.	9.04	14.75	29.01	51.00	50.02
Chromite		-		0.02	-	0.01	0.01	0.01	0.01	0.05	0.04	0.05	0.43	0.35	0.40
Usematite	5.002	0.02	12 49	0.02	12 45	11 20	10.31	11 64	11 71	0.05	12 80	12 01	10.04	10.20	11 29
Ilmanite	0.20	0.34	0.44	0.38	0 33	0.35	0.35	0 34	0.36	0.19	0.27	0.22	0.10	0.23	0.27
Sphane	0.30	2 10	231	2 74	2 34	21	2 40	2 32	2 32	-	3,33	-	-	0.90	0.85
Anatite	0.67	0.58	0.56	0.64	0.56	0.61	0.62	0.61	0.60	1 76	1 76	1 81	0.18	0.18	0.18
Rutile	-	-	-	-			-	•		1.46	-	1.48	0.48	-	

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· .	LRP3-11	LRP3-12	LRP3-13	LRP3-14	LRP3-15	LRP3-16	LRP3-17	LRP3-18	LRP3-19	LRP3-20	LRP3-21	LRP3-22	DKL5-1	DKL5-2	DKL5-3
Depth (metres)	585.00	598.76	602.74	611.60	640.75	647.00	658.00	662.10	675.90	683.25	700.50	713.85	260.95	278.12	320.00
Formation	Klip.	Klip.	K.lip.	Klip.	Klip.	Klir.	Klip.	Klip.	Klip,	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.
wt.%								•		•					
SiO <sub>2</sub>	50.43	59.62	56.58	54.69	52.42	52,5.5	54.00	51.95	51.67	53.76	53.70	53.83	55.81	54.05	54.08
TIO <sub>2</sub>	0,43	0,68	0,63	0,56	0.46	0,44	0.44	0.38	0.44	0.41	0.39	0.42	1.13	1.18	1.14
Al <sub>2</sub> O <sub>3</sub>	10.96	15.25	14.41	13.64	11.00	10.45	11.13	10.75	11.46	11.13	9.98	9.80	13.61	13.60	13.06
Fe <sub>2</sub> O <sub>3</sub>	11.10	9.67	8.66	9.46	10.81	10.72	-9.83	10.97	10.86	· 10.61	9.53	9.83	10.84	10.43	9.27
MnO	0.21	0.12	0.12	0.13	0.17	0. ŀ5	0.18	0.16	0.20	0.18	. 0.15	0.15	0.12	0.12	0.15
MgO	12.78	5.71	5.55	6.35	11.29	12.53	. 10.65	12.28	11.40	10.96	13.15	13.36	4.10	3.80	4.10
CaO ·	7.93	1.79	4.66	7.36	8.68	7.90	8.14	7.48	8.51	7.52	5.84	5.98	6.51	7.13	7.63
Na <sub>2</sub> O	1.51	3.16	3.15	1.91	2.03	1.34	2.15	1.40	2.36	2.11	0.05	1.03	3.63	3.32	2.35
К,О	0.01	0.54	0.40	3.56	0.66	0.59	0.47	0.21	0,34	0.29	3.06	0,88	1.20	1.96	1.19
P2O5	0.06	0.11	0.11	0.09	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.06	0.25	0.26	0.25
H <sub>2</sub> O-	0.18	0.07	0.06	0.08	0.19	0.24	0.22	0.24	0.24	0.28	0.20	0.14	0.06	0.05	0.06
LOI	5.20	3.78	5.82	2.67	3.05	3.88	3.10	4.59	2.90	3.25	3.70	3.81	2.05	3.06	7.16
тот	100.80	100.50	100.15	100.50	100.82	100.86	100.37	100,47	100.44	100.56	99.80	99.29	99.31	98.96	100.44
ppm															
Rb	0.01	7.20	3.40	91.80	15.30	13.00	10.50	1.20	6,30	5.50	86.10	20.60	17.50	31.60	16.50
Ba	29.90	351.50	535.90	5,433.00	472.90	583.50	300.60	148.40	257.40	184.10	2,285.50	358.20	537.70	1,177.60	486.90
Sr	153.40	136.60	326.50	410.30	165.90	116.20	208.50	101.00	126.10	101.10	87.80	78.70	656.90	613.20	261.70
Zr	50.20	88.80	80.20	76.50	57.40	56.70	54.50	48.30	57.60	51.60	51.70	51.50	183.90	194.00	172.80
ND	3.90	3.10	2.70	7.40	4.80	4.70	5.20	3.20	4.70	3.60	4.60	3.50	10.30	10.10	8.40
N1 7-	381.30	146.00	127.50	149.90	294.00	301.00	258.90	401.00	345.30	337.50	399.10	355.40	119.90	108.20	149.60
	2 074 70	502.20	404.40	265.40	1 308 10	1 012 10	1 501 10	2 100 20	1 004 00	1 001 60	2 506 40	2 386 20	93.40 21.70	36.00	13.60
	2,074.70	35.00	36 10	67.00	52 90	41 10	49 00	2,133.20	1,334.30	24 10	2,500.40	2,580.50	344.40	98.70	131.00
v	194 80	234 90	200.60	174 80	187.20	176.10	180.40	187 40	188 50	185 60	150.90	172 70	170 10	170.60	167 30
Y I	9.30	11.10	10.80	16.00	9.70	10.60	11.00	7.70	9.70	8.80	9.20	8.00	23.20	23.70	19.30
Sc	26.30	28.50	27.50	23.40	26.30	23.90	18.80	22.60	28,80	26.60	28.80	26.60	14.50	15.30	14.80
Co	79.30	65.10	52.10	50.40	70.60	70.00	63.60	78.60	73.40	67.00	68.00	72.20	55.90	57.60	51.60
CIPW Norms. (%)															
Quartz	9.58	28.02	19.82	8.72	8.11	11.29	11.31	12.45	6.52	12.08	12.41	14.67	13.94	11.10	18.46
Corundum	-	6.66	0.54	-	-	-	•	-	-	•		-	-	-	-
Zircon	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.04	0.04
Orthoclase	0.06	3.31	2.51	21.56	4.00	3:61	2.87	1.30	2.07	1.77	18.89	5.46	7.30	12.10	7.55
Albite	13.39	27.66	28.27	16.53	17.60	11.72	18.74	12.39	20.52	18.40	0.44	9.14	31.60	29.31	21.33
Anorthite	24.22	8.39	24.04	18.74	19.44	21,48 12,60	19.94	23,40	20.23	20.07	18.83	20.49	17.84	17.18	23.17
Wellestenite	12.10	-	-	14.21	10.10	13,09	15.65	10.65	10.94	12.75	0.15	0.99	0.27	11.52	9.03
Hypersthene	27 72	14 71	14.66	9.68	20 40	25.42	20.00	26.96	21 33	22.22	30.40	31.66	6.68	4 56	6 4 9
Olivine		-	-	-	20.50		-			-	50.10	-	-	-	
Chromite	0.47	0.13	0.09	0.08	0.29	0.43	0.33	0.49	0.44	0.44	0.56	0.54	0,01	0.01	0.01
Haematite	11.63	10.01	9.19	9.68	11.08	11,08	10.13	11.47	11.16	10.93	9.94	10,31	11.15	10.88	9.94
Ilmenite	0.28	0.23	0.26	0.28	0.27	0 18	0.26	0.15	0.25	0.21	0.08	0.09	0.31	0.31	0.39
Sphene	0.75	-		1.06	0.80	0.88	0.78	0.78	_0.78	0.77	. 0.90	0.97	2.47	2.64	2.50
Apatite	0.15	0.27	0.28	0.22	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.15	0.61	0.65	0.64
Rutile	·	0.58	0.53		-		l	<u> </u>	•					<u> </u>	·

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	DKL5-6	DKL5-7	DKL5-7A	DKL5-8	DKL5-8A	DKL5-9	DKL5-10	DKL5-10A	DKL5-12	DKL5-12A	DKL5-14	DKL5-15	DKL5-15A	DKL5-16	DKL5-16A
Depth (metres)	528.85	541.80	552.07	567.45	573.32	583.07	600.17	617.23	640.34	649.69	681.60	698.59	709.91	722.80	731.19
Formation	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.
wt.%										-					
SiO <sub>2</sub>	43.36	52.65	53.87	52.39	53,73	53.47	52.62	53.32	52.95	50.98	38.81	55.43	54.91	54.68	56.75
TIO,	0,41	0.51	0.58	0.52	0.50	· 0.49	0.48	0.14	0.48	0.58	1.03	0.64	0.58	0.56	0.57
A1,0,	í2.14	12.74	13.07	12,54	12.79	12.70	12.38	12.58	12.76	14.36	4.14	14.94	14.26	13.82	13.58
Fe-O1	8.61	9.96	10.15	9.81	9.89	10.99	10.49	. 10.41	10.70	9.76	10.79	10.22	9.89	10.95	9.67
MnO	0.19	0.18	0.14	0.14	0.13	0.14	0.14	0.14	0,19	0.11	0.09	0.15	0.14	0.15	0.14
MgO	5.36	8.62	7.52	7:57	7.84	9.65	9.00	8.77	8.78	5.62	17.68	5.82	6.50	7.40	6.97
CaO	13.70	7.38	7.66	7.76	7.26	6.55	6.47	6.82	. 7.99	7.97	14.87	5.70	8.05	7.18	7.13
Na <sub>2</sub> O	0.13	3.18	2.19	2.71	2.10	2.12	. 2.48	2.35	2.53	2.63	0.16	3.58	3.52	2.30	2.94
K,0	1.99	0.62	1.71	0.92	1.50	0.83	1.55	2.00	1.29	0.53	0.06	1.15	0.49	1.47	1.82
P.O.	0.07	0.07	0.09	0,09	0.08	0.08	0.08	0.08	0.07	0.12	0.35	0.10	0.09	0.09	0.09
H-0-	0.11	0.20	0.12	0.16	0.13	0,17	0.10	0.09	0.18	0.14	0.46	0.11	0.11	. 0.11	0.05
LOI	14.10	3.78	2.32	2.50	2.97	3.15	2.42	2.42	2.49	6.76	10.44	2.32	2.26	2.46	1.98
тот	100.17	99.89	99.42	97.11	98.92	100.34	98.21	99.12	100.41	99.56	98.88	100,16	100.80	101.17	101.69
ppm															
Rb	88.80	20.60	55.90	19.70	36.20	19.70	41.50	64.90	32.70	9.30	1.70	29.90	11.30	42.80	59.10
Ba	200.70	475.10	1,250.10	930.60	1,178.20	505.80	1,047.60	591.30	551.90	96.70	20.30	549.80	219.20	638.10	498.90
Sr	99.50	299.20	538.00	343.70	327.90	255.40	280.20	256.90	247.90	93.30	456.90	379.90	361.40	433.40	440.20
Zr	57.00	64.20	72.10	70.00	64.80	62.60	64,50	65.10	62.80	82.70	49.30	82.60	78.30	73.60	73.30
Nb	4.40	4.40	5.60	5.10	4.80	4.40	5.10	5.30	-5.10	4.50	10.80	5.90	5.60	0.10	5.00
Ni	239.00	203.50	154.20	163.20	189.50	228.70	213.70	214.50	244.80	138.70	400.80	120.10	141.60	158.20	70.10
	31.70	07.40	09.00	520.20	614.90	01.10	70.30	73.70	1 200 90	226.30	1 625 60	247.60	321.80	398.60	375.00
Cr Cu	1,030.90	57.00	447.00	40.20	47.70	56 50	66 40	56.90	40.90	173 10	247 30	57 20	57 40	39.90	54 50
v	181.50	189.90	177.40	193.60	193.40	205 50	184 80	183 60	187.10	196 70	171.90	193.70	184.80	187.80	174.40
v	10 80	12 30	14.50	13.00	12.30	12.80	13.10	12.60	13.00	13.00	9.00	14.30	14.90	14.20	14.10
Sc	33.20	29.00	25.30	28.30	25.10	31.20	30.00	28.80	25.80	27.50	11.80	24.10	26.10	· 26.10	29.50
Co	50.80	59.00	60.00	62.10	64.50	72.10	64.40	65.60	61.50	59.50	78.90.	59.40	55.40	62.20	57.40
CIPW Norms. (%)			·		· · · · · ·					_					
Quartz	7.70	7.34	11.03	9.94	12.31	12.09	8.41	8.08	7.62	12.21		11.16	9.81	12.20	10.76
Corundum	-	-	-	-	.	•	-	-	•	•	-			-	-
Zircon	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01
Orthoclase	13.72	3.83	10.44	5.77	9.27	5.06	9.59	12.26	7.81	3.38	0.40	6.97	2.95	8.83	10.82
Albite	1.28	28.05	19.11	24.28	18.54	18.49	21.93	20.58	21.90	24.01	1.54	30.99	30.20	19.74	24.90
Anorthite	31.01	19.48	21.49	20.52	11.03	23,42	10.93	12.52	14.86	9.61	51 19	3 95	12.03	862	11.83
Wollostanito	33.51	15.44	12.55	14.55	11.03	0.50	10.29	12.04	14.80	9.01	51.15	5.95	12.54	0.02	
Hypersthene	1.52	16.16	13.52	13.24	15.28	21.72	18.67	16.76	15.50	10.65	1.92	13.01	10.44	14.70	11.94
Olivine		-					-	-			17.10	-	-	] .	.
Chromite	0.26	0.18	0,10	0.12	0.14	0.21	0.18	0.16	0.26	0.05	0.40	0.05	0.07	0.09	0.08
Haematite	10.02	10.38	10.47	10.39	10.32	11.33	10.96	10.78	10.95	10.53	12.26	10.46	10.05	11.11	9.70
Ilmenite	0.38	0.35	0.30	0.30	0.26	0.25	0.27	0.27	0.32	0.27	0.11	0.34	0.31	0.32	0.30
Sphene	0.67	0.85	1.09	0.97	0.94	0.92	0.89	- 1	0.80 .	1.18	2.73	1.17	1.05	0.98	1.02
Apatite	0.19	0.17	0.22	0.23	0.20	0.20	0.20	0.20	0.17	0.31	0.94	0.24	0.22	0.22	0.21
Rutile		-	-		-	· · .			-		-	-	· •	-	•

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	DKL5-16B	DKL5-17	DKL5-17A	DKL5-17B	DKL5-17C	DKL5-18	DKL5-18A	DKL5-18B	DKL5-20
Depth (metres)	737.19	744.19	755.86	764.85	775.81	782.12	788.97	803.89	822.17
Formation	Klip.	Klip.	Klio.	Klip.	Klip.	Klip.	Klip.	Klip.	Klip.
wt.%									
SiO <sub>2</sub>	49.96	53.57	48.92	52.60	52.44	51.82	53.68	52.64	50.44
TIO,	0.50	0,46	0.47	0.45	· 0.46	0.42	0.41	0.37	. 0.43
Al <sub>2</sub> O <sub>2</sub>	11.55	10.97	11.51	11.11	11.64	10.17	10.23	8.86	10,18
Fe,O1	11.40	10,46	12.00	10.77	10.39	10.44	10.87	10.29	10.79
MnO	0.14	0.16	0.::6	0.17	0.16	0.15	0.15	0.16	0.14
MgO	11.64	10,96	13.03	11.14	12.03	13.93	12.50	14.42	14.64
CaO	7.41	8.12	7.88	8.17	7.04	7.62	7.01	7.77	6.79
Na <sub>2</sub> O	1.82	1.81	1.46	1.98	1.75	1.42	1.14	0.06	1.17
K20	1.09	0.90	0.22	0.23	0.92	0.40	0.28	0.37	0.79
P <sub>2</sub> O <sub>3</sub>	0.07	0.06	0.07	0.07	0.06	0.06	0.05	0.05	0.06
Н,О-	0.17	0.17	0.17	0.19	0.16	0.08	0.16	0.16	0.13
LOI	3.17	3.00	4.37	3.13	3.39	3.67	4.21	4,56	3.98
тот	98.92	100.64	100.26	100.01	100.44	100.18	100.69	99.71	99.54
ppm									
Rb	28.90	23.40	4.:50	3.40	24.90	12.10	5.50	16.10	23.30
Ba	415.10	311.60	76.70	77.10	338.10	128,70	108.00	49.70	272.60
Sr	196.10	185.60	219.30	271.80	253.10	100.60	141.80	169.40	111.60
Zr	63.10	56.30	58.30	54.40	55.80	52.20	48.60	43.90	52.00
Nb	5,10	3.90	4.60	4.40	4.00	3.60	3.90	3.70	4.20
Ni	311.90	301.10	343.00	300.60	314.40	379.80	403.70	431.40	431.00
Zn	84.00	70,80	/9.50	66.90	66.70	69.30	79.40	67.80	73,20
Cr	1,460.70	1,284.80	1,744.70	1,570.70	1,037.80	2,233.80	2,410.20	2,859.00	2,553.10
	109.10	43.30	205 50	197.00	104 70	178.60	165 20	170.00	186.20
v	133.10	1/2.40	12 70	11 30	10.80	9.80	8 90	8 90	9 40
Sc	30.20	27.30	27.50	32 40	24 60	25.60	24 60	29.30	26 90
Co	73 60	68 80	80.90	69.50	74.50	76 70	78.30	74.90	79.40
CIPW Norms. (%)									
Quartz	5.88	10.75	6.86	10.79	9.01	9.13	15.72	17.03	7.56
Corundum	-	-	•		-	-	-	-	-
Zircon	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Orthoclase	6.75	5.47	1.36	1.41	5.62	2.46	1.72	2.31	4.90
Albite	16,11	15.71	12 91	17.33	15.28	12.46	10.01	0.53	10.37
Anorthite	21.08	19.66	25.30	21.47	21.89	20.95	22.82	24.02	21.17
Diopside	12.17	15.77	10 78	14.73	9.87	12.94	9.13	11.71	9.64
Wollastonite	-	-		-	-	-	-	-	
Hypersthene	24.69	20.70	28.91	21.87	20.33	29.98	28.09	32.38	33.74
Chromito		-	0.20	- 0.35	- 0.26	0.50	- 0.54	- 0.65	-
Haemetite	11 03	0.28	12.59	11 14	10 72	10.30	11 20	10.83	11 31
Ilmenite	0.10	0.75	0.21	0.24	0.72	0.12	0 10	0.05	0.06
Snhene	1 03	0.20	0.94	0.83	0.89	0.12	0.92	0.88	1.03
Anatite	0.17	0.15	0.17	0.17	0.15	0.15	0,12	0,12	0.15
Rutile	-	-	-	-	-	-		-	-
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