THE GEOCHEMICAL STRATIGRAPHY OF THE VOLCANIC ROCKS OF THE WITWATERSRAND TRIAD IN THE KLERKSDORP AREA, TRANSVAAL

by

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Thesis submitted in fulfilment of the requirements for the degree of Master of Science.

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January 1984

This thesis represents the original work
of the author except where specific
acknowledgement is made to the work
of others.

January 1984

ABSTRACT

This study was initiated with the aim of identifying the existence of any geochemical criteria which may be used to distinguish between the various volcanic formations within the Witwatersrand triad.

The Witwatersrand triad comprises three sequences: the Dominion Group at the base, the Witwatersrand Supergroup in the middle, and the Ventersdorp Supergroup at the top. It is underlain by Archaean basement rocks, and covered by rocks of the Transvaal sequence. The Dominion Group consists of the sedimentary Rhenosterspruit Quartzite Formation at the base, overlain by a bimodal succession of lavas. Basaltic lavas are the major component of the Rhenosterhoek Formation, while the overlying Syferfontein Porphyry Formation consists primarily of dacitic porphyries. Intercalations of one lava type within the other are common, however, so each formation is not the exclusive domain of only one lava type.

The Witwatersrand Supergroup, a predominantly argillaceous and arenaceous sequence, contains two narrow volcanic horizons, one of which, the Jeppestown Amygdaloid (now Crown Formation), consisting of tholeiitic andesites, occurs in the study area. The overlying Ventersdorp Supergroup has, at its base, the basaltic Klipriviersberg Group, of which four out of six formations are present in the study area, namely, the Alberton, Orkney, Loraine and Edenville Formations. This group is succeeded unconformably by the Platberg Group, consisting of the sedimentary Kameeldoorns Formation, followed by the (informal) Goedgenoeg, Makwassie Quartz Porphyry and Rietgat Formations. The Goedgenoeg and Rietgat Formations are basaltic, while the Makwassie rocks range from basaltic to dacitic, the majority being tholeiitic andesites and andesites.

The Pniel sequence at the top of the Ventersdorp Supergroup consists of the sedimentary Bothaville Formation, and the Allanridge Formation, the lavas of which are basaltic with some andesitic tendencies.

A well-defined geochemical stratigraphy was found to exist. From the eleven volcanic formations examined, nine distinct geochemical units emerged, as the Loraine and Edenville Formations were found to have the same geochemical characteristics, as did the Goedgenoeg and Rietgat Formations. Despite having undergone low-grade greenschist facies metamorphism, very clear variation patterns with height are displayed by the immobile elements Ti, P, Nb, Zr and Y, and the light rare earth elements La, Ce and Nd. In contrast, much scatter was observed in the variation patterns of Na, K, Mn, Ba and Rb.

Three techniques were employed to effect discrimination between formations - orthogonal discrimination, interelement and ratio vs ratio plots, and discriminant analysis. Confidence limits placed on normal probability plots served to isolate outlier samples for further examination by the various discrimination techniques.

A successful test of the efficacy of the discrimination techniques was afforded when fourteen samples from an unknown succession were positively identified as representative of the Klipriviersberg Group.

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1. PREAMBLE

The Witwatersrand triad is a sequence of mildly deformed sedimentary and volcanic rocks, now classified into the Dominion Group, Witwatersrand Supergroup and Ventersdorp Supergroup. These rocks represent a continuous supracrustal sequence deposited in intracratonic basins of the Kaapvaal Province granite-greenstone belt, approximately between 2.8 and 2.3 Gy (see Figure 1.1). The distribution of these three sequences is shown in Figure 1.2, while currently recognised outcrops are indicated in Figures 1.3, 1.4 and 1.5. In addition to their close association spatially, structurally and temporally, the presence of detrital gold and uranium mineralisation has long provoked widespread interest in these rocks. They therefore have an extensive history of investigation, which is summarised in a literature review in Appendix I.

The name "Ventersdorp Beds" was first proposed by Hatch (1903c) for a succession of lavas, pyroclastic rocks and boulder beds that he found unconformably overlying the "Lower Witwatersrand Beds" and granite near Ventersdorp. During the following year the name was modified to "Ventersdorp Series" (Hatch and Corstorphine, 1904a).

Molengraaff (1905) suggested the name "Dominion Reef Series" for a succession of reefs found in the Klerksdorp district, comprising sericite schists interbedded with gold-bearing conglomerates. These reefs are overlain by amygdaloidal basic lavas and porphyritic lavas, which were subsequently included in the Dominion Reef Series by Nel (1934a). Truter (1949) elevated the sequence to the status of system, which it retained until SACS (1980) changed it to the rank of group. Although numerous attempts have been made to correlate the Dominion Group with other volcanic and volcano-sedimentary units in South Africa, present evidence implies that its development was restricted to the Western Transvaal (see Figure 1.3), where it represents a precursor to the main Witwatersrand basin (Watchorn, 1980).

Stratigraphically, the group is divided into three formations (see Figure 1.6):

(1) The <u>Rhenostersprui Quartzite Formation</u> at the base composed mainly of coarse arkosic sediments, lenticular grits and conglomerates;

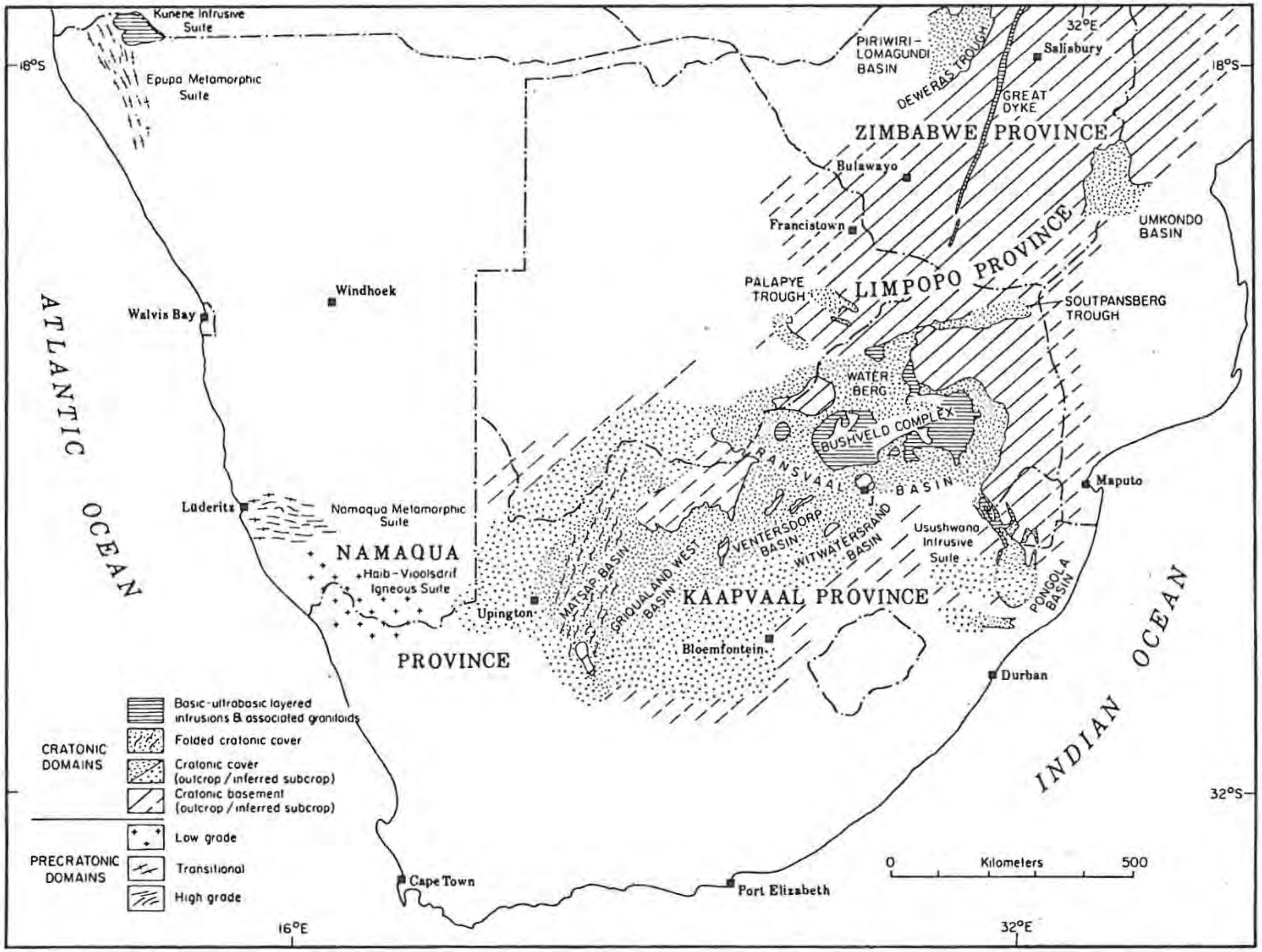


Figure 1.1 Nonpalinspastic map showing Late Archaean and Early Proterozoic supracrustal development from 2900 Ma to 1800 Ma (from Tankard et al., 1982)

Figure 1.2 Distribution of the Dominion, West Rand and Ventersdorp sequences (from Tankard et al., 1982)

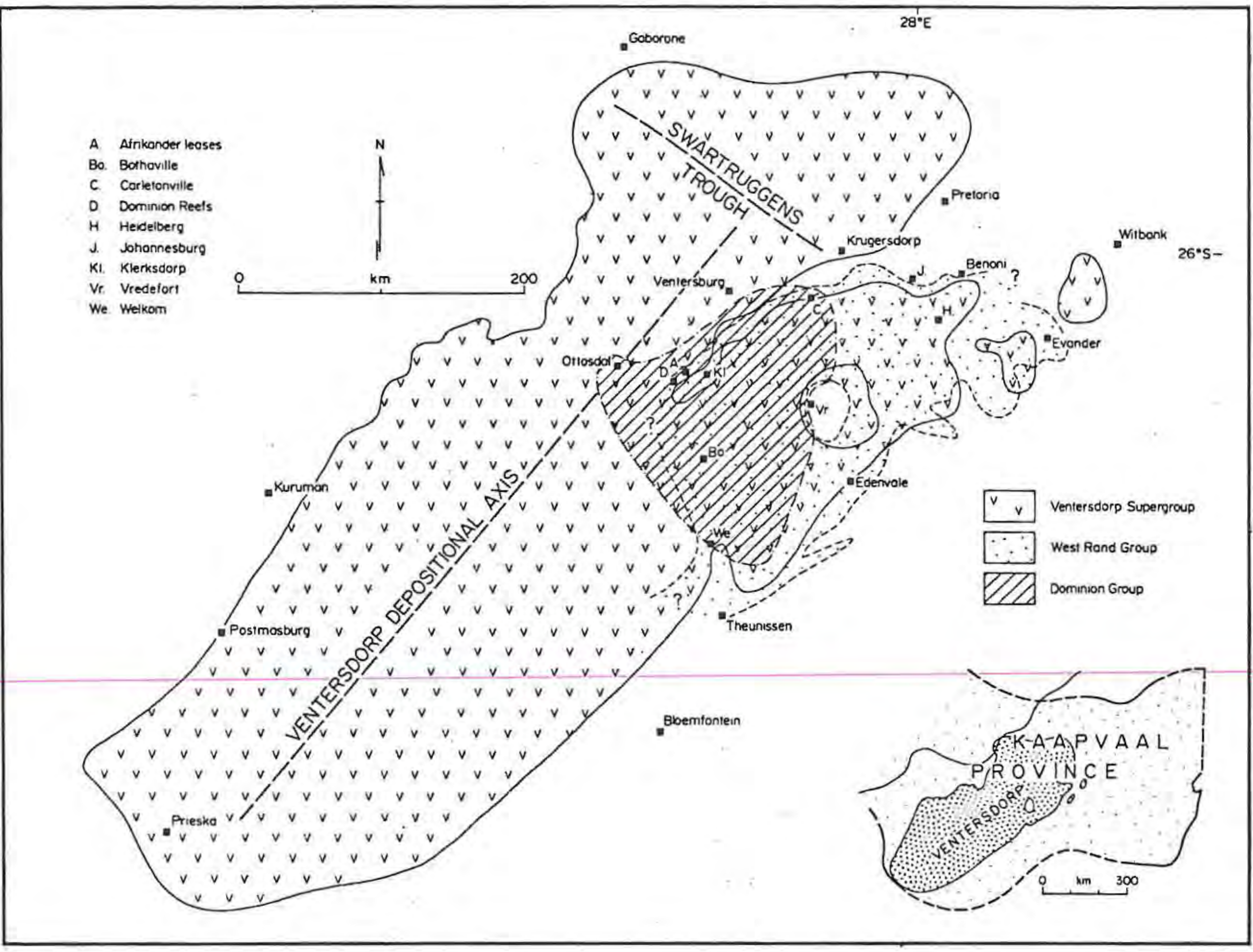


Figure 1.3 Distribution of outcrops of the Dominion Group (from SACS, 1980)

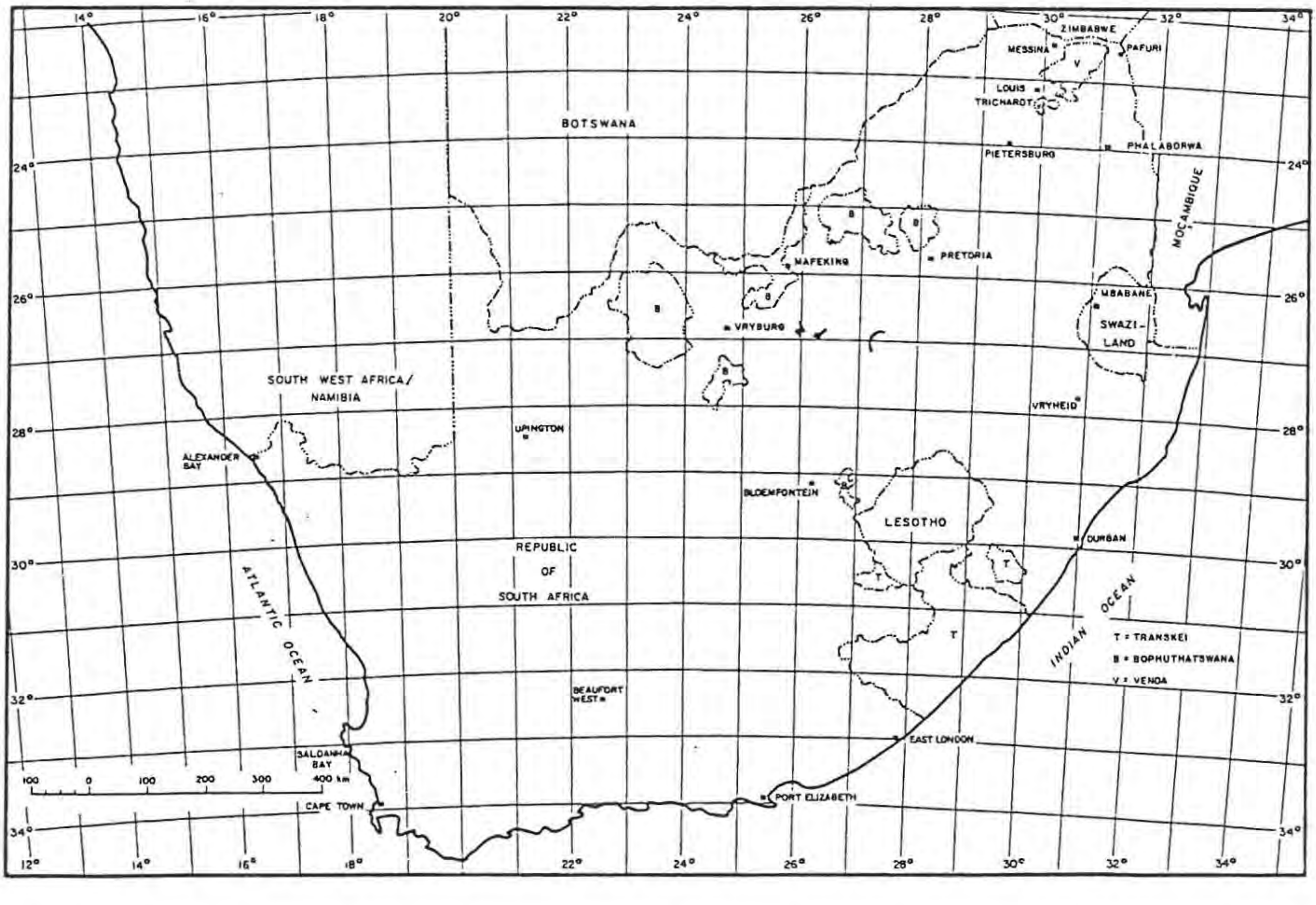


Figure 1.4 Distribution of outcrops of the Witwatersrand Supergroup (from SACS, 1980)

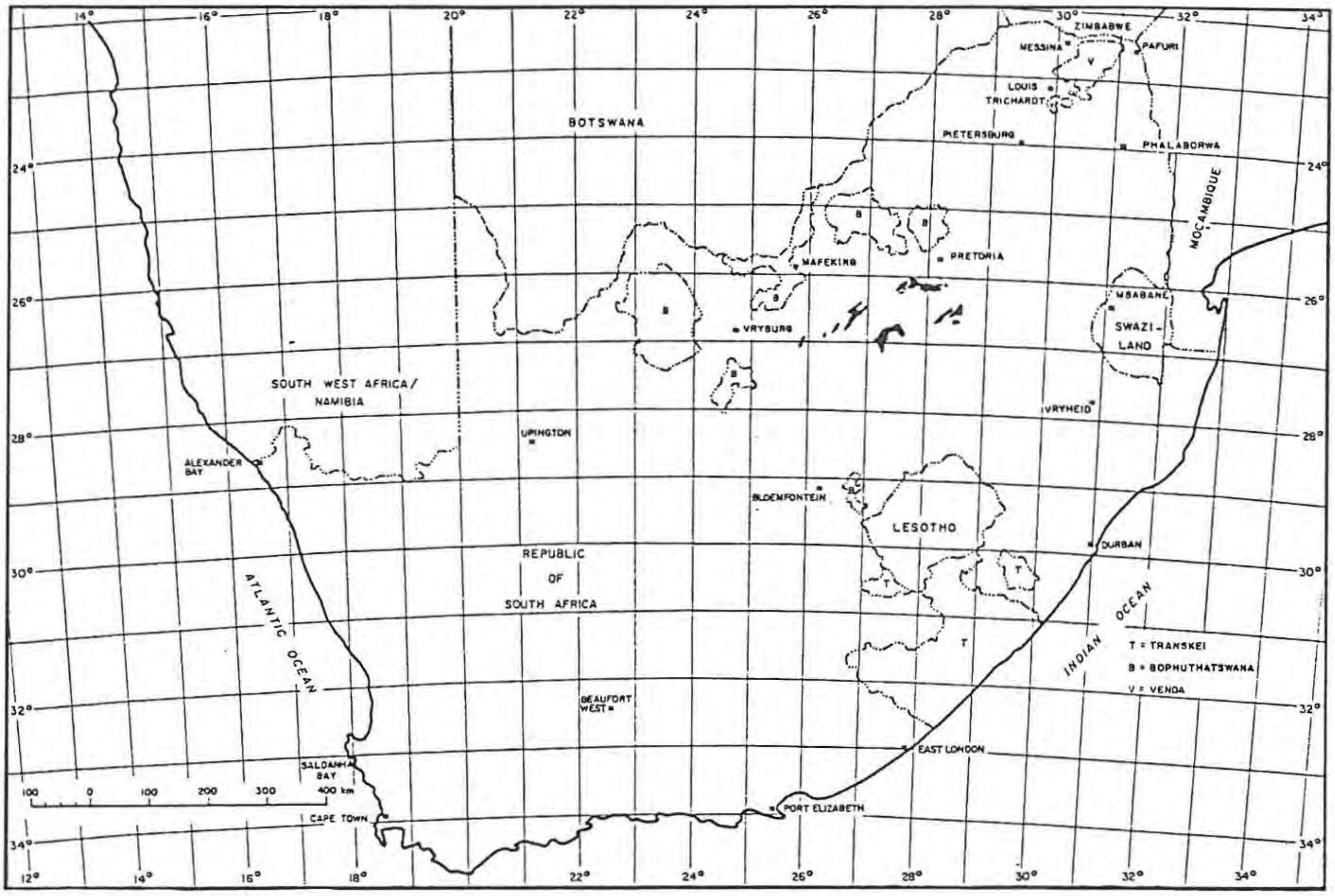


Figure 1.5 Distribution of outcrops of the Ventersdorp Supergroup (from SACS, 1980)

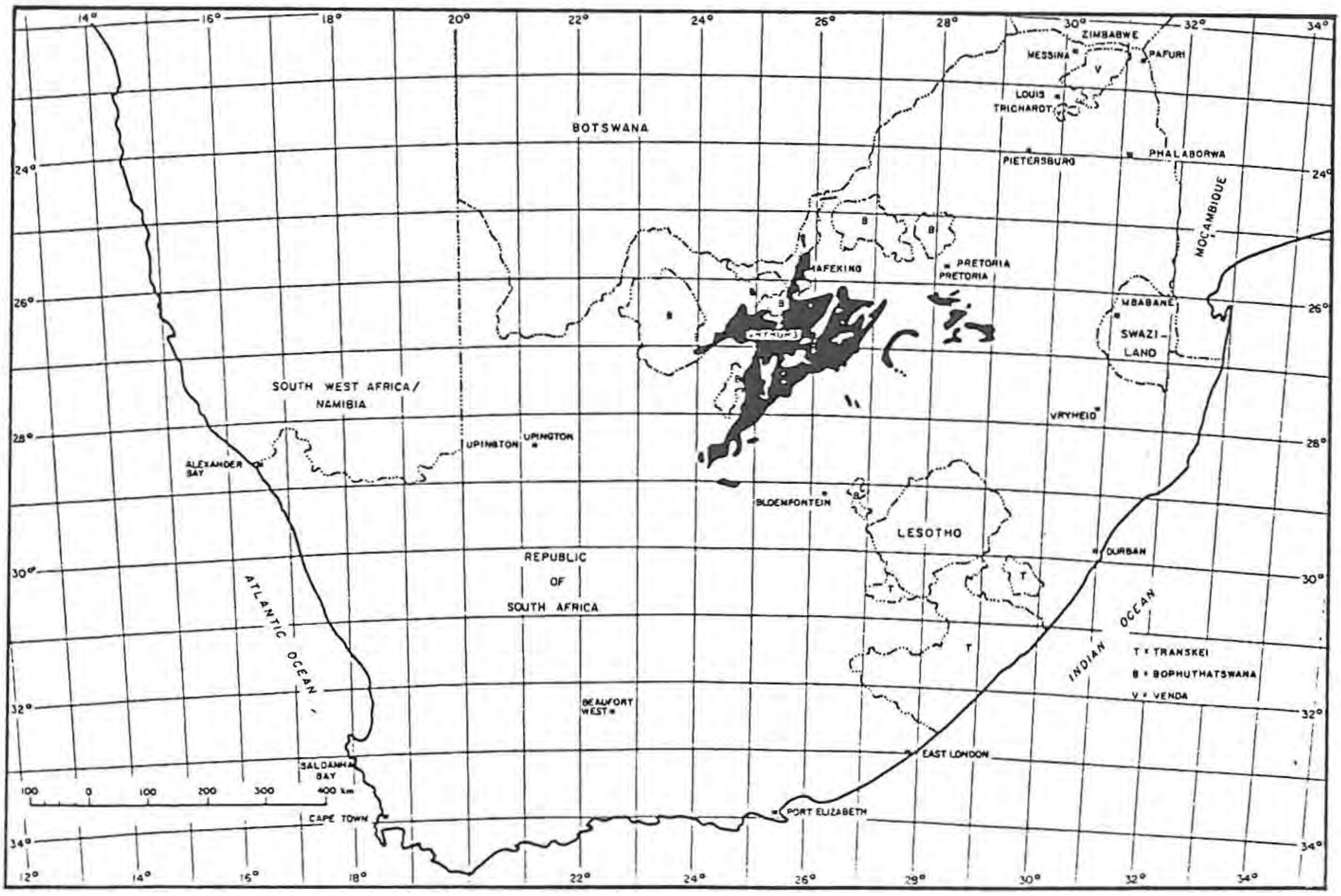
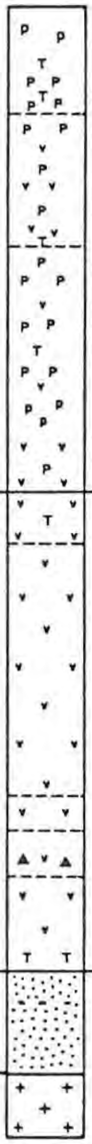


Figure 1.6 Lithostratigraphic column of the Dominion Group (after SACS, 1980)



FORMATION	LITHOLOGY	Thickness (m)
Syferfontein Porphyry	Medium-grained quartz-feldspar porphyry and tuff with elongated bodies of "Wonderstone" near the top of the succession	300
	Mainly silicified blue-grey quartz-feldspar porphyry (in some cases the phenocrysts cannot be distinguished) with zones of amygdaloidal basic lava, tuff, and flow breccia	500
	Fine- to medium-grained quartz-feldspar porphyry, often with the prismatic feldspar phenocrysts (1–6mm) altered to vitreous green; quartz phenocrysts smaller and less abundant There are four bands of amygdaloidal andesitic lava The amygdaloidal tops of flows contain bands of tuff	750
Rhenosterhoek Andesite	Dark green and dark grey andesitic lavas with a porphyritic zone at the top. Bands of tuff and brownish tints are characteristic	100
	Green to pale grey andesite, slightly schistose, silicified and altered. A typical flow has a narrow tuff layer at the top and amygdaloidal lava at the base	
	Brown amygdaloidal lava with cream-coloured flecks up to 2mm in diameter	
	Pale brown and dark grey contorted and flow-brecciated lavas and tuffs with characteristically rimmed, commonly elongated amygdaloids	630
	Green to grey andesitic flows, tuffaceous at the base	
Rhenosterspruit Quartzite	Tuffaceous porphyry, quartz-feldspar porphyry, altered diabase and serecitic quartzite	
	Archaean granite	

(2) the Rhenosterhoek Andesite Formation consisting of intermediate lavas and tuffs; and

(3) the Syferfontein Porphyry Formation, consisting of porphyritic felsic lavas, with interbedded tuffs and cherty amygdaloidal volcanics.

Palaeocurrent data indicate that the basal sediments prograded in a westerly direction and a braided fluvial regime is postulated for their origin (Watchorn, 1980), while the increased proportion of lenticular volcanic units towards the top of the Rhenosterspruit Formation indicates a period of coeval volcanism and sedimentation.

M P Bowen (in prep.) has shown that the basic to intermediate lavas of the Dominion Group as a whole, regardless of the formation in which they occur, represent a continuous differentiation sequence, while the felsic porphyries form a geochemically discrete group within which very little compositional variation occurs. For this reason, the Dominion lavas will be referred to in this study as members of either of two strictly informal groups, namely, the "Dominion Group basic lavas" and the "Dominion Group porphyries".

A major investigation of the structure and stratigraphy of the Ventersdorp Supergroup was undertaken by Winter (1965b). With the aid of an exhaustive array of literature and over two hundred boreholes, Winter devised a stratigraphic column based on three primary subdivisions incorporating six formations, as shown in Table 1.1. He selected the Bothaville area as his type areas as it includes all the type boreholes, maximum thicknesses of most of the formations, and most of the geographical areas from which the formation names are derived.

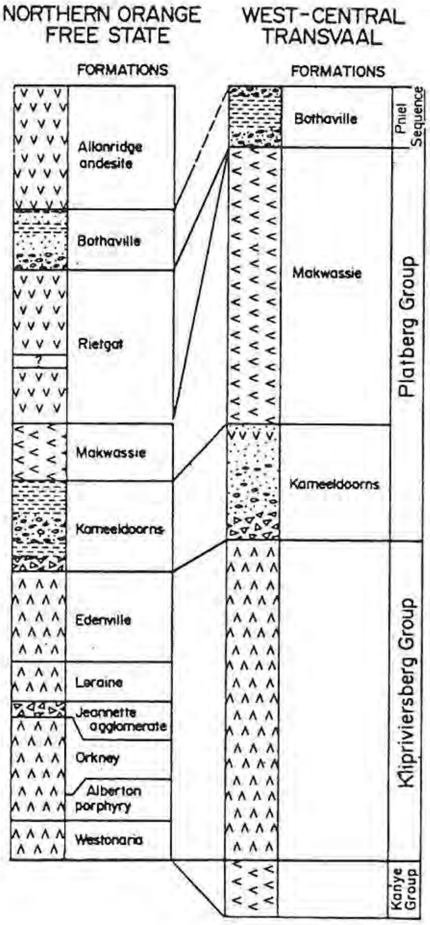
A portion of Winter's thesis was later updated (Winter, 1976) and a lithostratigraphic subdivision of the Ventersdorp Supergroup proposed. The most important change was the elevation of the Klipriviersberg Formation, formerly the Langgeleven Formation, to group status and its division into six formations. Figure 1.7 shows the stratigraphic nomenclature and correlation currently used.

The Venterspost Conglomerate Formation, which contains the gold-bearing Ventersdorp contact reef, is not included in either the underlying

Table 1.1 Stratigraphic column of the Ventersdorp System in the Bothaville type area (from Winter, 1965b).

Primary Subdivision	Formation		Representative Rocks
Upper	Allanridge (A)		Dark green amygdaloidal lavas
	Bothaville (B)		Quartzites, conglomerates, subordinate dark shales
vvvvvvvvvvv	vvvvvvvvvvvvvvvv	vvvvvvv	vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv
Middle	Rietgat (R)	Garfield (GP)	Green-grey amygdaloidal and porphyritic lavas; minor intercalated tuffaceous, calcareous and cherty shales; impure limestones; quartzites; conglomerates
	Makwassie (M)		Quartz and felspar porphyries, green-grey amygdaloidal lavas, minor intercalated sediments
	New Kameeldoorns (N)		Conglomerates; quartzites; tuffaceous, calcareous and cherty shales, impure calcareous rocks
vvvvvvvvvvv	vvvvvvvvvvvvvvvv	vvvvvvv	vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv
Lower	Langgeleven or Lower Volcanic (L)		Green-grey pyroclastics and amygdaloidal lavas

Figure 1.7 Stratigraphy of the Ventersdorp Supergroup in northern Orange Free State and west-central Transvaal (from Tankard *et al.*, 1982).



Witwatersrand Supergroup, or the overlying Ventersdorp Supergroup. It is overlain conformably by the Westonaria Formation, which is the lowermost of the six formations within the Klipriviersberg Group and which is developed only in the deepest parts of the depositional basin (SACS, 1980). The overlying formations lap on towards the basin margins, and are, from the base, the Alberton Porphyry, Orkney, Jeannette Agglomerate, Loraine and Edenville Formations. Certain distinctive characteristics enable these formations to be differentiated from one another (Winter, 1976), as shown in Table 1.2. Winter (1976) classified the group as "almost exclusively andesitic".

Table 1.2 Subdivision of the Klipriviersberg Group (from Winter, 1976).

Formations	Marker beds	Distinctive Characteristics	Contacts in type borehole, Langgeleven No. 1	Thickness	Correlative Areas (List Incomplete)
Edenville		Green chalcedony and clusters of milky quartz amygdales. 1.	1 827 2 395	568	Allanridge, Klerksdorp, S. East Rand
Loraine	AZ 1 AZ 2	Variolitic and spherulitic structures surrounded by whitish groundmass hence "altered zones"	AZ 1 flow 2 395-2 401 AZ 2 flows 2 492-2 535 2 612	217	O.F.S., Bothaville, Klerksdorp, East Rand
Jeannette Agglomerate		Prominent thick agglomerate at top. Many agglomerate beds in contrast with above. 2.	2 709	97	O.F.S., Bothaville East Rand
Orkney	PZ 1 PZ 2	Purple-topped ash-flow tuffs. 3. 4.	PZ 1 flow 2 709-2 750 PZ 2 flow 2 945-2 965 3 189	480	O.F.S., Klerksdorp, Bothaville, Edenville
Alberton Porphyry	Porphyritic Marker	Porphyritic lavas including "porphyritic marker". 6.	Porphyritic marker flow 3 352-3 360 3 360	171	South Vaal, Ventersburg (?), Edenville, West Rand, Klipriviersberg, East Rand, Vredefort, Evander, Greylingstad
Westonaria		Dark green "talcose tuffs"	Absent		South Vaal, Westonaria Alberton, S.E. Rand, Greylingstad

1. Some variolitic zones noted by Winter [1965] from Allanridge area.
2. Some porphyritic lavas south of Orkney
3. Pienaar distinguishes PZ 1 and PZ 2 in Klerksdorp and O.F.S. areas from other purple tops by their round chlorite amygdales.
4. Pienaar discovered a zone of pink chalcedony amygdales in O.F.S. goldfield in this stratigraphic position.
5. At base, Pienaar recognised a flow containing characteristic almond-shaped amygdales.
6. The "Porphyritic Marker" contains phenocrysts of felspar longer than 50 mm and thicker than 7 mm and consists of 1-4 flows of lava.

In the Klerksdorp area the Westonaria Formation is absent, so the Alberton Formation forms the basal unit. The Orkney Formation is present, but the Jeannette Agglomerate has not been recognised. The Loraine and Edenville Formations will be shown in this study to be indistinguishable geochemically, and will therefore be treated as one unit.

The Platberg Group overlies the Klipriviersberg Group with an extensive unconformity. The basal Kameeldoorns Formation consists of clastic wedges of immature sediments which accumulated in fault troughs when the bounding faults were active, and its distribution bears no relation to the depositional basin of the underlying Klipriviersberg Group. The Makwassie Quartz Porphyry Formation overlies the Kameeldoorns Formation without a break and consists of quartz porphyries with quartz-free porphyritic and non-porphyritic volcanic rocks and minor bodies of sediments. The overlying Rietgat Formation contains predominantly green-grey amygdaloidal porphyritic and non-porphyritic lavas, but also contains subordinate sediments and pyroclastic rocks. The basal Garfield Member is regarded as being transitional between the two latter formations (Winter, 1976), and may form a part of either.

In the Klerksdorp area, the Makwassie Formation consists of two discrete units - the usual quartz-feldspar porphyry above, underlain by a sequence of greenish-grey, crystalline, porphyritic lavas characterised by small, dark green and scattered larger feldspar phenocrysts. P.M. Strydom (pers.comm., 1980) has named this unit the "Goedgenoeg formation", restricting the use of the name "Makwassie Formation" for the actual quartz-feldspar porphyry. This nomenclature will be followed in the current study.

An unconformity separates the Platberg Group from the overlying Pniel sequence, consisting of the Bothaville Formation and Allanridge Andesite Formation. The former is a sedimentary unit of subgreywacke composition, comprising conglomerates, quartzites and shales, while the latter comprises alternating porphyritic and non-porphyritic lava flows (Winter, 1976).

The Ventersdorp Supergroup is overlain by the Transvaal Sequence, the basal unit of which is the Black Reef Quartzite Formation, while beneath the Ventersdorp Supergroup lies the Witwatersrand Supergroup, a predominantly argillaceous and arenaceous sequence. Formerly divided into the "Upper" and "Lower" divisions, now called the Central Rand and West Rand Groups respectively, the succession contains only two relatively thin volcanic horizons. The Bird amygdaloid marker in the Central Rand Group does not occur in the Klerksdorp area, and will not be included in the current study. The Crown Formation, formerly the Jeppestown Amygdaloid, however, is more widespread and will be considered briefly.

2. INTRODUCTION

2.1 Purpose of Study

The aim of this study was to analyse a large number of volcanic rocks of the Ventersdorp and Witwatersrand Supergroups and the Dominion Group from the Klerksdorp area in order to ascertain whether any geochemical criteria exist which may serve to discriminate between the various volcanic formations constituting these groups.

The need for such a study is borne out by the decision, as far back as 1961, by the Consultative Committee of the Economic Geology Research Unit at the University of the Witwatersrand, to investigate the problem of correlation within the Ventersdorp System. Their motivation was that:

> "Such a study would be of considerable interest to the mining companies engaged in exploration where it was necessary to drill through thick developments of this System before penetrating into the underlying Witwatersrand rocks. In many instances a very considerable footage had to be drilled in the Ventersdorp rocks before a recognisable marker horizon could be identified and an estimate given of the depth at which the Witwatersrand rocks might occur beneath the Ventersdorp. If it were possible to identify the lavas and sediments, then time and effort could be saved where it was indicated that an excessively thick succession of Ventersdorp rocks was likely to be present below the horizon recognised. In short, holes could be stopped sooner where it became evident that the cover above Witwatersrand rocks placed the latter at unfavourable depths." (Winter, 1961).

The logical extension of this was to include the lavas of the Dominion Group, which are, in many areas, stratigraphically intimately related to those of the Ventersdorp Supergroup, and are sometimes visually indistinguishable, especially where boundary outcrops are scarce. Of the two volcanic horizons in the Witwatersrand Supergroup, only one, the Crown Formation, more commonly known as the Jeppestown Amygdaloid, is present in the Klerksdorp area and is included briefly in this study for completeness' sake.

The EGRU project was conducted by reseachers such as Winter (1961, 1962, 1963a, 1964, 1965a) and Tyler (1979a,b), followed later by Watchorn (1980) with work on the Dominion Group. Their conclusions, however, were reached mainly by studying stratigraphic field relations and petrography. Until Wyatt (1976) presented his M.Sc. thesis, in which he provided 49 chemical analyses of rocks from the Klipriviersberg Group, no other rocks of the Ventersdorp Supergroup had been the subject of a systematic geochemical study. Only five chemical analyses of Dominion Group lavas have been published and these - two rhyolites and three andesites - were presented by Von Backström (1952, 1962).

Winter (1965b) stated that "the lavas of the Langgeleven Formation (now the Klipriviersberg Group) may be confused with flows occurring in and locally at the base of the Makwassie Formation. They may also be confused with similar volcanics of pre-Witwatersrand age where the latter do not show signs of a more intense deformation. They may easily be confused with flows of the Rietgat Formation, and have been confused with the Allanridge lavas. However, the Rietgat and Allanridge lavas are not interbedded with an abundance of agglomerates and tuffs, nor do they have an abundance of flows of the peculiar structure of amygdaloidal tuffs.".

Referring to the Makwassie Formation, he stated that "the isopach map establishes that the Formation containing quartz porphyries is extensive, thick and continuous. This is an important conclusion considering the possible confusion which may arise through correlation of this phase of the Ventersdorp volcanics with the acid rocks of the Dominion Reef System.". "The latter, however, are generally somewhat schistose and associated with other schistose rocks, they have a peculiar cherty appearance, being metamorphosed to a higher degree, and their phenocrysts do not appear to be as prominent as those of the Makwassie Formation.". Winter (1976) added that "it may be difficult to distinguish between the schistose structures and possible flow (rhyolitic) and compactive structures.".

Winter (1965b) also said that "the green-grey amygdaloidal lavas (of the Makwassie Formation) closely resemble the Langgeleven Formation and can only be distinguished from them if porphyry or sediments are intercalated with them. Others resemble flows of the Rietgat Formation. Establishment of the upper boundary becomes doubtful in areas where green-grey porphyritic lavas occur extensively in both formations.".

It is therefore clear that, although visual criteria can and do exist whereby formations may be distinguished from one another, very often these criteria are not evident or may even be absent. The need for an alternative method of identification is thus patently obvious and it is hoped that the geochemical methods employed in this thesis, which have yielded encouraging results, will be implemented by others in order to validate and elaborate on results in and further afield from the current study area.

The preliminary work on this project was executed jointly by T.B. and M.P. Bowen. This included the collection of core samples, subsequent processing and chemical analysis. All further interpretation and manipulation of data was performed individually unless otherwise acknowledged. Petrographic descriptions and petrogenetic interpretations of these data are included in a dissertation by M.P. Bowen (in prep.).

2.2 Sampling Procedure

Samples were obtained from borehole cores drilled in a triangular area of 1 500km^2 roughly defined by the towns Hartbeesfontein-Harrisburg-Vierfontein (see Figure 2.1). Borehole core was made available by Anglo American Prospecting Services (Pty) Ltd of Klerksdorp. Table 2.1 lists the boreholes which were sampled together with the number of samples used from each hole:

Table 2.1 Number of samples analysed from each borehole

Ventersdorp Supergroup		Dominion Group		Crown Formation	
JBF-1	31	DRS-6	22	R-1	3
JHA-1	9	DSF-7	49	JY-8	3
SH-1	8	DSF-10	16	Total	6
VHD-1	15	DHF-8	5		
WS-4	24	DRL-13	8		
WS-5	101	DRH-14	3		
PK-10	6	DRH-15	8		
W-20	15	Total	111		
Total	209				

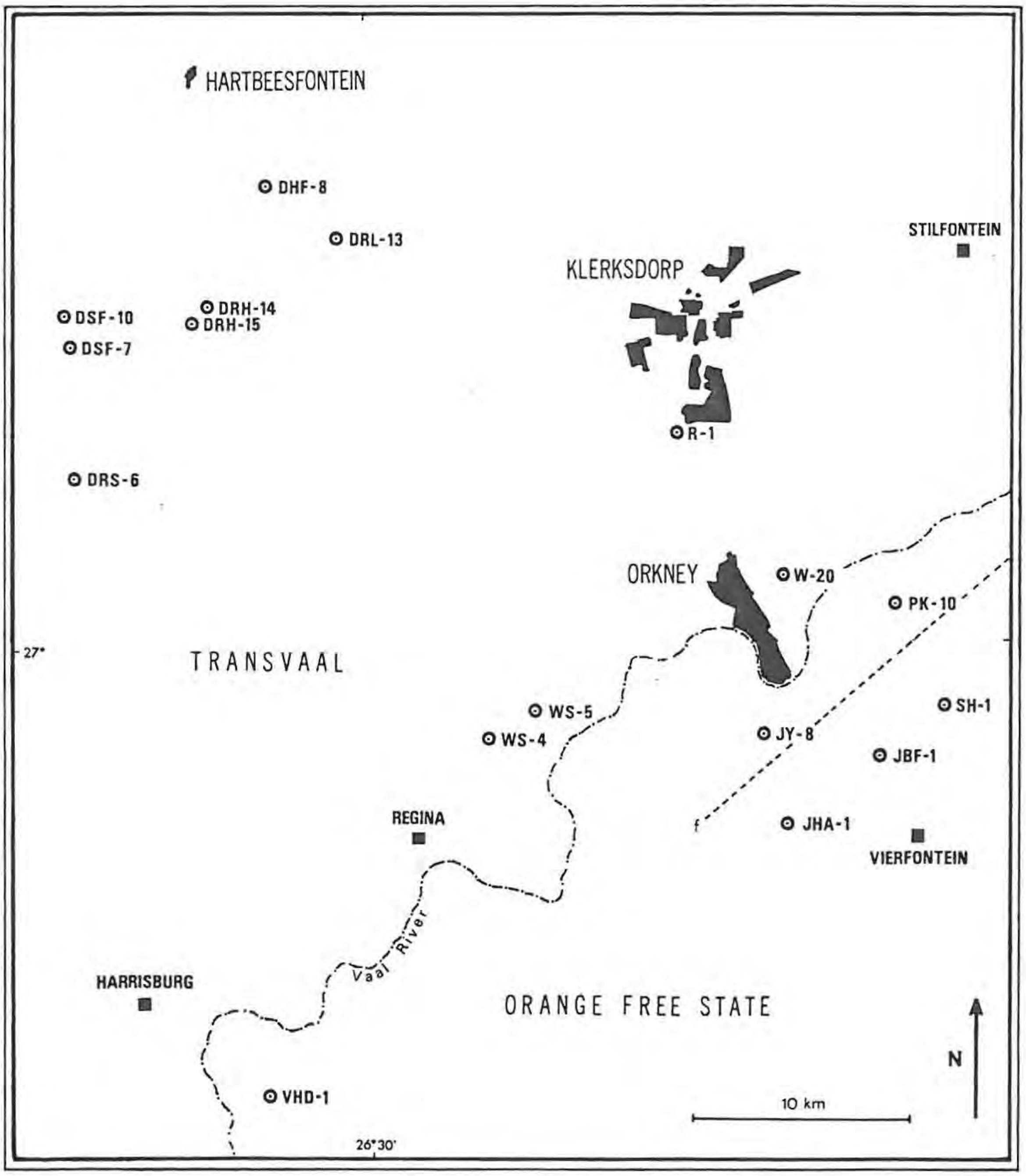
The localities of these boreholes are shown in Figure 2.1.

Those headed "Ventersdorp Supergroup" and "Crown Formation" are all situated to the south of Klerksdorp, four in the Transvaal and six across the Vaal River in the Orange Free State. WS-4, WS-5 and VHD-1 were drilled directly into Ventersdorp lavas. JBF-1, SH-1, PK-10 and W-20 had a cover of Transvaal Supergroup rocks ranging between 181 and 733m thick before the Ventersdorp lavas were reached, while the lavas in JHA-1 were capped by 165m of Karoo rocks. In the "Crown Formation" holes, the Jeppestown Amygdaloid or Crown Formation is found between 1688m and 1731.3m from the surface in R-1, and between 1754.1m and 1808.9m in JY-8. All the "Dominion Group" holes were drilled directly into Dominion Group lavas, with the exception of DRS-6, in which the lavas are capped by 86.26m of the Rietgat Formation of the Ventersdorp Supergroup.

Pemberton (1978) made a survey of major and trace element variations within individual Karoo basalt lava flows in order to determine the best position in which to sample a flow for chemical analysis. He concluded that flows should be sampled as close to their base as possible, because :

1. The major element abundances for the basal and topmost samples of each flow tend to be very similar but within the interior the composition varies erratically.
2. The base of a flow is easy to recognise and locate in the field.

Figure 2.1 Borehole locality map



The latter reason is especially relevant to flows in the Klipriviersberg Group, many of which have "swirled tops", (flow or brecciated tops, consisting of 0,3 to 6 metres of small, sub-rounded blocks of highly amygdaloidal lava (Winter, 1965b)) making the exact boundary difficult to determine in core samples. With a brecciated lava top the possibility of infiltration of the next flow down between the lava blocks of the underlying flow must be considered as well as alteration due to penetration of moisture into brecciated flow tops. A further phenomenon to avoid is the entrainment of clasts into the sole of an advancing lava flow as it moves across a rubble-strewn surface.

An alternative method is to take a number of samples throughout a flow and average the results to obtain a representative analysis. This was not suitable for the current study, however, as the average distance between samples in the boreholes in which the most detailed sampling was done, was about 22m. Within-flow sampling would have increased the number of samples to unmanageable numbers for a project, the aim of which was to determine inter- and intraformational variations. Consequently the samples for the current project were taken as close to the base of flows as possible, but above the basal amygdaloidal zone.

Pemberton (1978) found that the removal of amygdales from samples leads to a slight difference in element content from those with amygdales included. Although he concluded that the overall shift in concentration due to the presence of amygdales is a relatively minor one in comparison with the within-flow variations, highly amygdaloidal zones were nevertheless carefully avoided during sampling in the current study.

Boreholes WS-5 and DSF-7 were selected by P.M. Strydom as holes containing the most complete and representative sequences of the Ventersdorp Supergroup and the Dominion Group respectively in the study area. These two boreholes were therefore sampled in detail at intervals of about 22m, while the other boreholes were sampled at much wider but roughly equal intervals, in order to obtain information on possible lateral variations within different formations, and to facilitate correlation on a broad scale across the study area. WS-5, however, contains only 22.4m of the Makwassie Formation, so WS-4 which contains a thickness of 367m of this Formation, was sampled in detail.

Within WS-5 and DSF-7 samples were usually taken from between two and several flows apart, with very few being taken from adjacent flows. The thickness of flows can vary between a few metres and several tens of metres or even more, but is usually from about 5 to 25 metres.

A total of 504 samples was collected from the Anglo American core yards at Vaal Reefs, Vaal Reefs South, and Klerksdorp. Of these, 326 were eventually processed for chemical analysis. The remaining 174 were omitted due to time and manpower constraints. The positions of the samples within each borehole are indicated in Figure 2.2, which shows condensed lithostratigraphic logs adapted from those provided by Mr P.M. Strydom of Anglo American Prospecting Services, Orkney. A breakdown of the number of samples analysed from each formation is set out in Table 2.2.

Table 2.2 Number of samples analysed from each formation

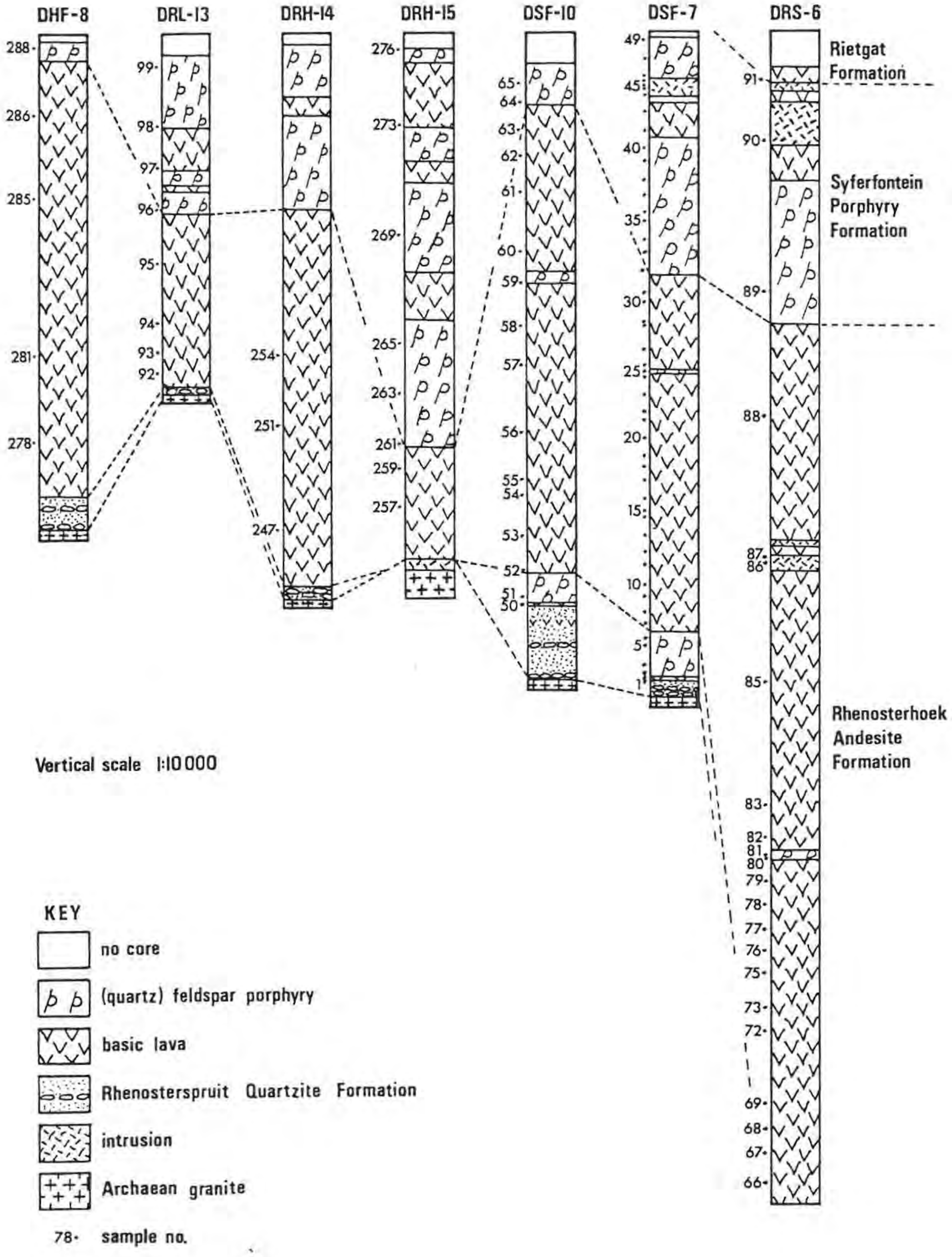
FORMATION	TOTAL
Allanridge	35
Rietgat	34
Makwassie	17
Goedgenoeg	35
Loraine-Edenville	46
Orkney	32
Alberton	19
Crown	6
Dominion Group acid porphyries	32
Dominion Group basic lavas	70
	326

2.3 Sample preparation and chemical analysis

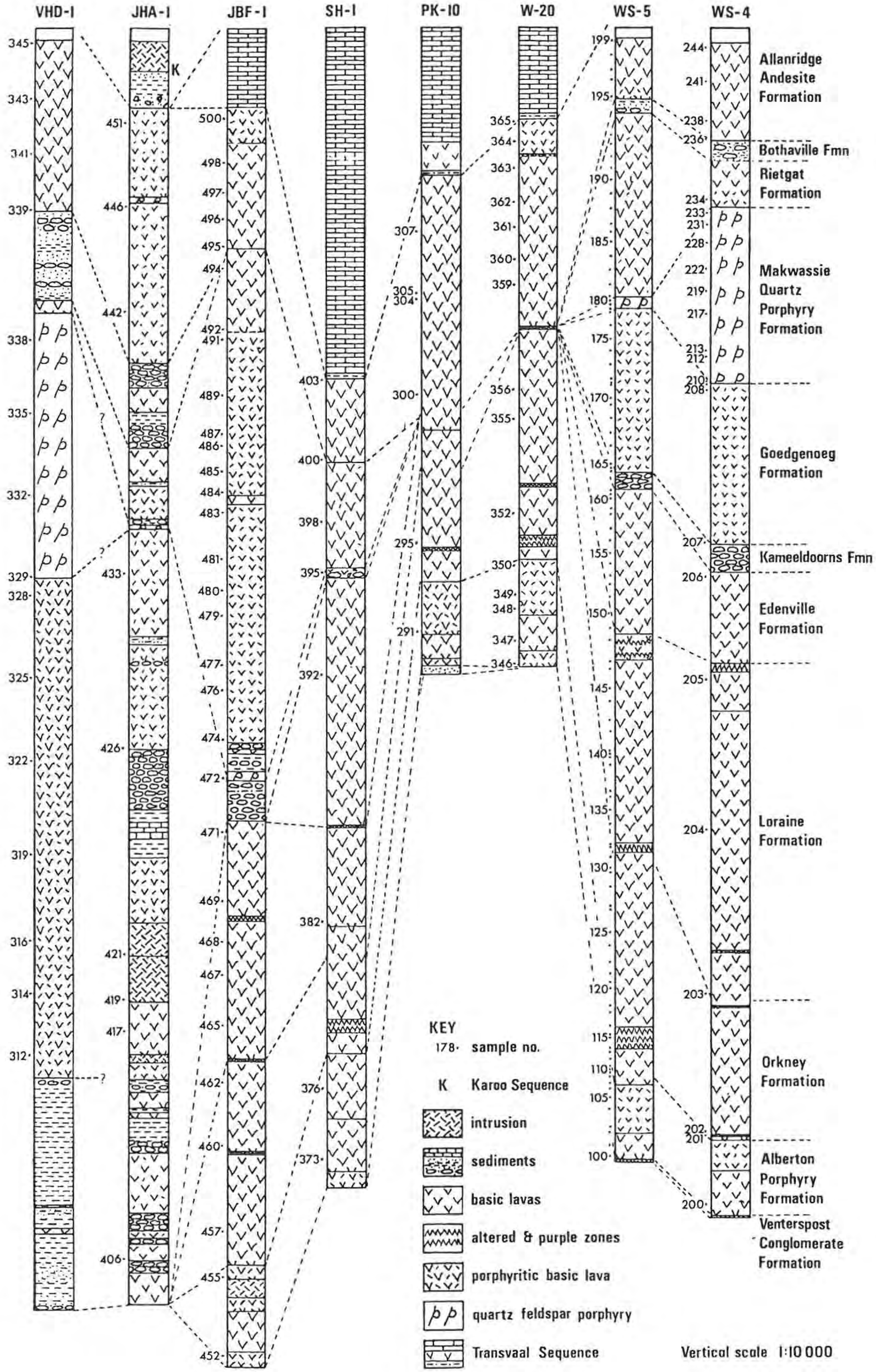
Each sample was prepared for chemical analysis by breaking up the sample in a rock splitter and removing the outer surface of the core by grinding, as this surface was frequently weathered and may have been

Figure 2.2 Condensed lithostratigraphic logs with sample positions

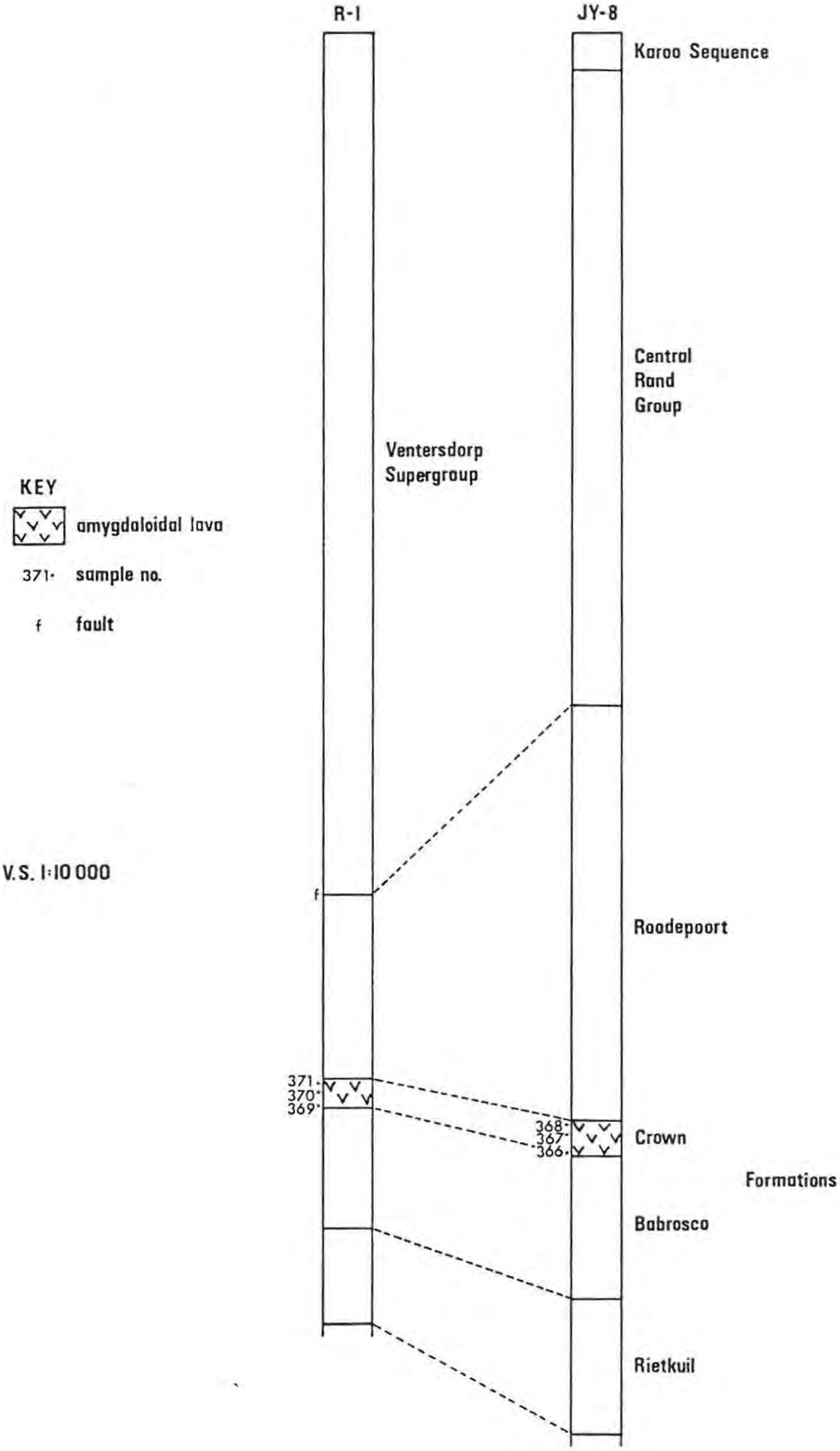
(a) Dominion Group boreholes



(b) Ventersdorp Supergroup boreholes



(c) Crown Formation boreholes



contaminated by metal smears from the core barrels and core trays. Any vein-filling material or amygdales were also removed at this stage. The rock fragments were then passed through a jaw crusher, and ground to approximately 200 mesh in a Hertzog swing mill, using a Mn-steel container. The final crush was quartered and seven grams were finely ground by hand, using an agate pestle and mortar.

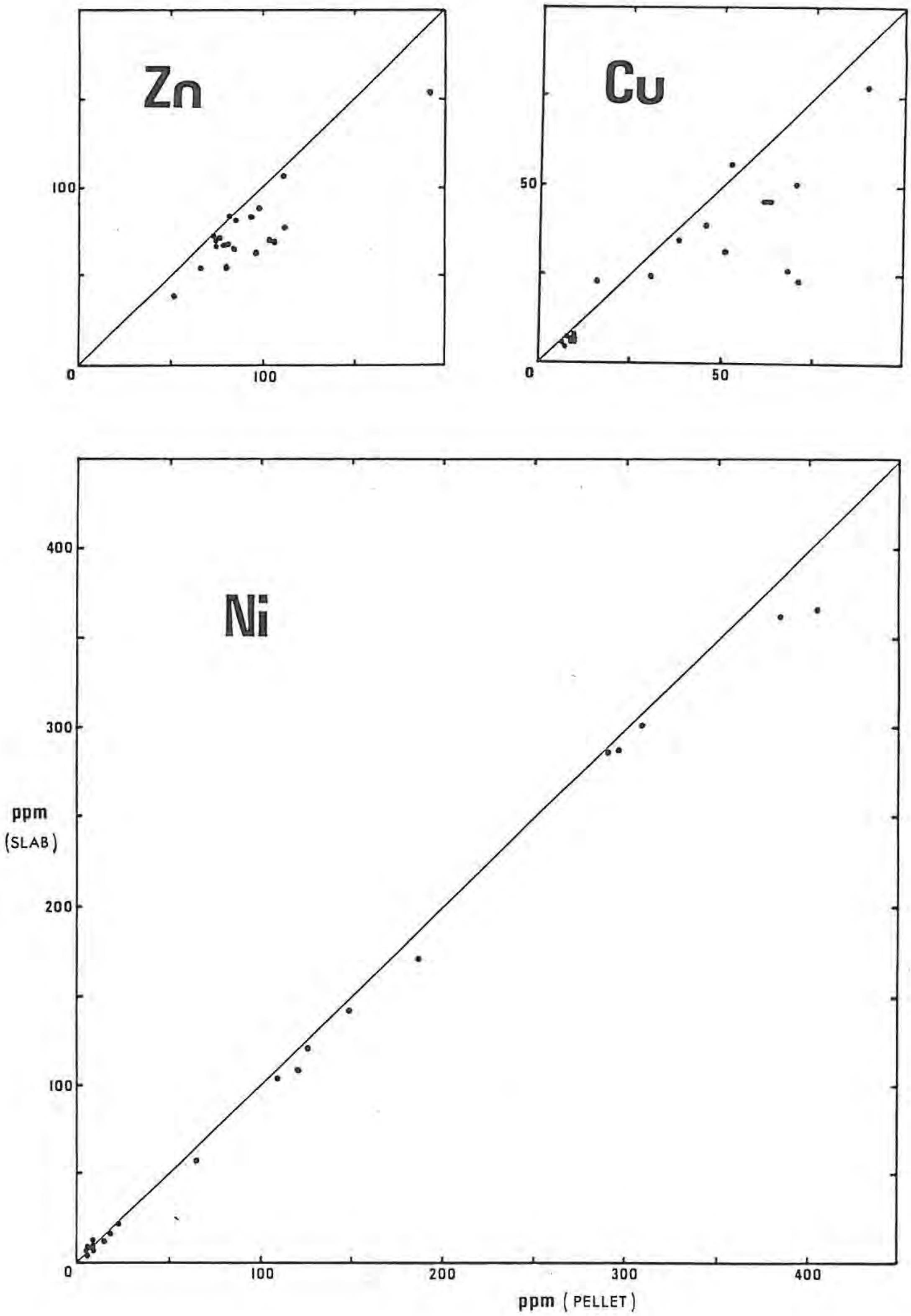
Of the seven grams, two were used for making a Norrish fusion disc for major element analysis, according to the method described in Norrish and Hutton (1969). This entailed mixing 1.5 grams of Spectroflux with 0.28 grams of sample which had been ashed at $1000^{\circ}C$ to eliminate all volatile material. The mixture was melted in a platinum crucible at more than $1000^{\circ}C$ and poured into a graphite mould to form a thin glass disc.

The remaining five grams were used for making a briquette of sample contained in a boric acid/bakelite case, which was compressed under 15 tons/sq. in. using a steel barrel and plunger. The briquettes were used for the analysis of Na_2O and the trace elements Ba, Nb, Zr, Y, Sr, Rb, Zn, Cu, Ni, Co, Cr, V, La, Ce and Nd.

An alternative to the briquette method - the use of polished slabs - was tested. A disc was simply sawn from the borehole core, ground flat and polished on one side, and inserted in the spectrometer for trace element analysis. A comparison between the two methods for a zinc-copper-nickel run is shown in Figure 2.3, in which concentrations determined on briquettes are plotted against concentrations obtained from the polished slabs. Nickel shows a far better correlation than either zinc or copper, but in general, the slab method resulted in lower values than those obtained from the pressed pellets. This discrepancy is to be expected, as a slab will very rarely display the same degree of homogeneity as a pressed pellet, unless the rock is extremely fine-grained.

Although this technique has not been pursued further, it may prove in practice that the time saved in using the slab method more than compensates for the loss of precision. This method might be viable for monitoring drilling, when decisions as to whether a particular borehole should be continued or abandoned cannot rest on elaborate and lengthy laboratory procedures.

Figure 2.3 Concentrations of Zn, Cu and Ni determined on slabs vs pellets



Major and trace element analyses were performed by X-ray fluorescence, using a Philips PW 1410 X-ray spectrometer. Both international and locally calibrated standards were used for calibration. International standards used include the following: AGV-1, BCR-1, G-2, GSP-1, JG-1, and PCC-1, while Rhodes University in-house standards used are CAR-08, KRF-13 and PRC-1. A number of standards calibrated at N.I.M. (now Mintek) were also used, viz. NIM-G, NIM-N, NIM-P, S-9, S-10, S-12 and S-15. Details of analytical techniques can be found in Appendix II.

Data reduction was performed initially on an ICL 1904S computer and subsequently on a CDC Cyber 170-825, using programs compiled at the Geochemistry Department, University of Cape Town, and modified for use at Rhodes University by Dr J.S. Marsh of the Rhodes Geology Department.

Major and trace element analyses for 326 samples are listed in Table 2.4. All iron was analysed as Fe_2O_3. Both major and trace element values have been recalculated to 100%, volatile-free. It was considered justified and indeed necessary to recalculate trace element as well as major element data, in the light of the high degree of hydration and carbonation of a number of the samples. Five samples had a volatile content of over 10%, the highest being 12.88% for sample AR-496. In cases such as these and many others, if recalculation of trace elements was not effected, major and trace element contents might prove irreconcilable. The original total ("TOTAL") and volatile content ("LOI") are provided for each sample in Table 2.4, should back-calculation to the original values be required.

The numerical part of the sample names indicates the order in which samples were taken, while the alphabetic prefix indicates the group and the formation to which each sample belongs, as shown in Table 2.3.

Major element values are expressed in weight percent, trace elements in parts per million. Trace elements listed as 0 ppm had values below the lower limit of determination (LLD). Those marked with an asterisk (*) had values below the LLD, but above the detection limit (DL), which is half the LLD (see Table 2.5).

Table 2.3 Derivation of sample names

GROUP	FORMATION	SYMBOL
	AR - Allanridge	AR
P - Platberg	R - Rietgat M - Makwassie G - Goedgenoeg	PR PM PG
K - Klipriviersberg	L - Loraine-Edenville O - Orkney A - Alberton	KL KO KA
J - Jeppestown	C - Crown	JC
D - Dominion	P - Porphyries B - Basic Lavas	DP DB
Unknown	IN - Intrusive	IN

In X-ray fluorescence analysis the precision of any determination may be considered to be a function of:

(i) the reproducibility of the sample preparation techniques, and
(ii) X-ray counting statistics.

The successful duplication of 45 analyses has demonstrated that the conditions required under (i) are sufficiently satisfied. X-ray counting statistics, expressed in terms of average counting error (CE) and lower limit of determination (LLD) for each batch of trace element analyses processed, are shown in Table 2.5, giving a measure of the precision attained during analysis. The samples were analysed in three separate batches consisting of 40, 48 and 238 samples respectively, with the exception of the rare earths La, Ce and Nd, which were analysed in two batches of 40 and 286 samples respectively.

Table 2.4 Major and trace element analyses

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	DB- 1	DB- 2	DB- 3	DP- 4	DP- 5	DP- 6	DB- 7	DB- 8	DB- 9	DB- 10
SIO2	57.76	58.44	58.78	68.32	70.84	69.87	52.21	52.19	53.77	57.55
TIO2	1.084	1.041	1.004	0.849	0.809	0.830	0.883	0.889	0.843	1.171
AL2O3	14.58	13.85	13.66	12.74	12.50	12.65	13.29	13.08	13.09	14.46
FE2O3	11.35	11.48	11.72	7.35	5.66	6.71	12.87	13.68	11.48	10.05
MNO	0.25	0.15	0.14	0.11	0.08	0.07	0.18	0.23	0.17	0.15
MGO	3.51	3.54	3.17	2.50	1.73	1.70	7.71	10.07	9.52	4.94
CAO	7.35	6.82	6.79	2.05	1.45	2.20	10.92	6.68	7.36	5.57
NA2O	3.33	3.03	3.17	3.65	3.42	2.70	1.67	2.85	3.43	5.11
K2O	0.50	1.37	1.34	2.16	3.22	3.03	0.08	0.11	0.15	0.57
P2O5	0.255	0.265	0.257	0.271	0.278	0.243	0.191	0.194	0.180	0.421
TOTAL:	99.21	99.86	99.75	99.69	99.49	99.11	99.32	99.30	100.12	99.55
LOI	5.72	1.65	1.48	1.32	1.68	2.33	6.89	2.62	2.13	1.71
BA	204	395	484	846	853	889	25	48	77	244
NB	8.5	7.5	7.1	12.9	13.4	15.0	4.2	2.4	5.3	7.7
ZR	173	162	171	256	277	275	91	89	93	174
Y	30.1	26.9	27.7	28.9	27.3	27.1	22.7	25.0	22.7	30.2
SR	286	460	465	214	111	71	386	132	165	147
RB	11.9	51.0	44.5	56.9	81.5	114.7	1.3	2.2	1.9	9.8
ZN	125	100	103	91	87	82	107	126	99	95
CU	28	16	42	10	9	7	58	60	43	53
NI	19	23	25	12	9	12	310	446	322	125
CO	55	54	53	26	16	21	68	87	71	58
CR	5	6	12	12	2*	4	1344	1510	1290	34
V	297	261	245	106	53	87	236	257	221	230
LA	27	25	27	44	46	35	10	13	7*	21
CE	48	59	50	77	94	76	29	27	15	45
ND	28	24	28	37	40	34	17	19	11	25

SAMPLE:	DB- 11	DB- 12	DB- 13	DB- 14	DB- 15	DB- 16	DB- 17	DB- 18	DB- 19	DB- 20
SIO2	54.10	61.12	57.18	60.41	53.72	52.45	50.82	52.78	52.70	52.51
TIO2	1.323	1.684	2.076	1.596	0.787	0.758	0.744	0.682	0.660	0.641
AL2O3	15.34	11.41	13.16	12.98	14.26	13.23	13.56	14.45	16.37	14.55
FE2O3	12.69	11.45	14.78	10.94	11.32	11.57	13.93	10.48	9.78	10.43
MNO	0.16	0.10	0.18	0.16	0.14	0.16	0.18	0.18	0.14	0.13
MGO	5.21	1.48	2.43	2.99	7.26	8.86	7.83	8.27	7.36	8.53
CAO	5.56	10.67	4.17	6.03	8.06	9.44	11.13	9.62	8.25	9.52
NA2O	4.76	0.29	3.74	3.63	3.18	2.73	1.44	2.69	3.94	2.96
K2O	0.44	1.16	1.51	0.73	1.08	0.64	0.19	0.69	0.65	0.62
P2O5	0.397	0.637	0.778	0.546	0.189	0.168	0.168	0.163	0.152	0.109
TOTAL:	99.79	100.03	98.97	99.08	99.31	99.99	99.97	99.99	99.32	99.86
LOI	1.77	1.89	2.72	2.62	1.91	2.02	3.69	2.94	2.35	2.53
BA	149	549	557	176	676	406	138	278	427	213
NB	9.3	12.3	16.5	12.9	5.6	2.9	2.8	2.6	4.3	3.4
ZR	196	260	351	259	105	90	89	80	95	82
Y	33.2	44.6	54.4	41.2	22.6	21.3	23.2	17.7	20.5	18.9
SR	121	2015	179	297	462	444	523	435	564	489
RB	7.9	37.9	90.7	28.4	17.2	11.0	3.9	13.9	14.1	15.8
ZN	123	93	142	116	104	90	96	83	85	77
CU	36	34	12	32	60	55	83	70	66	67
NI	135	19	28	67	262	290	360	318	240	258
CO	67	43	53	48	69	66	75	65	58	62
CR	41	9	17	7	772	926	1197	784	548	850
V	243	291	326	270	208	209	217	194	186	191
LA	20	34	43	31	12	13	8*	8	9	12
CE	50	79	88	86	25	27	22	25	18	20
ND	29	45	52	45	18	17	16	8	14	9

SAMPLE:	DB- 21	DB- 22	DB- 23	DB- 24	DP- 25	DB- 26	DB- 27	AR- 28	DB- 29	DB -30
SIO2	56.13	57.20	54.96	62.01	70.63	56.82	53.75	57.36	58.35	57.48
TIO2	0.624	0.644	0.715	1.430	0.795	0.625	1.251	1.413	1.541	1.139
AL2O3	15.26	15.50	16.11	12.75	12.53	15.94	14.79	15.51	13.99	14.17
FE2O3	9.47	9.19	9.95	12.30	6.28	7.95	13.58	16.43	15.19	14.19
MNO	0.11	0.12	0.14	0.16	0.07	0.12	0.17	0.15	0.13	0.16
MGO	5.59	5.18	5.73	1.94	1.06	5.57	3.67	2.80	2.85	3.29
CAO	8.00	7.66	7.41	4.89	3.60	7.29	8.90	2.44	4.21	5.60
NA2O	3.62	3.49	3.74	2.85	2.89	3.50	3.01	2.90	2.61	2.99
K2O	1.04	0.84	1.04	1.20	1.88	2.00	0.59	0.83	0.69	0.66
P2O5	0.163	0.171	0.195	0.465	0.253	0.177	0.297	0.171	0.458	0.319
TOTAL:	99.58	99.72	99.75	98.55	98.99	99.16	99.11	97.87	99.13	98.54
LOI	2.03	2.09	1.96	2.72	1.29	2.08	3.08	3.14	3.32	5.25
BA	341	327	504	373	637	567	306	341	423	214
NB	4.7	4.3	4.7	11.0	13.5	3.9	8.5	11.3	10.4	6.9
ZR	117	121	133	258	297	106	202	230	237	158
Y	19.7	20.7	22.7	35.5	30.8	18.9	33.0	25.9	38.2	27.4
SR	503	530	628	406	401	593	423	134	413	280
RB	22.2	17.0	20.2	42.1	37.3	52.3	14.8	15.6	21.9	24.7
ZN	78	78	88	73	69	77	117	146	149	146
CU	75	66	52	25	12	73	56	23	33	57
NI	90	94	98	14	12	131	35	27	21	33
CO	50	49	52	48	18	54	52	68	67	63
CR	53	51	49	9	9	52	0	0	10	10
V	161	164	169	285	48	166	223	259	435	329
LA	13	15	17	42	45	14	21	18	32	23
CE	26	29	31	76	85	35	56	39	72	42
ND	19	16	18	43	38	16	30	24	43	27

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	DB- 31	DP- 32	DP- 33	DP- 34	DP- 35	DP- 36	DP- 37	DP- 38	DP- 39	DP- 40
SIO2	55,68	67.18	58.44	64,02	71.41	71,65	70,04	71.04	71.61	76.74
TIO2	1,085	0.891	1.489	0.894	0.774	0,819	0,820	0.809	0,788	0.747
AL2O3	14.52	13,25	21.63	14,70	11.73	12,99	12,88	12.44	12,90	12.00
FE2O3	13,33	6.62	6.58	12,54	9.19	5.41	6.26	5.81	7.13	1.81
MNO	0,16	0.08	0.03	0,11	0.08	0.07	0,06	0.12	0,06	0.02
MGO	3,77	1.16	1.40	2,17	1.35	0,40	0.60	0.48	0,74	0.32
CAO	7.06	4.15	1.70	1,14	0.67	1,24	1.85	2.23	0,90	0.51
NA2O	3,33	4.03	1.29	1,01	1.85	4,12	4.16	3.48	4,26	3.45
K2O	0,77	2.35	7.12	3,10	2,69	3.03	3.07	3.31	1,36	4.14
P2O5	0,300	0,292	0.517	0,319	0.255	0.279	0.267	0.279	0.246	0.259
TOTAL:	98,90	98.50	98.91	99,87	99,44	99.93	99,37	97.89	99,42	99.05
LOI	3,11	3.60	3.02	3,06	2.12	1,46	1.98	2.54	1,62	0,80
BA	388	805	1121	390	430	1042	769	861	311	1207
NB	5.6	15.1	28.5	14.7	11,7	13,3	14,1	13.5	14,4	13.5
ZR	153	313	545	315	279	299	296	279	290	271
Y	29.2	30.2	60.7	33.8	27,5	29.2	30,6	28,4	31.7	24.6
SR	691	262	66	51	94	233	201	164	87	108
RB	28.6	40.8	204.4	90.9	90,4	68.2	56,1	74,5	37.5	112.0
ZN	116	86	46	125	183	58	65	83	127	51
CU	74	8	8	8	20	11	11	10	7	7
NI	38	7	16	10	11	10	9	7	10	6
CO	67	19	15	24	28	14	16	15	20	9
CR	7	0	3	2*	4	4	4	0	8	0
V	325	59	97	65	54	54	52	53	55	41
LA	25	72	21	118	40	50	52	46	48	49
CE	50	124	59	194	72	93	100	92	91	100
ND	28	54	36	77	34	40	44	38	41	45

SAMPLE:	DB- 41	KL- 42	KL- 43	KL- 44	KL- 45	KL- 46	DP- 47	DP- 48	DP- 49	DB- 50
SIO2	57,78	57.72	50.28	50,53	50,86	50.91	69,37	67.68	68,38	62.50
TIO2	1,324	0.539	0.459	0,423	0,433	0.462	0.749	0.766	0,794	1.045
AL2O3	13,43	17.38	14.40	14,37	15,01	14.85	12.65	12.83	12,78	14.67
FE2O3	15,09	12,72	10.27	9,56	9.51	10.10	7.53	8.16	8,74	8.65
MNO	0,14	0.16	0.14	0,14	0.15	0.15	0,09	0.11	0,18	0.16
MGO	3,02	5.03	10.58	10.19	9,67	9.06	0.70	0.50	0.26	1.94
CAO	5,80	0.79	11.07	12,57	12,19	12.05	2.02	2.87	1,90	6.47
NA2O	2,72	3.95	1.02	1,54	1.43	1,58	4.01	4.39	3,33	3.14
K2O	0,55	1.66	1.77	0,63	0.70	0,79	2.67	2.48	3.41	1.16
P2O5	0.148	0.043	0.059	0,035	0,044	0,041	0.211	0.208	0,234	0.251
TOTAL:	99.20	99.39	99.85	100,34	101,46	99.46	99,68	99.47	98,63	98.59
LOI	5,90	3.65	2.67	2,54	2,62	2.49	2,16	2.86	2,39	4.99
BA	226	214	313	108	111	130	628	492	669	788
NB	7.7	2.4	0.7	0.4	0.5	1.2	14,8	15.7	14.3	9.3
ZR	144	42	34	32	33	37	246	248	256	187
Y	28.5	6.9	17.9	16.7	16.3	17,9	35,6	36.7	32.9	29.8
SR	287	62	209	192	173	182	237	346	165	174
RB	15.9	46.4	63.0	27.6	31,0	35,1	87,8	90.1	126.8	44.4
ZN	133	118	85	59	61	73	94	116	82	76
CU	49	155	83	75	73	87	13	113	9	64
NI	19	143	246	220	192	171	12	11	9	21
CO	64	60	59	55	55	58	19	21	22	40
CR	4	164	814	1119	735	463	3	4	0	2*
V	479	237	229	225	214	234	17	20	25	173
LA	23	0	0	5*	0	4*	43	42	46	25
CE	38	0	0	0	0	0	82	83	92	51
ND	20	0	4*	0	0	15	39	38	35	26

SAMPLE:	DP- 51	DB- 52	DB- 53	DB- 54	DB- 55	DB- 56	DB- 57	DB- 58	DP- 59	DB- 60
SIO2	69,84	51.82	55.56	57.93	53.89	55.50	53.14	58.31	70,87	60.28
TIO2	0,785	0.806	1.152	1,669	0,752	0.664	0.647	0.970	0,771	0.990
AL2O3	12,65	12.68	14.36	12,93	13.68	14,96	14.93	14.40	12,31	13.54
FE2O3	6,25	12.51	11.65	12,21	10,22	8.96	9.60	10.28	5,57	10.42
MNO	0,08	0.21	0.15	0,14	0.16	0.14	0.16	0.14	0.06	0.13
MGO	0,97	11.36	4.67	2,18	7.54	6.17	7.56	3.52	1,21	3.45
CAO	2,12	7.57	7.25	7,07	10,25	9.13	9.74	8.22	1,85	7.70
NA2O	4,40	2.51	3.99	3,54	2.61	3.64	2.77	2.88	1,43	1.96
K2O	2,64	0.35	0.85	1,71	0.73	0.70	1.32	0.97	5,68	1.20
P2O5	0.265	0.184	0.363	0,619	0,170	0.144	0.128	0.315	0,260	0.320
TOTAL:	99,49	99.66	99.79	98.50	100.42	100,55	99.81	99.83	99,33	100.86
LOI	0,80	2,63	1.24	3.61	2,59	1,41	4.31	1.73	1,26	1.76
BA	589	190	271	836	369	372	542	552	1695	1011
NB	12.9	3.1	7.5	13.0	3.1	3,7	3,2	6.2	11.3	6.6
ZR	272	76	167	270	85	79	82	163	259	167
Y	29.0	18.8	30.8	41.3	19,4	18,4	19,7	25.2	25,3	26.3
SR	158	244	419	402	374	685	428	743	254	704
RB	83.9	8.8	23.4	65.3	11,2	11,0	22,9	14.5	107.1	18.3
ZN	86	168	103	122	84	74	77	91	112	89
CU	12	52	66	39	80	68	64	57	14	43
NI	10	364	86	34	313	182	242	46	12	27
CO	21	76	56	53	68	50	64	53	19	51
CR	5	1301	41	11	928	682	670	20	4	10
V	69	233	235	291	218	188	190	214	70	222
LA	47	9	20	38	8*	8	12	19	50	27
CE	85	18	50	77	17	20	21	44	91	42
ND	36	14	32	47	14	13	16	30	42	27

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	DB- 61	DB- 62	DB- 63	DP- 64	DP- 65	DB- 66	DB- 67	DB- 68	DB- 69	DB- 72
SIO2	56.49	58.47	55.05	71.19	70.82	56.32	57.38	56.39	60.67	60.33
TIO2	0.603	1.435	1.210	0.749	0.783	1.153	1.172	1.138	1.958	1.849
AL2O3	15.51	12.92	15.35	12.22	12.38	14.40	14.94	14.16	11.94	11.42
FE2O3	8.53	14.02	13.09	5.56	5.58	11.56	11.68	11.76	13.03	13.38
MNO	0.12	0.16	0.22	0.07	0.07	0.17	0.17	0.14	0.14	0.14
MGO	5.75	2.60	2.12	0.61	0.64	4.61	5.94	4.69	2.28	2.29
CAO	8.66	6.63	7.97	2.46	2.31	6.18	3.65	6.33	5.24	5.18
NA2O	2.96	2.34	3.96	3.83	4.35	4.06	3.43	3.98	2.89	2.63
K2O	1.21	1.01	0.69	3.06	2.80	1.19	1.27	1.07	1.14	2.11
P2O5	0.165	0.420	0.553	0.255	0.267	0.354	0.372	0.332	0.710	0.677
TOTAL:	100.50	100.14	98.71	100.17	99.50	98.40	97.99	99.73	99.32	99.99
LOI	1.78	3.05	4.68	1.66	1.74	1.67	2.93	1.54	2.76	2.06
BA	362	536	324	877	737	415	508	386	664	688
NB	3.8	9.2	7.6	11.9	13.3	7.8	8.4	8.0	14.8	13.9
ZR	95	214	165	267	271	173	174	168	316	285
Y	19.1	34.4	30.3	27.6	28.0	31.9	29.4	31.7	48.0	44.0
SR	750	514	715	299	300	437	239	485	375	264
RB	38.4	45.5	29.6	73.3	67.5	29.4	27.4	36.1	53.5	106.2
ZN	75	106	107	73	78	111	240	108	137	149
CU	86	34	65	13	11	79	70	78	26	18
NI	108	19	37	8	11	87	96	93	28	23
CO	54	58	72	17	16	56	62	57	49	57
CR	60	4	10	4	3	42	46	52	13	10
V	174	392	350	60	53	247	274	244	312	326
LA	16	33	22	52	50	20	24	18	40	37
CE	27	72	47	98	92	40	50	45	86	85
ND	18	39	28	44	43	29	32	27	50	52

SAMPLE:	DB- 73	DB- 75	DB- 76	DB- 77	DB- 78	DB- 79	DP- 80	DP- 81	DB- 82	DB- 83
SIO2	59.41	60.46	59.97	60.74	48.79	53.20	70.60	71.32	53.12	52.92
TIO2	1.889	1.823	1.706	1.632	1.037	0.722	0.746	0.744	0.682	0.679
AL2O3	12.00	12.49	12.47	12.98	20.33	16.00	12.25	12.31	13.28	13.57
FE2O3	13.87	12.66	13.05	10.65	14.60	9.96	5.51	5.99	11.49	10.99
MNO	0.15	0.14	0.15	0.15	0.20	0.14	0.07	0.09	0.18	0.17
MGO	2.15	2.37	3.21	2.72	7.98	8.32	0.88	0.83	8.46	8.38
CAO	4.95	5.52	5.05	6.44	3.09	6.74	1.80	4.58	10.18	10.02
NA2O	3.32	2.86	2.65	2.86	2.99	3.19	2.20	2.14	2.19	2.75
K2O	1.56	1.04	1.16	1.22	0.78	1.58	5.70	1.76	0.29	0.38
P2O5	0.702	0.684	0.592	0.596	0.204	0.147	0.246	0.241	0.136	0.136
TOTAL:	99.70	98.80	99.42	99.35	99.44	99.18	99.89	99.57	99.87	101.33
LOI	2.36	2.68	3.55	4.54	4.70	2.30	0.69	1.22	3.27	2.27
BA	617	473	549	711	184	1090	1230	645	135	230
NB	14.9	12.9	13.1	12.3	5.2	5.0	13.5	13.6	2.9	3.6
ZR	300	291	278	268	109	89	267	277	80	80
Y	46.6	45.5	43.9	37.1	26.0	20.4	27.4	29.2	17.5	19.0
SR	263	530	306	510	227	242	165	565	323	391
RB	93.8	39.8	44.7	30.3	21.2	29.7	121.0	33.6	5.1	8.0
ZN	146	128	141	119	155	92	78	74	85	75
CU	32	35	30	35	36	41	9	13	64	78
NI	25	32	31	34	601	220	12	11	318	320
CO	50	53	52	44	110	62	17	18	70	67
CR	10	9	9	8	1389	734	8	5	1012	974
V	310	315	311	264	269	204	50	49	204	198
LA	38	36	31	37	8	8	45	47	8	8
CE	81	76	75	85	30	23	94	100	19	24
ND	50	47	44	47	17	14	41	43	7*	14

SAMPLE:	DB- 85	KL- 86	KL- 87	DB- 88	DP- 89	KL- 90	PR- 91	DB- 92	DB- 93	DB- 94
SIO2	58.80	51.23	52.74	57.23	71.54	51.23	52.27	56.22	51.70	53.20
TIO2	0.794	0.409	0.614	1.167	0.832	0.468	1.880	1.598	0.763	0.676
AL2O3	14.76	14.99	14.38	14.61	12.47	14.64	13.30	13.05	13.06	13.70
FE2O3	9.24	9.15	11.21	13.90	6.58	9.11	14.44	14.50	12.36	10.36
MNO	0.14	0.15	0.17	0.17	0.06	0.16	0.26	0.18	0.18	0.14
MGO	4.86	9.12	7.69	4.43	1.17	10.13	7.75	3.41	9.15	8.47
CAO	4.95	12.18	9.99	4.15	0.78	10.71	7.08	6.91	9.54	9.46
NA2O	2.55	1.67	2.33	2.55	3.70	1.80	1.92	2.74	2.50	3.08
K2O	3.69	1.07	0.80	1.50	2.61	1.69	0.11	0.84	0.57	0.78
P2O5	0.219	0.033	0.064	0.292	0.259	0.046	0.987	0.546	0.172	0.135
TOTAL:	98.65	100.80	100.62	99.40	99.56	100.58	100.00	98.75	99.54	101.02
LOI	1.74	2.08	2.08	4.32	1.18	2.46	6.82	2.81	3.54	2.46
BA	2752	285	177	426	816	1470	105	510	223	304
NB	7.3	0.1	1.2	6.4	13.8	0.7	17.2	11.6	3.6	2.0
ZR	137	28	52	169	286	34	284	257	80	75
Y	23.3	15.2	21.4	28.9	27.4	16.7	57.4	42.1	20.3	17.5
SR	334	168	168	322	143	224	216	422	343	422
RB	59.7	41.9	39.2	41.5	73.1	101.0	6.5	31.4	14.7	18.3
ZN	90	64	78	122	84	69	167	137	93	77
CU	59	74	95	38	10	68	24	43	71	41
NI	64	181	117	28	10	186	187	40	321	292
CO	50	56	59	72	17	56	71	63	79	66
CR	28	774	120	7	12	932	659	19	1158	858
V	196	212	260	354	54	236	283	302	239	205
LA	17	0	5*	29	47	4*	52	40	9	10
CE	43	0	8*	68	88	0	122	84	24	20
ND	23	0	7	52	40	5*	64	45	16	16

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	DB- 95	DP- 96	DB- 97	DP- 98	DP- 99	KA-100	KA-101	KA-102	KA-103	KA-104
SIO2	56.08	71.09	56.94	70.79	71.46	56.26	57.07	55.49	57.29	55.29
TIO2	0.855	0.811	1.112	0.764	0.678	1.040	1.080	1.094	1.040	1.076
AL2O3	15.35	12.38	13.42	12.63	11.45	14.44	14.45	15.62	14.47	14.92
FE2O3	11.52	5.95	14.23	7.16	8.82	11.02	11.90	11.60	11.19	10.72
MNO	0.14	0.05	0.15	0.05	0.08	0.14	0.12	0.11	0.11	0.15
MGO	5.23	1.01	4.43	0.73	1.30	5.61	5.69	5.69	5.35	4.85
CAO	5.84	1.16	6.51	0.98	1.04	9.77	5.16	5.39	5.65	7.27
NA2O	3.44	3.37	2.86	2.36	2.76	0.67	3.70	4.09	4.08	4.00
K2O	1.30	3.93	0.21	4.34	2.22	0.91	0.69	0.75	0.66	1.54
P2O5	0.250	0.258	0.140	0.205	0.185	0.144	0.140	0.159	0.153	0.183
TOTAL:	98.98	100.14	100.42	99.43	100.15	100.74	100.50	99.95	100.76	99.65
LOI	2.33	1.64	6.58	1.78	2.41	10.35	2.99	3.47	2.83	3.51
BA	590	1019	104	853	482	1024	340	226	231	495
NB	5.4	13.6	5.5	14.5	14.0	4.9	5.1	6.2	6.3	6.2
ZR	152	275	114	244	220	113	119	126	120	124
Y	24.6	26.9	24.4	29.5	29.3	20.7	21.5	23.0	23.5	22.5
SR	539	173	282	71	54	507	278	232	245	396
RB	24.4	84.8	6.9	139.3	63.0	38.5	18.0	29.4	23.2	51.6
ZN	101	57	158	59	91	82	85	86	87	84
CU	55	11	61	15	14	85	86	88	77	107
NI	71	12	51	18	10	115	123	172	155	164
CO	62	17	67	22	21	61	58	65	61	57
CR	22	7	79	3	12	133	143	89	84	66
V	208	59	342	41	19	191	192	201	193	169
LA	21	48	21	59	39	11	5*	13	12	11
CE	47	89	36	116	79	25	28	33	28	32
ND	26	41	17	45	34	14	17	19	14	15

SAMPLE:	KA-105	KA-106	KA-107	KO-108	KO-109	KO-110	KO-111	KO-112	KO-113	KO-114
SIO2	53.96	55.46	56.70	53.85	53.80	54.30	52.31	53.26	53.20	51.77
TIO2	1.097	1.017	1.114	1.032	1.078	1.046	1.097	0.996	1.023	1.022
AL2O3	15.18	15.00	15.59	15.07	14.90	14.77	15.54	14.96	14.58	15.43
FE2O3	11.61	10.66	11.56	12.86	13.94	13.22	14.46	12.77	12.42	14.15
MNO	0.12	0.14	0.11	0.15	0.17	0.15	0.17	0.15	0.17	0.17
MGO	4.60	4.71	4.14	5.29	5.53	5.19	5.79	4.49	5.22	4.91
CAO	8.64	8.18	5.91	6.89	5.81	6.49	5.66	9.82	9.66	8.25
NA2O	3.22	3.38	4.02	3.99	3.43	3.91	3.90	2.69	2.73	2.89
K2O	1.40	1.29	0.70	0.75	1.22	0.79	0.95	0.76	0.85	1.28
P2O5	0.169	0.171	0.162	0.122	0.127	0.120	0.126	0.121	0.149	0.131
TOTAL:	100.77	100.23	99.35	100.56	100.06	99.64	100.18	100.58	98.94	100.69
LOI	2.13	3.36	3.17	1.99	2.19	2.00	2.11	1.89	2.38	2.15
BA	373	344	155	289	505	249	278	251	262	360
NB	5.1	4.9	8.1	5.6	4.2	5.6	5.4	6.6	6.8	4.0
ZR	123	117	131	103	103	104	109	98	105	101
Y	22.2	21.7	23.2	24.3	23.6	23.4	24.8	23.4	23.9	22.4
SR	493	517	147	330	332	369	282	671	497	304
RB	46.0	46.6	24.6	27.3	43.5	28.1	34.3	27.0	29.4	46.7
ZN	84	82	96	101	105	95	107	93	99	126
CU	114	108	105	104	106	113	112	119	92	64
NI	162	159	156	151	163	160	163	152	153	156
CO	64	57	63	74	75	74	79	75	66	84
CR	97	66	77	67	72	79	72	65	54	73
V	180	168	175	233	249	239	258	234	214	246
LA	10	10	17	12	9	12	8	8	8	12
CE	34	31	32	27	21	26	27	18	30	22
ND	15	12	16	12	13	13	15	10	10	15

SAMPLE:	KO-115	KO-116	KO-117	KO-118	KO-119	KO-120	KO-121	KO-122	KO-123	KO-124
SIO2	55.53	54.53	54.85	53.26	51.03	51.46	49.50	54.79	54.30	53.57
TIO2	0.991	1.025	1.013	0.931	1.068	1.022	0.940	0.934	0.879	0.887
AL2O3	13.96	14.75	14.55	15.05	15.05	14.32	16.75	14.77	14.27	14.57
FE2O3	11.47	13.23	13.16	11.78	13.90	13.31	10.01	12.35	11.83	11.62
MNO	0.14	0.14	0.14	0.13	0.17	0.18	0.10	0.18	0.16	0.14
MGO	5.29	5.77	5.44	4.80	5.74	6.21	2.33	5.39	4.58	4.50
CAO	7.49	5.67	6.02	10.66	8.13	6.48	19.61	6.82	5.89	7.25
NA2O	2.65	3.97	3.55	2.91	3.44	6.02	0.25	3.17	7.08	5.08
K2O	2.34	0.79	1.15	0.34	1.32	0.86	0.38	1.46	0.90	2.27
P2O5	0.138	0.124	0.123	0.134	0.143	0.138	0.150	0.125	0.108	0.113
TOTAL:	99.21	100.45	100.35	99.84	101.45	103.95	100.11	99.27	103.66	102.55
LOI	2.18	1.94	1.85	2.34	2.39	2.44	6.78	2.82	2.15	1.89
BA	691	392	361	128	277	358	126	494	218	1005
NB	6.0	5.5	5.2	3.1	5.6	5.6	5.1	5.1	4.2	3.9
ZR	100	103	98	91	103	100	100	97	90	91
Y	22.2	24.0	22.3	22.1	23.4	23.1	21.0	21.8	19.6	19.9
SR	356	353	303	781	504	214	266	258	174	249
RB	88.5	31.4	41.0	10.9	50.0	32.5	15.2	56.3	33.9	90.9
ZN	86	98	93	76	96	95	61	92	81	80
CU	137	103	106	65	121	77	117	96	89	91
NI	146	157	156	143	155	154	140	142	121	126
CO	64	78	71	63	70	67	55	66	58	63
CR	54	74	97	49	77	46	64	22	35	26
V	222	243	229	228	234	222	256	221	200	214
LA	10	18	12	9	11	8	12	10	11	16
CE	27	20	25	26	29	20	143	25	25	25
ND	10	15	15	12	16	11	80	11	0	15

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OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:       KO-125    KO-126    KO-127    KO-128    KO-129    KO-130    KL-131    KL-132    KL-133    KL-134
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SIO2           55,61     51.87     55.34     55,06     51.11     55,65     54,10     56.19     57,24     56.31
TIO2           0,908     0.925     0.914     0,903     1,014     0,902     0,769     0.763     0,780     0.649
AL2O3          14,89     15.27     14.42     14,61     15,59     14,59     13,79     14.10     13,33     12.53
FE2O3          11,99     12.87     12.45     11,99     13,72     11,55     11,51     11.05     11,09     10.72
MNO             0,13      0.16      0.16      0.15      0,16      0.16      0.18      0.13      0,12      0.18
MGO             4,90      5.47      4.52      4,59      4,85      4.47      6.62      6.48      6,19      6.54
CAO             6,45      8.24      6.60      7,18      9,28      7,58      7.12      7.06      6,82      9.15
NA2O            3,89      3.22      3.70      3,04      3,22      2,32      3.72      3.75      3,45      3.12
K2O             1,13      1.85      1.78      2,37      0,91      2,63      2,09      0.38      0,89      0.72
P2O5           0,114     0.125     0.125     0,108     0,134     0,136     0,098     0.095     0,092     0.082

TOTAL:        101,23    100.43    100.87    100,50     99,91     99,57    100,47    100.21    100,48     99.79

LOI             1,69      1.98      1.62      1,44      2,05      2,25      1.79      2.10      1,90      2.02

BA               299       453       477       653       178       816       328       134       209       179
NB               3.2       4.5       5.3       3.6       5.7       4.6       3,2       3.5       4.9       2.0
ZR                96        96        97        97       107        97        86        85        84        68
Y               23.0      21.6      25.1      22.8      25.5      21,2      19,1      20.0      20.1      17.8
SR               263       247       251       410       207       411        64       227       141       155
RB              44.0      65.9      68.0      95.2      33.9     108,9      74,7      12.7      29,8      19.5
ZN                87        94        86        82       104        87        90        77        84        77
CU                92        96        91        97       103        91        79        78       123        71
NI               127       133       115       111       131       111       172       180       164       190
CO                64        63        63        63        72        59        64        60        64        59
CR                29        26        26        20        28        16       233       272       238       400
V                216       209       212       222       235       215       193       187       193       195
LA                10         8        10        10        10         9         9         6         8        11
CE                22        23        30        15        28        31        22        23        17        15
ND                11        12        15         9        12         9        11        13         9        10


SAMPLE:       KL-135    KL-136    KL-137    KL-138    KL-139    KL-140    KL-141    KL-142    KL-143    KL-144
              ------    ------    ------    ------    ------    ------    ------    ------    ------    ------
SIO2           53,10     53,47     51.80     51,82     53,96     53.32     52.54     50.97     53,12     54.56
TIO2           0,487     0.655     0.683     0,694     0,700     0.533     0.571     0.627     0,612     0.616
AL2O3          10,35     13.61     14.10     15,13     14,69     11,30     11.87     13.46     12,96     13.69
FE2O3          11,88     11.83     12.28     11,94     12,15     10,99     11.69     12.06     11,46     11.20
MNO             0,18      0.16      0.19      0,20      0,17      0,21      0.18      0.18      0,17      0.18
MGO            13,62      7.28      7.71      6,84      7,55      9,91     10.60      8.33      8,32      7.59
CAO             8,29      9,54      9.72      8,46      6,91      9,44      9.21     10,55      9,31      7.18
NA2O            1,85      2.09      2.82      3,37      3.08      2,39      1.58      3,08      2,69      3.09
K2O             0,18      1.30      0.59      1,46      0,70      1,85      1.68      0.68      1,29      1.83
P2O5           0,046     0,075     0.099     0,087     0,097     0,059     0.078     0,064     0,070     0.076

TOTAL:        101,14    100.44     99.26    100,01     99,99    101,31     99.12     99.80    100,96     98.85

LOI             3,35      2.18      3.31      2,94      3,42      1,55      2.74      2.69      2,20      2.29

BA                70       403       227       644       186       468       599       208       334       641
NB               1.3       1.9       5.5       2.2       3.9      0.7*      1.7*       1.8       2.6       2.0
ZR                43        63        70        71        74        45        52        56        56        64
Y               12.5      18.5      18.2      18.4      18.1      14,6      14.9      17.4      17.6      18.8
SR                54       561       244       173        77       107       270       208       209       176
RB               8.8      60.4      22.6      43.3      20.8      55,2      79.7      20.3      56.9      78.6
ZN                78        79       107        81        98        81        76        93        74        80
CU                52        80        67        80        52        55        64        79        73        74
NI               438       206       196       166       173       281       308       221       225       220
CO                78        70        71        67        69        66        75        71        67        67
CR              2086       381       344       215       251       783       900       475       482       446
V                171       211       217       197       155       201       219       224       214       217
LA                 0        10        5*        10         9        6*        4*        6*         9        5*
CE               10*        18        14        21        16       13*        9*        21        20        13
ND                 0        11         0        10        6*        6*         0        11        6*        6*


SAMPLE:       KL-145    KL-146    KL-147    KL-148    KL-149    KL-150    KL-151    KL-152    KL-153    KL-154
              ------    ------    ------    ------    ------    ------    ------    ------    ------    ------
SIO2           54,50     51.77     53.95     54,12     53,26     52,11     56,82     54.87     52,25     53.59
TIO2           0,604     0.519     0.595     0,571     0,553     0,670     0,642     0.666     0,737     0.477
AL2O3          13,76     12.72     13,07     13,51     13,68     14,80     14,24     14.73     15,38     12.73
FE2O3          11,46     11,08     11.65     11,10     11,01     11,85     10,23     10.64     12,10     10.79
MNO             0,17      0.19      0.24      0,15      0,15      0,15      0,15      0.15      0,23      0.18
MGO             7,65     12.87      7.85      7,93      8,35      7,36      5,23      6.27      7,11     10.75
CAO             9,86      7.19      7.50      8,16      8,11      8,54      6,91      7.96      6,29      7.75
NA2O            0,15      1.98      3.48      3,11      3,03      3,01      3,38      3,42      3,31      2.16
K2O             1,75      1.60      1.59      1,26      1,78      1,43      2,27      1.20      2,49      1.52
P2O5           0,071     0.078     0,083     0,071     0,068     0,082     0.131     0.105     0,102     0.070

TOTAL:         99,50    100,01    100,87     99,83    100,35     98,81     99,56    100.13     99,61    100.55

LOI             1,98      4,00      0,27      2,45      2,20      2,79      2,02      2.48      2,57      3.12

BA               231       433       249       337       866       669       735       331       680       435
NB               6.1      2.3*       1.3       2.2       1.7       1.5       2.4      1.7*       3.0       1.6
ZR               113        60        62        60        55        73        75        77        81        56
Y               23.4      12.7      15.6      17.4      15.2      20.8      18.6      17.5      20.2      14.6
SR                54       109        49       259       213       258       314       524       140       361
RB              35.1      60.4      37.6      56.2      72.8      42.2      74.3      43.8      59.3      60.5
ZN               106       118        77        76        71        80        74        79        97        92
CU                69        48        63        65        60        62        80        72        82        56
NI               230       422       209       231       223       209       145       153       163       294
CO                63        72        65        66        65        66        56        60        67        69
CR               421      1369       449       526       543       423       156       158       171      1200
V                225       190       204       209       207       213       182       197       207       156
LA                15        6*         9         7         7        6*         9         8         9         9
CE                32        8*        16        18        16        18        23        20        18        18
ND                17         0         9        6*         7        10        12         8         9         9
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OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	KL-155	KL-156	KL-157	KL-158	KL-159	PG-160	PG-161	PG-162	PG-163	PG-164
SIO2	54.46	54.02	54.23	50.81	53.82	62.06	60.37	60.07	56.13	51.85
TIO2	0.514	0.409	0.416	0.458	0.409	1.198	1.284	1.251	1.628	1.644
AL2O3	13.01	10.64	10.58	11.25	10.57	13.78	13.64	14.54	13.71	14.33
FE2O3	10.22	10.96	10.86	12.05	11.24	9.83	9.01	9.68	11.48	11.60
MNO	0.16	0.19	0.17	0.18	0.19	0.09	0.11	0.13	0.15	0.16
MGO	11.22	13.43	14.27	14.89	14.07	5.84	4.25	5.37	6.80	6.96
CAO	6.56	8.23	7.68	8.37	7.94	2.94	4.78	3.38	5.87	8.65
NA2O	2.33	1.80	1.64	1.54	1.40	2.58	3.29	2.56	2.46	2.46
K2O	1.45	0.29	0.12	0.40	0.28	1.18	2.73	2.49	0.98	1.53
P2O5	0.084	0.052	0.042	0.060	0.066	0.520	0.540	0.535	0.795	0.815
TOTAL:	99.55	100.63	99.11	102.44	99.23	98.80	99.60	98.33	98.90	98.36
LOI	3.84	3.88	4.40	4.32	4.42	3.58	2.56	2.77	3.67	4.39
BA	430	111	49	146	120	777	1085	1010	886	806
NB	2.7	0.7*	1.1	1.6	0.0	17.4	17.5	16.6	14.2	13.3
ZR	63	38	41	45	41	302	310	313	253	254
Y	14.1	11.6	12.4	14.4	12.2	47.9	48.1	48.0	51.1	51.7
SR	443	215	137	126	180	494	351	228	401	1093
RB	52.8	11.0	4.1	9.4	5.9	27.9	60.5	60.9	23.9	35.0
ZN	78	84	114	101	112	120	112	149	141	131
CU	53	51	45	51	40	23	19	29	48	31
NI	304	385	402	344	405	96	88	93	159	162
CO	70	75	76	72	78	41	37	40	50	52
CR	1287	1935	2289	1577	1771	250	255	258	337	378
V	153	162	171	190	171	155	167	172	225	236
LA	6*	5*	6	5*	4*	51	60	55	48	50
CE	14	10*	13*	10*	9*	123	130	129	116	117
ND	5*	4*	6*	4*	0	60	59	66	66	66

SAMPLE:	PG-165	PG-166	PG-167	PG-168	PG-169	PG-170	PG-171 A	PG-171 B	PG-172	PG-173
SIO2	53.31	53.50	57.48	54.17	56.97	57.07	55.08	57.13	56.13	61.89
TIO2	1.637	1.579	1.686	1.614	1.569	1.667	1.666	1.611	1.599	1.460
AL2O3	13.49	14.84	14.49	14.70	13.97	15.55	15.71	14.15	15.32	13.70
FE2O3	12.81	11.67	10.83	12.31	10.55	10.35	9.71	10.04	9.25	7.77
MNO	0.16	0.14	0.14	0.18	0.14	0.11	0.11	0.13	0.12	0.09
MGO	7.09	6.20	5.28	7.13	3.71	5.61	3.71	3.61	3.83	2.88
CAO	6.74	6.95	5.70	5.24	8.74	4.86	7.29	8.15	7.42	6.18
NA2O	2.82	3.73	3.41	2.80	3.12	3.10	3.61	3.01	3.44	3.17
K2O	1.18	0.65	0.18	1.05	0.51	0.88	2.34	1.41	2.11	2.16
P2O5	0.760	0.742	0.793	0.799	0.735	0.805	0.792	0.765	0.794	0.713
TOTAL:	100.19	98.40	98.26	99.15	100.13	98.17	99.45	99.71	98.63	99.52
LOI	3.12	2.77	4.21	3.53	3.85	4.73	5.28	3.76	4.77	2.86
BA	522	443	172	659	384	977	1029	689	999	1131
NB	13.8	16.6	16.9	17.2	16.5	18.7	18.4	17.2	17.4	18.2
ZR	244	272	304	292	287	333	325	307	314	309
Y	50.7	51.9	55.8	51.6	50.1	56.9	58.7	51.6	50.5	45.4
SR	566	470	564	502	1022	469	555	830	587	596
RB	26.1	12.4	3.0	19.0	8.3	21.3	44.0	24.3	41.8	44.5
ZN	144	131	132	140	109	125	124	125	117	88
CU	43	33	29	36	38	41	38	36	33	42
NI	161	159	145	167	118	105	109	103	124	107
CO	53	49	48	51	46	43	44	42	45	36
CR	369	371	376	380	242	167	191	186	253	207
V	236	247	219	214	200	204	204	188	197	168
LA	53	51	58	47	54	46	65	56	60	55
CE	113	112	129	116	120	112	141	124	123	123
ND	58	60	71	59	64	60	75	65	65	63

SAMPLE:	PG-174	PG-175	PG-176	PG-177	PM-178	PM-179	PM-180	PR-181	PR-182	PR-183
SIO2	50.47	60.16	59.27	78.24	64.95	66.79	60.51	56.33	57.53	56.32
TIO2	1.733	1.431	1.399	0.254	1.122	1.172	1.300	1.434	1.280	1.440
AL2O3	17.27	14.83	14.57	5.91	13.97	14.21	15.38	15.39	13.66	15.74
FE2O3	13.65	9.20	8.62	9.05	7.79	5.75	8.83	10.69	9.84	8.86
MNO	0.16	0.11	0.12	0.13	0.08	0.08	0.09	0.16	0.10	0.11
MGO	6.26	4.22	2.86	3.85	3.38	2.08	3.69	6.52	5.79	4.14
CAO	6.09	4.03	8.12	2.03	2.21	4.52	5.45	5.33	6.61	6.78
NA2O	2.69	3.14	3.02	0.09	1.31	4.04	2.99	3.03	3.41	3.35
K2O	0.88	2.23	1.38	0.41	4.72	0.80	1.19	0.43	1.17	2.54
P2O5	0.796	0.658	0.658	0.036	0.461	0.542	0.560	0.683	0.609	0.735
TOTAL:	98.70	98.48	98.93	99.10	99.72	98.90	98.41	98.83	98.62	99.54
LOI	4.28	3.76	4.42	3.84	3.00	1.96	2.71	5.97	3.28	5.82
BA	1034	984	590	204	1670	171	1054	293	809	1291
NB	21.6	19.8	16.6	26.7	30.2	32.1	32.6	14.3	13.5	14.3
ZR	376	326	316	360	491	549	560	276	245	245
Y	61.0	48.6	48.8	37.4	62.1	73.4	66.0	42.1	39.6	44.5
SR	670	303	805	67	113	926	1270	312	385	232
RB	18.0	45.6	29.6	12.1	158.2	34.0	27.6	10.8	24.4	53.9
ZN	161	105	107	57	99	93	100	117	100	99
CU	40	30	31	10	12	13	23	27	36	33
NI	129	90	89	26	30	17	31	146	170	105
CO	54	42	39	21	23	20	29	50	50	42
CR	238	196	168	0	26	15	24	386	520	150
V	221	182	174	25	98	89	140	179	169	189
LA	64	56	56	52	73	100	94	48	47	45
CE	149	125	126	89	174	205	205	102	101	109
ND	79	61	62	33	81	94	94	53	51	55

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	PR-184	PR-185	PR-186	PR-187	PR-188	PR-189	PR-190	PR-191	PR-192	PR-193
SIO2	47.50	54.51	52.79	56.45	56.96	55.72	57.43	52.23	59.41	56.38
TIO2	2.202	1.831	1.924	1.713	1.711	1.642	1.602	1.601	1.444	1.386
AL2O3	16.47	13.66	14.66	14.31	14.62	14.59	13.91	16.79	15.85	14.89
FE2O3	14.26	12.92	12.52	11.11	11.21	10.90	10.09	13.11	6.29	11.90
MNO	0.16	0.18	0.15	0.13	0.13	0.14	0.13	0.14	0.07	0.16
MGO	5.41	6.48	5.68	4.43	4.50	5.45	4.24	5.50	2.59	5.41
CAO	9.39	6.22	7.97	5.72	6.51	6.55	6.22	5.60	8.14	5.91
NA2O	3.23	2.65	2.69	3.17	2.94	4.02	3.30	3.29	3.97	2.60
K2O	0.21	0.58	0.63	2.13	0.53	0.15	2.28	0.92	1.58	0.69
P2O5	1.168	0.966	0.975	0.831	0.877	0.842	0.788	0.820	0.657	0.674
TOTAL:	99.10	98.92	99.21	99.20	98.14	98.33	99.90	98.10	98.64	99.18
LOI	6.76	3.89	6.79	3.55	4.65	2.92	3.16	5.32	6.45	6.77
BA	312	696	482	1182	398	164	1599	799	832	433
NB	19.8	17.7	21.2	19.9	19.1	21.2	20.6	18.8	20.4	17.7
ZR	321	305	334	348	355	385	363	369	387	351
Y	67.6	55.8	59.2	56.7	55.4	56.8	54.0	58.2	48.4	50.4
SR	775	740	448	291	829	813	702	963	679	562
RB	8.4	12.8	12.8	40.1	7.9	3.2	39.7	15.0	63.6	24.5
ZN	162	152	143	129	119	146	121	151	75	116
CU	58	44	41	40	47	31	36	41	39	31
NI	153	166	133	120	101	115	106	133	82	115
CO	62	60	51	48	46	46	43	56	35	48
CR	362	479	306	260	211	246	300	318	184	294
V	314	234	229	234	227	218	202	240	184	195
LA	65	56	57	66	64	60	65	64	63	55
CE	144	132	131	151	139	139	147	136	135	123
ND	78	67	71	76	68	70	74	71	63	60

SAMPLE:	PR-194	AR-195	AR-196	AR-197	AR-198	AR-199	KA-200	KO-201	KO-202	KL-203
SIO2	53.93	58.33	56.70	55.38	61.26	57.15	57.47	56.84	54.06	54.55
TIO2	1.465	1.242	1.229	1.167	1.182	1.166	1.074	0.982	1.012	0.674
AL2O3	15.48	14.35	14.70	14.88	13.66	13.80	14.42	13.92	14.82	13.97
FE2O3	10.72	12.04	11.86	15.12	10.05	11.46	11.62	12.38	13.31	11.58
MNO	0.12	0.16	0.15	0.15	0.09	0.12	0.12	0.14	0.15	0.16
MGO	7.36	3.27	2.21	4.05	3.20	4.18	4.62	4.48	5.36	6.94
CAO	7.73	5.99	8.17	5.36	5.25	6.45	6.37	6.74	6.99	7.63
NA2O	1.05	4.12	4.15	3.16	3.80	4.05	2.70	2.21	3.21	3.05
K2O	1.47	0.30	0.62	0.53	1.30	1.42	1.45	2.18	0.97	1.38
P2O5	0.671	0.207	0.218	0.198	0.210	0.228	0.161	0.127	0.127	0.075
TOTAL:	100.43	99.30	100.36	99.36	100.13	99.98	98.77	99.32	100.28	98.26
LOI	9.30	5.92	7.77	6.12	5.19	3.32	6.48	2.02	2.14	2.12
BA	385	524	259	271	362	565	1189	617	254	518
NB	20.2	10.4	10.3	10.3	10.5	7.7	5.5	4.3	4.5	3.0
ZR	367	178	180	177	180	157	124	101	105	68
Y	51.6	27.5	26.9	28.2	28.0	27.4	24.4	22.9	23.7	18.6
SR	217	723	690	802	678	1472	353	358	461	328
RB	51.2	10.7	24.2	11.8	29.3	40.0	39.8	86.9	36.4	58.6
ZN	129	115	111	138	93	94	82	89	97	77
CU	11	118	123	164	115	123	95	114	122	80
NI	115	110	106	116	113	143	163	148	151	190
CO	46	62	62	64	56	60	64	63	69	71
CR	286	10	13	14	16	20	98	57	62	390
V	213	164	180	186	164	177	199	213	221	217
LA	64	26	30	25	24	26	16	15	11	4*
CE	138	55	60	51	55	56	38	25	25	12*
ND	69	25	30	25	27	25	17	11	13	5*

SAMPLE:	KL-204	KL-205	PG-206	PG-207	PG-208	PM-209	PM-210	PM-212	PM-213	PM-217
SIO2	55.60	54.90	58.23	53.67	52.50	59.75	68.29	66.24	68.03	65.41
TIO2	0.499	0.427	1.285	1.599	1.897	1.373	1.064	1.226	1.217	1.151
AL2O3	12.42	10.53	13.96	13.60	16.10	15.48	13.09	15.19	13.91	13.74
FE2O3	10.17	10.43	10.15	11.84	12.41	8.59	6.05	6.38	5.86	7.45
MNO	0.17	0.18	0.12	0.16	0.16	0.05	0.05	0.09	0.02	0.10
MGO	9.22	12.24	5.15	6.42	5.74	3.76	0.77	1.66	1.72	1.71
CAO	7.99	8.82	5.43	8.15	5.86	2.44	2.65	2.04	2.51	4.09
NA2O	2.39	1.90	2.86	3.04	3.88	0.51	2.96	6.56	1.54	3.56
K2O	1.47	0.52	2.24	0.75	0.42	7.67	4.64	0.07	4.68	2.31
P2O5	0.073	0.060	0.564	0.782	1.029	0.584	0.436	0.545	0.517	0.478
TOTAL:	98.91	101.56	100.78	99.72	99.92	99.43	99.07	98.63	99.14	99.56
LOI	2.54	3.16	2.78	3.74	5.15	2.92	2.04	1.70	2.74	2.62
BA	419	187	745	541	595	2784	2017	25	1721	1942
NB	2.2	0.7*	16.4	14.8	18.9	36.9	28.3	34.6	33.9	28.2
ZR	66	45	315	271	317	594	476	561	527	511
Y	16.5	13.9	48.0	51.7	68.4	76.8	66.4	76.7	78.1	73.2
SR	67	256	493	672	583	191	330	203	207	888
RB	51.4	23.6	53.2	17.5	7.6	207.2	112.3	2.0	234.4	55.8
ZN	84	60	121	123	136	125	96	99	74	112
CU	52	50	49	40	42	15	11	10	13	17
NI	258	338	98	138	168	38	25	17	27	26
CO	62	69	44	50	59	25	19	20	18	21
CR	1032	1697	272	392	398	27	20	21	27	21
V	180	167	172	209	223	120	91	98	109	100
LA	10	4*	60	49	77	104	88	107	128	98
CE	15	12*	135	114	159	208	192	205	243	193
ND	11	5*	64	59	82	96	85	94	102	93

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	PM-219	PM-222	PM-228	PM-231	PM-233	PR-234	AR-236	AR-238	AR-241	AR-244
SIO2	63,71	68.23	66.00	61,88	59,78	58,46	56,15	58.43	55,90	51.43
TIO2	1,249	1.082	1.068	1,541	1,187	1,346	1,322	1.193	1,251	1.228
AL2O3	14,55	13.54	12.96	16,87	14,78	14,26	15,53	14.54	14,79	14.31
FE2O3	9,86	6.04	6.42	7,70	13,11	9,91	5,09	10.15	12,46	14.47
MNO	0,12	0.10	0.09	0,08	0,15	0,13	0,25	0.11	0,18	0.22
MGO	3,28	1.70	1.06	2,51	5,22	4,71	2,02	2.28	3,55	5.38
CAO	1,84	3.85	7.93	2,64	2,01	6,61	14,66	8.29	6,83	9.14
NA2O	2,86	3.94	3.42	3,33	2,24	3,21	0.16	4.26	3,67	2.99
K2O	1,98	1.05	0.60	2,77	1,00	0,74	4,59	0.54	1,14	0.58
P2O5	0,538	0.460	0.453	0,669	0,531	0,636	0,228	0.208	0,228	0.252
TOTAL:	98,99	99,65	99,41	98,25	98,63	99,61	99,60	99.62	99,21	98.34
LOI	2,93	1,99	3.15	2,98	4,29	4,57	12,61	6,95	6,50	8,62
BA	660	337	229	1104	568	686	998	386	379	233
NB	32.8	28.8	23.6	40.1	31.0	15,9	10,1	11.0	9.9	7.2
ZR	540	489	464	678	515	341	187	179	179	174
Y	69.2	69,9	65.4	84.6	63,1	49,1	30,1	27.6	28.9	26.2
SR	178	962	2943	488	428	1395	402	874	305	342
RB	82.7	45.5	22.2	103.2	34,7	9,6	172,4	16.3	25.8	15.2
ZN	151	113	78	140	204	112	117	119	96	121
CU	14	16	28	17	10	42	130	129	125	103
NI	27	22	22	28	20	107	76	104	146	193
CO	26	16	19	19	33	42	51	54	64	64
CR	24	23	30	25	17	283	21	11	32	78
V	108	95	90	134	94	184	184	166	176	211
LA	45	94	83	140	58	63	28	30	27	31
CE	112	193	176	282	132	134	60	57	61	48
ND	65	88	83	186	61	68	31	26	29	27

SAMPLE:	DB-247	DB-251	DB-254	DB-257	DB-259	DP-261	DP-263	DP-265	DP-269	DB-273
SIO2	59,58	54.52	51.84	53,85	49,95	69,32	55,93	78.93	68,93	60.28
TIO2	1,660	0.664	0.691	0,624	1,319	0.845	1.080	0.660	0.788	1.147
AL2O3	12,45	15.89	14.76	14,37	17,25	13,17	15.11	10.93	12,63	13.70
FE2O3	12,81	9.46	12.34	9,42	17.15	6,74	11,78	2.43	7,46	13,20
MNO	0,18	0.15	0.17	0,16	0,21	0.09	0.12	0.03	0,11	0.17
MGO	3,18	6.76	7.85	8,20	5,53	1.57	5.34	0.85	0,50	2.39
CAO	6,66	7.39	8.57	9,87	4,76	1.70	5.32	0.42	2,79	4.65
NA2O	1,72	3.93	3.40	2,33	2,72	4,36	4.39	0.20	3,21	2.29
K2O	1,20	1.08	0.43	1,03	0,75	1,92	0.76	5.34	3,37	2.01
P2O5	0,567	0.166	0.140	0,138	0,362	0,286	0,156	0.208	0,219	0.168
TOTAL:	99,83	99,28	100.54	100,18	100,25	99,16	99.13	99.48	99,53	98.09
LOI	3,72	2,02	2,24	2,04	4,22	2,21	2,57	1.55	2,84	5.35
BA	951	662	232	321	278	516	473	1013	692	376
NB	11.7	3,4	2.5	2.9	8,2	12,8	16,1	11.4	14.5	5.9
ZR	258	97	85	80	172	271	353	233	245	139
Y	40.0	18.9	18.7	17.3	30,7	25,7	36,0	23.4	33.8	24.2
SR	505	441	325	463	337	159	203	43	213	244
RB	31.8	16.8	6.5	29.2	13,3	40,1	56,3	150.1	97.6	91.4
ZN	121	81	94	76	166	68	93	40	90	116
CU	31	57	77	76	6	6	9	3	9	44
NI	31	216	389	275	44	9	10	13	10	26
CO	50	57	69	61	78	19	17	10	18	61
CR	10	299	883	746	5	3	2*	9	3	0
V	281	180	201	182	402	76	59	50	26	387
LA	31	13	8	11	29	38	50	27	47	25
CE	80	27	21	25	60	77	97	51	88	51
ND	45	12	8	7	27	35	42	22	55	18

SAMPLE:	DP-276	DB-278	DB-281	DB-285	DB-286	DP-288	KA-291	KO-295	AR-300	AR-304
SIO2	73,65	55.35	52.78	55,49	56,56	69,39	56,60	55.55	61,89	60.38
TIO2	0,522	1.252	0.671	0,818	1,413	0,814	1.047	1.074	1,222	1.271
AL2O3	12,70	15,79	14.39	15,69	14,31	12,57	15,39	14.66	14,36	14.80
FE2O3	5,04	11,28	10.63	9,85	14,26	6,39	11.74	13.47	9,75	7.64
MNO	0,07	0.18	0.16	0,14	0.18	0,09	0,12	0.15	0,12	0.13
MGO	0,68	5.93	8.35	5,20	3,20	0,94	5,07	5.23	3,64	2.88
CAO	0,98	5,01	9.81	7,88	6,02	3,46	5,23	5.52	2,80	5.60
NA2O	3,14	3,99	2,51	3,22	2,90	3,36	3,92	3.34	2,81	3.62
K2O	3,09	0,83	0.55	1,48	0,81	2,72	0,74	0.90	3,18	3.46
P2O5	0,125	0,383	0.151	0,238	0,344	0,259	0,140	0.124	0,220	0.227
TOTAL:	99,41	98,10	100.47	96,24	98,76	98,98	100.53	99.35	99,69	98.69
LOI	1,86	1,86	2.11	1,64	5,06	3,38	3,48	2.89	3,52	4.96
BA	370	416	230	837	501	625	304	233	707	741
NB	14.8	8.1	3.3	5.4	8.5	13.4	5.5	5.4	11.9	12.2
ZR	269	185	78	150	223	272	122	110	187	193
Y	24.4	33.8	17.7	26.8	34.5	28,7	21,4	21.3	23.1	24.3
SR	89	203	428	607	409	275	360	197	71	95
RB	102.5	11.6	12.9	26.5	14.0	73,4	25,8	31.9	69.3	75.1
ZN	51	132	84	91	140	80	92	105	84	64
CU	13	48	71	67	39	5	72	68	10	5
NI	8	115	292	71	25	9	167	161	113	96
CO	11	61	63	53	62	20	59	76	57	47
CR	5	47	801	29	0	0	81	60	18	9
V	21	276	199	210	372	73	180	208	179	147
LA	52	22	6	19	31	43	14	9	14	16
CE	95	55	22	50	69	83	23	23	37	38
ND	38	31	7*	22	34	35	10	7	18	19

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	AR-305	AR-307	PG-312	PG-314	PG-316	PG-319	PG-322	PG-325	PG-328	PM-329
SIO2	58,00	57,97	59,07	50,68	63,42	57,89	59,32	56,96	60,06	54,93
TIO2	1,295	1,201	1,292	1,732	1,289	1,281	1,364	1,530	1,267	1,729
AL2O3	14,79	14,27	14,15	19,44	13,48	13,95	15,14	13,57	15,34	18,55
FE2O3	14,04	10,00	11,59	14,30	8,10	9,99	9,87	11,01	8,68	10,18
MNO	0,13	0,16	0,14	0,12	0,14	0,18	0,16	0,14	0,11	0,12
MGO	4,78	4,95	5,34	4,60	2,35	3,97	5,61	6,66	4,46	4,07
CAO	2,43	6,23	4,28	2,76	4,99	7,03	3,08	5,62	4,38	3,16
NA2O	2,78	3,45	2,72	3,00	2,81	2,54	4,11	3,19	4,38	2,93
K2O	1,58	1,50	0,87	2,63	2,87	2,62	0,81	0,57	0,73	3,64
P2O5	0,176	0,266	0,551	0,748	0,541	0,550	0,542	0,754	0,591	0,687
TOTAL:	99,83	98,33	99,92	98,60	98,73	98,75	98,42	97,62	99,23	97,08
LOI	3,87	4,84	5,83	4,25	2,10	3,22	2,87	2,56	2,88	2,90
BA	301	349	865	1042	1198	1475	522	549	413	2147
NB	9.5	7.6	18.4	32,6	24,4	18,1	22,8	18.0	21.3	45.8
ZR	180	185	355	705	493	323	425	297	410	748
Y	22.2	28.9	50.1	95.5	64,2	48,5	54,4	52.2	54.6	92.9
SR	53	451	421	360	775	851	414	491	525	523
RB	33.8	24,6	24.4	103,0	67,3	56,6	21,8	15,6	13.8	132.7
ZN	116	103	136	174	100	114	110	130	102	139
CU	7	41	12	15	11	28	18	11	12	17
NI	162	198	70	59	33	94	60	161	55	37
CO	72	63	40	39	26	43	38	47	33	31
CR	21	128	171	100	68	253	213	442	120	39
V	197	208	189	253	151	181	158	219	182	157
LA	14	24	65	90	93	62	51	49	81	123
CE	41	57	136	196	199	126	121	113	163	263
ND	20	29	64	96	93	60	58	60	75	119

SAMPLE:	PM-332	PM-335	PM-338	AR-339	AR-341	AR-343	AR-345	KA-346	KA-347	KA-348
SIO2	66,91	68,75	67,40	59,05	55,76	52,42	57,15	52,56	58,13	53,26
TIO2	1,090	1,116	1,082	1,190	1,332	1,174	1,071	1,129	1,005	1,078
AL2O3	13,24	12,75	13,61	14,42	14,67	14,27	14,91	14,87	14,13	15,13
FE2O3	6,76	6,60	6,13	9,93	11,70	12,76	11,82	12,51	10,10	12,27
MNO	0,14	0,07	0,08	0,18	0,14	0,16	0,15	0,14	0,14	0,13
MGO	1,58	0,76	2,42	3,35	4,03	4,91	4,81	7,29	4,89	5,16
CAO	2,94	2,53	3,93	8,06	7,35	9,36	5,37	8,24	6,43	8,13
NA2O	3,30	3,16	2,79	1,18	3,78	4,06	3,93	2,04	4,46	3,80
K2O	3,56	3,78	2,10	2,41	0,97	0,65	0,58	1,07	0,58	0,87
P2O5	0,462	0,468	0,459	0,225	0,271	0,241	0,224	0,152	0,137	0,165
TOTAL:	99,92	100,18	100,37	99,16	100,07	101,05	98,79	101,77	100,21	100,72
LOI	2,06	1,85	3,62	8,74	6,43	5,06	3,58	10,11	2,25	2,23
BA	1330	1310	509	509	208	349	347	445	204	591
NB	28.8	31.9	30.4	11.4	9,0	7.3	6,5	2.0	5.2	6.4
ZR	478	468	452	178	178	168	167	60	108	118
Y	67.9	67.9	63.9	28.3	25.3	28.3	24,4	17.7	20.7	23.7
SR	493	202	224	269	283	606	499	280	257	588
RB	88.0	91.2	85.5	98.5	23,9	17.4	17,4	87.7	11.7	26.7
ZN	104	87	91	96	127	93	135	81	67	105
CU	10	10	8	114	92	50	57	70	77	122
NI	22	23	20	102	176	184	165	211	101	167
CO	20	19	18	56	78	71	71	69	54	63
CR	11	17	20	18	48	57	55	413	124	64
V	96	106	106	167	215	201	195	211	179	171
LA	93	84	70	25	23	23	24	11	13	11
CE	191	177	140	51	51	42	51	17	25	34
ND	88	79	68	22	26	26	27	8	13	16

SAMPLE:	KA-349	KA-350	KO-352	KO-355	KO-356	AR-359	AR-360	AR-361	AR-362	AR-363
SIO2	55,12	54,83	54,75	53,50	58,88	57,76	53,96	55,38	55,09	54,18
TIO2	0,973	1,092	0,984	0,919	0,925	1,240	1,241	1,321	1,181	1,102
AL2O3	15,54	14,98	14,62	15,10	15,77	14,38	15,06	14,14	14,15	13,39
FE2O3	10,83	11,12	12,45	13,37	11,07	9,93	13,16	12,89	11,75	12,04
MNO	0,13	0,15	0,15	0,18	0,11	0,13	0,18	0,13	0,14	0,16
MGO	4,41	4,82	4,65	5,79	3,57	3,12	5,00	4,71	4,98	5,32
CAO	7,43	6,41	7,42	6,21	5,17	7,71	5,93	6,55	8,13	8,75
NA2O	4,57	3,67	3,52	3,21	3,64	3,44	4,11	2,80	3,26	3,34
K2O	0,84	2,77	1,52	1,61	0,75	2,08	1,14	1,80	1,06	1,47
P2O5	0,144	0,169	0,132	0,106	0,114	0,207	0,220	0,282	0,259	0,241
TOTAL:	101,66	102,31	100,51	101,55	101,62	100,63	100,97	100,22	99,55	99,73
LOI	1,94	2,18	1,96	2,42	2,57	5,56	4,22	6,20	5,09	4,79
BA	235	730	408	1208	164	649	350	355	255	396
NB	5.8	6,0	2.9	4,0	4,1	10,6	9,6	8,7	8.7	5.5
ZR	116	120	97	96	96	183	180	194	176	170
Y	22.3	24,4	22.2	19,6	19,1	25,1	26,5	31,6	26.0	27.7
SR	244	332	466	317	728	426	311	122	519	579
RB	24.5	86,8	52.3	57,4	22,1	57,1	34,0	29,6	16.2	20.2
ZN	94	84	94	104	67	99	125	106	98	106
CU	92	97	99	77	16	104	118	97	83	90
NI	160	152	139	128	126	112	128	164	209	220
CO	61	62	65	69	47	54	73	67	69	67
CR	64	66	59	25	29	15	17	53	147	176
V	171	186	225	255	188	164	187	207	201	195
LA	14	19	11	11	10	23	23	23	25	20
CE	33	34	25	27	25	55	47	50	51	53
ND	16	17	15	13	12	26	23	27	26	28

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	AR-364	AR-365	JC-366	JC-367	JC-368	JC-369	JC-370	JC-371	KA-373	KA-376
SIO2	57.10	57.86	64.68	64.52	66.82	65.09	65.58	50.22	55.74	52.77
TIO2	1.135	1.092	0.998	1.046	1.042	1.026	1.017	1.670	1.015	1.174
AL2O3	14.05	14.37	12.92	12.30	11.94	12.94	12.88	19.57	14.36	16.66
FE2O3	9.66	10.49	11.46	11.69	12.65	11.92	11.28	16.75	10.59	12.23
MNO	0.11	0.13	0.13	0.17	0.17	0.17	0.16	0.26	0.17	0.16
MGO	4.32	3.37	0.84	0.86	1.09	0.86	0.89	1.61	4.66	4.66
CAO	7.05	6.70	3.27	3.25	2.90	3.37	1.96	3.26	9.03	6.81
NA2O	4.03	3.77	3.65	4.20	2.72	3.61	3.84	4.20	3.43	3.39
K2O	2.27	1.99	1.53	1.45	0.15	0.51	1.90	1.59	0.86	1.97
P2O5	0.248	0.231	0.503	0.504	0.512	0.517	0.496	0.869	0.140	0.172
TOTAL:	101.00	101.34	99.51	99.82	98.31	98.58	100.17	98.88	99.79	98.45
LOI	3.52	5.82	2.40	2.29	2.52	2.91	2.07	3.20	2.42	5.54
BA	556	360	554	644	122	363	840	1210	403	355
NB	7.9	8.8	14.2	16.1	15.7	14.4	15.2	23.4	6.1	6.0
ZR	179	177	235	241	255	247	233	383	114	137
Y	26.4	25.8	51.7	52.1	54.3	51.4	46.8	72.3	22.1	22.4
SR	636	386	594	219	194	354	211	487	929	249
RB	28.6	24.0	48.2	66.8	4.3	12.1	55.5	34.5	26.7	63.7
ZN	90	84	161	155	164	164	160	232	79	95
CU	103	58	23	30	13	21	22	26	78	59
NI	121	133	13	14	15	11	12	18	113	173
CO	52	55	26	29	29	29	24	37	51	59
CR	50	57	9	6	3	6	9	8	115	86
V	189	202	15	18	18	17	17	27	172	188
LA	24	24	42	43	40	47	41	59	6	13
CE	50	60	87	88	90	98	81	124	23	32
ND	26	27	47	46	46	48	41	57	10	12

SAMPLE:	KL-382	KL-392	PR-395	PR-398	AR-400	AR-403	PG-406	PG-417	IN-419	PG-421
SIO2	54.47	53.56	48.52	56.06	53.60	54.32	59.06	56.70	49.28	58.73
TIO2	0.500	0.505	1.654	1.531	1.167	1.167	1.425	1.501	1.834	1.402
AL2O3	12.79	14.50	15.99	14.17	14.77	14.38	13.85	13.39	14.95	13.42
FE2O3	10.86	11.08	9.14	11.13	11.58	14.70	10.07	11.05	16.29	10.00
MNO	0.17	0.17	0.24	0.18	0.19	0.16	0.13	0.17	0.18	0.16
MGO	9.00	8.83	7.19	5.09	4.59	5.57	5.74	6.00	6.51	4.26
CAO	8.04	6.88	12.68	6.97	9.93	6.77	4.33	6.19	6.86	5.58
NA2O	2.15	3.05	3.38	2.48	2.02	1.50	2.25	2.83	3.33	3.48
K2O	1.95	1.36	0.50	1.66	1.88	1.22	2.58	1.50	0.46	2.35
P2O5	0.071	0.070	0.687	0.713	0.277	0.224	0.579	0.677	0.293	0.606
TOTAL:	101.17	98.95	98.24	98.82	98.54	98.55	98.99	98.03	100.18	99.55
LOI	2.34	3.17	10.65	6.76	9.59	9.78	5.82	3.31	2.60	1.74
BA	297	384	213	899	261	104	1005	821	231	845
NB	1.4*	0.0	19.6	16.4	6.6	9.2	18.7	14.9	6.7	18.7
ZR	59	66	336	288	181	180	286	276	159	348
Y	15.9	15.5	59.3	52.3	28.1	27.6	46.5	49.9	47.3	51.1
SR	217	144	268	986	324	207	374	759	484	616
RB	89.6	36.0	15.9	30.3	54.1	39.7	88.8	35.2	8.8	46.5
ZN	74	117	100	127	108	109	143	115	118	82
CU	53	49	3	34	37	97	28	27	85	62
NI	216	202	192	134	214	124	150	136	92	88
CO	66	65	51	48	67	70	46	49	69	43
CR	584	503	542	347	49	189	457	374	233	277
V	178	179	199	221	226	211	181	207	331	159
LA	7	8	49	53	21	21	49	46	9	56
CE	14	13	105	118	57	54	113	103	28	124
ND	6*	4*	58	61	29	20	56	57	18	62

SAMPLE:	PG-426	PG-433	AR-442	AR-446	AR-451	KA-452	KA-455	KO-457	KO-460	KO-462
SIO2	55.85	54.54	53.98	58.88	58.44	53.91	54.76	56.09	54.26	54.11
TIO2	1.614	1.580	1.298	1.076	0.891	1.046	1.081	1.008	0.951	0.946
AL2O3	14.06	16.76	16.66	14.67	14.37	13.76	15.21	13.69	14.89	14.95
FE2O3	10.67	10.46	12.58	10.64	8.11	12.30	11.84	13.35	12.14	12.94
MNO	0.17	0.09	0.17	0.15	0.14	0.15	0.14	0.16	0.13	0.15
MGO	5.50	5.62	5.17	4.02	4.49	6.57	4.50	5.54	5.17	4.91
CAO	6.02	5.16	5.60	4.62	6.95	9.52	7.07	5.92	6.62	5.99
NA2O	2.63	4.46	3.76	4.03	4.05	2.23	3.24	3.18	4.13	2.98
K2O	2.71	0.70	0.50	1.68	2.41	0.38	1.99	0.92	1.57	2.90
P2O5	0.782	0.633	0.278	0.237	0.164	0.139	0.163	0.125	0.123	0.121
TOTAL:	98.08	98.04	98.81	98.37	99.32	101.56	99.30	100.66	98.96	99.37
LOI	3.33	4.83	6.02	3.14	3.46	4.15	1.76	2.00	1.70	1.95
BA	1201	391	213	741	924	241	638	348	293	835
NB	17.2	28.6	8.1	8.7	6.6	4.0	5.6	6.3	4.6	4.7
ZR	309	515	191	177	141	106	122	100	101	100
Y	49.1	66.1	30.8	26.1	22.5	22.0	23.3	23.1	22.5	23.2
SR	527	430	332	393	451	566	512	258	213	190
RB	71.1	15.0	13.0	38.2	52.8	10.1	68.5	36.6	61.3	111.9
ZN	119	102	138	99	52	73	84	90	83	96
CU	27	18	5	68	95	109	103	79	95	103
NI	154	98	226	145	104	226	162	152	146	138
CO	49	41	82	66	49	64	63	69	64	68
CR	446	277	86	61	145	415	85	68	68	27
V	227	186	252	192	187	194	179	236	221	238
LA	53	70	20	23	21	14	13	10	11	10
CE	128	156	44	53	41	27	34	20	31	27
ND	66	75	23	22	17	14	15	9	16	17

OXIDES AND TRACE ELEMENTS RECALCULATED VOLATILE FREE, ALL FE AS FE2O3, TOTAL = ORIGINAL TOTAL:

SAMPLE:	KL-465	KL-467	KL-468	KL-469	KL-471	PR-472	PR-474	PR-476	PR-477	PR-479
SIO2	55.52	56.34	52.81	54.78	56.61	56.14	56.59	61.59	58.92	58.24
TIO2	0.878	0.736	0.400	0.637	0.599	1.667	1.264	1.350	1.427	1.355
AL2O3	14.31	14.47	8.59	14.92	17.75	17.01	13.54	14.46	14.47	13.74
FE2O3	11.98	10.90	12.17	11.08	10.53	10.96	10.15	7.38	10.15	10.32
MNO	0.14	0.14	0.17	0.18	0.12	0.13	0.14	0.07	0.10	0.15
MGO	4.16	5.53	17.46	6.65	4.37	2.96	5.54	3.04	4.83	5.19
CAO	7.77	7.90	8.06	6.54	2.66	4.01	6.97	5.19	5.56	6.22
NA2O	3.40	3.09	0.19	3.61	4.30	4.23	2.74	3.74	3.20	2.49
K2O	1.70	0.82	0.11	1.53	2.92	2.24	2.52	2.59	0.68	1.72
P2O5	0.118	0.081	0.039	0.077	0.125	0.657	0.540	0.595	0.670	0.590
TOTAL:	100.06	100.83	99.59	99.56	100.81	100.86	101.68	100.88	99.19	100.31
LOI	1.25	2.08	4.95	3.71	3.88	3.03	4.08	4.07	4.53	4.35
BA	457	262	16	235	376	1054	987	1481	482	703
NB	3.6	3.4	1.2	3.3	3.5	33.3	15.1	24.0	16.1	17.7
ZR	97	78	34	63	84	750	288	421	283	311
Y	22.3	20.6	10.4	16.1	19.9	85.7	50.3	52.1	48.2	49.1
SR	400	498	20	90	173	328	741	367	664	545
RB	66.6	25.2	7.6	43.4	80.2	64.6	67.9	66.1	15.3	41.7
ZN	84	73	76	80	70	101	107	88	115	110
CU	19	88	43	65	113	10	37	12	18	23
NI	108	123	516	180	163	25	165	103	144	124
CO	58	57	88	64	58	29	46	36	46	40
CR	21	186	2618	336	437	17	421	302	457	432
V	221	206	178	224	215	158	196	159	201	187
LA	12	5*	0	5*	15	113	58	75	49	57
CE	24	19	8*	20	29	169	127	166	109	124
ND	12	10	0	10	13	84	61	81	58	61

SAMPLE:	PR-480	PR-481	PR-483	PR-484	PR-485	PR-486	PR-487	PR-489	PR-491	PR-492
SIO2	56.72	56.53	58.06	55.32	55.20	55.80	59.85	59.56	59.29	59.82
TIO2	1.486	1.426	1.241	1.469	1.513	1.377	1.435	1.381	1.376	1.744
AL2O3	15.33	14.73	13.96	13.62	13.78	12.02	13.65	13.96	14.02	13.68
FE2O3	9.98	11.59	10.12	11.03	11.78	11.99	8.34	9.55	9.92	10.17
MNO	0.11	0.12	0.13	0.15	0.16	0.18	0.13	0.13	0.13	0.14
MGO	4.39	7.90	4.04	6.05	5.49	8.20	3.75	3.90	3.90	2.87
CAO	6.04	3.92	6.76	7.67	6.91	6.66	7.56	6.20	5.45	6.12
NA2O	3.31	2.92	2.05	1.90	2.88	1.93	3.50	2.62	2.95	2.75
K2O	1.98	0.17	3.10	2.14	1.57	1.26	1.03	2.09	2.34	1.91
P2O5	0.665	0.693	0.544	0.655	0.718	0.625	0.752	0.602	0.624	0.801
TOTAL:	100.48	98.72	100.20	101.03	99.68	99.21	100.41	98.78	100.31	100.66
LOI	5.45	3.64	5.00	3.10	3.87	2.93	2.92	3.51	3.73	5.82
BA	1025	83	1202	929	992	477	788	991	987	913
NB	19.6	14.6	16.8	14.8	14.5	14.7	16.8	17.2	19.6	25.6
ZR	349	299	310	276	273	244	318	350	354	426
Y	51.4	45.1	48.6	48.5	51.1	45.4	53.4	51.4	51.0	62.4
SR	488	291	537	529	460	400	955	837	1045	607
RB	49.1	3.2	78.3	50.1	33.1	24.3	23.0	45.4	38.8	39.5
ZN	124	116	111	114	126	123	78	104	109	104
CU	21	9	34	37	44	34	39	30	35	39
NI	92	165	92	157	139	220	68	78	89	50
CO	47	57	45	50	53	58	35	41	39	35
CR	257	546	241	462	415	936	126	252	276	53
V	195	218	169	199	223	195	183	170	168	233
LA	58	48	57	52	52	44	65	59	61	77
CE	142	122	124	106	113	98	136	128	133	163
ND	66	62	60	55	62	51	70	62	63	81

SAMPLE:	PR-494	AR-495	AR-496	AR-497	AR-498	AR-500
SIO2	51.80	52.68	53.74	51.76	56.77	56.74
TIO2	1.775	1.276	1.201	1.210	1.146	1.018
AL2O3	14.13	16.37	15.35	15.75	15.16	14.29
FE2O3	13.37	12.73	12.23	13.67	11.41	11.16
MNO	0.17	0.11	0.13	0.16	0.14	0.18
MGO	5.31	5.06	4.07	5.78	5.61	4.96
CAO	7.63	7.49	9.17	7.76	5.64	5.86
NA2O	2.47	2.24	2.46	3.34	3.52	3.29
K2O	2.47	1.78	1.38	0.34	0.37	2.29
P2O5	0.879	0.266	0.264	0.229	0.233	0.220
TOTAL:	100.87	99.13	99.54	100.12	98.70	100.38
LOI	10.47	8.60	12.88	7.72	5.06	3.36
BA	580	416	175	97	202	705
NB	16.9	8.4	7.8	7.4	8.1	8.1
ZR	300	192	182	181	189	159
Y	54.8	32.1	28.7	24.2	32.0	28.0
SR	555	403	196	242	553	539
RB	68.5	58.8	48.2	10.9	5.7	31.8
ZN	132	117	97	106	105	93
CU	41	182	129	137	95	88
NI	166	210	157	213	166	97
CO	50	71	63	64	69	56
CR	426	61	51	213	56	83
V	253	265	258	222	208	188
LA	51	21	27	16	25	23
CE	118	53	57	48	50	52
ND	62	30	29	22	27	27

TABLE 2.5 X-ray counting statistics - LLD and CE - for each batch of samples processed

		Nb		Zr		Y		Sr		Rb	
BATCH	N	LLD	CE	LLD	CE	LLD	CE	LLD	CE	LLD	CE
1	40	2.42	.71	1.81	.76	2.19	.68	1.95	1.08	2.11	.69
2	48	2.42	.72	1.81	.80	2.20	.69	1.96	1.06	2.12	.70
3	238	.76	.23	.57	.25	.69	.22	.61	.36	.65	.22
		Co		Cr		V		Zn		Cu	
BATCH	N	LLD	CE	LLD	CE	LLD	CE	LLD	CE	LLD	CE
1	40	2.52	.83	2.56	1.31	3.34	1.41	2.16	1.10	2.45	1.04
2	48	2.56	.84	2.64	1.31	3.58	1.50	2.45	1.17	2.68	1.06
3	238	2.46	.82	2.54	1.41	3.27	1.45	2.67	1.26	2.80	1.17
		Ni		La		Ce		Nd		Ba	
BATCH	N	LLD	CE	LLD	CE	LLD	CE	LLD	CE	LLD	CE
1	40	3.26	1.59	5.84	1.56	11.58	2.98	6.47	1.65	14.0	6.0
2	48	3.46	1.61	6.55	1.62	12.32	3.11	6.64	1.67	14.7	5.8
3	238	3.38	1.63								

X-ray counting statistics are calculated as follows:

Counting error

Counting error is the standard deviation of the net peak count rate, i.e.

$$\sigma = \sqrt{\frac{R_P}{T_P} - \frac{R_B}{T_B}}$$

where R_P, R_B = count rates at peak and background positions
T_P, T_B = counting times at peak and background positions

Expressed in terms of concentration, this is:

$$\mathrm{C.E.} = \frac{\sqrt{\dfrac{R_P}{T_P} - \dfrac{R_B}{T_B}}}{R_P - R_B} \,.\, \text{concentration}$$

When $R_P \longrightarrow R_B$, counting error $\longrightarrow \infty$ so the concept of a lower limit of determination must be introduced.

Lower limit of determination

Due to the Gaussian distribution of X-ray emission intensity, the existence of a peak above background can only be confirmed if it has a count rate in excess of the mean background count rate, plus 3 standard deviations of the background count rate. Therefore,

$$\text{Detection limit} = 3\sqrt{\frac{R_B}{T_B}}$$

Expressed in terms of concentration, this is

$$\mathrm{D.L.} = \frac{3}{M}\sqrt{\frac{R_B}{R_T}}$$

Where M = counts per second per unit concentration.

At the detection limit counting errors are large, so the lower limit of determination (L.L.D.) is defined as twice the D.L., i.e.

$$\mathrm{L.L.D.} = \frac{6}{M}\sqrt{\frac{R_B}{T_B}}$$

3. GEOCHEMISTRY

3.1 Classification

The classification scheme of Irvine and Baragar (1971) was selected to aid the classification of the Witwatersrand triad volcanic rocks for three important reasons:

(1) The scheme is based on 2500 analyses of Precambrian (therefore applicable to the current study) and Cenozoic rocks.

(2) The scheme can be applied to metamorphosed as well as unaltered volcanic rocks, as it is based on a chemical, rather than a mineralogical or modal composition.

(3) Classification into the three main series - the tholeiitic basalt, calc-alkali and alkali olivine basalt series - has no genetic implications, as their boundaries appear to be natural divisions.

The initial distinction in Irvine and Baragar's classification scheme is that between alkaline and subalkaline rocks. For this purpose, a weight percent plot of (Na_2O + K_2O) against SiO_2 is employed, as shown in Figure 3.1. The curved line, marked (1), is Irvine and Baragar's dividing line between the alkaline and subalkaline fields. They found this line to be a more effective divider than that of MacDonald (1968) (marked (2)), which had been widely used.

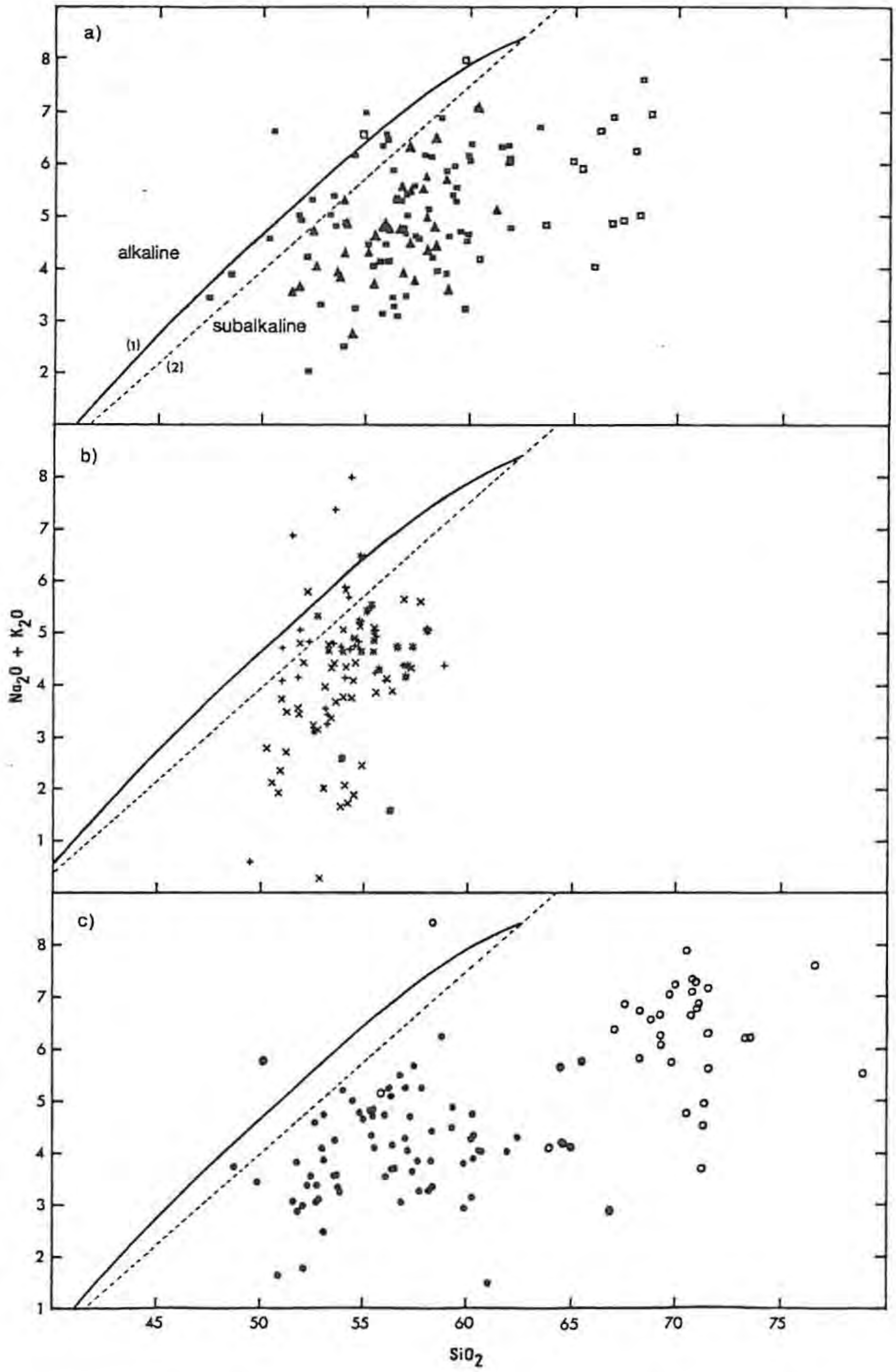
The Witwatersrand triad volcanic rocks have been altered as a result of low-grade greenschist facies metamorphism. Variation diagrams (Figures 3.9a and 3.11a) show that a large amount of scatter is exhibited by Na_2O and K_2O concentrations, suggesting that these two oxides were fairly mobile. While it may be true that individual samples have lost or gained Na or K, the average compositions of formations as a whole should provide a good estimate of the original concentrations. Systematic trends are still evident, as well as clear compositional breaks between formations, e.g., between the Klipriviersberg Group and Platberg Group, and again at the top of the latter. Na_2O and K_2O concentrations thus seem to have remained basically unchanged overall and average concentrations can be regarded as valid for each formation, and can thus be used in the following classification diagram.

Figure 3.1 Alkalies vs silica diagram with dividing lines of (1) Irvine and Baragar (1971) and (2) MacDonald (1968)

a) Platberg Group and Allanridge Formation

b) Klipriviersberg Group

c) Dominion Group and Crown Formation



see pages 62 and 72 for symbols

From Figure 3.1 it is clear that almost all the Witwatersrand triad volcanic rocks are subalkaline. In Figure 3.1a, only two samples from the Makwassie Formation (□), two from the Rietgat-Goedgenoeg Formations (■) and none from the Allanridge Formation (▲) plot in the alkaline field. In Figure 3.1b, one Alberton (*), three Orkney (+) and one Loraine-Edenville sample (x) plot in the alkaline field, while in Figure 3.1c, one Dominion Group porphyry and one Crown Formation sample are alkaline. Thus 96.6% of all the samples are subalkaline.

Having established the subalkaline nature of these rocks, the next subdivision is into either the tholeiitic basalt series, or the calc-alkali series. AFM triangular plots, with A = $Na_2O + K_2O$, F = $FeO + 0.8998\ Fe_2O_3$, and M = MgO, all in weight percent, are shown in Figures 3.2a (Ventersdorp Supergroup) and 3.2b (Dominion Group and Crown Formation).

The Ventersdorp Supergroup samples straddle the dividing line, with the following proportion of samples plotting in the tholeiitic field:

Allanridge	- 51%	
Rietgat	- 35%	
Makwassie	- 29%	
Goedgenoeg	- 33%	Total: 40%
Loraine & Edenville	- 48%	
Orkney	- 45%	
Alberton	- 21%	

Figure 3.2a appears, at first glance, to suggest that all formations of the Ventersdorp Supergroup have calc-alkaline affinities. This needs to be examined more closely, however, as Irvine and Baragar (1971) themselves imply that the AFM plot does not satisfactorily separate tholeiitic from calc-alkaline types if the rocks are basic. In such instances, it is more important to look at the trend of samples from a particular formation. The Loraine-Edenville samples, for instance, display a clear tholeiitic trend towards FeO, even though most of the samples lie on the calc-alkaline side of the boundary line. The trends in some of the formations are less obvious, although the Dominion Group porphyries and basic rocks, and the Crown Formation are all clearly tholeiitic.

Figure 3.2 AFM triangular plots for
a) Ventersdorp Supergroup
b) Dominion Group and Crown Formation

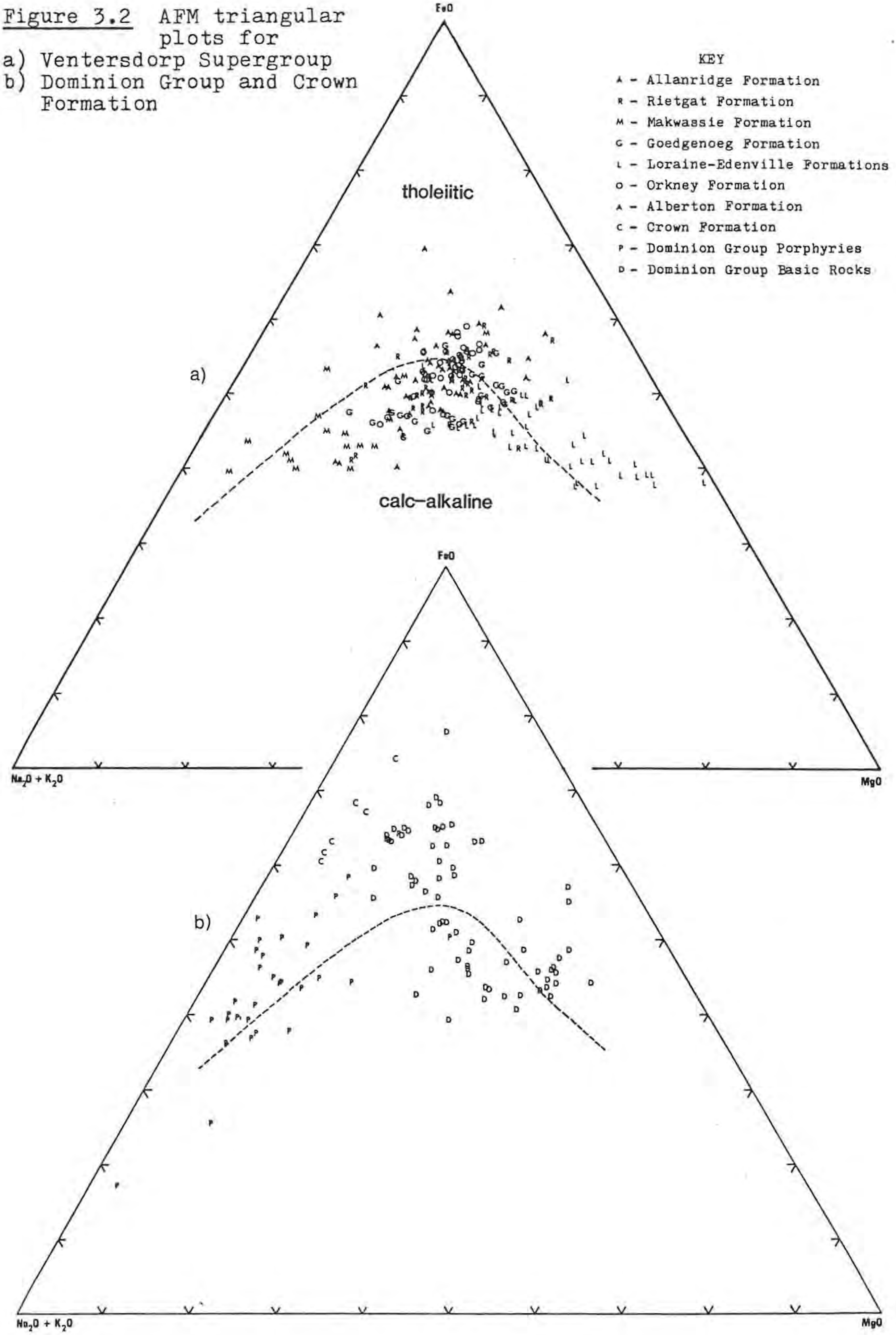
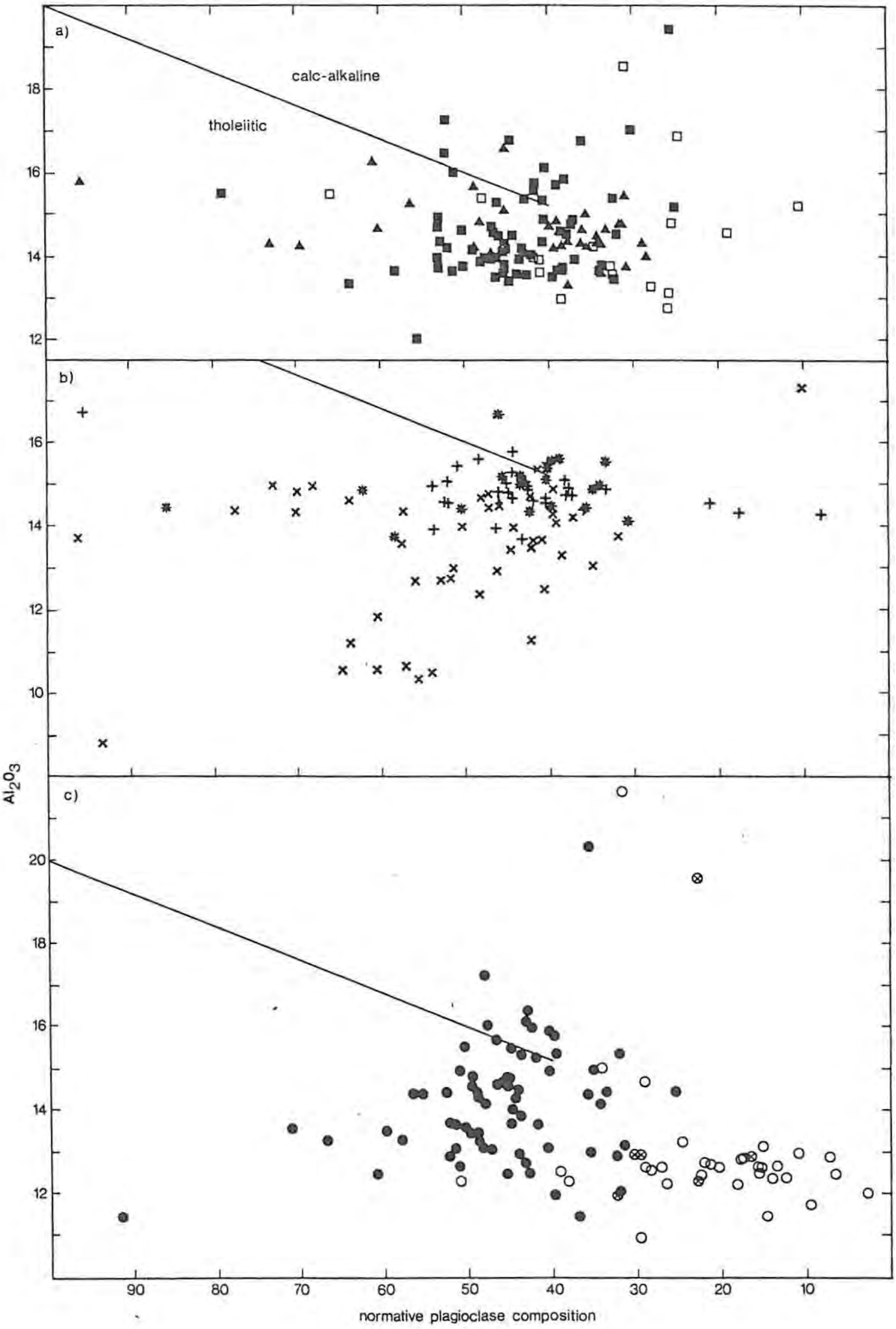


Figure 3.3 Al_2O_3 vs normative plagioclase composition (after Irvine and Baragar, 1971) for
a) Platberg Group and Allanridge Formation
b) Klipriviersberg Group
c) Dominion Group and Crown Formation



The most prominent chemical difference between the more basic members of typical calc-alkali and tholeiitic series of Cenozoic age is their alumina content (Irvine and Baragar, 1971): the calc-alkali basalts and andesites are generally high-alumina types, containing 16 to 20% Al_2O_3, whereas their tholeiitic counterparts have only 12 to 16%. They suggested that a plot of Al_2O_3 against normative plagioclase composition (100 An/(An + Ab + 5/3 Ne)) provides a more significant separation of the two series than the AFM plot. Figures 3.3a (Platberg Group and Allanridge Formation), 3.3b (Klipriviersberg Group) and 3.3c (Dominion Group and Crown Formation) show that the following proportions of samples plot below the dividing line (or its projection) in the tholeiitic field:

Allanridge - 86%
Rietgat & Goedgenoeg - 79%
Makwassie - 71%
Loraine - 96%
Orkney - 77%
Alberton - 63%
Total Ventersdorp average - 81%
Crown - 83%
Dominion porphyries - 84%
Dominion basic lavas - 83%

The increase in the proportion of tholeiitic samples towards the top of the Klipriviersberg Group is again evident, and in this plot 81% (as opposed to 40% in Figure 3.2) of the Ventersdorp samples plot in the tholeiitic field. The three underlying units are again conclusively tholeiitic.

Figures 3.4a, b and c are plots of normative colour index (Ol + Opx + Cpx + Mt + Il + Hm) against normative plagioclase composition, in which rock names are defined. The results of these plots are summarised as follows, with b = basalt, ta = tholeiitic andesite, a = andesite, d = dacite and r = rhyolite:

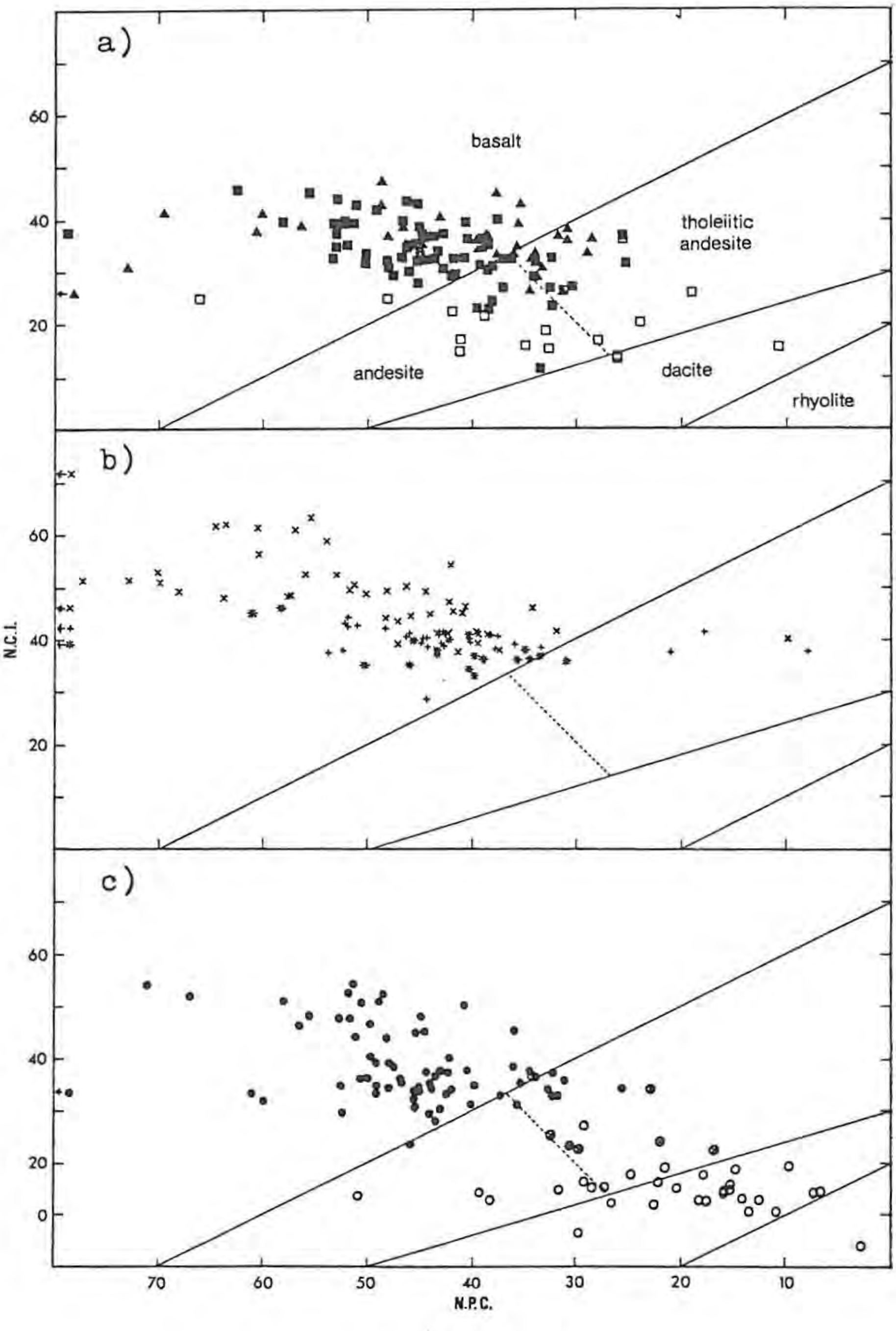
	b	ta	a	d	r	name
Allanridge	66%	31%	3%			b-ta
Rietgat & Goedgenoeg	75%	12%	13%			b
Makwassie	12%	29%	41%	18%		ta-a
Loraine & Edenville	98%	2%				b
Orkney	91%	9%				b
Alberton	95%	5%				b
	77%	13%	8%	2%	0%	
Crown		100%				ta
Dominion porphyries	13%	13%	19%	63%	3%	d
Dominion basic lavas	88%	9%	3%			b

It must be stressed that names like dacite and andesite are used here without tectonomagmatic connotations. Using these definitions, the Allanridge, Rietgat, Goedgenoeg, Loraine, Orkney and Alberton Formations, as well as the Dominion Group basic lavas, are all overwhelmingly basaltic. The Dominion Group porphyries are predominantly dacitic, with an andesitic component, the Crown lavas are all tholeiitic andesites, while the Makwassie samples spread over almost the entire range, from basalts through to dacites, with most of the samples being andesitic.

The (Na_2O + K_2O) versus SiO_2 classification diagram of Cox et al., (1979) has also been used, as shown in Figure 3.5, with the following results (abbreviations as above, but also ba = basaltic andesite, h = hawaiite, tb = trachybasalt, ta = trachyandesite and u = unclassified):

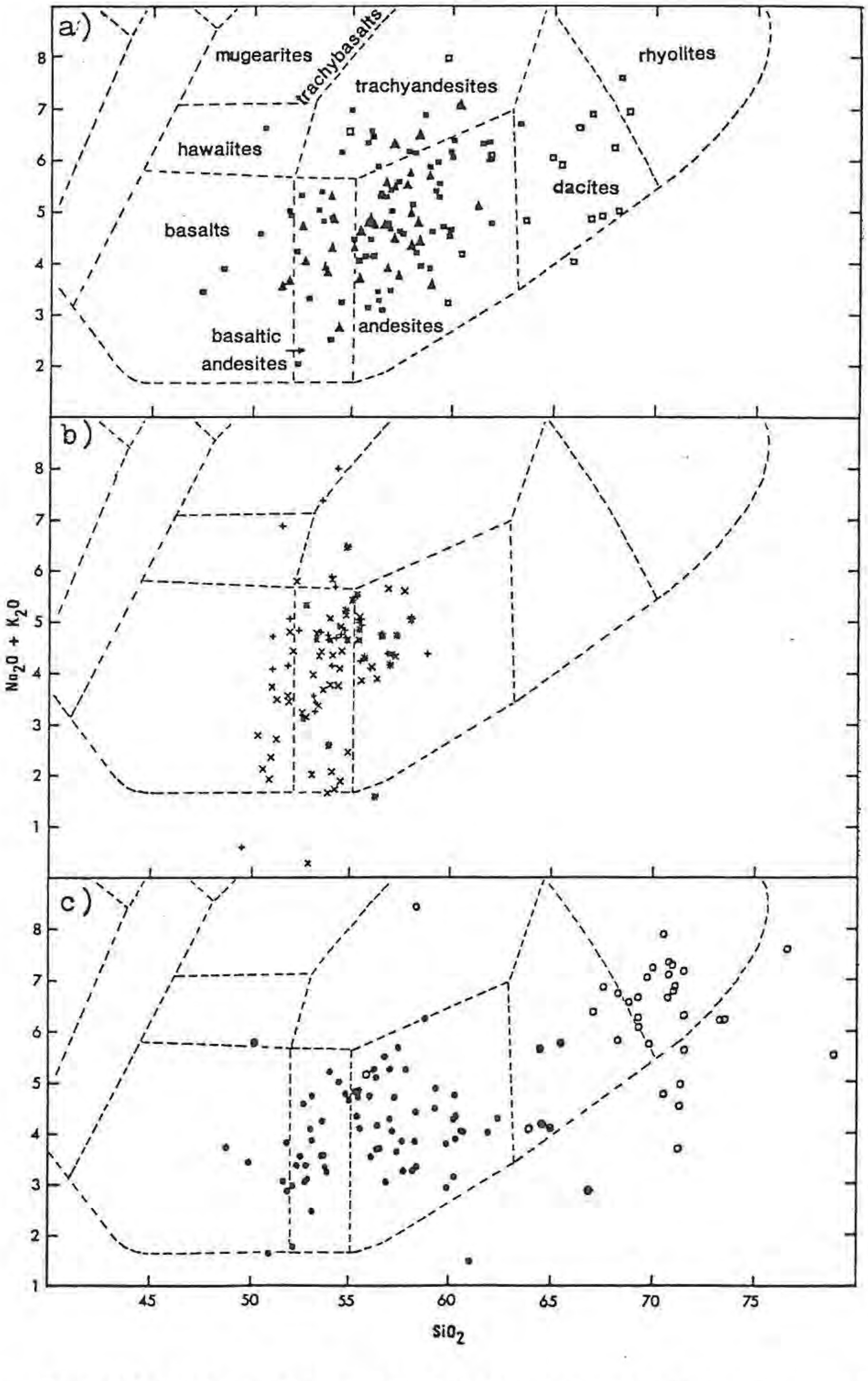
	b	ba	a	d	r	h	tb	ta	u	name
Allanridge	6%	23%	63%					9%		a
Rietgat & Goedgenoeg	7%	15%	63%	1%		1%		12%		a
Makwassie			18%	53%	12%			12%	5%	d
Loraine	26%	52%	15%					4%	2%	b-a
Orkney	13%	47%	22%			3%	6%	6%	3%	ba-a
Alberton		42%	47%					5%	5%	ba-a
	11%	30%	42%	5%	1%	1%	1%	8%	2%	
Crown				67%		17			17%	d
Dominion porphyries			3%	16%	50%			3%	28%	r
Dominion basic lavas	9%	30%	59%						1%	ba-a

Figure 3.4 Normative colour index versus normative plagioclase composition (after Irvine and Baragar, 1971) for
a) Platberg Group and Allanridge Formation
b) Klipriviersberg Group
c) Dominion Group and Crown Formation



Under the Cox et al., (1979) classification, therefore, the names given to the individual units in all cases imply a slightly more acid rock type than those defined for the same unit by the Irvine and Baragar (1971) scheme. For example, the Dominion porphyries are dacites by Irvine and Baragar's definition, but rhyolites according to Cox et al..

Figure 3.5 Nomenclature of volcanic rocks - alkalies versus SiO_2 plot (after Cox et al., 1979) for
a) Platberg Group and Allanridge Formation
b) Klipriviersberg Group
c) Dominion Group and Crown Formation



The final classification phase of Irvine and Baragar is that for distinguishing between potassium-rich, "average", or potassium-poor varieties of .rock. A series of triangular An-Ab-Or plots is illustrated in Figure 3.6. The percentage of samples from each formation plotting within each of these three fields is as follows:

	K-poor	average	K-rich
Allanridge	26%	46%	28%
Rietgat & Goedgenoeg	15	37	48
Makwassie	24	29	47
Loraine & Edenville	9	39	52
Orkney	22	52	26
Alberton	37	37	26
Crown	83	17	0
Dominion porphyries	16	53	31
Dominion basic lavas	22	56	22
Total average	28%	41%	31%

For the Dominion Group (see Figure 3.6c), over half the samples of both porphyries and basic rocks lie within the "average" field. The remainder of the basic rocks are spread evenly throughout the K-poor and K-rich fields, while the rest of the porphyries lie mostly in the K-rich field, but with a fair number in the K-poor field. The Crown Formation samples are almost all K-poor, with one sample in the "average" field.

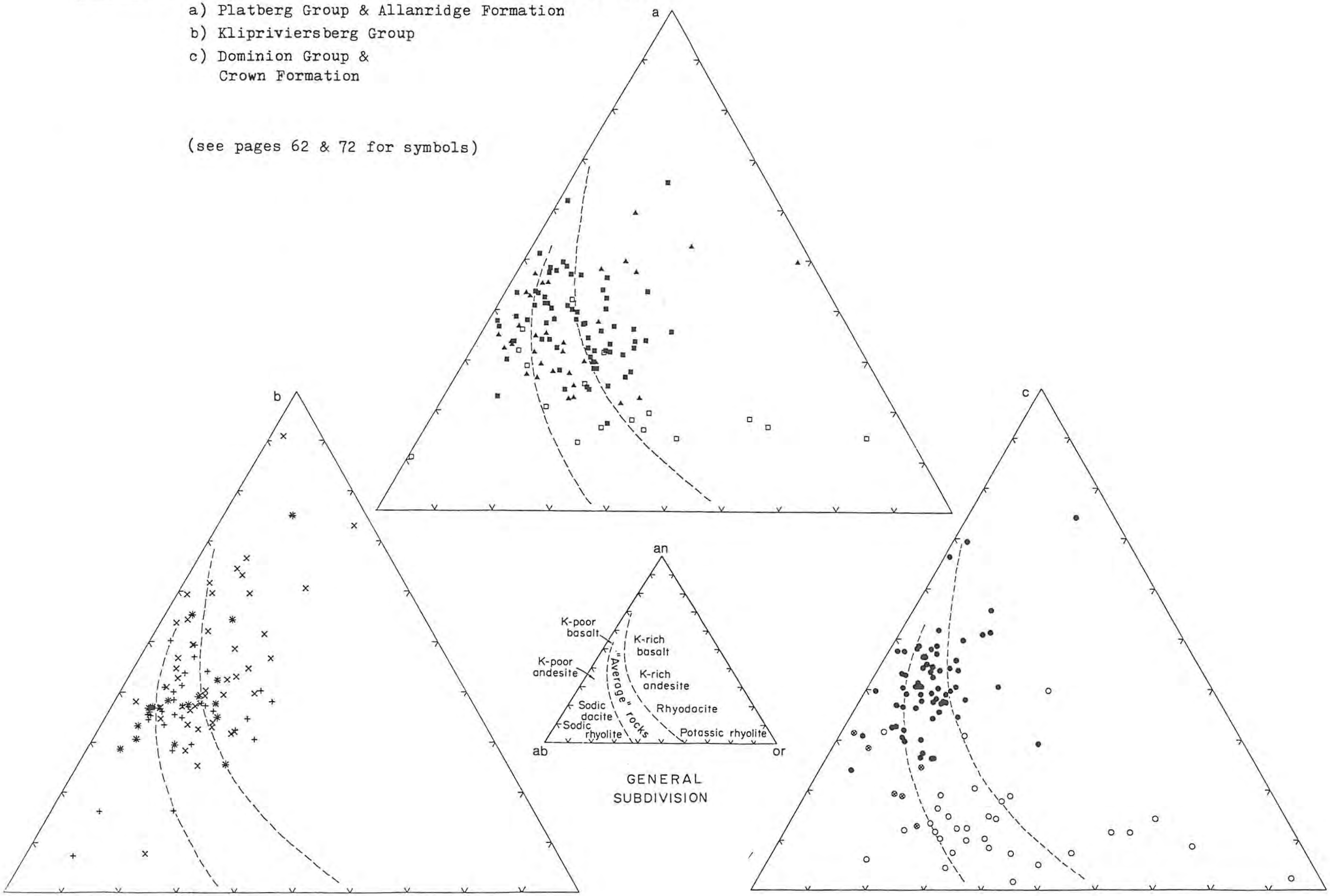
Figure 3.6b shows that the Klipriviersberg Group becomes progressively more potassic towards the top. The majority of the Alberton samples are K-poor to "average", most of the Orkney samples are "average", while K-rich samples predominate in the Loraine and Edenville Formations.

The Platberg Group is represented mostly by K-rich rocks, but the other two fields still accommodate many of them. The Allanridge samples also show a complete spread, most of the samples being "average".

Because, as has been suggested earlier in section 3.1, K appears to have been mobile during low-grade metamorphism, the spread of samples across the three fields in Figure 3.6 should be studied carefully. The equal K-poor and K-rich scatter about the K-average field for Allanridge, Orkney and Dominion basic samples may indicate that these samples were originally K-average, but alteration has spread them out. Similarly, the smearing out of samples in other formations may be the result of alteration.

Figure 3.6 An-Ab-Or projection (after Irvine & Baragar, 1971)
a) Platberg Group & Allanridge Formation
b) Klipriviersberg Group
c) Dominion Group &
Crown Formation

(see pages 62 & 72 for symbols)



In conclusion, the Witwatersrand triad volcanic rocks examined are virtually exclusively subalkaline. Both AFM and Al_2O_3 vs normative plagioclase compostion (NPC) plots show that the Dominion Group basic lavas and porphyries are predominantly tholeiitic, as is the Crown Formation. The Klipriviersberg Group samples plot in both the tholeiitic and calc-alkaline fields on an AFM diagram. The calc-alkaline nature predominates marginally in the upper formations and more strongly in the lower formations. Irvine and Baragar (1971), however, recommended the use of the Al_2O_3 vs NPC plot for basaltic rocks, and on this diagram the majority of the Klipriviersberg samples plot in the tholeiitic field. They are therefore classified as tholeiitic with calc-alkaline tendencies, the latter increasing towards the base.

Similar reasoning requires that the Rietgat-Goedgenoeg and Makwassie rocks also be classified as tholeiitic with calc-alkaline tendencies, while the Allanridge samples are mostly tholeiitic, according to both plots.

Irvine and Baragar's (1971) diagram of normative colour index vs normative plagioclase composition classifies as basaltic the Dominion Group basic lavas, the Klipriviersberg Group formations, and the Rietgat-Goedgenoeg Formations. The Allanridge Formation samples are basalts to tholeiitic andesites, those of the Crown Formation are tholeiitic andesites, the Dominion Group porphyries are dacitic with an andesitic to tholeiitic andesitic tendency, while the Makwassie Formation samples are tholeiitic andesites to andesites, with tendencies toward both the basaltic and dacitic extremities.

The $Na_2O + K_2O$ vs SiO_2 plot of Cox <u>et</u> <u>al</u>. (1970) names the majority of the Ventersdorp and Dominion basic rocks as andesites and basaltic andesites. This is based almost entirely on their SiO_2 content and does not consider Al_2O_3 values at all, which, in most of these rocks, is below 16%. Wyatt (1976) reviewed the common usage of the name "andesite" for the Ventersdorp basic rocks and concluded that the Al_2O_3 content of the Klipriviersberg lavas he examined was too low to justify the name "andesite", although their SiO_2 content was acceptable. For similar reasons, the Irvine and Baragar (1971) nomenclature is preferred for the current study.

Finally, the potassium content of all the formations (except the Crown Formation) ranges from K-poor, through "average" to K-rich, with the "average" field dominating in the Dominion Group rocks, the Alberton, Orkney and Allanridge Formations. The Loraine and Edenville, Makwassie, Rietgat and Goedgenoeg Formations tend to be more K-rich, while the Crown Formation is K-poor.

3.2 A Comparision Between Rocks From the Klipriviersberg Group and Komatiitic Lavas

The Westonaria Formation at the base of the Klipriviersberg Group contains a succession of volcanic rocks, termed the "Meredale Member" by Wyatt (1976), which are considerably more basic than those constituting the upper formations. McIver, Cawthorn and Wyatt (1982) suggested that this unit might represent the youngest komatiitic sequence in South Africa, and compared these high-MgO rocks with typical analyses from komatiitic suites having a comparable MgO content. The only differences they found were higher TiO_2, Zr and Sr values in the Meredale rocks.

A number of high-MgO rocks has been analysed in the current study, but these samples occur near the top of the Klipriviersberg Group, in the Loraine-Edenville Formations. Figure 3.11a, which illustrates MgO variation with height in borehole WS-5, shows the existence of three sharp spikes defining narrow (<50m) high-MgO horizons, culminating in a steady increase in MgO in the top 180 metres of the unit. There are 21 samples with MgO content greater than 8.5%, which is about the value above which the high MgO peaks begin to manifest themselves, and values range up to 17.46% MgO.

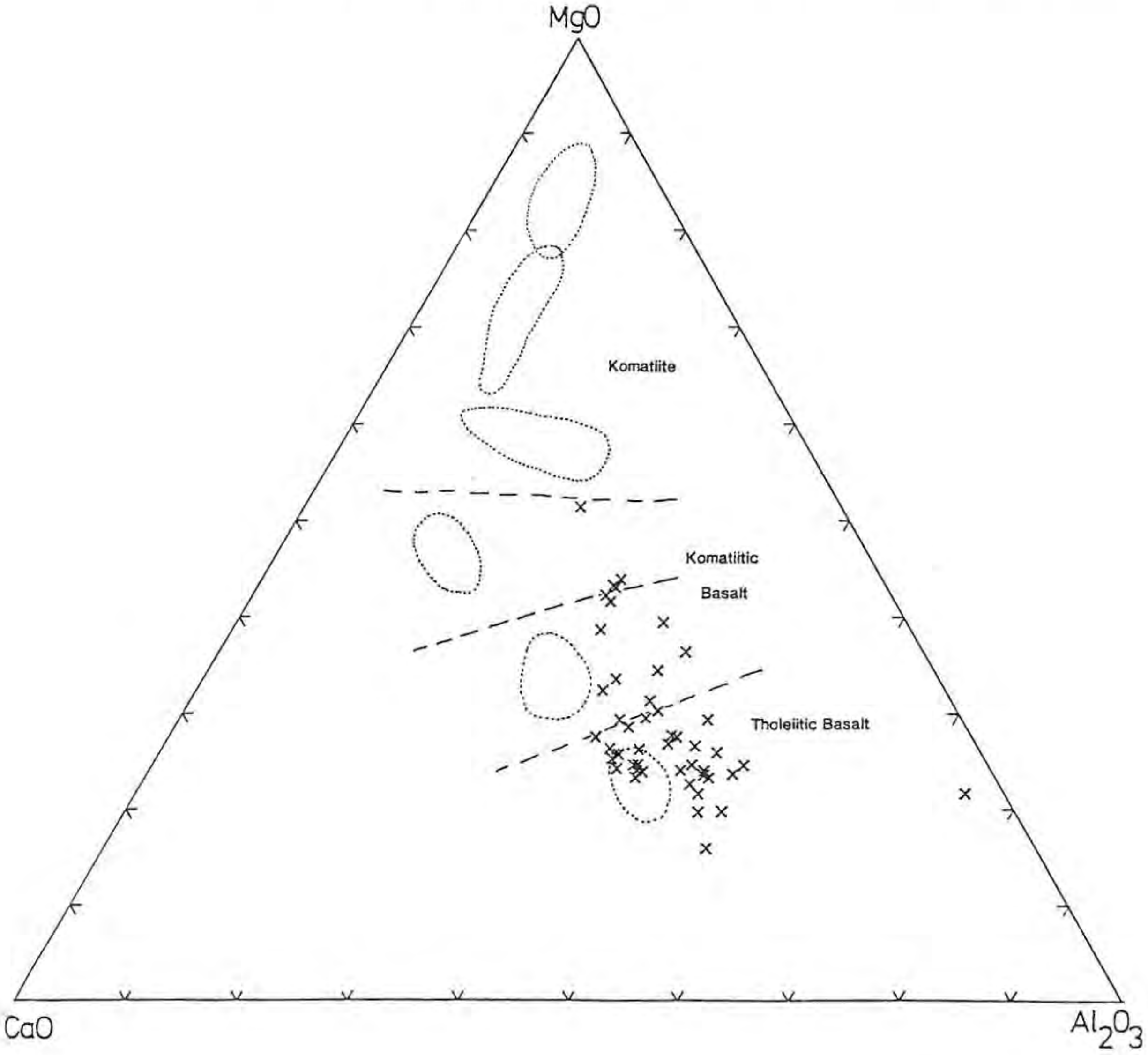
Figure 3.7, a triangular plot of MgO-CaO-Al_2O_3, shows the original fields of komatiites and associated rocks as defined by Viljoen and Viljoen (1969) (finely dotted lines), as well as data breaks delineated by original and newer data from the Barberton and other South African greenstone belts (dashed lines).

Samples from the Loraine-Edenville Formations have been plotted on this diagram, which shows that 14 samples lie within the field of what Viljoen _et al_. (1982) now term komatiitic basalts, while the remaining

Figure 3.7 MgO-CaO-Al_2O_3 triangular plot (after Viljoen and Viljoen, 1982)

... = original fields of komatiites and associated rocks, as defined by Viljoen and Viljoen (1969)

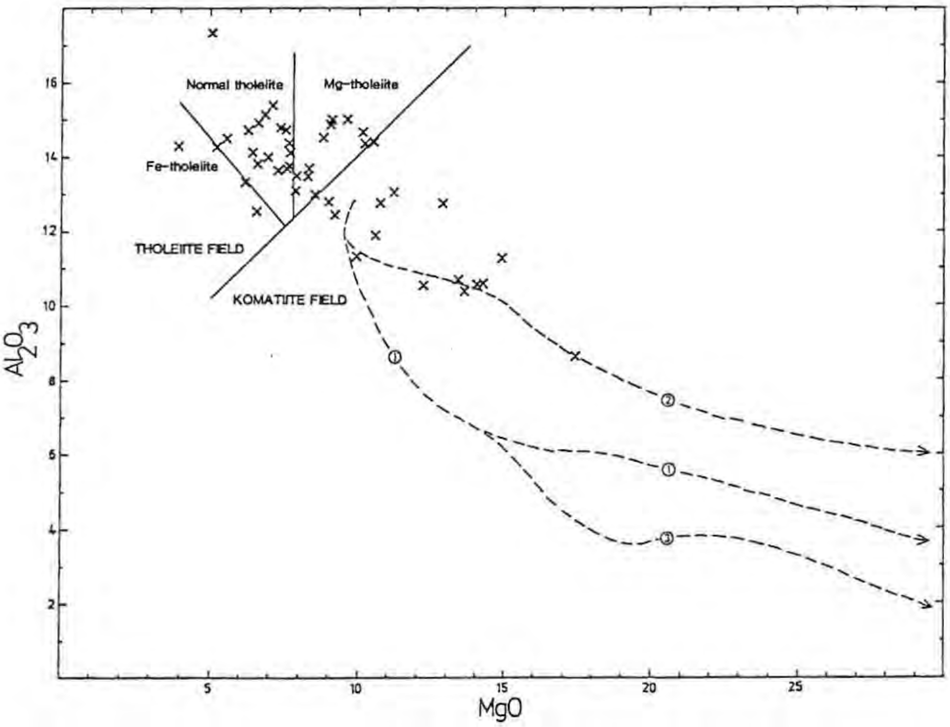
--- = data breaks delineated by original and new data from the Barberton and other South African greenstone belts



32 samples plot in the tholeiitic basalt field. CaO:Al_2O_3 ratios in the latter area compare well with those of the Viljoen et al. samples, while those in the komatiitic basalt field have slightly higher ratios. Some of the more recently analysed samples of Viljoen et al., however, have similar ratios.

The Loraine-Edenville samples were also plotted on the Al_2O_3 vs MgO diagram of Viljoen et al. (1982) (see Figure 3.8). The tholeiitic field is divided into three parts, delineating Fe-rich, normal and Mg-rich tholeiites. Of the Klipriviersberg samples, four plot in the

Figure 3.8 Al_2O_3 vs MgO plot with tholeiite and komatiite fields of Viljoen and Viljoen (1982)
1 = Main trend of aluminium depletion
2 = Secondary trend of aluminium undepletion
3 = Possible minor trend of pronounced aluminium depletion



Fe-tholeiite field, sixteen amongst the normal tholeiites, 11 with the Mg-tholeiites and 15 in the komatiitic field. The majority of the komatiitic samples lie directly on the "trend of aluminium undepletion" as defined by Viljoen <u>et</u> <u>al</u>. (1982).

Having shown that a number of Loraine-Edenville samples plots in komatiitic fields, it is advisable at this point to examine a more formal definition of a komatiite and a komatiitic basalt. Arndt and Nisbet (1982) define <u>komatiites</u> as ultramafic volcanic rocks with more than 18% MgO (anhydrous basis), and which form the ultramafic portion of a magmatic suite - the komatiitic suite or series - which also includes mafic volcanic rocks called <u>komatiitic basalts</u>. The chemistry of the latter is characterised by high MgO, Ni and Cr, low alkalis, TiO_2 and Fe:Mg ratio, high SiO_2 at the given MgO value, and $CaO:Al_2O_3$ ratios greater than 0.8-1.0. They emphasise that these features are characteristic, but not necessarily diagnostic, as it is only their link with true komatiites which permits their being called komatiitic basalts. Under other circumstances, they would simply be called Mg-rich tholeiites, or some such term. Cameron and Nisbet (1982), however, suggested that the term "komatiitic basalt" could be used if mineralogical traits are sufficiently similar, without implying that the komatiitic basalts have fractionated from komatiites.

Of the 46 Loraine-Edenville samples, 17 lie within the komatiitic basalt field in either Figure 3.7 or 3.8, or both. The MgO values of these 17 are all greater than 9.00%, Ni ranges between 186 and 516 ppm, Cr from 584 to 2618 ppm, Na_2O from 0.19 to 2.39%, K_2O from 0.11 to 1.95% and TiO_2 from 0.400 to 0.533%. $CaO:Al_2O_3$ ratios are generally lower than strictly required, with only 8 samples having a value greater than 0.80, while 7 others lie between 0.70 and 0.79, and the remainder below this. Fe:Mg ratios range from 0.81 to 1.40, while SiO_2 values lie between 50.28 and 55.60%.

In the light of the foregoing discussion, if it is accepted that the Meredale Member contains komatiites, it can be concluded that the following samples (in decreasing order of MgO) may be classed as komatiitic basalts: KL-468, 158, 157, 159, 135, 156, 146, 205, 155, 154, 141, 43, 44, 90, 140, 204 and 382. However, until the case of McIver et al. (1982) is conclusively proved, it is preferable to designate these rocks Mg-rich tholeiites. Further sampling in the vicinity of these samples is recommended to ascertain whether samples with higher MgO values, comparable to true komatiites, are present.

3.3 Statistics

Table 3.1a contains the means, standard deviations and coefficients of variation (CV's) for all major element oxides for each formation. The oxide values are expressed in weight percent. Table 3.1b lists the means, standard deviations and CV's for the trace elements, values for which are given in parts per million. The following formulae were used in the calculations :

$$\text{Mean} = \bar{X} = \frac{\Sigma x}{N}, \text{ and}$$

$$\text{Standard deviation} = s = \sqrt{\frac{\Sigma(x - \bar{X})^2}{N - 1}}$$

where x = element values, and
N = number of samples.

In Table 3.1b, N represents the maximum number of samples used in the calculations for that particular formation. The actual N used may be less than that given, because certain samples have trace element values below the lower limit of determination (LLD). In such a situation, the sample has been omitted from the calculations for that particular element, and the resulting mean will therefore be slightly higher than the true mean. The affected elements, together with the number of samples below the LLD, in brackets, are Nb (9), Cr (14), La (29), Ce(19) and Nd (28), giving a total of 99 unusable analyses, or 2.02 percent of all the trace element determinations.

In an attempt to reduce the number of unusable analyses, it was decided to distinguish between values which lay below the LLD and those below the detection limit (DL). The DL is half the LLD and is not usually used as the counting errors at the DL are large. For the purpose of the present calculations, however, it was decided that it would be expedient to use those values (marked in Table 2.4 with an *) which were below the LLD but above the DL, in order to obtain more representative statistics. This resulted in a reduction in the number of unusable analyses, to the following: Nb (2), Cr (10), La (6), Ce (7) and Nd (11), a total of 36, or 0.74 percent of the trace element analyses.

The coefficients of variation were included for the following reason. The actual variation or dispersion of an element as determined from the standard deviation is called the absolute dispersion. However, a variation or dispersion of 2 weight percent relative to an average of, say, 70 weight percent is quite different from the same variation of 2 weight percent relative to 5 weight percent. A measure of this effect is provided by the relative dispersion, which is defined as

$$\text{Relative Dispersion} = \frac{\text{Absolute Dispersion}}{\text{Average}}$$

If the absolute dispersion is the standard deviation, s, and the average is the mean, $\bar{X}$, the relative dispersion is called the coefficient of variation, given by :

$$\text{Coefficient of Variation} = \text{CV} = \frac{s}{\bar{X}}$$

and is usually expressed as a percentage. The lower the CV, the less scatter about the mean is displayed by that particular element.

Scatter may be the result of a number of causes. Firstly, a skewed distribution will result in a high CV, as shown by Cr within the Dominion Group basic lavas, where it in fact exceeds 100 percent. A skewed distribution will also be produced by differentiation, and is more readily displayed by the trace elements than the major elements.

Alternatively, scatter may be the result of the mobility of elements during secondary processes. This is demonstrated by Ba in all formations, for which CV's range from 38.4 percent for the Dominion Group porphyries, to 79.5 percent for the basic lavas in the same group.

The Witwatersrand triad rocks have been subjected to regional, low-grade greenschist facies metamorphism, resulting in alteration of the original mineralogy to a moderate extent. Figures 3.9a, 3.9b, 3.11a and 3.11b show that certain elements appear to have been unaffected by this process, while others show erratic variation profiles.

Bearing in mind the aforementioned circumstances, the coefficients of variation can generally be used to facilitate comparison between elements, especially major elements at different levels of concentration.

Tables 3.2a and 3.2b list the ranges of major and trace elements respectively, for each formation.

Table 3.1a Means, standard deviations and coefficients of variation for major element oxides

ALLA = Allanridge
RIET = Rietgat-Goedgenoeg
MAKW = Makwassie
LORA = Loraine-Edenville
ORKN = Orkney
ALBE = Alberton
JEPP = Jeppestown Amygdaloid
DR-P = Dominion porphyries
DR-B = Dominion basic rocks

MAJOR ELEMENTS

MEANS

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
N	35	67	17	46	31	19	6	32	69
SIO2	56.37	56.54	64.56	53.59	54.14	55.40	62.82	69.78	56.05
TIO2	1.197	1.524	1.222	0.574	0.981	1.067	1.133	0.812	1.085
AL2O3	14.68	14.58	14.46	13.39	14.78	14.95	13.76	12.92	14.18
FE2O3	11.59	10.66	7.62	11.11	12.76	11.44	12.63	6.70	11.82
MNO	0.15	0.14	0.09	0.17	0.15	0.13	0.18	0.08	0.16
MGO	4.18	5.14	2.43	9.01	5.09	5.12	1.02	1.13	5.25
CAO	6.87	6.22	3.34	8.41	7.06	7.19	3.00	2.01	7.16
NA2O	3.25	3.01	3.03	2.48	3.56	3.40	3.70	3.16	3.02
K2O	1.48	1.47	2.73	1.20	1.35	1.13	1.19	3.15	0.97
P2O5	0.231	0.715	0.521	0.072	0.125	0.156	0.567	0.253	0.308

STANDARD DEVIATIONS

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
SIO2	2.56	3.19	3.91	1.87	1.72	1.61	6.23	4.20	3.15
TIO2	0.098	0.195	0.181	0.121	0.062	0.047	0.264	0.151	0.399
AL2O3	0.69	1.19	1.51	1.68	0.47	0.66	2.88	1.76	1.43
FE2O3	2.21	1.62	1.98	0.84	0.86	0.67	2.08	2.08	1.91
MNO	0.03	0.03	0.03	0.02	0.02	0.02	0.04	0.03	0.03
MGO	1.03	1.37	1.27	2.90	0.55	0.78	0.30	0.93	2.47
CAO	2.27	1.64	1.55	1.98	1.36	1.45	0.54	1.19	1.93
NA2O	0.93	0.61	1.30	0.92	1.00	0.94	0.55	1.11	0.74
K2O	0.96	0.85	1.96	0.61	0.65	0.60	0.69	1.33	0.56
P2O5	0.029	0.132	0.074	0.022	0.010	0.014	0.148	0.062	0.179

COEFFICIENTS OF VARIATION

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
SIO2	4.5	5.6	6.1	3.5	3.2	2.9	9.9	6.0	5.6
TIO2	8.2	12.8	14.8	21.1	6.3	4.4	23.3	18.5	36.8
AL2O3	4.7	8.1	10.4	12.5	3.2	4.4	20.9	13.6	10.1
FE2O3	19.0	15.2	26.0	7.5	6.7	5.9	16.4	31.1	16.2
MNO	21.1	23.4	36.7	13.9	10.8	13.0	24.7	39.3	18.3
MGO	24.7	26.6	52.3	32.2	10.8	15.2	29.4	81.8	47.1
CAO	33.1	26.3	46.4	23.5	19.3	20.2	17.8	59.1	27.0
NA2O	28.6	20.3	45.1	37.3	28.0	27.7	14.7	35.0	24.5
K2O	64.9	57.6	71.7	51.2	48.0	53.4	58.2	42.2	57.8
P2O5	12.6	18.4	14.2	31.2	8.0	8.9	26.1	24.6	58.2

Table 3.1b Means, standard deviations and coefficients of variation for trace elements (see Table 3.1a for abbreviations)

TRACE ELEMENTS

MEANS

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
N	35	67	17	46	31	19	6	32	69
BA	417.	768.	1152.	349.	431.	438.	622.	768.	453.
NB	8.9	18.5	32.4	2.0	4.8	5.5	16.5	14.2	7.0
ZR	180.	336.	535.	59.	100.	117.	266.	282.	159.
Y	27.2	53.5	71.6	16.6	22.5	22.2	54.8	30.2	28.3
SR	439.	579.	622.	205.	347.	394.	343.	187.	430.
RB	36.7	34.7	89.2	43.4	51.1	39.5	36.9	85.5	28.0
ZN	106.	121.	112.	84.	93.	85.	173.	83.	110.
CU	89.	31.	14.	68.	95.	92.	22.	13.	52.
NI	145.	120.	25.	236.	142.	158.	14.	10.	139.
CO	63.	46.	22.	66.	68.	61.	29.	18.	61.
CR	59.	311.	23.	745.	50.	125.	7.	4.	328.
V	198.	202.	108.	201.	225.	184.	19.	54.	256.
LA	23.	59.	93.	6.	11.	12.	45.	48.	21.
CE	51.	130.	194.	13.	25.	30.	95.	92.	46.
ND	25.	66.	93.	6.	12.	14.	48.	40.	26.

STANDARD DEVIATIONS

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
BA	221.	345.	807.	262.	256.	278.	378.	295.	362.
NB	1.7	3.9	5.1	1.3	1.0	1.2	3.5	2.9	3.7
ZR	14.	88.	79.	19.	5.	16.	58.	54.	73.
Y	2.5	8.7	8.2	3.2	1.5	1.5	8.9	6.5	9.1
SR	276.	242.	688.	126.	152.	184.	167.	115.	247.
RB	31.4	22.9	64.9	24.0	26.6	23.2	24.7	37.0	22.4
ZN	20.	21.	32.	15.	11.	8.	29.	28.	30.
CU	45.	12.	5.	22.	22.	17.	6.	18.	19.
NI	47.	40.	6.	93.	16.	30.	2.	2.	135.
CO	8.	8.	5.	7.	7.	4.	4.	4.	11.
CR	56.	148.	6.	637.	22.	105.	2.	3.	469.
V	28.	31.	19.	25.	15.	12.	4.	21.	70.
LA	4.	12.	24.	3.	2.	3.	7.	15.	10.
CE	7.	20.	43.	8.	4.	5.	15.	23.	22.
ND	4.	9.	28.	5.	3.	3.	5.	9.	13.

COEFFICIENTS OF VARIATION

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
BA	53.0	44.9	70.1	75.0	59.5	63.4	60.8	38.4	79.9
NB	18.6	21.0	15.7	64.8	20.7	21.7	21.0	20.1	52.2
ZR	7.6	26.0	14.7	31.8	4.9	13.3	21.8	19.3	45.6
Y	9.1	16.2	11.5	19.5	6.7	6.9	16.3	21.4	32.2
SR	62.8	41.8	110.7	61.6	43.8	46.7	48.6	61.4	57.3
RB	85.7	66.0	72.7	55.3	52.0	58.7	66.9	43.2	80.0
ZN	18.6	17.0	28.7	18.4	11.9	9.7	16.9	33.6	27.8
CU	50.7	38.9	35.8	32.0	23.6	18.5	25.3	137.4	36.5
NI	32.6	33.3	24.1	39.5	11.0	19.2	18.0	22.9	97.7
CO	13.0	17.1	22.4	10.8	10.8	6.9	15.3	22.6	18.3
CR	93.7	47.6	28.2	85.5	44.0	84.1	33.9	77.4	142.9
V	14.4	15.5	18.0	12.3	6.6	6.6	22.6	39.8	27.5
LA	17.8	20.4	26.0	55.2	21.7	24.9	15.7	32.1	50.4
CE	12.8	15.5	22.4	56.0	15.4	17.6	16.3	25.3	49.0
ND	14.0	13.8	30.0	69.3	27.6	19.8	11.0	21.3	49.8

Table 3.2a Ranges of major elements (see Table 3.1a for abbreviations)

SIO2	min	max
ALLA	51.43	61,89
RIET	47.50	63,42
MAKW	54.93	68,75
LORA	50,28	57.72
ORKN	51.03	58,88
ALBE	52.56	58,13
JEPP	50.22	66,82
DR-P	55.93	78.93
DR-B	48,79	62,50

TIO2		
ALLA	0.891	1.413
RIET	1,198	2,202
MAKW	1.064	1,729
LORA	0.400	0,878
ORKN	0.879	1,097
ALBE	0.973	1,174
JEPP	0.998	1,670
DR-P	0,522	1,489
DR-B	0.603	2.076

AL2O3		
ALLA	13.39	16,66
RIET	12,02	19.44
MAKW	12.75	18,55
LORA	8.59	17.38
ORKN	13,69	15,77
ALBE	13.76	16,66
JEPP	11.94	19,57
DR-P	10.93	21,63
DR-B	11.41	20,33

FE2O3		
ALLA	5.09	16,43
RIET	6,29	14,44
MAKW	5.75	13,11
LORA	9.11	12,72
ORKN	11.07	14.46
ALBE	10,10	12.51
JEPP	11.28	16.75
DR-P	1.81	12,54
DR-B	7,95	17,15

MNO		
ALLA	0.09	0.25
RIET	0.07	0.26
MAKW	0.02	0,15
LORA	0,12	0,24
ORKN	0.11	0,18
ALBE	0.11	0.17
JEPP	0.13	0,26
DR-P	0.02	0.18
DR-B	0.10	0.29

MGO	min	max
ALLA	2.02	5.78
RIET	2.35	8.20
MAKW	0.76	5,22
LORA	4.18	17,46
ORKN	3.57	6.21
ALBE	4.14	7.29
JEPP	0.84	1,61
DR-P	0.26	5.34
DR-B	1.48	11,36

CAO		
ALLA	2.43	14.66
RIET	2.76	12.68
MAKW	1.84	7.93
LORA	0.79	12,57
ORKN	5.17	10.66
ALBE	5.16	9,77
JEPP	1,96	3.37
DR-P	0.42	5.32
DR-B	3.09	11,13

NA2O		
ALLA	0.16	4.26
RIET	1.05	4,46
MAKW	0.51	6,56
LORA	0.15	3,95
ORKN	2.21	7,08
ALBE	0,67	4,57
JEPP	2,72	4,20
DR-P	0.20	4.40
DR-B	0.29	5,11

K2O		
ALLA	0.30	4.59
RIET	0.11	3.10
MAKW	0.07	7.47
LORA	0.11	2,49
ORKN	0.34	2,90
ALBE	0.38	2.77
JEPP	0.15	1.90
DR-P	0.76	7.12
DR-B	0,08	3,69

P2O5		
ALLA	0.164	0,282
RIET	0.520	1,168
MAKW	0.436	0,687
LORA	0,033	0.131
ORKN	0.106	0,149
ALBE	0.137	0,183
JEPP	0.496	0,869
DR-P	0.125	0,517
DR-B	0.109	0.778

Table 3.2b Ranges of trace elements (see Table 3.1a for abbreviations)

BA	min	max
ALLA	97	998
RIET	83	1599
MAKW	25	2784
LORA	16	1470
ORKN	128	1208
ALBE	155	1189
JEPP	122	1210
DR-P	311	1695
DR-B	25	2752

RB	min	max
ALLA	5.7	172.4
RIET	3.0	103.0
MAKW	2.0	234.4
LORA	4.1	101.0
ORKN	10.9	111.9
ALBE	10.1	87.7
JEPP	4.3	66.8
DR-P	33.6	204.4
DR-B	1.3	106.2

CR	min	max
ALLA	0	213
RIET	17	936
MAKW	11	39
LORA	21	2618
ORKN	16	97
ALBE	64	415
JEPP	3	9
DR-P	0	12
DR-B	0	1510

NB		
ALLA	5.5	12.2
RIET	13.3	33.3
MAKW	23.6	45.8
LORA	0.0	6.1
ORKN	2.9	6.8
ALBE	2.0	8.1
JEPP	14.2	23.4
DR-P	11.3	28.5
DR-B	2.0	16.5

ZN		
ALLA	52	146
RIET	75	174
MAKW	74	204
LORA	59	118
ORKN	67	126
ALBE	67	103
JEPP	155	232
DR-P	40	183
DR-B	73	240

V		
ALLA	147	265
RIET	151	314
MAKW	89	157
LORA	153	260
ORKN	188	258
ALBE	168	211
JEPP	15	27
DR-P	17	106
DR-B	161	479

ZR		
ALLA	141	230
RIET	244	750
MAKW	452	748
LORA	28	113
ORKN	90	110
ALBE	60	137
JEPP	233	383
DR-P	220	545
DR-B	75	351

CU		
ALLA	5	182
RIET	3	62
MAKW	8	28
LORA	19	155
ORKN	16	137
ALBE	59	122
JEPP	13	30
DR-P	3	113
DR-B	6	86

LA		
ALLA	14	31
RIET	44	113
MAKW	45	140
LORA	0	15
ORKN	8	18
ALBE	5	19
JEPP	40	59
DR-P	21	118
DR-B	6	43

Y		
ALLA	22.2	32.1
RIET	39.6	95.5
MAKW	62.1	92.9
LORA	6.9	23.4
ORKN	19.1	25.5
ALBE	17.7	24.4
JEPP	46.8	72.3
DR-P	23.4	60.7
DR-B	17.3	54.4

NI		
ALLA	27	226
RIET	25	220
MAKW	17	38
LORA	108	516
ORKN	111	163
ALBE	101	226
JEPP	11	18
DR-P	6	18
DR-B	14	601

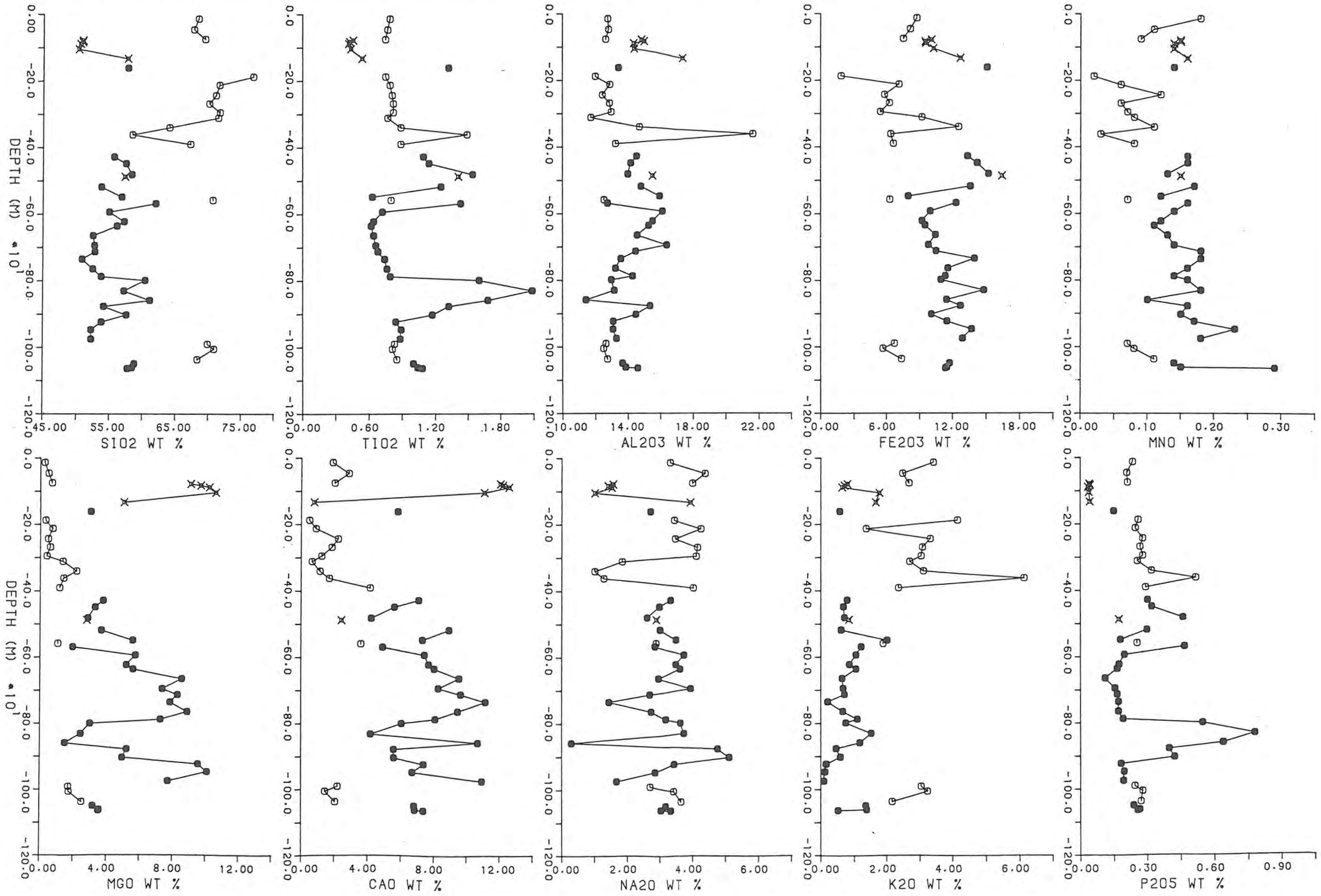
CE		
ALLA	37	61
RIET	98	199
MAKW	112	282
LORA	0	32
ORKN	15	31
ALBE	17	38
JEPP	81	124
DR-P	51	194
DR-B	15	88

SR		
ALLA	53	1472
RIET	216	1395
MAKW	113	2943
LORA	20	561
ORKN	174	781
ALBE	147	929
JEPP	194	594
DR-P	43	565
DR-B	121	2015

CO		
ALLA	47	82
RIET	26	71
MAKW	16	33
LORA	55	88
ORKN	47	84
ALBE	51	69
JEPP	24	37
DR-P	9	28
DR-B	40	110

ND		
ALLA	17	31
RIET	51	96
MAKW	61	186
LORA	0	17
ORKN	0	17
ALBE	8	19
JEPP	41	57
DR-P	22	77
DR-B	7	52

Figure 3.9a Major element variations with height in the Dominion Group - borehole DSF-7



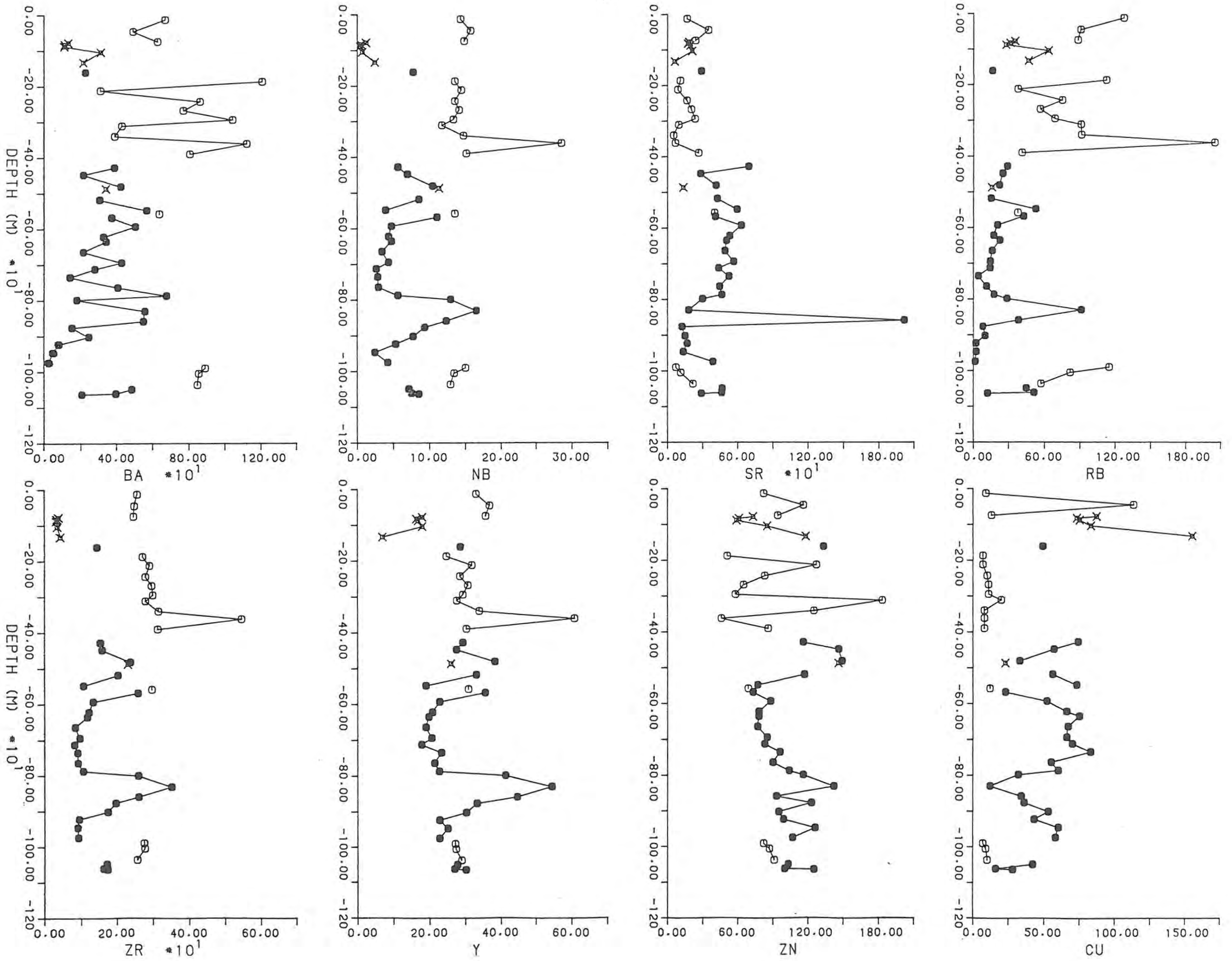
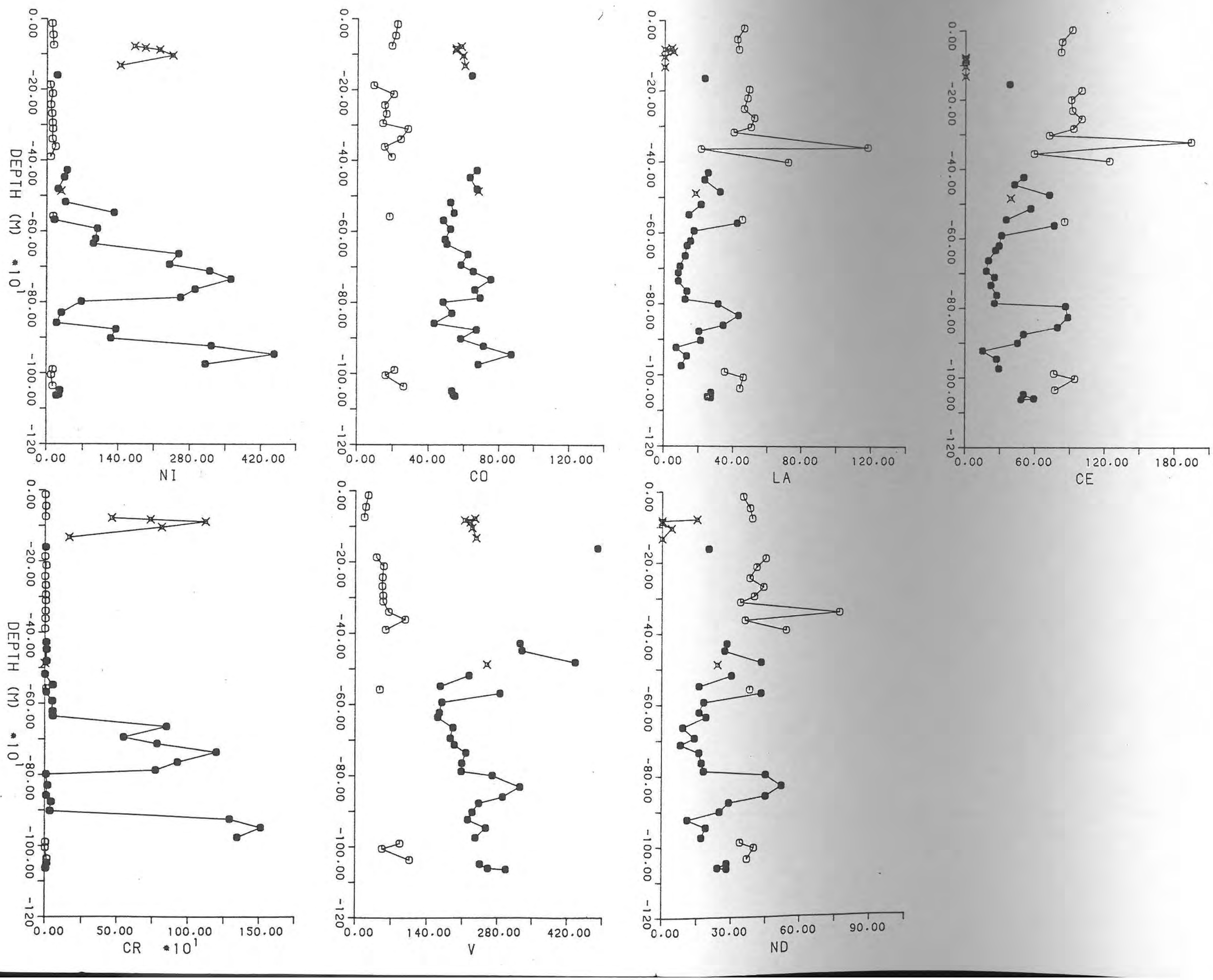


Figure 3.9b Trace element variations with height in the Dominion Group - borehole DSF-7

Figure 3.9b continued



3.4 Dominion Group

The description and discussion of the chemical data for the Dominion Group porphyries and basic lavas below is in reference to Figures 2.2a, 3.9a and 3.9b. Borehole DSF-7, the representative hole for the Dominion Group, is shown in Figures 3.9a and 3.9b with major and trace element abundances respectively plotted against vertical depth down the borehole. The vertical scale is the same as that in Figure 2.2a in order to facilitate comparison. The zero mark represents the borehole collar. The solid circles represent Dominion Group basic lavas, the open circles, the Dominion Group porphyries, while the "sputniks" indicate intrusive samples of other formations. The discussion which follows encompasses the Dominion Group stratigraphy encountered in all boreholes examined, but space does not permit the illustration of each hole.

SiO_2

The Dominion Group porphyries are the most silicic of the Witwatersrand triad volcanic rocks by virtue of their high SiO_2 content, with a mean of 69.78%. Although their SiO_2 values range between 55.93% and 78.93%, the majority lie above 67%, with only three samples below this value: DP-34 (64.02%), DP-33 (58.44%) and DP-263 (55.93%).

SiO_2 abundances are distinctively higher in the porphyries than in the basic lavas (see Fig. 3.9a). The thickest porphyritic unit (see Figure 2.2a), containing samples DP-32 to DP-40, shows a definite increase in SiO_2 content upwards, while the basic lavas display the same trend, to a lesser degree. The basic lavas cluster about a mean of 56.06% and none of them exceeds 62.5% SiO_2. Some of the most basic lavas of the Witwatersrand triad are found amongst this group, with SiO_2 values as low as 48.79% (in DB-78).

TiO_2 and P_2O_5

TiO_2 and P_2O_5 behave sympathetically and the highly constant values shown by the low-TiO_2 and -P_2O_5 samples are clearly evident in Figure 3.1a. The porphyries, with the exception of DP-33, show a very tight clustering around .790% TiO_2. A slight decrease upwards is evident in the thick porphyritic unit in borehole DSF-7, with TiO_2 decreasing systematically from .891% in DP-32 to .747% in DP-40. The basic lavas also show a very smooth linear trend decreasing from 1.084% TiO_2 in DB-1 at the base of DSF-7, to .625% in DB-26, halfway up the hole. This smooth trend is, however punctuated twice by sharp increases, the first peak occurring about 70m above the lowermost porphyry, with a maximum at DB-13 of 2.076%, and the second just below the thick porphyritic unit. This pattern is echoed in borehole DSF-10, which was also sampled at fairly close intervals, and seems to be associated with an increase in the SiO_2 content of the lava.

The pattern of P_2O_5 variation in borehole DSF-7 is virtually identical to that of TiO_2. The two large spikes shown by TiO_2 variation in the basic lavas are also evident in the P_2O_5 data, reaching a maximum at DB-13 of .778% P_2O_5, whereas the majority of basic rocks have P_2O_5 varying from .255% at the base to .177% in DB-26. The lowest value is .109% in DB-20. In the porphyries, P_2O_5 values are again very constant, with the exception of DP-33, but show a slight decrease upwards within the thick unit from .292% in DP-32 to .259% in DP-40, decreasing even further near the top of the hole to .208% in DP-48.

Nb, Zr and Y

The elements Nb, Zr and Y, usually regarded as immobile during low grade metamorphism and alteration of igneous rocks, and the rare earths La, Ce and Nd display virtually identical trends in borehole DSF-7. In the basic lavas high concentrations of these elements occur in the SiO_2-rich samples. Amongst the other samples values decrease from the bottom of the hole until just below the first SiO_2-rich horizon, after which they increase towards the top of the hole. Average values for Nb, Zr and Y are respectively, 7.0 ppm, 159 ppm and 28.3 ppm. The maximum values for all 6 trace elements are found in sample DB-13, in the middle of the lower SiO_2-rich horizon in borehole DSF-7.

The trends displayed by the porphyries are identical for Nb and Zr, but less so for Y and the light rare earth elements. With the exception of sample DP-33, which is highly enriched in these six elements, the following patterns emerge: Nb has a limited range from 11.3 ppm to 16.1 ppm, with an average of 14.2 ppm. No increase or decrease with depth is evident, although a very slight depletion towards the top of the hole may be observed in the thick porphyritic unit of DSF-7, from 15.1 ppm in DP-32 to 13.5 ppm in DP-40.

A more discernible trend in the same unit is shown by Zr, which decreases from 313 ppm in DP-32 to 271 ppm in DP-40. The range of Zr values overall is again fairly narrow, from 220 ppm in DP-99 to 353 ppm in DP-263, with a mean of 282 ppm.

Y and the light rare earth elements show slightly more erratic variations and no particular trend can be discerned in the thick porphyry. With the exclusion of DP-33, the range for Y is from 23.4 ppm to 36.7 ppm.

La, Ce and Nd

In the basic lavas La, Ce and Nd average 21 ppm, 46 ppm and 26 ppm respectively. La ranges from 6 ppm (DB-281) to 43 ppm (DB-13), Ce from 15 ppm (DB-9) to 88 ppm (DB-13) and Nd from 7 ppm (DB-257) to 52 ppm (DB-13). The profiles produced by the variations of these light rare earth elements with depth are almost identical to one another and to those of Nb, Zr and Y.

Within the porphyries the average values for La, Ce and Nd are 48 ppm, 92 ppm and 40 ppm respectively, roughly double those for the basic rocks. However, the variation patterns depart from those shown by Nb, Zr and Y, which decrease upwards within the thick porphyry, as the rare earth element concentrations behave highly erratically in the lower part of the porphyry unit, thus obscuring any possible trends present. Ranges are : La, from 21 ppm (DP-33) to 72 ppm (DP-32), except DP-34 (118 ppm); Ce, from 51 ppm (DP-265) to 124 ppm (DP-32), except DP-34 (194 ppm); Nd, from 22 ppm (DP-265) to 54 ppm (DP-32), except DP-34 (77 ppm).

MgO, Cr and Ni

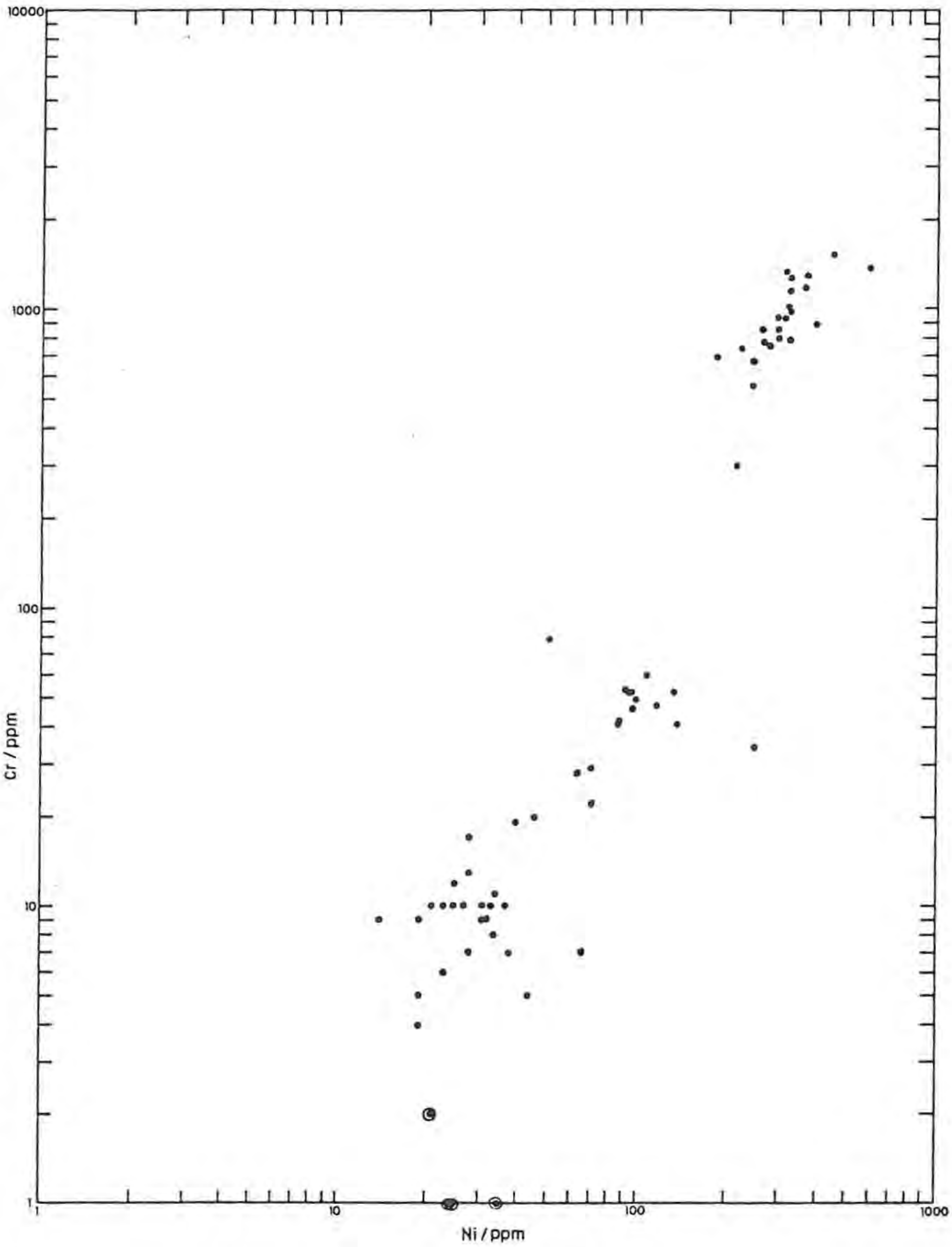
The average MgO content of the porphyries - 1.13% - is, with the exception of that for the Jeppestown amygdaloid, the lowest of all the Witwatersrand triad volcanic rocks. The porphyries display a progressive decrease in MgO content from 2.50% in DP-4 near the base of the Dominion Group, to 0.26% in DB-49 at the top of borehole DSF-7. The latter is the minimum MgO value obtained throughout all the porphyry samples, while the maximum - 5.34% - occurs in DP-263, the sample with the lowest SiO_2 value. The second highest MgO value is the aforementioned 2.50% in DB-4. MgO values in the porphyries at the top and bottom of the hole differ, therefore, by a factor of almost ten.

The basic lavas also show a marked decrease in MgO content from the bottom to the top of DSF-7. The three lowermost samples show relatively low values around 3.5%, but a marked increase is evident just above the basal porphyry, with DB-8 containing 10.07% MgO. This is very close to the maximum of 11.36% shown by DB-52, which occurs in the same stratigraphic position in borehole DSF-10. A prominent negative peak in the upward variation is delineated by samples DB-10 through to DB-14, and again by DB-24. These correspond with the SiO_2-rich samples which also show the very high TiO_2 and P_2O_5 values mentioned earlier.

The trends displayed by Cr and Ni are very similar in borehole DSF-7, and follow closely that of MgO. Both Cr and Ni concentrations are very low in the porphyries, with Cr averaging 4 ppm and Ni averaging 10 ppm, the lowest of all the formations. Cr values lie between 0 ppm (DP-32, 38, 40, 48 and 288) and 12 ppm (DP-4, 89 and 99), while Ni ranges from 6 ppm (DP-40) up to 18 ppm (DP-98), with all but three samples lying below 12 ppm, viz. DP-265 (13 ppm), DP-33 (16 ppm) and DP-89 (18 ppm).

The basic lavas, on the other hand, have fairly high average Cr and Ni contents, 328 ppm and 139 ppm respectively. These averages need to be examined more closely, however, as they are misleading. Within the complete range of values displayed by Cr, 0 to 1510 ppm, there are in fact two distinct populations. Forty six out of the sixty nine basic rock samples, i.e. exactly two thirds, have relatively low concentrations between 0 (DB-27, 273 and 286) and 79 ppm (DB-97).

Figure 3.10 Plot of Cr vs Ni values for the Dominion Group basic lavas showing separation into two distinct groups



Their average is 21 ppm Cr. The remaining twenty three samples have very much higher values, lying between 548 ppm (DB-19) and 1510 ppm (DB-8), with one sample at 299 ppm (DB-251). The average for this group is 942 ppm, almost 45 times that of the low-Cr group. Within the high-Cr group in borehole DSF-7, the highest values are to be found near the bottom, and a general upward decrease is evident.

A similar bimodal grouping emerges when Ni concentrations are examined. Concentrations in the low-Ni group range between 14 ppm (DB-24) and 135 ppm (DB-11) and between 182 ppm (DB-56) and 601 ppm (DB-78) in the high-Ni group. Average values for the two groups are 52 ppm and 311 ppm respectively, with the high-Ni values decreasing towards the top of the borehole. Figure 3.10 is a plot of Cr vs Ni for the basic lavas and the separation of the rocks into two distinct groups is clear.

Fe_2O_3, V and Zn

Within the basic lavas there is a gradual decrease in Fe_2O_3 from roughly between 11.5% and 13.5% at the base, to 7.95% in DB-26, followed by an increase in the overlying silicic horizon to between 13.33% and 16.43% Fe_2O_3. DB-26 reflects the minimum within the basic lavas, while the maximum occurs at 17.15% in sample DB-259 from borehole DRH-15. This sample has low SiO_2 (49.95%). DB-259 corresponds stratigraphically to the upper silicic horizon which shows similar high values. Interestingly, the lower SiO_2-rich horizon is not demarcated by Fe_2O_3 values.

The average Fe_2O_3 value for the porphyries is 6.70%, the lowest of the nine formations of the Witwatersrand triad. Maximum and minimum values are displayed by DP-34 (12.54%) and DP-40 (1.81%) respectively. Within a vertical sequence there appears to be a decrease in Fe_2O_3 content upwards - see DP-32 to DP-40 - although some values are rather erratic. This is reflected in a fairly large CV of 31.3%.

V in the porphyries has an average concentration of 54 ppm, the second lowest after that of the Jeppestown Amygdaloid. The limiting values are 17 ppm (DP-47) and 106 ppm (DP-4). Within the porphyries, a decrease in V content from 106 to 25 ppm is evident towards the top of borehole DSF-7.

The basic lavas have an average of 256 ppm V, the highest of all the formations. Values range between 161 ppm in DB-21 and 479 ppm in DB-41. Again, there is a general decrease towards the top of DSF-7, from 297 ppm at the bottom to 166 ppm in DB-26. Concentrations then show a sudden increase, culminating in 479 ppm in DB-41.

The variation of Zn concentrations in the basic lavas produces a pattern in borehole DSF-7 which is similar to that of V, decreasing towards the top of the hole, but with a few high values near the top. The lower and upper limits are 73 ppm (DB-24) and 168 ppm (DB-52), with the exception of a high 240 ppm in DB-67. The average is 110 ppm.

In the porphyries, Zn values average 83 ppm, the lowest of all the formations, and range between 40 ppm (DP-265) and 183 ppm (DP-35). Unlike V, the Zn concentration in the porphyries has a rather erratic variation and no trend is evident. Both V and Zn follow the general pattern shown by Fe_2O_3.

MnO

MnO in the basic lavas shows a relatively smooth decrease from .29% in DB-1 at the base of DSF-7, to .16% in DB-31, just below the thick porphyritic unit. Extreme values are the aforementioned .29% and .10% in DB-12. In the porphyries MnO values are variable and range from .02% in DP-40 up to .18% in DP-49, averaging .08%.

CaO and Sr

The basic lavas have an average of 7.09% CaO. Values are highly variable, but there is a slight decrease upwards. The maximum value of 11.13% occurs in DB-17 from the lower half of borehole DSF-7, while the minimum of 3.09% is found in DB-78 from borehole DRS-6.

CaO concentrations in the porphyries are very low, in fact, the lowest of all the Witwatersrand triad volcanics, averaging 2.01%. The range is fairly small, from 0.42% in DP-265 to 5.32% in DP-263, with no particular trends emerging.

The porphyries have an average Sr content of 187 ppm, the lowest of all the volcanics. Values lie between 43 ppm (DP-265) and 565 ppm (DP-81) and are clearly widely scattered about the mean. There is no discernible trend in the variation of concentration with depth.

In the basic lavas Sr ranges between 121 ppm (DB-11) and 750 ppm (DB-61), with the exception of DB-12 which has 2015 ppm Sr. The average Sr value is 430 ppm, and the lower values appear to be near the bottom of the hole.

Al_2O_3

Al_2O_3 content in the porphyries is extremely constant, the majority of samples ranging between 12.00 and 13.00%, and only six samples fall outside these limits. These are DP-265 (10.93%), DP-35 (11.73%), DP-32 (13.25%), DP-34 (14.70%), DP-263 (15.11%) and DP-33 (21.63%). There appears to be no systematic increase or decrease with height. The average Al_2O_3 value of 12.92% is the lowest of all the formations of the Witwatersrand triad volcanics.

The basic lavas have an average of 14.23% Al_2O_3 and range between 11.41% in DB-12 and 16.37% in DB-19, with the exception of two very high values occurring in DB-259 (17.25%) and DB-78 (20.33%). Concentrations are slightly lower in the bottom half of borehole DSF-7, but decrease again near the top.

Na_2O

Na_2O values in both the porphyries and the basic lavas are highly variable, ranging in the basic lavas from 0.29% (DB-12) up to 5.11% (DB-10), with an average of 3.04%. In the porphyries the range is slightly smaller, from 0.20% (DP-265) to 4.40% (DP-51). The average is 3.16% and again there is no discernible trend with depth.

K_2O, Rb and Ba

K_2O concentrations in the porphyries average 3.15%, the highest of all the formations under scrutiny. Values lie between 0.76% (DP-263) and 5.70% (DP-80), except for DP-33 which has 7.12% K_2O. Within the thick porphyritic unit in borehole DSF-7, concentrations increase upwards from 2.35% (DP-32) to 4.14% (DP-40).

Within the basic lavas, a general increase in K_2O towards the top is also evident, producing a trend very similar to that of SiO_2. With an average of 1.00%, the lowest of the nine formations, values range between 0.08% (DB-7) and 2.11% (DB-72), with the exception of DB-85, which has 3.69% K_2O.

The average Rb concentration in the porphyries is 85 ppm, the range being from 34 (DP-81) to 150 ppm (DP-265), with the exception of DP-33, which has 204 ppm Rb. The variation with height is highly erratic with no discernible trend with depth.

In contrast, the basic lavas, show a systematic increase in Rb content with height in the thickest unit, the trend being punctuated by two large peaks delineated by samples which also have high Nb, Zr, Y and light rare earth elements. The average Rb content is 28.0 ppm, the lowest in all the volcanics. Values range from 1.3 ppm (DB-7) up to 106 ppm (DB-72), with all except four values lying below 70 ppm.

In the basic lavas Ba concentrations show a large degree of scatter. Despite the scatter, there is a general upward increase in Ba, similar to that of K_2O. The average is 453 ppm and values range from 25 ppm in DB-7 to 1090 ppm in DB-79, with an excessive amount of 2752 ppm in DB-85. This very high value corresponds with a high K_2O content of 3.69% in a group of lavas whose average K_2O content is only 1.00%.

Amongst the porphyries the spread of Ba values is very large and erratic, but higher on average than in the basic lavas. Values range from 311 ppm in DP-39 to 1695 ppm in DP-59, with an average of 768 ppm. Ba seems to be amongst the most mobile of the trace elements determined in the Dominion Group and as such should not be utilised for any petrogenetic interpretation.

Cu

The Cu profile down borehole DSF-7 is much the same as that of Ni, but without the strong polarisation into high- and low-concentration groups within the basic lavas. The average for the basic lavas is 52 ppm, extreme values being 6 ppm in DB-6, and 86 ppm in DB-61.

The porphyries have a rather restricted Cu content, averaging 13 ppm, the lowest of all the formations. Values range from 3 ppm (DP-265) up to 20 ppm (DP-35), with the exception of DP-48 (113 ppm). There is no particular trend with depth in either the porphyries or the basic lavas.

Co

The range of Co concentrations in the porphyries extends from 9 ppm (DP-40) up to 28 ppm (DP-35), with an average of 18 ppm, the lowest for all the volcanics. There is very little spread about the mean, and no discernible systematic variation with depth.

Concentrations of Co in the basic lavas display a distinct decrease with height in the thickest unit. The average value for Co is 61 ppm, with limiting values at 40 ppm (DB-50) and 87 ppm (DB-8), except for a high 110 ppm in DB-78. The tight clustering about the mean is reflected in a low CV of 18.3.

3.5 Crown Formation

Only six samples were taken from the Crown Formation, three from borehole R-1, immediately south of Klerksdorp, and three from borehole JY-6, south of Orkney, about 14.5 km away. The small number of samples did not warrant the plotting of variation-with-depth diagrams, so only a very cursory description of the major and trace element concentrations follows.

The first five samples, JC-366 to JC-370, are very similar in major element composition, while the last sample, JC-371, differs sharply in all respects except CaO, Na_2O and K_2O values (see Table 2.4). It must be borne in mind, therefore, when examining mean values, that they will have been influenced by some extreme values from JC-371.

Of all the formations studied, the Crown Formation has the highest average MnO and Na_2O concentrations, 0.18% and 3.70% respectively, and the lowest average MgO (1.02%). For such low-MgO and relatively high-SiO_2 rocks, the Fe_2O_3 average of 12.63% is very high.

Trace element determinations show that sample JC-371 again has very different concentrations from those of the other five samples, values being higher for all trace elements except Sr, Rb and Cr. The average value of V - 19 ppm - is the lowest of all the formations, while the Zn average of 173 ppm is the highest.

3.6 Ventersdorp Supergroup

Figures 3.11a and 3.11b show major and trace element concentrations respectively plotted against vertical depth down borehole WS-5, the representative borehole for the Ventersdorp Supergroup. The lithostratigraphic log of borehole WS-5, which also shows the positions of samples (see Figure 2.2b), has been drawn at the same vertical scale as the down-the-hole plots in order to facilitate comparison between the two. Symbols used are as follows:

▲ - Allanridge
■ - Rietgat
□ - Makwassie
◇ - Goedgenoeg
x - Loraine-Edenville
+ - Orkney
* - Loraine

An examination of chemical analyses has revealed a number of interesting points: the three lowermost samples in the Goedgenoeg formation, PG-160, 161 and 162, overlie the Klipriviersberg Group directly and are separated from the rest of the Goedgenoeg formation by a 36-metre conglomerate intercalation of the Kameeldoorns Formation. In borehole WS-4, which is nearest to WS-5, a similar situation occurs, where sample PG-206 is overlain by 55 metres of conglomerate, which in turn is overlain by the rest of the Goedgenoeg formation. In borehole SH-1, sample PR-395, which was collected from a volcanic horizon within the Kameeldoorns conglomerates, has chemical characteristics identical to those of other samples of the Goedgenoeg-Rietgat volcanic rocks.

As this study progressed, several changes were proposed, on the basis of chemistry, to the positioning of formational boundaries which had been visually demarcated by company geologists, in boreholes W-20, PK-10 and WS-5. In W-20, the interval from 192m to 267m had been logged as part of the Goedgenoeg formation, followed by 4.5m of

Figure 3.11a Major element variations with height in the Ventersdorp Supergroup - borehole WS-5

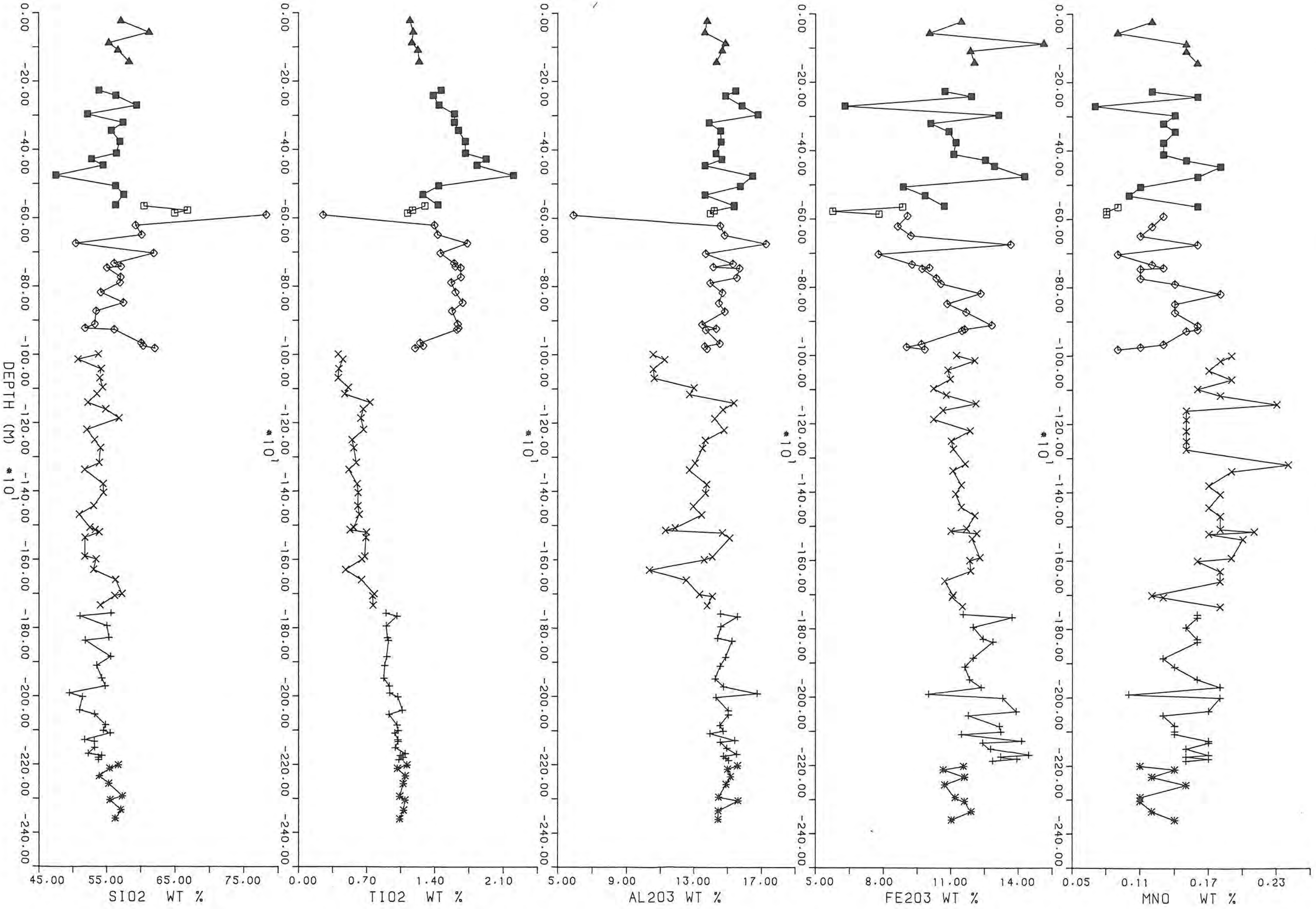


Figure 3.11a continued

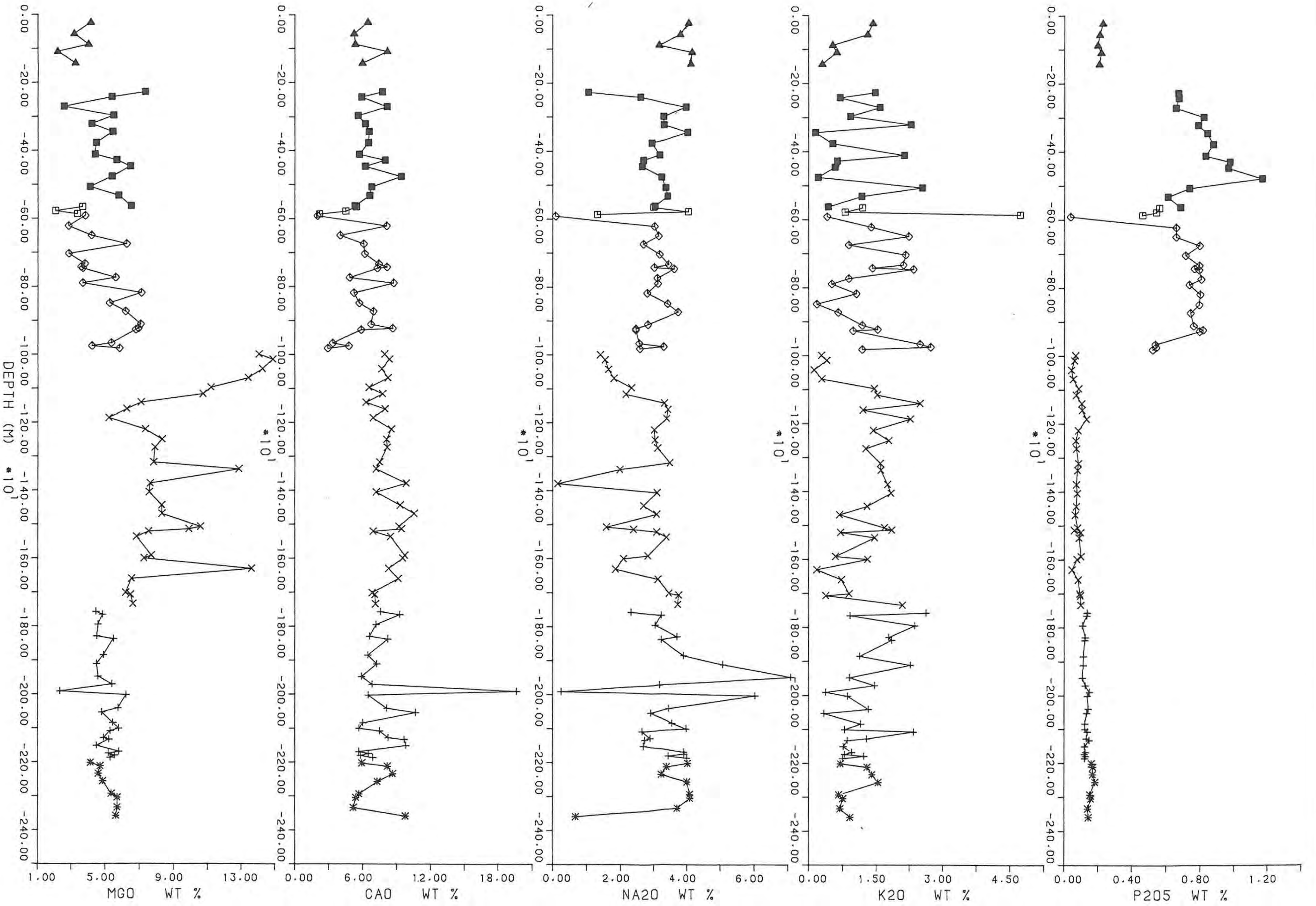


Figure 3.11b Trace element variations with height in the Ventersdorp Supergroup - borehole WS-5

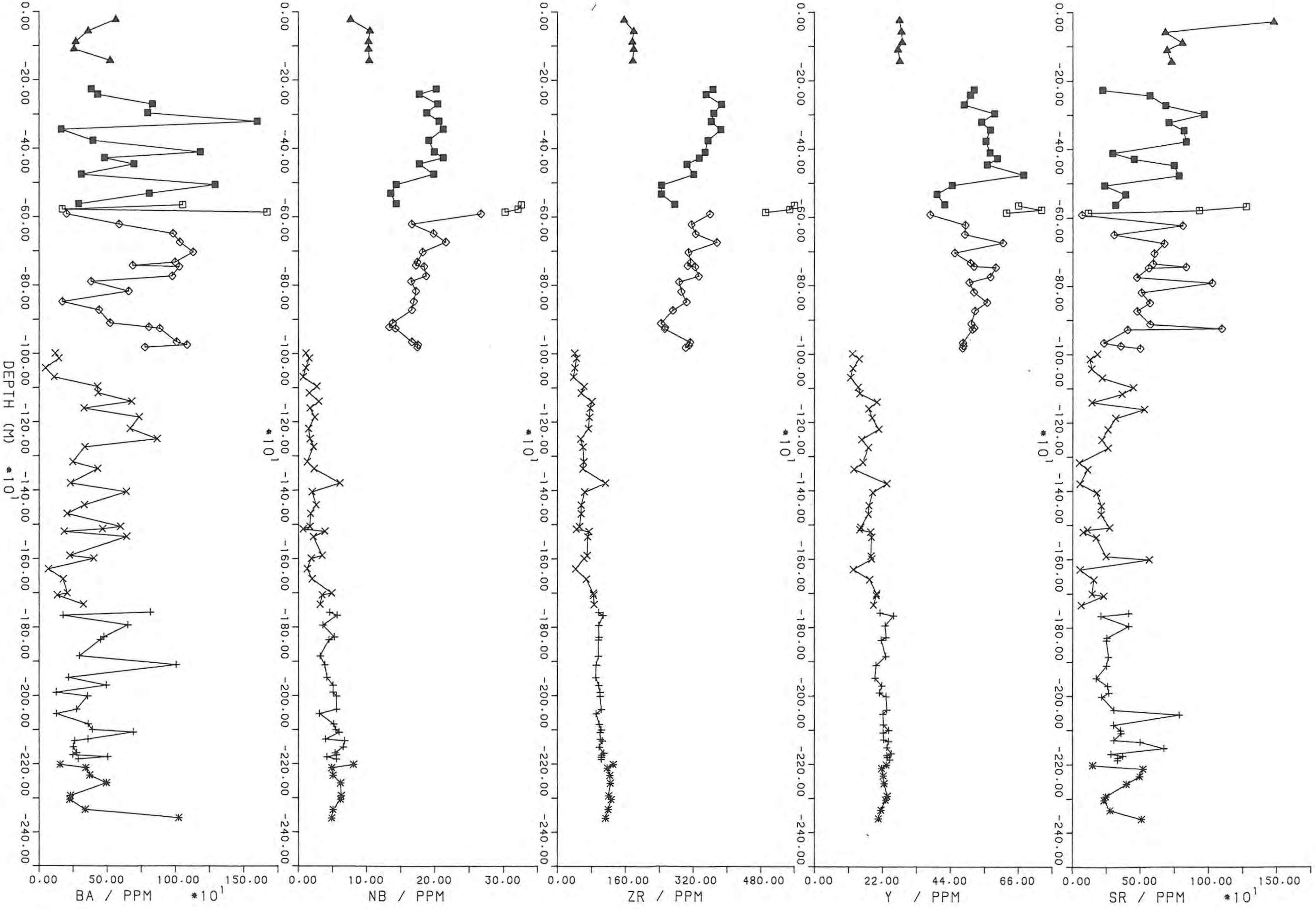


Figure 3.11b continued

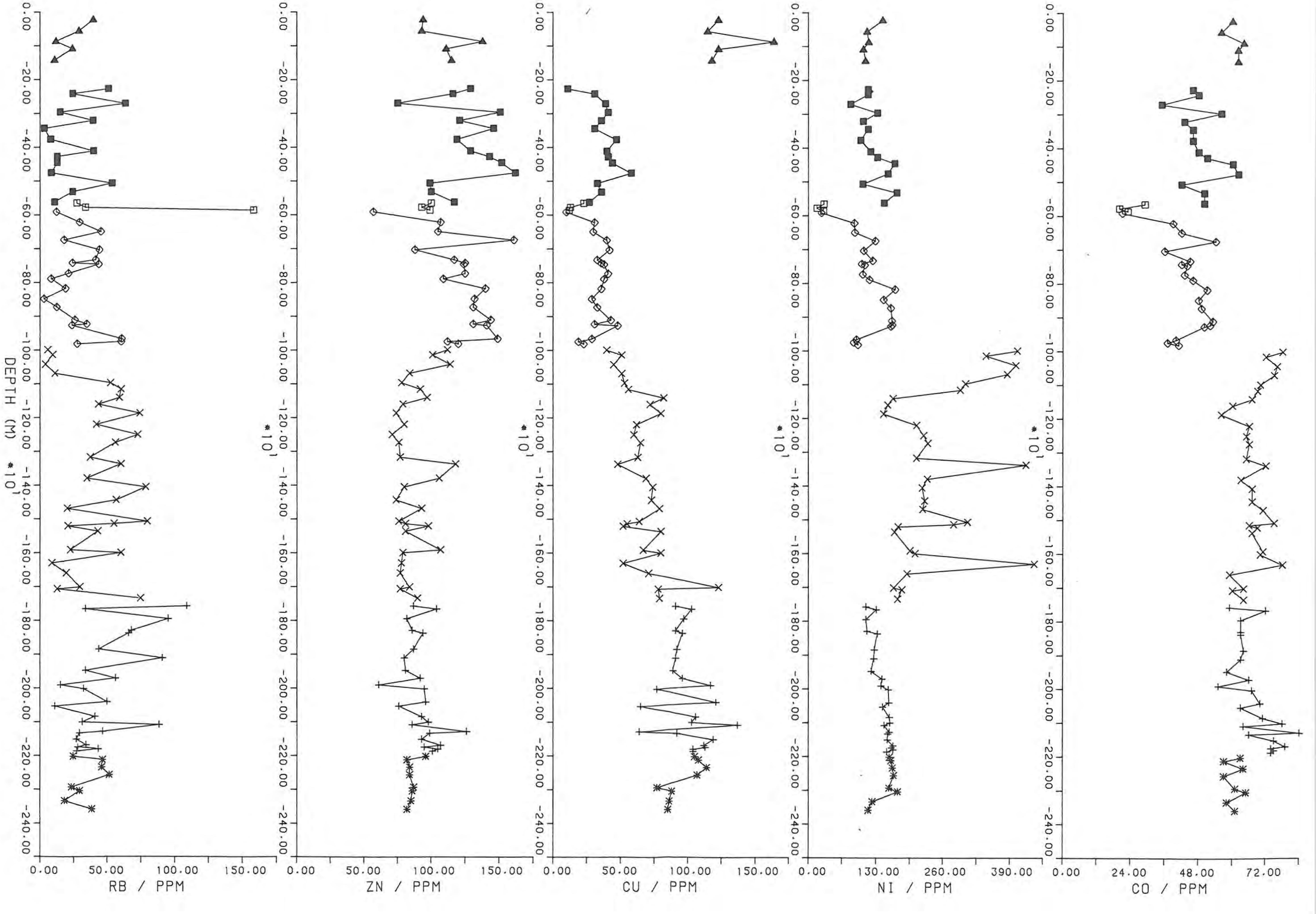
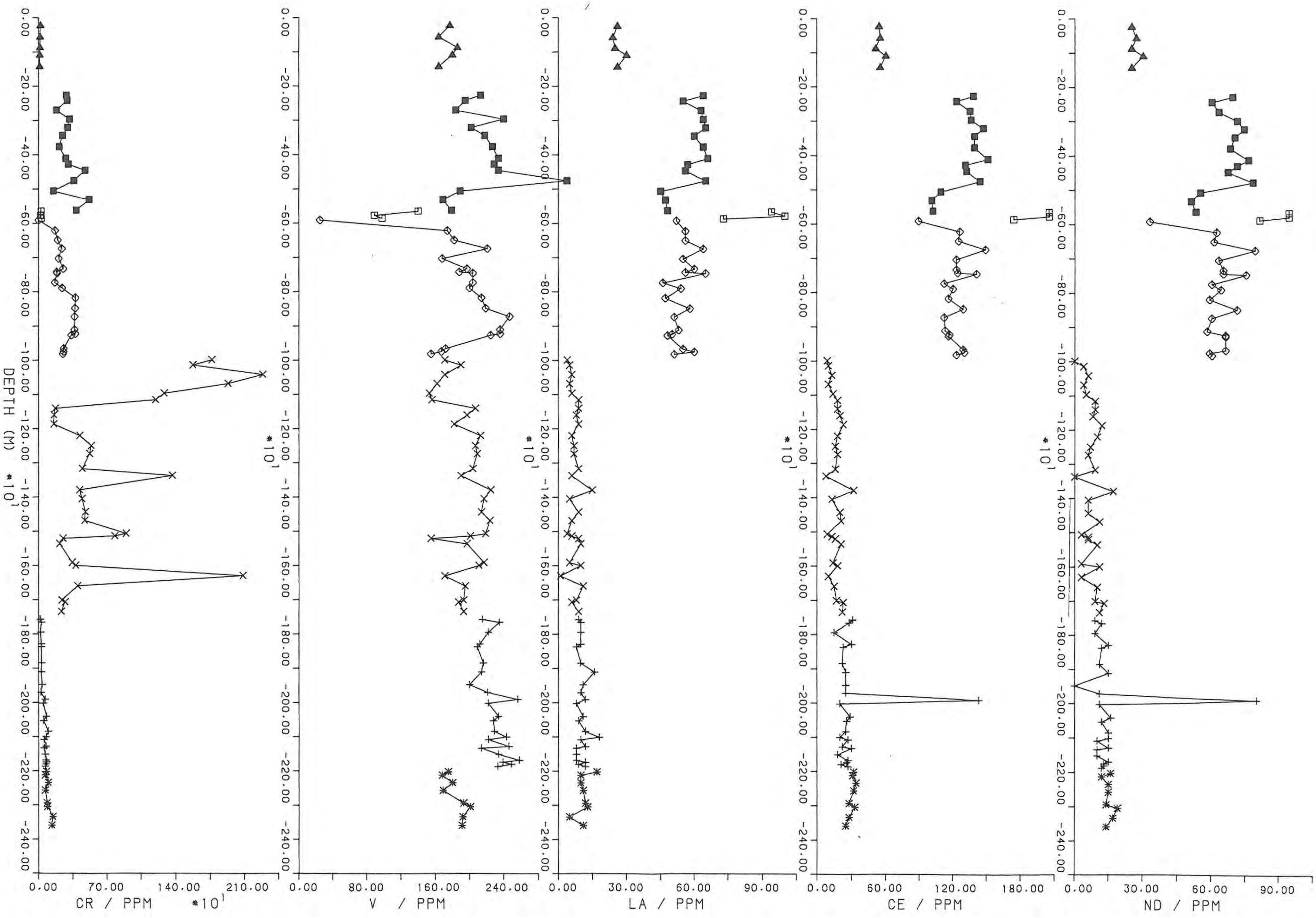


Figure 3.11b continued



Kameeldoorns conglomerate, with the underlying Loraine Formation occurring to 960m. Chemical analyses suggested, however, that the upper limit of the Orkney Formation was not at 960m, but higher. Unfortunately the sampling interval here is large, but the suggested boundary must be between 626m (depth of altered zone) and 550m (base of flow containing sample AR-350) from surface. Above this, all samples are classified as Allanridge lavas.

In borehole PK-10 the geochemical boundary between the Loraine and the overlying Allanridge Formation has been moved from 573m down to somewhere below 769m, the depth of sample AR-300. Finally, in borehole WS-5, the Loraine-Orkney boundary was shifted from 1873m up to somewhere between 1734m and 1738m (the boundaries of the flows from which samples KL-131 and KO-130 were taken). The Orkney-Alberton boundary was also moved slightly, from 2207m up to somewhere between 2202m and 2186m (between samples KO-108 and KA-107) It must be stressed that these boundary changes were made purely on a geochemical basis. It appears superficially as if the original visual logging was incorrect, but, it may well transpire that visual and chemical criteria for boundaries do not coincide. This cannot be resolved until the borehole core is re-examined visually in the light of geochemical results.

SiO_2

SiO_2 content in the Klipriviersberg Group (KRBG) decreases upwards, the Alberton Formation (AF) averaging 55.40% SiO_2, the Orkney (OF), 54.14% and the Loraine-Edenville (LEF), 53.59%, the lowest of all the Witwatersrand triad lavas. There is very little scatter, shown by low CV's of 2.9, 3.2 and 3.5 respectively.

The Goedgenoeg and Rietgat Formations (GRF) are more silicic, averaging 56.54% SiO_2, while the intervening Makwassie Formation (MF) has an average of 64.56% SiO_2. Sample PG-177, a vitric tuff, has anomalous chemistry and was not included in the calculation of averages. There is more scatter in the Platberg Group (PG) than in the KRBG, shown by larger CV's, but no systematic trends are evident.

The Allanridge Formation (ARF) has a mean SiO_2 content of 56.37%, similar to that of the GRF, and exhibits no systematic trend.

MgO, Cr, Ni and Co

MgO in the AF decreases consistently towards the top, averaging 5.12%. A similar trend is evident in the OF, for which the average is a slightly lower 5.09%. A sudden increase occurs, however, at the base of the LEF, and is continued towards the top, where MgO values up to 17.46% (KL-468) occur. In addition, three sharp spikes delineating narrow MgO-rich zones are present.

Cr and Ni values follow almost exactly the same trends as MgO. Concentrations of Cr in the AF and OF are fairly low, averaging 125 and 50 ppm respectively, while in the overlying LEF, the mean increases to 745 ppm, with some values as high as 2618 ppm. The AF Ni average of 158 ppm and the OF average of 142 ppm are again lower than that of the LEF, which is 236 ppm, with some values as high as 516 ppm.

Overlying the high-MgO KRBG lavas, the PG has relatively low MgO, averaging 5.14% in the GRF and 2.43% in the MF. There appears to be a decrease in MgO upwards in Goedgenoeg samples, and possibly the same in the Rietgat unit, but the trend in the latter is rather obscure. Cr and Ni concentrations, however, do decrease upwards in both the Goedgenoeg and Rietgat units. No systematic variations of Cr and Ni with height are observed in the MF, the averages of which are both 6 ppm. Concentrations of MgO, Cr and Ni, which average 4.18%, 59 ppm and 145 ppm respectively, increase upwards in the ARF.

The variation in Co is broadly similar to that of MgO, although Co content does not decrease upwards in the AF, nor does it increase upwards in the ARF. In addition, the OF has a higher Co average (68 ppm) than the LEF (66 ppm), although Co concentrations do increase in the same horizons as do MgO, Ni and Cr, but not to such a large degree.

TiO_2 and P_2O_5

Sympathetic variations are shown by TiO_2 and P_2O_5. Although concentrations increase slightly upwards in the AF, within the KRBG as a whole there is a general decrease upwards, the mean TiO_2 values for the AF, OF and LEF being 1.06%, 0.981% and 0.574% respectively, the latter the lowest average TiO_2 of all the Witwatersrand triad lavas. P_2O_5 averages 0.156%, 0.125% and 0.075% respectively, the latter again being the lowest overall mean.

Compared with the KRBG, TiO_2 and P_2O_5 contents in the PG are much higher, and are in fact the highest of all the Witwatersrand triad lavas. Within the GRF, TiO_2 ($\bar{X}$ = 1.524%) and P_2O_5 ($\bar{X}$ = 0.715%) decrease upwards, while within the MF these elements display no systematic trend with height and average 1.222% and 0.521% respectively. The ARF averages 1.197% TiO_2 and 0.231% P_2O_5, with TiO_2 decreasing upwards and P_2O_5 showing no systematic variation.

Nb, Zr and Y

These immobile trace elements exhibit vertical variations similar to those of TiO_2 and P_2O_5. Concentrations of these elements in the AF increase slightly upwards, but an overall decrease upwards in the KRBG as a whole is shown by the means for the AF, OF and LEF, which are, for Nb, 5.5, 4.8 and 2.0 ppm respectively; for Zr, 117, 100 and 59 ppm respectively, and for Y, 22.2, 22.5 and 16.6 ppm respectively. The means for the LEF are the lowest of all the Witwatersrand triad lavas for these three elements.

The various members of the PG have the highest Nb, Zr and Y contents of all the Witwatersrand triad lavas. The means for Nb, Zr and Y for the MF are 30, 535 and 72 ppm respectively, while those for the GRF are 18.5, 336 and 54 ppm respectively. In both the Goedgenoeg formation (GF) and the Rietgat Formation (RF) an upward increase in these elements is evident, while in the MF there is no systematic trend.

The averages of Nb, Zr and Y for the ARF are respectively 8.9, 180 and 27.2ppm, and no systematic variation in the concentration of these elements with height is discernible.

La, Ce and Nd

These light rare earth elements (LREE) form a further group which varies sympathetically with TiO_2 and P_2O_5. In the KRBG, a general decrease upward is evident, with the averages of La, Ce, Nd in the AF, OF and LEF being respectively 12, 11 and 6 ppm for La, 30, 25 and 13 ppm for Ce, and 14, 12 and 6 ppm for Nd. The sharp spike showing anomalously high Ce and Nd represents sample KO-121, which has highly aberrant chemistry and was therefore not included in the various statistical calculations.

The base of the PG is demarcated by a sudden increase in the LREE concentrations. The averages for the GRF are 23, 51 and 25 ppm for La, Ce and Nd respectively, all of which show slight increases upwards. The MF has the highest average LREE concentrations, namely 93, 194 and 93 ppm for La, Ce and Nd respectively, but these elements show no systematic trend with depth.

The concentrations of LREE in the ARF lie between those of the KRBG and the PG, with La, Ce and Nd averaging 23, 51 and 25 ppm respectively. No particular systematic trends with depth are evident.

Fe_2O_3, V and Zn

Within the AF Fe_2O_3 decreases slightly upwards, averaging 11.44%. At the base of the overlying OF Fe_2O_3 increases sharply, thereafter decreasing towards the top, with an average of 12.76%. Values decrease still further towards the top of the LEF, which averages 11.11% Fe_2O_3.

The GRF has a more variable Fe_2O_3 content, but it appears to decrease upwards in each unit, the average being 10.66%. The MF has a still lower average Fe_2O_3 content - 7.62% - with no particular variation with height being evident.

In the overlying ARF the mean Fe_2O_3 content is 11.59%, with no systematic increase or decrease evident.

V behaves sympathetically with Fe_2O_3, averaging 184 ppm in the AF, 225 ppm in the OF, and 201 ppm in the LEF. Within each individual formation Fe_2O_3 contents decrease upwards. Within the GF and RF Fe_2O_3 contents also decrease upwards, averaging 202 ppm, about the same as that of the underlying KRBG. The MF, however, has much lower V contents, the average being 108 ppm, while that of the ARF is 198 ppm.

Zn averages 85 ppm in the AF, 93 ppm in the OF, and 84 ppm in the LEF. Zn decreases upwards in the OF, and then increases towards the top of the LEF. Within the GF Zn concentrations decrease upwards, the mean being 121 ppm. In the MF Zn averages 112 ppm, and in the ARF 106 ppm, with an upwards decrease in Zn concentration being evident in the ARF.

K_2O, Rb and Ba

K_2O concentrations are highly variable, but there appears to be an upward-increasing trend in the OF and the LEF, followed by a decrease in the uppermost samples of the latter. Averages for the AF, OF and LEF are, respectively, 1.13%, 1.35% and 1.20%. No vertical trends are evident in the GRF, or in the MF, the averages for which are 1.47% and 2.73% respectively. K_2O averages 1.48% in the ARF and increases upwards in the sequence.

The variation shown by Rb is almost identical to that of K_2O. Averages for the AF, OF and LEF are 40, 51 and 43 ppm respectively, and the same increase upwards in Rb concentration in the OF and LEF is evident. However the uppermost samples in the LEF reflect a sharp decline in Rb. The GRF averages 35 ppm, and the MF, 89 ppm, the highest of all the Witwatersrand triad lavas. Rb increases upwards in the ARF and averages 37 ppm Rb.

Ba concentrations are also highly variable, but similar trends to those shown by Rb and K_2O are apparent. The average Ba values for the AF, OF and LEF are 438, 431 and 349 ppm respectively, the latter being the lowest of all the Witwatersrand triad lavas. The average Ba content for the GRF is 768 ppm, while that of the MF is 1152 ppm, the highest of all the formations. The ARF has an average of 417 ppm Ba, and the expected increasing-upwards trend has begun to be obscured by the variation.

CaO and Sr

CaO increases slightly from the base to the top of the KRBG, with the average for the AF being 7.19%, that of the OF marginally lower at 7.06%, and that of the LEF 8.41%. The large spike amongst the Orkney samples is produced by sample KO-121, which has anomalously high CaO (19.61%) accompanied by a dilution of most of the other major element constituents. Interestingly, TiO_2 and P_2O_5 concentrations, as well as those of the immobile trace elements, Nb, Zr and Y, have been unaffected. Also of note, is the fact that the Sr concentration - 266 ppm - is not sympathetically high.

The average Sr content in the AF is 394 ppm, 347 ppm in the OF, and 205 ppm in the LEF. There is thus an overall decrease in Sr concentration towards the top of the KRBG. In the GRF no systematic trend is evident, and CaO averages 6.22%. The average Sr value is 579 ppm, but concentrations are highly variable. There are no systematic CaO or Sr trends in the MF, and averages are 3.34% and 622 ppm respectively, the latter being the highest Sr average of the Witwatersrand triad lavas. This is unusual for a formation which has the lowest CaO average after the Dominion Group porphyries.

Neither CaO nor Sr show any systematic trend in the ARF, and averages are 6.87% and 439 ppm respectively.

Al_2O_3 and Cu

Al_2O_3 in the KRBG averages 14.95%, 14,78% and 13.39% in the AF, OF and LEF respectively, producing an upward-decreasing profile. The GRF average is marginally higher at 14.58%, and there appears to be a slight increase upwards in Al_2O_3 content. No systematic trend is evident in the MF, the average of which is 14.46%. The ARF has the highest Al_2O_3 average of all, 14.68%.

Cu behaves sympathetically with Al_2O_3 in the KRBG, averaging 92, 95 and 68 ppm in the AF, OF and LEF respectively, indicating a general decrease in Cu content towards the top of the group. In the overlying PG, however, the Cu-Al_2O_3 relationship appears to be antipathetic in the GF, and Cu averages are lower in the GRF and MF, being 31 and 14 ppm respectively. Cu values are higher again in the ARF, averaging 89 ppm.

Na_2O

Na_2O variation is very erratic in the KRBG, especially in the OF, but values appear to decrease upwards overall. The averages for the AF, OF and LEF are 2.40%, 2.56% and 2.48% respectively, the latter being the lowest of all the Witwatersrand triad lavas. Three prominent negative peaks in the LEF samples correspond with the high-MgO peaks described earlier. Concentrations of Na_2O in the GRF show a slight increase with height, the average being 3.01%, while that for the MF is similar, at 3.03%. The average Na_2O content of the ARF is a little higher, 3.25%, and the profile shows no systematic trend.

MnO

All the samples were crushed in Mn-steel containers, and although Mn contamination of samples can be expected this has been shown (J.S. Marsh, pers.comm.) to be slight. Nevertheless Mn variations described here should be treated with circumspection. There appears to be a general increase in MnO towards the top of the KRBG, with averages being 0.13%, 0.15% and 0.17% for the AF, OF and LEF respectively. MnO concentrations in the PG show no systematic trends, but averages for the GRF and MF are 0.14% and 0.09% respectively, while that of the ARF, in which there seems to be a decrease with height, is 0.15%.

To conclude, despite the effects of low grade metamorphism to which these rocks have been subjected, the variation patterns with depth for most elements are still reasonably clear. Those showing the greatest amount of scatter, namely Na, K, Mn, Ba and Rb, should be avoided in making any petrogenetic deductions, while the immobile elements Ti, P, Nb, Zr and Y, and also the light rare earth elements La, Ce and Nd, appear to have been little affected by any post-extrusive processes.

4. DISCRIMINATION TECHNIQUES

4.1. Analysis of Multivariate Data

Most mineralogical and petrological observations are multivariate. Composition data, whether obtained by chemical, modal or other analysis, are multivariate. Multivariate data also occur because the science of geology often involves the dimensions of space and time (Koch and Link, 1971).

Univariate observations can be plotted on a straight line (Fig. 4.1a). If the straight line is divided into class intervals, the number of observations in each interval can be counted, and a histogram can be formed, the plotting of which requires two dimensions.

Bivariate observations can be plotted on a scatter diagram in two dimensions (Fig. 4.1b). If the diagram is divided into cells, the number of observations in each cell can be counted and plotted on a histogram. This histogram takes three dimensions to plot and may be represented by a contour map.

Trivariate observations can be plotted on a scatter diagram in three dimensions (Fig. 4.1c). The most usual configuration of points defines an ellipsoid. If the three-dimensional space is divided into cubes or other solid figures, the number of observations in a histogram would require four dimensions to plot. Trivariate observations of constant sum can also be plotted on triangular coordinates.

Observations with four or more variables cannot be represented on ordinary plots. Discriminant analysis is designed to cater for this type of situation.

4.2. Theory of Discriminant Analysis

Discriminant analysis is a set of methods which yields a function for classifying multivariate observations into two or more groups through developing one or more linear combinations of the variables that

Figure 4.1 Plots of observations in various dimensions (from Koch and Link, 1971)

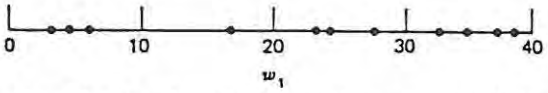


Fig 4.1a Plot of univariate observations on a straight line.

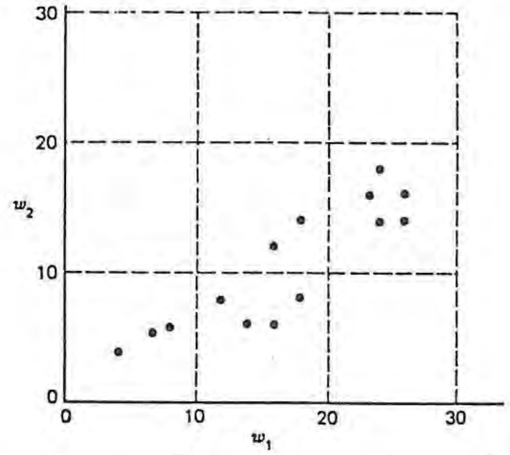


Fig 4.1b Plot of bivariate observations on a scatter diagram in two dimensions.

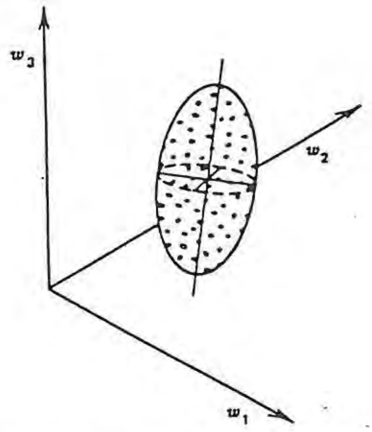


Fig 4.1c Plot of trivariate observations on a scatter diagram in three dimensions.

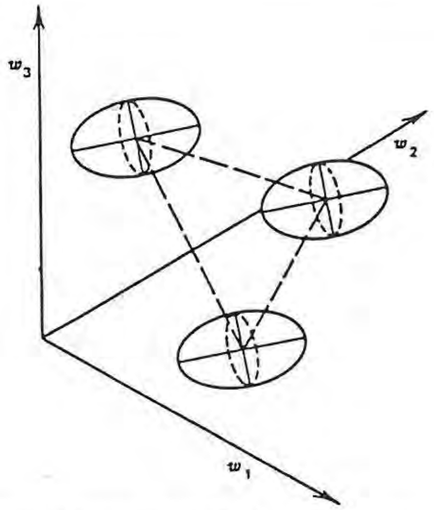


Fig 4.1d Three ellipsoids representing clouds of observations that are classified by discriminant analysis.

comprise the observations. In principle, ellipsoid centres are located and the directions and lengths of the distances connecting paired ellipsoid centres are examined. Figure 4.1d shows three ellipsoids and three dashed lines denoting paired distances.

Discriminant analysis is one of the statistical options forming part of the SPSS (Statistical Package for the Social Sciences) program (Release 3), developed at the University of Nottingham, England. Klecka (1975), who designed and programmed the discriminant analysis package used in this study, stated that "the statistical theory of discriminant analysis assumes that the discriminating variables (which in this study are major and trace element abundances, together with selected ratios of these) have a multivariate normal distribution and that they have equal variance-covariance matrices within each group. In practice, the technique is very robust and these assumptions need not be strongly adhered to.". In other words, the data used need not necessarily be strictly normally distributed, and the technique can therefore be applied perfectly satisfactorily to geological data. (The distribution of the data used in this study is discussed in chapter 5). In addition, Koch and Link (1971) explained that they omitted several multivariate methods from their book because they require data more nearly normal than those usually found in geology. The obvious implication is that discriminant analysis, which is included in the book, does not require strictly normal data.

The SPSS program was run on the Rhodes University ICL 1904S computer. The data used are shown in Figure 4.2. Line 3 lists the discriminating variables, which are read in according to the format in line 5. Lines 8 to 10 define the ratio calculations which need to be performed. The normalised, volatile-free data for each sample fill two lines - the first contains the sample name and number (S and SANO), followed by a number (See Figure 4.3) denoting the formation to which the sample belongs (FMTS), and the major element analyses (in weight percent), while the second line lists trace element concentrations (in parts per million). At the end of the sample data, discriminant analysis is requested (lines 661 to 663) giving the number of groups into which the data is divided, and the variables which must be used to calculate the discriminant functions. The "OPTIONS" and "STATISTICS" lists allow the user to choose which tables and statistics are to be printed out.

Figure 4.2 Data for SPSS program.

```
0001 RUN NAME          TEST
0002 FILE NAME         FILF
0003 VARIABLE LIST     S,SANO,FMTS,SIO2,TIO2,AL203,FE203,MNO,MGO,CAO,NA20,K20,P205,
0004                   GAP,BA,NB,ZR,Y,SR,RB,ZN,CU,NI,CO,CR,V,LA,CE,ND
0005 INPUT FORMAT      FIXED(A3,F3.0,F2.0,10F6.0/F7.0,F5.0,3F4.0,2F5.0,4F4.0,F5.0,4F4.0)
0006 INPUT MEDIUM      CARD
0007 NO. OF CASES      324
0008 COMPUTE           TI:ZR=(TIO2*5995)/ZR
0009 COMPUTE           P:TI=(P205*4363)/(TIO2*5995)
0010 COMPUTE           ZR:P=ZR/(P205*4363)
0011 TRANSFORM
0012 READ INPUT DATA
0013 DB-  110 57.76 1.084 14.58 11.35  0.29  3.51  7.35  3.33  0.50 0.255  0.00
0014          204. 8.5173.30.1 286. 11.9125. 28. 19. 55.   5.297. 27. 48. 28.
0015 DB-  210 58.44 1.041 13.85 11.48  0.15  3.54  6.82  3.03  1.37 0.265  0.00
0016          395. 7.5162.26.9 460. 51.0100. 16. 23. 54.   6.261. 25. 59. 24.
0017 DB-  310 58.78 1.004 13.66 11.72  0.14  3.17  6.79  3.17  1.34 0.257  0.00
0018          484. 7.1171.27.7 465. 44.5103. 42. 25. 53.  12.245. 27. 50. 28.
0019 DP-  4 9 68.32 0.849 12.74  7.35  0.11  2.59  2.05  3.65  2.16 0.271  0.00
0020          846.12.9256.28.9 214. 56.9 91. 10. 12. 26.  12.106. 44. 77. 37.
0021 DP-  5 9 70.84 0.809 12.50  5.66  0.08  1.73  1.45  3.42  3.22 0.278  0.00
0022          853.13.4277.27.3 111. 61.5 87.  9.  9. 16.   2.. 53. 46. 94. 40.
  .
  :
  .
0653 AR-496 1 53.74 1.201 15.35 12.23  0.13  4.07  9.17  2.46  1.38 0.264  0.00
0654          175. 7.8182.28.7 196. 48.2 97.129.157. 63.  51.258. 27. 57. 29.
0655 AR-497 1 51.76 1.210 15.75 13.67  0.16  5.78  7.76  3.34  0.34 0.229  0.00
0656           97. 7.4181.24.2 242. 10.9106.137.213. 64. 213.272. 16. 48. 22.
0657 AR-498 1 56.77 1.146 15.16 11.41  0.14  5.61  5.64  3.52  0.37 0.233  0.00
0658          202. 8.1189.32.0 553.  5.7105. 95.166. 69.  56.208. 25. 50. 27.
0659 AR-500 1 56.74 1.018 14.29 11.16  0.18  4.96  5.86  3.29  2.29 0.220  0.00
0660          705. 8.1159.28.0 539. 31.8 93. 88. 97. 56.  83.188. 23. 52. 27.
0661 DISCRIMINANT      GROUPS=FMTS(1,10)
0662                   VARIABLES=SIO2 TO P205,BA TO ND,TI:ZR,P:TI,ZR:P/
0663                   ANALYSIS=SIO2 TO P205,BA TO ND,TI:ZR,P:TI,ZR:P/
0664                   METHOD=MAHAL/
0665                   PRIORS=EQUAL/
0666 OPTIONS           3,5,6,7,11,12,17,18,19
0667 STATISTICS        1,2
0668 FINISH
```

There are two aspects to discriminant analysis: (1) classifying groups of observations, and (2) classifying a single observation into one of a number of predefined groups.

Discriminant analysis begins with the desire to statistically distinguish between two or more groups of cases (geological units, in the current study). The mathematical objective of discriminant analysis is to weight and linearly combine the discriminating variables in some fashion so that the groups are forced to be as statistically distinct as possible. These "discriminant functions" are of the form

$$D_i = d_{i1}Z_1 + d_{i2}Z_2 + \ldots + d_{ip}Z_p \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where D_i is the score on discriminant function i,
the d's are weighting coefficients, and
the Z's are the standardised values of the p discriminating variables used in the analysis.

The maximum number of functions which can be derived is either one less than the number of groups, or equal to the number of discriminating variables, if there are more groups than variables. Ideally, the D's for the cases within a particular group will be fairly similar. The functions are formed in such a way as to maximise the separation of the groups. Once the discriminant functions have been derived, the two research objectives of this technique, analysis and classification, may be pursued.

During the analysis phase, if there are more than two groups, it may be possible to obtain satisfactory discrimination with fewer than the maximum number of functions. Since the discriminant functions (i's) can be thought of as the axes of a geometric space, they can be used to study the spatial relationships among the groups. The weighting coefficients (d's) serve to identify the variables which contribute most to differentiation along the respective dimension or function.

4.2.1 Analytical features of discriminant analysis

4.2.1.1 Discriminant functions

Two measures are provided for judging the importance of the discriminant functions. One of these is the relative percentage of the eigenvalue associated with the function. It is computed in the process of deriving the discriminant function and is a measure of the relative importance of the function. A portion of the program output in Table 4.1 shows that the first discriminant function, with an eigenvalue of 72.36 percent, is very much more important than the remaining functions. The relative percentages of the last three functions show that they are fairly insignificant compared with the others.

The second measure for judging the importance of a discriminant function is its associated canonical correlation. This is a measure of association between the discriminininant function and the set of variables which define the group memberships, i.e. it measures the function's ability to discriminate among the groups. In Table 4.1 it can be seen that the first six discriminant functions are each well correlated with the groups, while the next two are moderately correlated.

Table 4.1 Portion of discriminant analysis output from the SPSS program.

```
DISCRIMINANT EIGENVALUE  RELATIVE    CANONICAL     :  FUNCTIONS WILKS' CHI-SQUARE     DF      SIGNIFICANCE
  FUNCTION              PERCENTAGE CORRELATION     :   DERIVED  LAMBDA
                                                   :
                                                   :
                                                       0     0,0000  3559.226     208          0.000
      1        50,03636     72.36      0,990       :
                                                       1     0,0004  2365.700     175          0,000
      2         6,65657      9.63      0,932       :
                                                       2     0,0032  1747,906     144          0,000
      3         4.60026      6.65      0,906       :
                                                       3     0,0177  1225,033     115          0,000
      4         3.69825      5.35      0,887       :
                                                       4     0,0830   755.460      88          0,000
      5         2.31371      3.35      0.836       :
                                                       5     0,2750   391,847      63          0,000
      6         1,34362      1.94      0,757       :
                                                       6     0,6444   133,357      40          0,000
      7         0.32912      0.48      0,498       :
                                                       7     0,8565    47,005      19          0,000
      8         0.16751      0.24      0,379       :
```

It has already been stated that the maximum number of discriminant functions which can be derived is either one less than the number of groups, or equal to the number of discriminating variables, whichever is the smaller. This stems from basic geometric principles, i.e. two points define a line, three define a plane, etc. An exception to this geometric rule that x points define (x-1) dimensions is the "degenerate" situation of, for example, three points falling on the same line, four on the same plane, etc. That is, the last point is situated such that it does not add a new dimension. Thus, in discriminant analysis, two functions may be adequate for describing four groups, for example.

A second criterion for eliminating discriminant functions is to test for the statistical significance of discriminating information not already accounted for by the earlier functions. Thus Wilks' lambda is computed as each function is derived, starting with no functions. Lambda is an inverse measure of the discriminating power in the original variables which has not yet been removed by the discriminant functions, i.e. the larger lambda is, the less information remains. Lambda can be transformed into a chi-square statistic for an easy test of statistical significance.

Table 4.1 shows that Wilks' lambda was zero before any functions were removed, indicating that immense discriminating power exists in the variables being used. After some of this discriminating power has been removed by placing it into the first discriminant function, lambda increases very slightly to 0.0004, and the chi-square shows that a statistically significant amount of discriminating information still exists. It is only after the seventh function has been derived that a fairly large (0.8565) but still significant lambda is found. A significance of zero means that a lambda of this magnitude or smaller has no probability of occurring due to the chances of sampling, even if there was no further information to be accounted for by an eighth function in the population. Clearly, an eighth function is statistically significant in this case.

4.2.1.2 Discriminant function coefficients

The standardised discriminant function coefficients are shown in Table 4.2. These coefficients correspond to the values of the d_{ij}'s given in equation (1). They are used to compute the discriminant score for a case in which the original discriminating variables are in standard form, i.e. Z scores. The discriminant score (D) is computed by multiplying each discriminating variable by its corresponding coefficient and adding together these products. Each case has a separate score on each function.

Table 4.2 Standardised discriminant function coefficients.

STANDARDIZED DISCRIMINANT FUNCTION COFFFICIENTS

	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5	FUNC 6	FUNC 7	FUNC 8
SIO2	0.01420	0.47917	0.05585	-0.64850	-1.59610	-2.05176	4.55288	5.83264
TIO2	-0.05306	0.48813	-2.59056	1.28369	-0.27572	0.30511	1.89024	1.61214
AL2O3	-0.02857	0.18205	-0.29379	-0.34104	-0.45153	-0.45999	1.50384	1.80944
FE2O3	-0.07083	0.05096	-0.02194	-0.62449	-1.26712	-0.90223	2.26101	1.78941
MGO	0.04858	0.70829	0.31024	0.08662	-0.24321	-0.51184	2.52677	3.38678
CAO	-0.01952	0.35838	0.00336	-0.39002	-0.76979	-1.07839	1.54588	2.32507
NA2O	-0.00516	0.13776	0.06557	-0.16927	-0.30734	-0.36690	0.91262	0.35363
P2O5	0.82454	-0.97344	2.85151	-1.88591	1.86502	2.01634	-2.77942	-0.56699
BA	-0.02060	0.14329	-0.02743	-0.05875	-0.20776	-0.09444	0.36333	0.37877
NB	-0.64170	0.47492	0.81368	1.25941	0.00331	-1.86725	-0.33422	-0.77026
ZR	0.61879	-0.45065	0.06809	-0.55609	1.20833	0.08972	-0.06953	0.25478
Y	-0.32675	0.35944	0.61153	0.22145	-2.18198	0.52812	-0.59835	0.73190
SR	-0.01427	0.06170	0.07040	0.16577	0.06920	-0.09702	0.11568	-0.11587
RB	0.01861	-0.06160	0.13862	-0.13160	-0.14711	-0.29581	0.69696	-0.06266
ZN	-0.03683	-0.12985	-0.00979	-0.05551	-0.07889	-0.19551	-0.63014	0.21964
CU	0.04806	0.08934	-0.16758	0.18286	0.11342	0.15855	-0.08956	-0.13039
NI	-0.07725	-0.03462	-0.05627	0.30152	0.36824	-0.29235	0.40721	0.35942
CO	0.19367	0.25804	0.45292	0.64371	-0.05640	0.20750	-1.48416	-1.81855
CR	-0.08332	-0.07113	-0.53375	-0.72429	-0.30963	-0.25200	-0.06467	0.08923
V	-0.05557	0.58138	0.26195	-0.51014	0.65303	-1.10041	0.73050	-0.47199
LA	0.04262	-0.17579	-0.65132	-0.15067	0.42185	-0.22494	-0.39450	-0.11770
CE	-0.13492	0.25026	0.55236	0.71804	0.41094	1.64089	0.90160	0.28076
ND	0.02295	-0.01182	0.15589	-0.12987	-0.20543	-0.92546	-0.23079	0.05327
TI:ZR	-0.21314	-0.26445	0.45245	0.53248	-0.55447	0.56275	1.61407	-0.56624
P:TI	-1.44448	0.03414	-1.87460	0.42604	-1.20211	-0.36442	3.27993	-2.72300
ZR:P	-0.24841	-0.24336	0.02965	0.14924	0.26997	0.46076	0.51714	-1.44628

The coefficients have been derived in such a way that the discriminant scores produced are in standard form, i.e. over all cases in the analysis, the score from one function will have a mean of zero and a standard deviation of one. Thus, any single score represents the number of standard deviations that case is away from the mean for all cases on the given discriminant function.

Averaging the scores for all cases within a particular group will give the group mean on the respective function. For a single group, the means on all the functions are referred to as the group centroid, which is the most typical location of a case from that group in the discriminant function space. A comparison of the group means on each function reveals how far apart the groups are along that dimension (see Table 4.3).

Table 4.3 Centroids of groups in reduced space.

```
CENTROIDS OF GROUPS IN REDUCED SPACE
              FUNC  1    FUNC  2    FUNC  3    FUNC  4    FUNC  5    FUNC  6    FUNC  7    FUNC  8
GROUP   1    0.75759    0.08470   -1.09620    1.20585    0.39884   -0.07252   -0.99785   -0.04265
GROUP   2   -1.09770    0.88147   -0.14300   -0.23024    0.37493    0.87255    0.04938   -0.07578
GROUP   3   -2.18379   -0.07184    1.69889    1.98341   -0.05452   -1.55854    0.04538    0.19110
GROUP   5    0.95347   -0.30109    1.69197   -0.58750    0.12164    0.39064   -0.36792    0.16622
GROUP   6    1.00930   -0.04622    0.26384    0.87191   -0.74439    0.20837    0.63293   -0.82804
GROUP   7    0.97197   -0.16909   -0.68555    1.15109   -0.44052    0.72004    0.93037    1.06922
GROUP   8   -1.98780   -1.65217   -0.79465   -0.94412   -5.15565    0.71662   -1.03364    0.14768
GROUP   9   -0.59037   -2.36177   -0.60938   -0.50115    0.90956   -0.07180    0.22786   -0.11255
GROUP  10    0.30953    0.62584   -0.42967   -0.87941   -0.15180   -1.00781    0.13596    0.05428
```

The standardised discriminant function coefficients themselves are of great analytical importance. When the sign is ignored, each coefficient represents the relative contribution of its associated variable to that function. The sign merely denotes whether the variable is making a postive or negative contribution. In Table 4.2 it can be seen that for the first function, which is by far the most important, the greatest contribution is made by the ratio P:Ti, followed by P_2O_5, Nb and Zr. Y is almost half as important as Zr, and this is followed by two more ratios, Zr:P and Ti:Zr, etc.

On the second function the most important variables, in order, are P_2O_5, MgO, P:Ti, V, Zr, TiO_2 and SiO_2. If all the functions are considered together, with values on each function being weighted in accordance with their eigenvalues, the order of importance of the discriminating variables is as follows: P_2O_5, P:Ti, SiO_2, TiO_2, V, Ce, Y, Ti:Zr, Nb, Fe_2O_3, CaO, Al_2O_3, MgO, Co, Zr, Zr:P, Na_2O, Cr, La, Ni, Nd, Rb, Zn, Cu, Ba, Sr.

4.2.2 Classification in discriminant analysis

The use of discriminant analysis as a classification technique comes after the initial computation. By classification is meant the process of identifying the likely group membership of a case when the only information known is the case's values on the discriminating variables. Another use of classification is in testing the adequacy of the derived discriminant functions. By classifying the cases used to derive the functions in the first place, and comparing predicted group membership with actual group membership, one can empirically measure the success in discrimination by observing the proportion of correct classifications.

Classification is achieved through the use of a series of classification functions, one for each group. They are derived from the pooled within-groups covariance matrix and the centroids for the discriminating variables. The resulting classification coefficents are multiplied by the raw variable values, summed together and added to a constant as follows:

$$C_i = c_{i1}V_1 + c_{i2}V_2 + \dots + c_{ip}V_p + C_{i0} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

where C_i is the classification score for group i,
the c_{ij}'s are the classification coefficients,
c_{i0} is the constant, and
the V's are the raw scores on the discriminating variables.

There is always a separate equation for each group. The case would be classified into the group with the highest score, i.e. for which it has the greatest probability of membership. If required, adjustments are made on the basis of prior probabilities being proportional to the number of cases in each group, i.e. cases will more likely be assigned to a larger group. For the current study the SPSS program was run using both equal and proportional probabilities. The result was the same in both cases.

Table 4.4 shows an excerpt from the SPSS program output in which the discriminant scores for each case are printed together with the predicted group membership. The largest probability P(G/X) is also printed and if the value for the second highest probability is greater than .0005, it too is printed. Another useful probability P(X/G) which appears on the output is the probability that a member of the predicted group would be as far from the centroid as the case being considered.

Table 4.4 Portion of output showing probabilities of group membership and discriminant scores.

```
      ACTUAL       HIGHEST PROBABILITY   2ND HIGHEST      DISCRIMINANT SCORES
SEQNUM GROUP       GROUP P(X/G) P(G/X)  GROUP P(G/X)      FUNC 1      FUNC 2      FUNC 3      FUNC 4      FUNC 5

                                                          FUNC 6      FUNC 7      FUNC 8

    1.    10          10  1.000  1.000                     0.355       0.636      -0.320      -1.222      -0.111

                                                           -2.315      -0.819       0.220
    2.    10          10  1.000  1.000                     0.347       0.335      -0.012      -1.035      -0.149

                                                           -1.308       0.365      -0.466
    3.    10          10  1.000  1.000                     0.491       0.043      -0.255      -1.168      -0.283

                                                           -1.551      -0.446      -0.550
    4.     9           9  0.995  1.000                    -0.410      -1.391      -0.511      -0.820       0.760

                                                           -0.836       0.414       0.586
    5.     9           9  1.000  1.000                    -0.598      -2.151      -0.762      -0.620       1
```

4.3 Application of Discriminant Analysis to the Witwatersrand Triad Samples

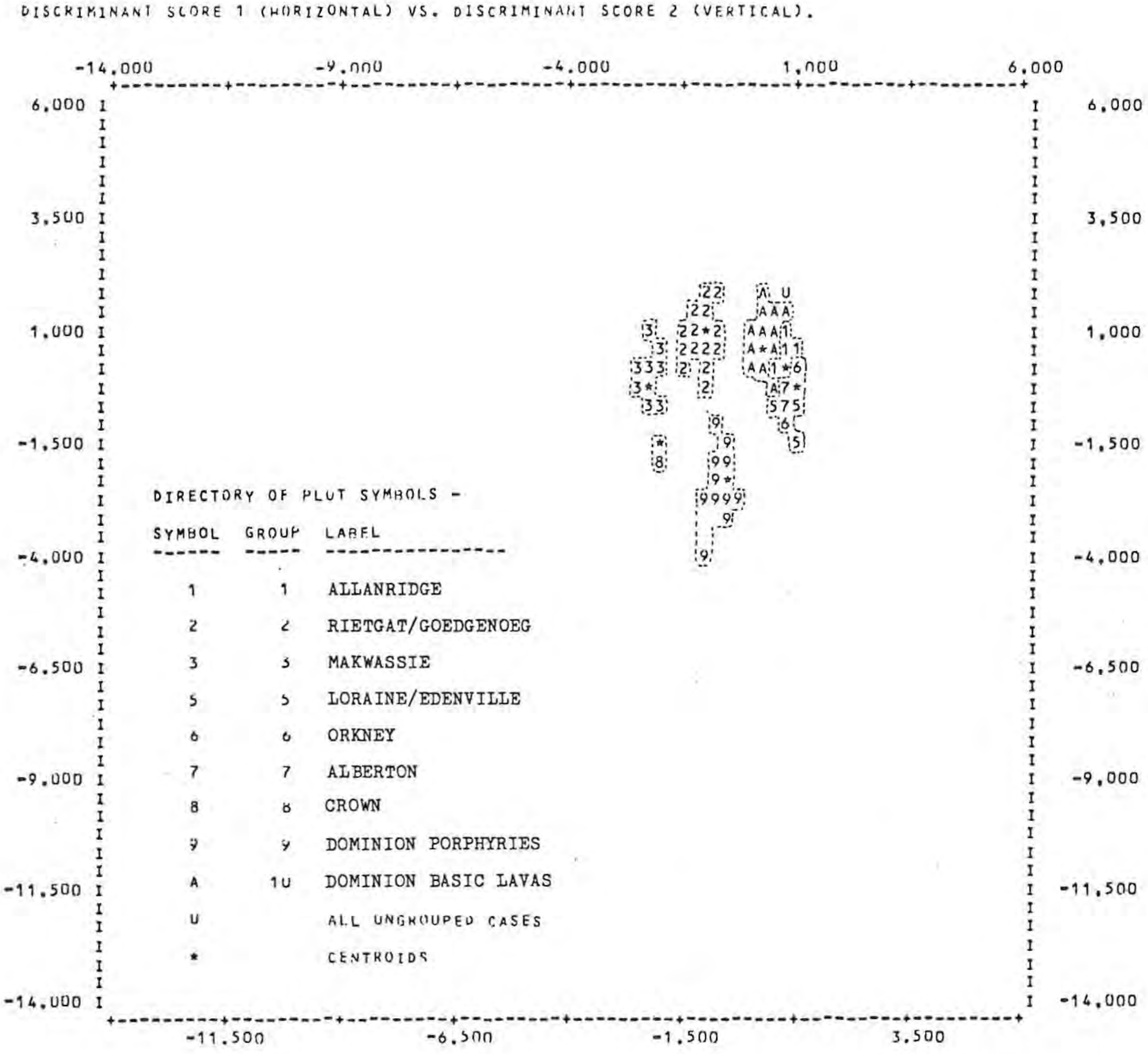
4.3.1 Evaluation of discriminant plots and grouping of samples

The SPSS program produces plots of the cases along the first two discriminant function continuums. Because the functions are arranged in order of decreasing importance, the graph will represent the two most important functions.

It is essential in applying discriminant analysis to a set of data, that a preliminary classification of some or all of the data into groups must exist. The discriminant functions are derived such that the first function separates the groups as much as possible. The second function separates them as much as possible in an orthogonal direction given the first separation. The third function provides maximal separation in another orthogonal direction, etc. The end result is that the groups are as distinct as possible given the original discriminating variables. In this way the discriminant functions can be considered as defining geometric axes in space in which each case and group centroid are points. In Figure 4.3 the first two discriminant functions are plotted. It can be seen that groups 3, 8 and 9, the Makwassie Formation, the Crown Formation and the Dominion Group porphyries respectively, are separated completely from one another and from the rest of the points by these two functions. Groups 2 and 4 (the Rietgat and Goedgenoeg Formations) together form a separate cluster, but in the two dimensions shown there is considerable overlap between the groups themselves. The original listings of group centroid positions confirmed that the centroids for groups 2 and 4 were very closely spaced along function 1 (-1.02745 and -1.05813 respectively) and were almost coincident along function 2 (0.88064 and 0.87991 respectively). On function 3, however, a more satisfactory separation was achieved (-0.28846 and 0.07967), and also on most of the other functions. Due to the limitations of the graph these were not evident graphically. It must be remembered, though, that because the functions are arranged in order of decreasing importance, a given difference between group centroids on the third or fourth function is not as meaningful as the same difference on the first function.

The separation of the two centroids in other dimensions was thus still not sufficient to eliminate all overlap between the two groups. This was shown in the original output, where four members (12.5%) of group 2 (the Rietgat Formation) were classified as members of group 4 (the Goedgenoeg Formation) and eight members (25%) of group 4 were classified as group 2 types. This relatively large amount of overlap suggests that the differences between these two groups may not be as significant as those between the other groups, and the possibility of classifying them as a single group was implicitly suggested by these results.

Figure 4.3 Plot of discriminant score 1 (horizontal) vs discriminant score 2 (vertical)



Petrogenetic studies undertaken by M.P. Bowen (in prep.) on the same samples have also led to the conclusion that the Rietgat and Goedgenoeg Formations cannot be separated geochemically. He has therefore treated them as a single group in all subsequent work. Further investigation in the current study has supported this contention and Table 4.5 shows the classification of cases after these two groups had been merged. Group 2, which now contains both the Rietgat and the Goedgenoeg Formations, shows a 100% correct classification of cases.

The remaining five groups form a cluster on the right-hand side of Figure 4.3. Group 1, the Allanridge Formation, overlaps with a number of other groups, but Table 4.5 shows that total separation is achieved when taking the other dimensions into account. Group 10 (the Dominion Group basic lavas), represented by an 'A' in the diagram, falls on the left-hand side of the cluster, overlapping groups 1 and 5 slightly. Table 4.5 shows, however, that separation of group A from the others is virtually perfect, and only two samples (2,8%) belonging to Group 10 were classified as members of other groups. DB-28 had a probability of .985 of being a member of the Allanridge Formation, with a probability of only .011 of belonging to the Dominion Group basic lavas. DB-42 was classified as a Loraine-Edenville member with a probability of .999, and a very weak probability of .001 of belonging to the Orkney Formation.

Table 4.5 Predicted group memberships of previously grouped cases.

```
PREDICTION RESULTS -

                 NO. OF PREDICTED GROUP MEMBERSHIP
  ACTUAL GROUP  CASES GP.    1  GP.    2  GP.    3  GP.    5  GP.    6  GP.    7  GP.    8  GP.    9  GP.   10
--------------- ------ --------  --------  --------  --------  --------  --------  --------  --------  --------

GROUP    1        35.      35.        0.        0.        0.        0.        0.        0.        0.        0.
                        100.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%

GROUP    2        67.       0.       67.        0.        0.        0.        0.        0.        0.        0.
                          0.0%    100.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%

GROUP    3        17.       0.        0.       17.        0.        0.        0.        0.        0.        0.
                          0.0%      0.0%    100.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%

GROUP    5        46.       0.        0.        0.       45.        1.        0.        0.        0.        0.
                          0.0%      0.0%      0.0%     97.8%      2.2%      0.0%      0.0%      0.0%      0.0%

GROUP    6        31.       0.        0.        0.        0.       30.        1.        0.        0.        0.
                          0.0%      0.0%      0.0%      0.0%     96.8%      3.2%      0.0%      0.0%      0.0%

GROUP    7        19.       0.        0.        0.        0.        0.       19.        0.        0.        0.
                          0.0%      0.0%      0.0%      0.0%      0.0%    100.0%      0.0%      0.0%      0.0%

GROUP    8         6.       0.        0.        0.        0.        0.        0.        6.        0.        0.
                          0.0%      0.0%      0.0%      0.0%      0.0%      0.0%    100.0%      0.0%      0.0%

GROUP    9        32.       0.        0.        0.        0.        0.        0.        0.       32.        0.
                          0.0%      0.0%      0.0%      0.0%      0.0%      0.0%      0.0%    100.0%      0.0%

GROUP   10        69.       0.        0.        0.        0.        1.        0.        0.        0.       68.
                          0.0%      0.0%      0.0%      0.0%      1.4%      0.0%      0.0%      0.0%     98.6%

UNGROUPED CASES    2.       0.        0.        0.        0.        0.        1.        0.        0.        1.
                          0.0%      0.0%      0.0%      0.0%      0.0%.    50.0%      0.0%      0.0%     50.0%

          PERCENT OF "GROUPED" CASES CORRECTLY CLASSIFIED:  99.07%
```

4.3.2 Aberrant and unclassified samples in the Dominion Group

An examination of the stratigraphic position (see Figure 2.2a) of DB-42 showed that it comes from borehole DSF-7 at a depth of 133m from the surface. Between this position and the surface a very clearly intrusive horizon was logged. The intrusion extends from 76.9m to 103.9m below the surface. It has a fairly coarse-grained texture with finer-grained chilled margins. Some alteration in colour of the overlying rock is evident near the upper contact. The intrusion was sampled in four places, at 103, 88, 82 and 78m below the surface, one sample at each margin and two in the centre. During the classification phase of the program these four samples, IN-43, IN-44, IN-45 and IN-46, were all unambiguously allocated to the Loraine-Edenville Formations. Probabilities of membership were 1.0 for all four samples, and they were therefore prefixed "KL".

DB-42, the single sample under consideration, was classified in exactly the same way. At the time of sampling, it was not recognised as an intrusive horizon due possibly to the absence of chilled margins in a thin unit, but an examination of its major and trace element analyses in relation to the nearby intrusive and the other basic lavas suggested strongly that this might be so. The major element values on their own are not conclusive, but the trace elements, especially Zr, Ni, Cr and the rare earths, provide strong evidence for the possible relationship between the five samples. As a result, DB-42 was reclassified and prefixed "KL" to indicate this relationship, but in the absence of unequivocal field relationships, final judgement must be reserved.

The second errant sample DB-28 occurs in the same borehole as the aforementioned intrusion, but at a depth of 487m. It shows no obvious differences in major and trace element contents from the surrounding Dominion Group basic lavas, but discriminant analysis has shown that it is more likely to belong to the Allanridge Formation lavas.

The cryptic differences between the two aforementioned sets of lavas come to light when the ratios Ti:Zr and Ti:P are plotted against one another. Figures 4.6 and 4.7 shows that DB-28 lies near the Allanridge samples and not with the rest of the Dominion Group basic lavas. It was therefore considered that this sample is either an intrusive one of Allanridge origin, or that some Allanridge-like lavas occur in the Dominion Group. As with sample DB-42, further work is necessary to resolve this.

A second borehole, DRS-6, six kilometers to the south of DSF-7, also contains a number of intrusive horizons, from which samples IN-86, IN-87 and IN-90 were taken. Classification of these intrusives of unknown affinity indicated that all three had a probability of 1.0 of belonging to the Loraine-Edenville Formations, and their prefixes were therefore also changed accordingly.

Sample DR-91, taken near the top of the same hole, proved to be a somewhat enigmatic sample. The horizon was not regarded as an intrusive, but a flow, as evidenced by the presence of prominent amygdaloidal zones at both the top and the bottom of the unit. The geochemistry differs markedly from all the other Dominion Group basic lavas, but it was considered unjustified to omit the analysis from the rest of the data without a valid reason simply because it did not "fit" well. The explanation was provided almost simultaneously and independently from two different sources. During field studies carried out in the vicinity of borehole DRS-6, M.P. Bowen (pers. comm., 1982) discovered that lavas of the Platberg Group lapped onto Dominion Group lavas in this area, with the usual intervening rocks missing. At about the same time, sample DR-91 was classified by discriminant analysis as either a member of the Rietgat Formation of the Platberg Group with a probability of .962, or as part of the Goedgenoeg Formation, also of the Platberg Group, with a much lower probability of .038. With this conclusive evidence, the sample was renamed PR-91.

With these eliminations the Dominion Group basic lavas would therefore now be completely separable from all the other groups, as shown in Table 4.5, except that a new sample, DB-97, has been misclassified as a result of changing parameters. Investigation showed, however, that there was no justifiable reason for excluding it from the Dominion Group basic lavas.

4.3.3 Aberrant samples in the Klipriviersberg Group

Users of discriminant analysis should be wary of developing a blind acceptance of all reclassifications without carefully investigating the reasons for this. The lavas of the Klipriviersberg Group provide a salutary lesson in this respect. Groups 5, 6 and 7 represent the following formations within the Klipriviersberg Group respectively: the Loraine-Edenville, Orkney and Alberton Formations. Table 4.5 shows that group 7, the Alberton Formation is separated completely from the others. However, sample KO-356 from the Orkney Formation in borehole W-20 was reclassified by the SPSS program as an Alberton sample with .987 probability against a probability of .013 that it was an Orkney sample. Examination of the stratigraphic column for that borehole (Figure 2.2b) shows that the sample lies well within the Orkney Formation.

Two possibilities may be considered to explain this. Firstly, it is conceivable that an interfingering of two different lava types might exist, i.e. extrusion of the underlying Alberton lavas may not have been entirely completed before the Orkney-type emissions began from a different source. Sample KO-356 may thus represent one of the final pulses of extrusion from a virtually exhausted Alberton source. Alternatively, the close similarity between the chemistry of the Alberton and Orkney lavas may be the reason for this classification. The sample has the highest SiO_2 value of all the Orkney samples analysed and in this respect it resembles the Alberton lavas. All Orkney samples, however, have Zr values between 90 and 110 ppm, with all Alberton samples (except one at 60 ppm) between 106 and 137 ppm Zr. Sample KO-356, with 96 ppm Zr, clearly has Orkney affinities, and this is corroborated by Zr vs TiO_2 (Figure 4.8) and Zr vs Fe_2O_3 plots, in which this sample lies well within the Orkney field. It was therefore decided that KO-356 should remain as an Orkney member and not be reclassified.

In group 5, the Loraine-Edenville Formations, two samples were misclassified. KL-133 had a probability of .940 of belonging to the Orkney Formation and only .059 of being part of its expected formation. This sample was taken in the lower altered zone of borehole WS-5, about 37m above the contact between the Orkney and Loraine Formations. The top of the Orkney Formation is defined as the top of the flow of the upper purple band (Winter, 1976 and 1965b, after Pienaar, 1956). This marker horizon is absent in WS-5 and the division was made on a geochemical basis. In some boreholes e.g. JBF-1 and WS-4 this horizon does coincide with the geochemical boundary within the limits of sampling intervals, but not in others, e.g. W-20. The problem of membership is resolved unequivocally by TiO_2 values, which lie between .400 and .878 weight percent for Loraine-Edenville lavas, and between .879 and 1.097 for Orkney lavas. KL-133, with a TiO_2 content of .780, must therefore belong to the Loraine-Edenville Formations. Zr vs TiO_2 (Figure 4.8) and Zr vs Fe_2O_3 plots confirm this, as does the Cr content of 238 ppm, as no Orkney lava contains more than 97 ppm Cr. This misclassification must be again be ascribed to either the similar chemical characteristics shown by the different formations within the Klipriviersberg Group, or to interfingering of two lava types.

The second erroneous sample, KL-471 was classified unambiguously as a Dominion Group basic lava (probability = 1.0). This sample was taken from the uppermost flow of the Klipriviersberg Group lavas, which is overlain by Kameeldoorns sediments. A possible explanation for its presence at a much higher stratigraphic level than expected is offered. An examination of the stratigraphic log of JBF-1, the borehole from which KL-471 was collected, showed that the thickness of Kameeldoorns sediments in this hole (85m) was fairly substantial compared with that in some of the adjacent boreholes, such as SH-1 (20m). This suggests the proximity of a fault, as Winter (1970) stated that "the greatest depths at which the Kameeldoorns Formation is found are adjacent to major faults and this formation subsided as clastic wedges against these. The coarsest sediments adjoin the faults.". In support of this is the fact that virtually the whole intersection of the Kameeldoorns sediments in this hole comprises conglomerate. Winter (1965b, Fig. 5) showed that there is indeed a fault in this area, the Jersey Fault, which strikes NE-SW and lies immediately to the north-west of JBF-1 (see Figure 2.1), and against which the Kameelsdoorns sediments are abruptly truncated. The north-western side of the fault is upthrown. Evidence of this can be seen in borehole JY-8, which contains rocks of the Central Rand Group and the Jeppestown Subgroup of the West Rand Group. The stratigraphic log stops in the Rietkuil Formation, so it is not known at what depth the Dominion Group first occurs.

Movement along the Jersey Fault has therefore caused older lithologies to be brought closer to the surface in the north west. It is possible that Dominion Group basic lavas were exposed at the fault scarp and that fragments may have broken away and become incorporated with the lavas and sediments filling the graben-like depository adjacent to the fault. In this manner the position of KL-471, a lava showing Dominion Group chemical characteristics, found in the uppermost flow of the last Klipriviersberg lavas extruded before the onset of sedimentation, may be explained. Major and trace element values and interelement plots are, however, inconclusive. There appears to be a bias towards the Dominion lavas, but some of the evidence is contradictory. As a result, it was decided to leave this sample out of the analytic phase of the discriminant analysis program, until further work is able to resolve its affinity.

4.3.4 Other aberrant samples

Four unknown samples still remain to be classified. IN-419 and IN-421 both occur in borehole JHA-1, in which a very unusual succession is present (see Figure 2.2b). From the surface down to 876m the lithologies are quite normal: rocks of the Karoo Supergroup occur down to 165m and are underlain by the Allanridge and Bothaville Formations. From 876m to 2658m, where pre-Ventersdorp rocks are reached, the sequence consists of Kameeldoorns-type sediments interbedded with flows of porphyritic and non-porphyritic lavas. A 4m intersection of lava with Makwassie-type phenocrysts occurs between 1041 and 1045m. The thickness proportion of lavas to sediments is about 3:1. The sediments include conglomerates, shales, dolomites and cherts. No particular sequence is evident - for example, one conglomerate horizon overlies a shale-dolomite-chert succession, suggesting a number of episodes of movement along the Jersey Fault (see Figure 2.1). Some of the volcanic rocks have been logged by company geologists as "possibly intrusive". It was from two such horizons that IN-419 and IN-421 were taken. Four other lava samples analysed from the intercalated succession (viz. PG-406, PG-417, PR-426 and PG-433) were classified with the Goedgenoeg-Rietgat group of lavas. IN-421 was also allocated to the Rietgat Formation, and its prefix was thus changed to accommodate this classification. IN-419 was named as an Alberton lava with a probability of 1.0, but the probability that any other member of the Alberton Formation would be as far from the centroid as IN-419, was 0. This implies that IN-419 lies outside the bounds of the Alberton Formation, but closer to this formation than to any other. Both the Transvaal and the Karoo Supergroups outcrop in the area, and the possibility must be entertained that this intrusive horizon might represent one of these. This sample was therefore excluded from the analysis part of the program on the grounds of its tenuous association with the lavas under consideration in this project.

KO-121 was the only sample analysed which contained a large number of amygdales. The predominant filling is calcite, which also occurs together with epidote in the groundmass. The major element analysis for this sample shows a very high CaO value (19.61 percent), as expected, and a relatively high Al_2O_3 value (16.75 percent), resulting in a dilution of the other major elements. Trace element values remain comparable with those of other samples taken nearby, with the exception of Ce (143 ppm) and Nd (80 ppm), which are enriched roughly six and seven times respectively compared with the average values for the Orkney Formation (Ce - 25 ppm, Nd - 12 ppm). The La value (12 ppm) is, however, normal (formation average - 11 ppm).

Wendlandt and Harrison (1979) showed that in the presence of a CO_2-rich vapour, light REE are fractionated preferentially into the vapour relative to silicate melts, with maximum REE solubility in CO_2 vapour occurring at near-surface pressures. This could explain the enrichment of Ce and Nd in this sample, but not the low La value, which should also have shown enrichment, unless the original La concentration was about 2 ppm, in which case equivalent enrichment would have increased the value to the present 12 ppm. Discriminant analysis grouped this sample with either the Dominion Group basic lavas (P(G/X) = .933) or with the Allanridge lavas (P(G/X) = .062). As this sample occurs in the middle of the Orkney Formation, this misclassification is clearly due to the unusual chemistry displayed by this sample and on this basis it was excluded from the data file.

PG-177 was taken 4.3m from the top of the uppermost flow of the Goedgenoeg Formation in borehole WS-5. The 7.8m flow is overlain by quartz-feldspar porphyries of the Makwassie Formation. During logging the unit was described as "atypical of usual top of flow" and "possibly intrusive". Microscope examination, however, showed that the rock is clearly a vitric tuff. Analysis of major elements (Table 2.4) showed an anomalously high SiO_2 content of 78.24 percent, very low TiO_2, Al_2O_3, CaO and Na_2O, extremely low P_2O_5, and normal Fe_2O_3, MgO and MnO. Most of the trace element values differ widely from those in the other Goedgenoeg rocks. On various interelement plots this sample lies extremely far away from all other plotted samples. Discriminant analysis did not group it into any of the nine formations under consideration, so this sample was also omitted from the data file.

4.3.5 Conclusions

The final outcome of the discriminant analysis exercise was thus a correct classification of 99.07% of all samples used (see Table 4.5). It is an essential prerequisite of discriminant analysis that, in order to apply the technique to a set of data, a preliminary classification of some or all of the data into groups must exist. Naturally, the greater the number of pre-classified cases, the better defined the groups will be. The outcome of any subsequent work may result in the need for reclassification of samples already on the file. In this way the file may be periodically updated and the discriminant functions will thereby become progressively refined. Users are cautioned, however, against reclassifying samples blindly on the basis of discriminant analysis recommendations, without fully investigating the reasons for this.

4.4 Orthogonal Discrimination

Discriminant analysis, as described in section 4.2, is a highly sophisticated method of discrimination, but it has a number of disadvantages. Firstly, the researcher must have access to a computer with adequate facilities, viz. a discriminant analysis package as part of the software. Secondly, assuming that the first condition is satisfied, graphical representation of the discrimination is awkward to plot, as only the scores on the two most important discriminant functions are plotted by the program. In the current exercise, there are nine chemically distinct sets of rocks giving eight discriminant functions. In order to plot each against the other, so that the situation might be examined in all its dimensions, it would require 36 graphs to be plotted. Thirdly, if the user wishes to find out which elements are the most important in discriminating between two particular formations, the program will have to be run using data from those two formations only. This is due to the fact that the discriminant functions are set up with the objective of separating as much as possible all formations under consideration simultaneously. To isolate the most favourable discriminating elements between each and every formation in this study, would therefore require 36 separate runs.

As an alternative, a second, perhaps less sophisticated but systematic approach has been adopted, which may prove to have greater and more rapid practical application than discriminant analysis.

All major element and trace element analyses were stored on a computer file, using the format shown in Figure 4.4. Each sample is represented by two lines of data, the first of which contains the sample name (6 columns), a number representing the formation, if known (2 columns) and the major element analysis. Line two contains trace element values.

Figure 4.4 Format for computer data file in which sample name, formation number, major and trace element analyses are stored

```
DB-  110 57.76 1.084 14.58 11.35  0.29  3.51  7.35  3.33  0.50 0.255  0.00
         204. 8.5173.30.1 286. 11.9125. 28. 19. 55.   5.297. 27. 48. 28.
DB-  210 58.44 1.041 13.85 11.48  0.15  3.54  6.82  3.03  1.37 0.265  0.00
         395. 7.5162.26.9 460. 51.0100. 16. 23. 54.   6.261. 25. 59. 24.
DB-  310 58.78 1.004 13.66 11.72  0.14  3.17  6.79  3.17  1.34 0.237  0.00
         484. 7.1171.27.7 465. 44.5103. 42. 25. 53.  12.245. 27. 50. 28.
DP-  4 9 68.32 0.849 12.74  7.35  0.11  2.50  2.05  3.65  2.16 0.271  0.00
         846.12.9256.28.9 214. 56.9 91. 10. 12. 26.  12.106. 44. 77. 37.
DP-  5 9 70.84 0.809 12.50  5.66  0.08  1.73  1.45  3.42  3.22 0.278  0.00
         853.13.4277.27.3 111. 81.5 87.  9.  9. 16.   2. 53. 46. 94. 40.
DP-  6 9 69.87 0.830 12.65  6.71  0.07  1.70  2.20  2.70  3.03 0.243  0.00
         889.15.0275.27.1  71.114.7 82.  7. 12. 21.   4. 87. 35. 76. 34.
DB-  710 52.21 0.883 13.29 12.87  0.18  7.71 10.92  1.67  0.08 0.191  0.00
          25. 4.2 91.22.7 386.  1.3107. 58.310. 68.1344.236. 10. 29. 17.
DB-  810 52.19 0.889 13.08 13.68  0.23 10.07  6.68  2.85  0.11 0.194  0.00
          48. 2.4 89.25.0 132.  2.2126. 60.446. 87.1510.257. 13. 27. 19.
DB-  910 53.77 0.843 13.09 11.48  0.17  9.52  7.36  3.43  0.15 0.180  0.00
          77. 5.3 93.22.7 165.  1.9 99. 43.322. 71.1290.221.  7. 15. 11.
DB- 1010 57.55 1.171 14.46 10.05  0.15  4.94  5.57  5.11  0.57 0.421  0.00
         244. 7.7174.30.2 147.  9.8 95. 53.125. 58.  34.230. 21. 45. 25.
```

A computer program, ELEMENT (see Figure 4.5), was developed which reads in the above data, sorts the samples into their respective formations, and calculates the largest and smallest value for each major and trace element within each formation. These ranges are output as shown in Tables 3.2a and 3.2b. The program then compares each formation with every other formation and prints a summary of the elements whose ranges do not overlap for each pair. Table 4.6 has been constructed to show which pairs of formations can be separated from one another on the basis of discrete ranges of certain elements. Major element separators are located in the upper half of the table above the main diagonal, while trace element separators are listed below the diagonal.

Use of the table is best demonstrated by working through an actual example. One may wish, for instance, to determine which elements may be used to distinguish between the Allanridge and Loraine Formations. Following row 1 (Allanridge) and column 4 (Loraine), a block is reached

Figure 4.5 Computer program ELEMENT (in FORTRAN)

```
        LIST
        PROGRAM(ELEM)
        INPUT 5 = CR0
        OUTPUT 6 = LP0
        COMPRESS INTEGER AND LOGICAL
        TRACE 2
        END

        MASTER ELEMENTS

C----------------------------------------------------------------------!
C PROGRAM TO GIVE RANGES OF MAJOR OR TRACE ELEMENTS FOR EACH FORMATION  !
C AND TO DISCRIMINATE BETWEEN FORMATIONS USING MAJOR OR TRACE ELEMENTS  !
C----------------------------------------------------------------------!

        INTEGER EL,DISCRIM
        DIMENSION ELEM(330,15), HEAD(15)
        DIMENSION FORM(10), SMALL(10,15), BIG(10,15)
        DIMENSION INDEX(10,100)
        DIMENSION DIFF(10,10,15), DISC(10,10,15)

C   READ PROGRAM PARAMETERS
C   ***********************
        READ (5,1010) EL,DISCRIM

C   INITIALISE ARRAY 'INDEX'
C   ************************
        DO 2 J = 1,10
        DO 2 K = 1,100
2       INDEX(J,K) = 0

C   READ ELEMENT HEADING & NAMES OF FORMATIONS
C   ******************************************
        IF (EL.EQ.10) READ (5,1002) (HEAD(J), J=1,EL)
        IF (EL.EQ.15) READ (5,1022) (HEAD(J), J=1,EL)
        READ (5,1003) (FORM(J), J=1,10)

C   READ ELEMENT DATA & SET UP INDEX OF FMNS
C   ***************************************
        READ (5,1000) ICOUNT
        DO 5 I = 1,ICOUNT
        IF(EL.EQ.10) READ (5,1001) SANO,  IFMN, (ELEM(I,J), J=1,EL)
        IF(EL.EQ.15) READ (5,1011) SANO, IFMN, (ELEM(I,J), J=1,EL)
        IF (IFMN.EQ.0) GO TO 5
        INDEX(IFMN,1) = INDEX(IFMN,1) + 1
        J = INDEX(IFMN,1)
        INDEX(IFMN,J+1) = I
5       CONTINUE

C   INITIALISE ARRAYS 'BIG' & 'SMALL'
C   *********************************
        DO 1 I=1,10
        DO 1 J=1,EL
        DO 1 K=1,EL
        SMALL(I,J) = 9999.999
1       BIG(I,J) = 0.0

C   FIND LARGEST & SMALLEST ELEMENT VALUES FOR EACH FORMATION
C   *********************************************************
        DO 100 J = 1,EL
        DO 100 L = 1,10
        DO 100 M = 2,INDEX(L,1)+1
        I = INDEX(L,M)
        IF (I.EQ.0) GO TO 100
        IF(ELEM(I,J).LT.SMALL(L,J)) SMALL(L,J) = ELEM(I,J)
        IF(ELEM(I,J).GT.BIG(L,J)) BIG(L,J) = ELEM(I,J)
100     CONTINUE

        IF (DISCRIM.EQ.0) CALL RANGES(EL,HEAD,FORM,BIG,SMALL)
        IF(DISCRIM.EQ.1)CALL DISCRIMINATE(EL,HEAD,FORM,BIG,SMALL,DIFF,
       *DISC)

1000    FORMAT (I3)
1001    FORMAT (A6,I2,F6.2,F6.3,/F6.2,F6.3,/)
1011    FORMAT (A6,I2,/,7X,F5.0,F4.1,F4.0,
       * F4.1,F5.0,F5.1,4F4.0,F5.0,4F4.0)
1002    FORMAT (10A5,/)
1022    FORMAT (/,15A2)
1003    FORMAT (10A4)
1010    FORMAT (I2,I1)

        STOP
        END
```

Figure 4.5 continued

```
      SUBROUTINE RANGES(EL,HEAD,FORM,BIG,SMALL)
C     ########################################

      INTEGER EL
      DIMENSION HEAD(EL), FORM(10)
      DIMENSION SMALL(10,EL), BIG(10,EL)

101   DO 110 J=1,EL
      IF(EL.EQ.10) WRITE(6,5003) HEAD(J)
      IF(EL.EQ.15) WRITE (6,5000) HEAD(J)
      DO 105 L=1,10
      IF(BIG(L,J).EQ.0.AND.SMALL(L,J).EQ.9999.999) GO TO 105
      IF(EL.EQ.10) WRITE (6,5001) FORM(L),SMALL(L,J),BIG(L,J)
      IF(EL.EQ.15) WRITE (6,5002) FORM(L),SMALL(L,J),BIG(L,J)
105   CONTINUE
      WRITE (6,5012)
110   CONTINUE

5000  FORMAT (1X,A2)
5001  FORMAT (1X,A4,F7.3,F7.3)
5002  FORMAT (1X,A4,F6.1,F7.1)
5003  FORMAT (1X,A5)
5012  FORMAT (1H0)

      RETURN
      END


      SUBROUTINE DISCRIMINATE(EL,HEAD,FORM,BIG,SMALL,DIFF,DISC)
C     ##########################################################

      DIMENSION DIFF(10,10,EL),DISC(10,10,EL)
      DIMENSION KEY(100), INFO(100)
      DIMENSION BIG(10,EL), SMALL(10,EL), FORM(10), HEAD(EL)
      REAL INFO,KEY
      INTEGER EL,BMIN1

C  INITIALISE ARRAYS 'DIFF' & 'DISC'
C  *********************************
400   DO 3 L=1,10
      DO 3 M=1,10
      DO 3 J=1,EL
      DIFF(L,M,J) = -1.0
3     DISC(L,M,J) = -1.0

C  CALCULATE DIFF. BETWEEN LIMITS & CALCULATE DISCRIMINATION VALUE
C  ***************************************************************
      DO 203 J=1,EL
      DO 201 L=1,10
      DO 200 M=1,10
      IF(L.EQ.M) GO TO 200
      IF(SMALL(M,J).LT.BIG(L,J)) GO TO 200
      IF(SMALL(M,J).EQ.9999.999.AND.BIG(M,J).EQ.0) GO TO 200
      DIFF(L,M,J) = SMALL(M,J) - BIG(L,J)
      IF(SMALL(M,J).EQ.0.0) GO TO 200
      DISC(L,M,J) = DIFF(L,M,J) / SMALL(M,J)
200   CONTINUE
201   CONTINUE
203   CONTINUE

C  INITIALISE ARRAYS 'INFO' & 'KEY'
C  ********************************
      DO 300 I = 1,100
      KEY(I) = -1.0
300   INFO(I) = X

C  SORT & PRINT DISCRIMINATION VALUES
C  **********************************
      DO 700 L=1,10
      DO 700 M=1,10
      IF(L.EQ.M) GO TO 700
      I=0
      DO 600 J=1,EL
      IF(DIFF(L,M,J).LT.0.0) GO TO 600
      I=I+1
      INFO(I)=HEAD(J)
      KEY(I) = DISC(L,M,J)
600   CONTINUE
      B=I
610   N = 0
      BMIN1 = B-1
      IF(BMIN1.LT.1) GO TO 625
```

Figure 4.5 continued

```
      DO 620 J=1,BMIN1
      IF(KEY(J).GE.KEY(J+1)) GO TO 620
      TEMP = KEY(J)
      KEY(J) = KEY(J+1)
      KEY(J+1) = TEMP
      TEMP = INFO(J)
      INFO(J) = INFO(J+1)
      INFO(J+1) = TEMP
      N=J
620   CONTINUE
625   IF(N.EQ.0) GO TO 630
      B=N
      GO TO 610
630   WRITE(6,4000) FORM(L), FORM(M)
      IF(I.EQ.0) GO TO 700
      DO 640 K=1,I
      IF(EL.EQ.10) WRITE (6,4002) K, INFO(K), KEY(K)
640   IF(EL.EQ.15) WRITE (6,4001) K, INFO(K), KEY(K)
700   CONTINUE

4000  FORMAT(1X,/,1X,A4,1H:,A4,/)
4001  FORMAT (1X,I2,1X,A2,1X,F4.3)
4002  FORMAT (1X,I2,1X,A5,1X,F4.3)
      RETURN
      END



      FINISH
```

which contains the major element separators for those two formations, P_2O_5 and TiO_2. A similar exercise using row 4 (Loraine) and column 1 (Allanridge) isolates the trace element separators, Zr, Ce and Nd. The figure next to each element name indicates on a scale between 0 and 1 the relative magnitude of the separation, and is calculated as follows: Looking at Zr values, for example, for the two formations under consideration, Table 3.2b shows that Zr values for the Loraine Formation lie between 28 and 113 ppm, while those for the Allanridge Formation range between 141 and 230 ppm. The two sets are therefore separated by an amount of 28 ppm. A separation of 28 ppm at about the 100 ppm level, as in this case, is obviously of much greater significance than a similar separation at about the 1000 ppm level. In order to reflect this discrepancy, the number is divided by the lower limit of the higher range, i.e. 28/141 = .199. This number will be referred to as the orthogonal discriminator or OD, and has limiting values of 0 and 1. The OD attains its lower limit when the two ranges under consideration are immediately adjacent to one another, as shown by Nd for the Loraine Formation (0 to 17 ppm) and the Allanridge Formation (17 to 31 ppm)(see Table 3.2b). The OD will then be equal to (17 - 17)/17, which is zero. The upper limit of 1 will only be reached if a particular element is entirely absent from one of the formations, in which case the OD will be equal to (x - o)/x, giving 1. In practice this limit is only approached, the highest OD in Table 4.6 being .859 for Cr between the

Jeppestown amygdaloid and the Alberton Formation. Their ranges are, respectively, 3 to 9 ppm and 64 to 415 ppm, resulting in an OD of (64 - 9)/64 = .859.

The computer program ELEMENTS was expanded to extend the approach described above to include major:major element ratios, trace:trace element ratios and major:trace element ratios. The results are listed in Tables 4.7a, 4.7b and 4.7c respectively, and are read in the same manner as Table 4.6. The ranges from which these three tables were derived are shown in Tables 4.8a, 4.8b and 4.8c respectively. For Table 4.7c and 4.8c the major element oxide values have been converted to their respective cation values.

The OD for a particular ratio is the same, no matter which way around the ratio is expressed. For example, the OD for the ratio P_2O_5:TiO_2 between the Allanridge and Rietgat Formations is (0.394-0.237)/0.394= .398, while that for the inverse ratio, TiO_2:P_2O_5, is (4.213-2.537)/4.213 = .398. Because of this, in Tables 4.7a, 4.7b and 4.7c, ratios have been expressed in only one way, but it is implied that the inverses for those ratios are also valid.

Five of the trace elements have values of zero in certain samples: Nb, in the Loraine Formation; Cr, in the Allanridge Formation, Dominion Group porphyries and basic lavas; La, Ce and Nd in the Loraine Formation; and Nd in the Orkney Formation. These cannot be used in the denominator of a ratio, as the resulting ratio would be infinity, so these particular ratios are omitted when calculating the ranges for the ratios. This only affects the upper limit of the range, which takes the value of the next highest ratio.

An examination of Tables 4.6, 4.7a, 4.7b and 4.7c reveals that, of the 36 possible pairs of formations, only 4 pairs are not able to be separated by orthogonal discrimination. All four pairs involve the Dominion Group basic rocks:

Dominion Group basic rocks - Allanridge
Dominion Group basic rocks - Loraine
Dominion Group basic rocks - Orkney
Dominion Group basic rocks - Alberton

Table 4.6 Separation of formations using major and trace elements (see Table 3.1a for abbreviations)

	ALLA	RIET	MAKW	LORA	ORKN	ALBE	JEPP	DR-P	DR-B
ALLA		P205.458	P205.353	P205.201 TI02.015	P205.091		P205.431 MGO .203		
RIET	ND .392 CE .378 LA .295 Y .189 NB .083 ZR .057			P205.748 TI02.267	P205.713 TI02.084	P205.648 TI02.020	MGO .315	P205.006	
MAKW	ND .492 ZR .491 Y .483 NB .483 CE .455 LA .311 CO .298			P205.700 TI02.175	P205.658	P205.580			
LORA	ZR .199 CE .135 ND .000	CE .673 ND .667 LA .659 NB .541 ZR .537 Y .409	ZR .750 NB .742 ND .721 CE .714 LA .667 NI .648 Y .623 CO .400		TI02.001	TI02.098 P205.044	P205.736 MGO .615 TI02.120		
ORKN	ZR .220 CE .162 ND .000	CE .684 ND .667 LA .591 ZR .549 NB .489 Y .356	ZR .757 CE .723 ND .721 NB .712 NI .658 LA .600 Y .589 CO .298 V .165				P205.700 MGO .549 CAO .348		
ALBE	ZR .028	ND .627 CE .612 LA .568 ZR .439 NB .391 Y .384	ZR .697 ND .689 CE .661 NB .657 NI .624 Y .607 LA .578 CU .525 CR .391 CO .353 V .065				P205.631 MGO .611 CAO .347		
JEPP	V .816 NI .333 Y .314 CE .247 ND .244 LA .225 CO .213 NB .141 ZN .058 ZR .013	V .821 CR .471 NI .280	V .697 CR .182 ZR .153 ND .066 NB .008	NI .833 V .824 LA .625 CE .605 ND .585 CR .571 NB .570 ZR .515 Y .500 CO .327 ZN .239	V .856 NI .838 CE .617 ND .585 LA .550 ZR .528 NB .521 Y .455 CR .438 CO .213 ZN .187	CR .859 V .839 NI .822 ND .537 CE .531 LA .525 CU .492 Y .479 NB .430 ZR .412 ZN .335 CO .275			
DR-P	CO .404 NI .333 V .279	V .298 CR .294 NI .280	Y .023	NI .833 CO .491 ZR .486 NB .460 CR .429 CE .373 V .307 LA .286 ND .227 Y .000	NI .838 ZR .500 V .436 CO .404 NB .398 CE .392 CR .250 ND .227 LA .143	NI .822 CR .813 CO .451 ZR .377 V .369 NB .283 CE .255 ND .136 LA .095			
DR-B		CE .102 LA .023	NB .301 ZR .223 CE .214 CO .175 ND .148 Y .124 LA .044 V .025				V .832 CO .075	V .342 CO .300	

TABLE 4.7a Separation of formations using major element ratios

	ALLANRIDGE	RIETGAT	MAKWASSIE	LORAINE	ORKNEY	ALBERTON	JEPPESTOWN	DR PORPHYRIES
RIETGAT	P205 :AL203 .443 P205 :TIO2 .398 P205 :SIO2 .383 P205 :MNO .155 P205 :FE203 .058							
MAKWASSIE	P205 :TIO2 .403 P205 :AL203 .396 P205 :MNO .267 P205 :SIO2 .191							
LORAINE	MGO :P205 .227 SIO2 :P205 .178 AL203:P205 .166 FE203:TIO2 .050 MNO :P205 .042 AL203:TIO2 .010	AL203:P205 .743 FE203:P205 .731 SIO2 :P205 .725 MNO :P205 .695 MGO :P205 .630 TIO2 :P205 .482 FE203:TIO2 .343 AL203:TIO2 .257 SIO2 :TIO2 .181 MNO :TIO2 .057	MNO :P205 .735 MGO :P205 .722 AL203:P205 .721 FE203:P205 .684 SIO2 :P205 .639 TIO2 :P205 .486 AL203:TIO2 .228 FE203:TIO2 .191 MNO :TIO2 .165 MGO :TIO2 .076 CAO :P205 .047					
ORKNEY	MGO :P205 .126 AL203:P205 .073 SIO2 :P205 .001	FE203:P205 .747 AL203:P205 .715 SIO2 :P205 .666 MNO :P205 .638 TIO2 :P205 .617 CAO :P205 .585 MGO :P205 .581 NA20 :P205 .555 FE203:TIO2 .225 AL203:TIO2 .109	FE203:P205 .703 AL203:P205 .690 MGO :P205 .686 MNO :P205 .686 TIO2 :P205 .621 CAO :P205 .607 SIO2 :P205 .561 NA20 :P205 .294 AL203:TIO2 .074 FE203:TIO2 .046					
ALBERTON		AL203:P205 .657 FE203:P205 .641 SIO2 :P205 .605 TIO2 :P205 .568 MGO :P205 .487 MNO :P205 .486 CAO :P205 .456 FE203:TIO2 .100 AL203:TIO2 .080	AL203:P205 .628 MGO :P205 .615 FE203:P205 .579 TIO2 :P205 .572 MNO :P205 .554 CAO :P205 .484 SIO2 :P205 .482 AL203:TIO2 .044	TIO2 :FE203 .138 TIO2 :SIO2 .085 P205 :SIO2 .022 TIO2 :AL203 .020				
JEPPESTOWN	P205 :MGO .760 P205 :TIO2 .507 P205 :CAO .488 P205 :AL203 .482 FE203:MGO .436 P205 :SIO2 .317 TIO2 :MGO .315 AL203:MGO .298 NA20 :MGO .247 MNO :MGO .200 P205 :MNO .184 SIO2 :MGO .109	FE203:MGO .644 MNO :MGO .615 AL203:MGO .441 P205 :MGO .406 NA20 :MGO .386 TIO2 :MGO .364 SIO2 :MGO .135 FE203:TIO2 .106	MNO :MGO .405 FE203:MGO .165 P205 :TIO2 .040 MNO :TIO2 .014	P205 :MGO .940 MNO :MGO .784 TIO2 :MGO .780 P205 :AL203 .761 FE203:MGO .725 P205 :MNO .705 P205 :SIO2 .695 AL203:MGO .685 P205 :FE203 .684 NA20 :MGO .674 P205 :CAO .645 P205 :TIO2 .577 SIO2 :MGO .574 TIO2 :AL203 .206 TIO2 :FE203 .110 CAO :MGO .082	P205 :MGO .932 P205 :CAO .854 MNO :MGO .769 P205 :AL203 .735 TIO2 :MGO .729 P205 :FE203 .703 FE203:MGO .702 P205 :TIO2 .687 P205 :MNO .650 P205 :SIO2 .629 AL203:MGO .597 P205 :NA20 .511 SIO2 :MGO .471 NA20 :MGO .381 TIO2 :CAO .361 FE203:CAO .271 SIO2 :CAO .261 MNO :CAO .244 AL203:CAO .194 TIO2 :AL203 .047	P205 :MGO .917 P205 :CAO .808 MNO :MGO .764 FE203:MGO .732 TIO2 :MGO .719 P205 :AL203 .681 AL203:MGO .656 P205 :TIO2 .647 NA20 :MGO .585 P205 :FE203 .578 P205 :SIO2 .562 SIO2 :MGO .561 P205 :MNO .503 MNO :CAO .409 FE203:CAO .342 TIO2 :CAO .313 SIO2 :CAO .282 AL203:CAO .222 NA20 :CAO .191 CAO :MGO .043 TIO2 :AL203 .016		
DR PORPHYRIES		AL203:P205 .332 AL203:TIO2 .135 TIO2 :P205 .095	AL203:P205 .276 TIO2 :P205 .102 AL203:TIO2 .101	P205 :MNO .328 P205 :AL203 .065 P205 :MGO .034 P205 :FE203 .033	P205 :CAO .234 P205 :MNO .203 P205 :FE203 .091		AL203:P205 .379 TIO2 :P205 .259 K20 :P205 .214 AL203:TIO2 .075 AL203:FE203 .003	
DR BASICS		TIO2 :P205 .040	TIO2 :P205 .048				MGO :MNO .329 MGO :AL203 .296 MGO :FE203 .256 MGO :NA20 .251 TIO2 :P205 .215 MGO :P205 .084	

Table 4.7b Separation of formations using trace element ratios

	Allanridge	Rietgat	Makwassie	Loraine	Orkney	Alberton	Crown	Dominion Gp porphyries
Rietgat	CO:ND .309 CO:CE .304 V :ND .255 CO:Y .246 CO:LA .241 V :CE .196 V :Y .158 ZN:ND .147 V :LA .016							
Makwassie	CO:ZR .737 CO:NB .724 V :ND .720 CO:CE .706 CO:Y .691 CO:LA .679 V :ZR .672 CO:ND .671 V :CE .666 NI:CE .652 V :NB .644 V :Y .638 NI:ND .631 NI:LA .600 NI:NB .569 V :LA .566 NI:Y .525 NI:ZR .455 CO:ZN .337 ND:CR .077	V :NB .095						
Loraine	V :ZR .288 CO:ZR .214 V :ND .169 ZN:ZR .067 V :CE .055 CO:CE .053 CE:Y .043 V :LA .041 V :NB .039 CO:ND .029	CE:CO .699 ND:CO .693 LA:CO .675 CE:V .670 ND:V .666 LA:V .637 NB:CO .600 CE:ZN .575 ZR:CO .552 LA:ZN .541 ND:NI .521 V :NB .519 Y :CO .509 CE:NI .501 NB:NI .501 ZR:V .500 ND:ZN .464 LA:NI .444 Y :V .424 NB:ZN .391 CE:CU .368 ND:CU .368 NB:CU .360 ZR:ZN .319 LA:CU .301 CE:Y .228 LA:Y .207 ZR:NI .190 ND:Y .143 Y :ZN .121 ZR:CU .031	NB:NI .966 ND:NI .954 CE:NI .946 ZR:NI .943 LA:NI .933 Y :NI .898 NB:CO .897 ZR:CO .885 V :NB .894 ND:V .874 ZR:V .874 CE:CO .873 CE:V .863 LA:CO .862 ND:CO .854 LA:V .840 CE:CU .799 Y :CO .799 ND:CR .789 LA:CU .787 ND:CU .787 NB:CR .782 NB:CU .775 CE:CR .755 Y :V .752 ZR:CR .701 ZN:NI .699 LA:CR .695 ZR:CU .692 NB:ZN .616 ZR:ZN .543 CE:ZN .520 Y :CR .513 LA:ZN .498 Y :CU .498 ZN:CO .430 ND:ZN .313 V :NI .296 CO:NI .184 CE:Y .155 ND:Y .108 ZR:Y .098 Y :ZN .085 NB:Y .036 ZN:V .018 LA:Y .014					
Orkney	V :ZR .250 V :ND .204 CO:ZR .105 Y :ZR .091 CO:ND .081 V :CE .042 CO:CE .009	CO:ND .710 CO:CE .685 V :ND .680 V :CE .666 CO:LA .653 V :LA .593 CO:NB .575 ZN:ND .497 ZN:CE .489 CO:ZR .489 CO:Y .481 V :ZR .473 V :Y .449 V :NB .436 NI:ND .427 NI:CE .373 NI:LA .365 ZN:LA .358 CU:LA .308 NI:NB .298 ZN:NB .259 CU:ND .250 Y :ND .229 CU:CE .219 NI:ZR .212 CO:ZN .210 CE:Y .174 ZN:ZR .154 CU:NB .134 ZN:Y .097 NI:CR .086 Y :LA .005 NI:Y .005	NB:NI .952 ND:NI .945 ZR:NI .944 CE:NI .933 LA:NI .924 Y :NI .898 NB:CO .890 ND:V .880 ZR:CO .869 ZR:V .868 CE:CO .867 V :NB .864 ND:CO .862 CE:V .861 LA:CO .853 LA:V .821 LA:CU .789 Y :CO .787 ND:CR .768 Y :V .763 CE:CU .751 ND:CU .747 ZN:NI .704 NB:CU .696 LA:CR .672 ZR:CU .638 NB:CR .635 ZR:CR .608 CE:CR .585 ZN:CO .563 NB:ZN .533 Y :CU .489 ZR:ZN .432 CE:ZN .423 Y :CR .392 V :NI .367 ND:ZN .355 LA:ZN .297 ZN:V .246 ZR:Y .235 NB:Y .212 ND:Y .198 CO:NI .137 CE:Y .097 Y :ZN .060					
Alberton		CU:ND .784 CU:LA .756 CU:CE .729 CO:ND .667 CU:NB .656 CO:CE .649 V :ND .582 CO:LA .582 CU:ZR .559 V :CE .539 CU:Y .539 CO:NB .469 CO:Y .446 NI:CE .444 V :LA .444 ZN:ND .424 CO:ZR .419 NI:ND .404 ZN:CE .366 NI:LA .356 V :Y .317 ZN:LA .274 V :ZR .254 NI:NB .192 V :NB .179 Y :ND .155 CO:ZN .143 NB:ZN .120 ZN:NB .120 ZN:ZR .049 ZN:Y .041 Y :LA .037 NI:ZR .036 NI:Y .007	NI:NB .944 NI:ND .943 NI:CE .940 NI:ZR .932 CU:ND .927 CU:LA .926 NI:LA .923 CU:CE .914 CR:ND .905 NI:Y .899 CR:CE .886 CU:NB .879 CR:ZR .879 CR:NB .866 CO:NB .863 CU:ZR .860 CO:CE .852 CO:ZR .851 CR:LA .846 V :ND .843 CO:ND .841 CU:Y .837 CR:Y .830 CO:LA .823 V :ZR .813 V :CE .808 V :NB .801 CO:Y .773 V :LA .755 NI:ZN .740 V :Y .706 CO:ZN .526 ZN:NB .445 NI:V .439 CU:ZN .422 CR:ZN .381 ZN:ZR .361 ZN:CE .284 ZN:ND .261 ZN:LA .204 NI:CO .187 Y :ND .121 V :ZN .113 Y :ZR .094 CR:V .061 CE:Y .038 Y :NB .032 CU:V .009 ZN:Y .001					
Crown	Y :V .936 CE:V .925 ND:V .920 LA:V .917 ZN:V .914 ZR:V .902 V :NB .902 CE:NI .759 LA:NI .750 Y :NI .735 CO:V .715 ND:NI .710 Y :CO .667 CE:CO .612 ND:CO .605 NB:NI .600 LA:CO .597 ZN:CO .571 ZR:CO .506 ZN:NI .505 ZR:NI .499 NB:CO .477 Y :CR .471 ND:CR .451 LA:CR .401 CE:CR .389 ZN:CR .353 SR:V .228 SR:NI .204 BA:V .200 ZR:CR .172 NB:CR .141 Y :ZR .067	V :ZN .899 V :Y .797 V :CO .783 V :NB .751 V :CE .713 V :ND .708 CR:CU .699 V :LA .673 CR:ZN .666 V :ZR .645 NI:ZN .630 V :CU .460 NI:CO .400 CR:CO .360 V :SR .297 ND:ZN .226 CE:ZN .182 CR:SR .177 CO:ZN .165 NI:CU .100 LA:ZN .080 NI:Y .053 ND:Y .045 CR:Y .031 ZR:ZN .026	V :ZN .747 V :CO .744 V :Y .692 CR:CU .608 V :NB .574 V :CU .569 V :ZR .539 V :NI .511 V :CE .498 V :LA .463 ZR:ZN .346 V :ND .342 ZR:CO .337 NB:CO .326 CR:ZN .325 NB:ZN .316 CR:CO .272 ZR:Y .215 CE:CO .155 NI:CO .147 NB:Y .100 CE:ZN .076 NI:ZN .067 ND:CO .022 LA:CO .013 ND:ZN .008 ND:Y .006	V :LA .969 V :CE .969 NI:NB .968 V :NB .968 V :ND .964 NI:ND .964 NI:CE .963 V :ZR .962 NI:LA .958 V :Y .956 NI:ZR .947 NI:Y .943 NI:ZN .925 V :ZN .922 CR:NB .891 CR:LA .875 CR:ND .875 CR:CE .873 CO:CE .833 CO:LA .827 CO:ND .825 CR:ZR .822 CO:NB .805 CR:Y .796 CO:ZR .784 CO:Y .783 CR:ZN .775 V :SR .731 NI:CO .722 NI:SR .687 CU:NB .647 V :CO .639 CO:ZN .632 CR:CU .613 CU:ND .588 CU:CE .569 CU:LA .559 CR:BA .465 ZN:LA .414 ZN:CE .386 CU:ZR .364 ZN:NB .336 CU:Y .324 ZN:ZR .207 CR:SR .188 CE:Y .175 ZN:ND .164 CU:ZN .144 Y :LA .130 V :CU .094 V :BA .081 ZN:Y .032 NI:BA .028	CE:V .969 LA:V .966 ND:V .966 V :NB .962 ZR:V .961 Y :V .958 ND:NI .957 NB:NI .955 CE:NI .953 LA:NI .952 ZR:NI .949 Y :NI .943 ZN:V .940 ZN:NI .926 LA:CR .865 ND:CR .862 ND:CO .834 CE:CO .825 NB:CR .818 LA:CO .816 NB:CO .793 CE:CR .785 Y :CO .771 ZR:CR .766 ZR:CO .754 Y :CR .745 CO:V .733 ZN:CO .718 CO:NI .706 ZN:CR .694 SR:V .641 LA:CU .564 SR:NI .553 NB:CU .523 ND:CU .511 CE:CU .467 Y :CU .313 CE:ZN .262 ZR:CU .253 BA:V .242 ND:ZN .215 NB:ZN .192 ZN:CU .190 LA:ZN .180 CU:V .146 CE:Y .118 LA:SR .091 ND:Y .044 ZR:ZN .016 CE:ZR .013 CE:SR .006 Y :ZN .006	NI:CE .959 V :CE .957 V :ND .955 NI:ND .955 V :LA .953 NI:LA .952 NI:NB .948 V :Y .948 V :NB .945 V :ZR .944 CR:ND .943 NI:Y .943 CR:CE .941 CR:LA .937 NI:ZR .937 NI:ZN .935 CR:NB .933 V :ZN .930 CR:Y .929 CR:ZR .927 CR:ZN .909 CU:ND .859 CU:LA .846 CU:CE .815 CU:NB .811 CO:ND .810 CO:CE .804 CU:Y .781 CO:LA .778 CO:Y .756 CO:NB .741 V :CO .731 NI:CO .723 CO:ZR .721 CU:ZR .711 CR:BA .702 CO:ZN .694 CU:ZN .688 CR:CO .631 CR:SR .608 V :SR .499 NI:SR .364 CR:CU .220 NI:CU .120 V :BA .118 ZN:ND .101 ZN:CE .085 CR:RB .082 ZN:LA .073 CE:Y .060 ZR:CE .053 ZN:NB .039 V :CU .012		
Dominion Gp porphyries	CE:NI .608 LA:CO .603 ZR:CO .583 BA:NI .578 CE:CO .542 ND:V .517 ND:CO .499 LA:NI .492 NB:NI .480 ND:NI .475 ZR:V .456 CE:V .430 Y :NI .415 Y :CO .399 NB:CO .379 Y :V .374 ZR:NI .372 V :NB .318 RB:NI .257 LA:V .165 ZN:CO .145 LA:CR .091 BA:V .041 CE:CR .029	RB:NI .154 RB:CR .083 RB:V .070		NI:NB .959 NI:CE .940 NI:ND .934 NI:ZR .934 NI:LA .915 NI:Y .874 CR:NB .841 CO:LA .830 CO:ZR .818 CR:LA .810 CO:CE .802 CR:CE .798 NI:RB .798 V :ZR .792 V :ND .784 CO:ND .778 V :NB .777 CO:NB .768 CR:ND .766 V :CE .766 CR:ZR .748 NI:BA .746 NI:ZN .713 V :LA .692 CO:Y .609 V :Y .572 CR:Y .535 CR:BA .440 ZN:LA .346 NI:CO .302 CO:ZN .267 ZN:ZR .243 CR:RB .235 ZN:CE .210 Y :NB .163 CR:ZN .100 Y :ZR .099 ZN:NB .088 V :RB .046 CO:RB .034	NI:NB .942 NI:ZR .936 NI:CE .924 NI:ND .922 NI:LA .903 NI:Y .875 CO:LA .819 CR:LA .795 CO:CE .793 V :ND .793 CO:ZR .793 CO:ND .790 V :ZR .781 V :CE .763 CO:NB .753 CR:ND .742 V :NB .739 CR:NB .733 NI:ZN .717 NI:BA .697 NI:RB .679 CR:ZR .669 CR:CE .658 V :LA .655 V :Y .590 CO:Y .586 CO:ZN .438 CR:Y .420 Y :NB .316 NI:CO .262 Y :ZR .236 SR:LA .228 SR:CE .178 V :BA .091 ZN:LA .085 ZN:ZR .060 ZN:CE .051 V :RB .040 CO:RB .011	NI:CE .933 NI:NB .933 NI:ZR .921 NI:ND .918 CR:CE .906 CR:LA .904 NI:LA .902 CR:NB .902 CR:ZR .898 CR:ND .895 NI:Y .875 CR:Y .838 NI:RB .813 CO:LA .781 CO:CE .769 CO:ZR .764 CO:ND .759 NI:ZN .752 V :ND .729 NI:BA .714 CO:NB .692 V :ZR .690 CR:BA .688 CR:RB .683 V :CE .673 CR:ZN .638 V :NB .620 CO:Y .559 V :LA .528 V :Y .492 CU:LA .407 CO:ZN .390 CU:ND .358 NI:CO .305 CU:NB .268 CU:CE .262 CO:RB .250 Y :NB .160 V :RB .116 CR:CO .114 Y :ZR .095	V :ZN .325 NB:Y .219 V :Y .218 ZR:Y .216 V :CO .184	
Dominion Gp basics		V :CE .253 V :ND .213 V :LA .198 V :Y .151 V :NB .046	V :NB .769 V :ZR .730 V :ND .704 V :CE .690 CO:NB .669 V :LA .646 V :Y .635 CO:ZR .576 CO:CE .517 CO:LA .494 CO:Y .458 CO:ND .422 NI:NB .191 Y :NB .081 ZN:NB .008				V :NB .937 V :Y .936 V :LA .933 V :CE .930 V :ZR .919 V :ND .916 V :ZN .898 V :CO .702 CO:Y .415 CO:NB .373 CO:LA .366 CO:CE .363 V :SR .359 NI:ZN .351 V :CU .316 CO:ND .307 NI:Y .300 CO:ZN .276 NI:NB .249 CO:ZR .203 NI:CE .095 ZR:NB .022	V :NB .558 V :ZR .552 V :ND .490 V :CE .471 V :RB .383 CO:LA .375 V :Y .368 CO:ZR .327 V :LA .319 CO:NB .255 CO:CE .249 Y :NB .203 CO:ND .120 NI:NB .025

Table 4.7c Separation of formations using major:trace element ratios

	ALLANRIDGE FORMATION	RIETGAT FORMATION	MAKWASSIE FORMATION	LORAINE FORMATION
RIETGAT FORMATION	P:CO .552 P:V .440 AL:ND .393 SI:CE .378 AL:CE .364 SI:ND .358 AL:LA .242 SI:LA .236 TI:ND .221 AL:Y .183 SI:NB .139 TI:CE .134 SI:Y .115 AL:NB .088 TI:LA .085 SI:ZR .058 TI:Y .049 AL:ZR .047 P:ZN .012			
MAKWASSIE FORMATION	P:CO .700 P:V .614 TI:ZR .605 P:NI .588 TI:NB .559 AL:ZR .553 AL:NB .545 AL:ND .493 TI:ND .484 AL:Y .477 AL:CE .458 TI:Y .450 SI:ND .436 SI:NB .435 MN:NB .433 MN:ZR .414 SI:ZR .402 TI:CE .387 SI:CE .379 SI:Y .357 MN:CE .306 AL:LA .300 TI:LA .299 AL:CO .297 CA:LA .295 SI:CO .275 MN:LA .273 MN:ND .262 MN:Y .260 TI:CO .248 CA:CE .240 FE:NB .161 FE:CO .160 MG:NB .158 SI:LA .147 AL:V .084 TI:V .069 FE:ZR .065 MG:ZR .062 CA:ND .060	TI:NB .096 P:NB .027 AL:V .020		
LORAINE FORMATION	MG:CE .309 MG:ZR .259 MG:ND .200 CA:LA .191 CA:CE .187 MN:ND .176 MG:NB .167 AL:ZR .163 FE:ZR .158 SI:ZR .141 MN:CE .137 MN:LA .118 AL:CE .075 MN:ZR .064 P:CO .043 TI:V .030 SI:CE .018	P:CO .783 P:V .739 SI:CE .666 FE:CE .658 SI:LA .651 FE:ND .651 SI:ND .648 AL:CE .646 AL:ND .641 FE:LA .637 AL:LA .619 P:NI .615 CA:LA .600 CA:CE .598 MN:ND .586 MN:CE .570 MN:LA .559 MG:ND .538 SI:NB .523 MG:NB .520 MG:CE .520 SI:ZR .513 AL:NB .512 P:ZN .507 FE:NB .506 FE:ZR .482 AL:ZR .472 MG:LA .465 FE:Y .461 MN:NB .383 AL:Y .378 SI:Y .376 P:CU .365 TI:CO .362 MN:ZR .359 TI:V .294 MN:Y .241 MG:ZR .220 CA:ND .170 TI:CE .165 TI:LA .100 P:Y .081 TI:ND .046 MG:Y .036	P:NI .929 P:CO .855 MG:NB .855 CA:LA .852 CA:CE .850 P:V .820 MN:NB .802 MN:ZR .795 MN:CE .786 FE:NB .775 TI:NI .775 MG:CE .773 MG:ZR .765 MN:LA .765 AL:NB .757 MG:ND .754 MN:ND .754 AL:ZR .753 FE:ZR .749 MG:LA .742 FE:CE .723 FE:LA .704 AL:ND .701 AL:CE .698 SI:ND .691 SI:ZR .691 SI:NB .687 FE:ND .681 AL:NI .675 SI:CE .666 SI:NI .654 AL:LA .648 CA:ND .637 P:CR .628 P:CU .616 SI:LA .610 MN:Y .602 AL:Y .602 TI:CO .579 FE:Y .576 MG:Y .559 TI:ZR .552 SI:Y .547 TI:NB .543 TI:V .514 FE:NI .489 SI:CO .427 TI:CE .409 TI:ND .368 AL:CO .353 P:ZN .320 TI:LA .311 FE:CO .263 TI:Y .197 AL:V .137 MG:ZN .134 CA:ZR .091 FE:ZN .060 MN:ZN .007	
ORKNEY FORMATION	FE:ZR .255 AL:ZR .235 TI:ZR .195 MG:CE .157 AL:CE .155 MG:ZR .141 SI:ZR .132 SI:CE .044 AL:ND .039 MG:ND .036 FE:ND .031 P:Y .028 P:CO .008	P:CO .775 P:V .747 FE:ND .690 AL:CE .676 SI:CE .675 FE:CE .672 AL:ND .670 SI:ND .646 FE:LA .618 NA:ND .596 SI:LA .581 AL:LA .573 P:NI .569 NA:CE .546 FE:ZR .542 AL:ZR .518 P:ZN .509 SI:ZR .508 FE:NB .492 MN:ND .491 FE:Y .489 AL:NB .487 TI:ND .472 TI:CE .459 SI:NB .455 MN:CE .455 NA:LA .453 MG:ND .443 CA:CE .416 MG:CE .414 AL:Y .383 CA:ND .380 NA:NB .371 NA:ZR .364 MN:LA .357 TI:LA .346 MG:LA .337 MN:NB .335 CA:NB .308 SI:Y .275 P:CU .271 TI:ZR .262 CA:ZR .248 MN:ZR .201 MN:Y .199 TI:V .192 MG:NB .180 CA:LA .178 TI:NB .178 TI:CO .171 P:Y .163 TI:Y .137 NA:Y .108 MG:ZR .096 CA:Y .063 MG:Y .034	P:NI .920 P:CO .849 P:V .826 MN:NB .786 CA:CE .782 FE:ZR .778 TI:NI .775 AL:ZR .774 FE:NB .768 MG:NB .752 MN:ZR .744 AL:NB .744 TI:ZR .743 FE:CE .733 MN:CE .729 CA:ND .729 MG:ZR .727 AL:ND .724 AL:CE .724 MG:CE .723 FE:ND .717 MG:ND .704 TI:NB .699 MN:ND .697 CA:LA .697 FE:LA .689 SI:ND .689 SI:ZR .688 MG:LA .680 AL:NI .677 SI:CE .675 SI:NI .662 CA:ZR .659 MN:LA .657 TI:ND .650 SI:NB .643 CA:NB .642 TI:CE .617 AL:LA .605 AL:Y .605 NA:ND .602 FE:Y .598 MN:Y .579 NA:CE .572 NA:LA .569 P:CU .560 MG:Y .557 SI:LA .533 NA:NB .528 TI:Y .501 TI:LA .499 FE:NI .493 SI:Y .474 CA:Y .469 NA:ZR .466 TI:CO .453 TI:V .444 P:CR .437 P:ZN .323 SI:CO .293 AL:CO .251 AL:V .236 FE:ZN .214 FE:CO .181 NA:Y .114 SI:V .105 P:ZR .066 MG:ZN .053 P:Y .018 MN:ZN .002	

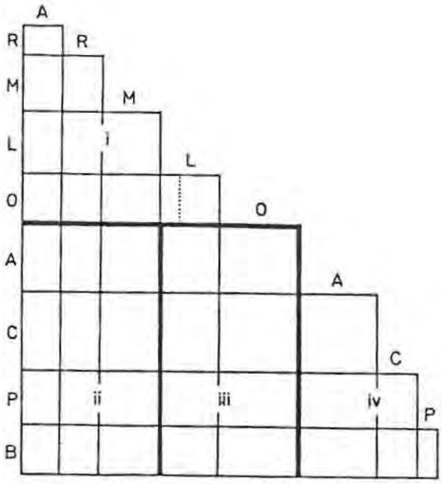


Table 4.7c continued

	ALLANRIDGE FORMATION	RIETGAT FORMATION	MAKWASSIE FORMATION
ALBERTON FORMATION	AL:ZR .124 TI:ZR .108 FE:ZR .012 MG:CE .010	P:CO .702 P:CU .702 AL:ND .647 SI:CE .623 FE:ND .615 SI:ND .614 P:V .607 FE:CE .600 AL:CE .599 SI:LA .561 AL:LA .556 FE:LA .526 P:NI .523 TI:ND .490 AL:ZR .448 TI:CE .443 AL:NB .428 FE:Y .421 FE:ZR .393 P:ZN .393 SI:NB .391 SI:ZR .390 AL:Y .381 MG:ND .379 TI:LA .369 SI:Y .353 FE:NB .350 MG:CE .312 MN:ND .285 MN:CE .276 CA:CE .261 MG:LA .235 CA:LA .233 CA:ND .229 MN:LA .227 TI:Y .219 TI:ZR .182 TI:CO .162 TI:CU .120 CA:ZR .118 CA:NB .109 TI:NB .101 CA:Y .088 MN:Y .032 TI:V .004	P:NI .912 P:CU .820 P:CR .816 P:CO .800 AL:ZR .741 P:V .729 TI:NI .725 CA:CE .724 CA:LA .717 AL:NB .715 TI:ZR .715 FE:ZR .706 AL:ND .705 FE:NB .704 MG:ZR .679 FE:CE .675 MG:CE .675 TI:NB .671 MG:NB .671 MG:ND .669 CA:ND .663 TI:ND .662 SI:ND .661 AL:CE .658 AL:NI .657 MN:ZR .651 FE:ND .648 MN:NB .642 MN:CE .640 MG:LA .630 SI:CE .624 SI:CU .621 FE:LA .614 SI:ZR .613 SI:NI .612 TI:CE .605 AL:Y .604 SI:NB .600 CA:ZR .600 AL:LA .590 MN:LA .588 MN:ND .575 TI:Y .549 FE:Y .544 CA:NB .539 FE:NI .539 MG:Y .536 SI:Y .531 TI:CR .527 TI:LA .517 SI:LA .509 MN:Y .492 CA:Y .483 TI:CU .478 TI:CO .447 AL:CR .438 AL:CU .390 SI:CR .389 SI:CO .383 AL:CO .370 TI:V .314 FE:CO .278 FE:ZN .234 AL:V .173 P:ZN .163 MG:ZN .144 CA:CU .104 FE:CR .104 P:ZR .101 FE:CU .096 SI:V .056 P:NB .040
CROWN FORMATION	P:V .945 FE:V .869 TI:V .851 AL:V .848 MN:V .843 NA:V .830 P:NI .814 SI:V .779 P:CO .722 MG:Y .668 MG:NB .653 MG:LA .622 MG:CE .614 MG:ZR .604 MG:ZN .598 MG:ND .567 P:CR .542 MN:NI .444 MG:V .429 CA:LA .426 NA:NI .408 FE:CO .401 AL:Y .385 CA:CE .366 TI:Y .355 AL:CE .336 CA:V .309 CA:ND .305 TI:NB .305 CA:Y .304 TI:LA .285 AL:ND .282 AL:LA .281 TI:ZR .280 AL:NI .278 FE:NI .271 TI:CE .260 TI:NI .247 AL:NB .246 SI:NI .239 P:ZR .238 TI:CO .236 AL:CO .235 TI:ND .223 AL:ZN .206 AL:ZR .180 SI:Y .146 NA:CO .119 SI:CE .117 TI:ZN .093 SI:ND .089 SI:NB .080 SI:CO .054 FE:CR .039 MN:CO .020	FE:V .888 MN:V .861 AL:V .838 P:V .835 NA:V .823 TI:V .818 SI:V .774 MG:ZN .705 FE:CR .486 MN:NI .480 FE:NI .475 SI:CR .474 MN:CR .471 CA:V .447 MG:CO .407 NA:CR .386 MG:Y .355 AL:CR .301 P:CR .299 P:NI .230 MG:NB .219 SI:NI .195 AL:NI .145 TI:ZN .143 MG:V .120 TI:CR .116 NA:NI .067 FE:CO .062 TI:NI .040 FE:ND .036 CA:NI .018	MN:V .816 P:V .783 FE:V .775 TI:V .773 AL:V .759 SI:V .597 NA:V .557 P:ZR .486 MN:ZR .471 MN:NB .469 FE:ZR .418 TI:ZR .414 FE:NB .409 P:NB .387 FE:CR .385 AL:ZR .357 TI:NB .303 AL:NB .278 MN:NI .250 MN:CE .240 P:CR .238 CA:V .236 NA:CR .230 FE:NI .215 P:ND .187 FE:CE .183 AL:CR .159 MN:LA .138 MG:ZN .135 MN:CR .119 FE:ND .119 MN:ND .111 FE:LA .109 TI:CR .106 P:Y .100 P:CE .089 TI:ND .084 AL:ND .067 NA:LA .065 FE:Y .063 P:NI .061 MN:Y .055 SI:CR .031 AL:CE .016
DOMINION GROUP PORPHYRIES	SI:CO .496 TI:ZR .453 P:CO .452 P:NI .444 SI:NI .418 P:V .396 TI:NB .336 SI:V .318 AL:CO .248 AL:ZR .228 CA:LA .215 K:NI .205 AL:NI .181 AL:V .162 AL:NB .097 TI:Y .082 CA:CE .075 TI:CO .022	SI:CR .420 SI:NI .385 SI:V .303 K:CR .225 AL:V .104 SI:CO .044 AL:NI .030	AL:Y .330 AL:NB .276 AL:ZR .241 TI:Y .056
DOMINION GROUP BASICS		P:V .134 SI:CE .123 TI:ND .091 SI:LA .046 TI:CE .037 FE:LA .035 FE:CE .024 TI:V .004	TI:NB .584 TI:ZR .550 FE:NB .501 P:V .403 MN:NB .402 TI:ND .398 TI:Y .367 FE:ZR .359 TI:CE .318 TI:V .314 AL:NB .311 MN:ZR .238 FE:LA .215 FE:CE .207 AL:ZR .197 SI:NB .193 FE:Y .191 TI:LA .185 AL:CO .181 AL:V .126 SI:CE .125 SI:CO .118 MN:CE .102 SI:ND .099 MN:LA .093 SI:ZR .085 P:CO .079 FE:ND .052 CA:CE .049 AL:CE .033 AL:Y .032 FE:CO .030 CA:LA .015 P:NB .001

Table 4.7c continued

	LORAINE FORMATION	ORKNEY FORMATION
ALBERTON FORMATION	TI:V .156 TI:CO .051	TI:V .035 P:V .028
CROWN FORMATION	P:V .974 P:NI .968 MG:NB .940 MG:CE .925 TI:V .922 MG:LA .922 MG:ND .919 MG:ZR .901 P:CR .898 TI:NI .883 MG:Y .881 CA:LA .880 CA:CE .875 FE:V .874 NA:V .867 FE:NI .867 P:CO .865 MN:V .864 AL:V .857 MN:NI .855 MG:ZN .837 AL:NI .834 NA:NI .826 SI:NI .816 SI:V .809 CA:ND .732 AL:LA .638 AL:CE .630 P:CU .630 TI:CR .623 MN:LA .611 FE:CE .608 MN:CE .605 NA:CR .601 AL:NB .597 FE:LA .586 SI:CR .579 AL:ND .576 TI:CO .572 FE:ND .564 FE:NB .559 AL:ZR .546 FE:CR .545 MN:ND .544 SI:LA .540 MN:CR .538 AL:Y .532 SI:CE .525 AL:CR .524 MN:NB .518 FE:ZR .511 FE:Y .508 MN:ZR .506 CA:V .502 SI:ND .501 SI:NB .490 CA:NI .477 FE:CO .474 MG:SR .462 P:ZN .429 CA:Y .427 SI:ZR .416 SI:Y .398 MN:Y .398 MG:CO .396 NA:CO .298 TI:LA .297 AL:CO .296 CA:NB .289 TI:CE .286 TI:NB .279 MN:CO .262 CA:ZR .260 P:Y .253 SI:CO .252 TI:ZR .183 FE:ZN .179 MN:ZN .173 P:ZR .130 AL:ZN .091 TI:Y .058 SI:ZN .051 TI:ND .049	P:V .975 P:NI .964 TI:V .911 MG:CE .909 MN:V .906 MG:LA .903 MG:ND .902 MG:NB .898 FE:V .896 MG:ZR .885 TI:NI .883 MG:Y .881 AL:V .874 FE:NI .868 P:CO .860 MN:NI .856 P:CR .846 AL:NI .835 SI:V .832 MG:ZN .822 SI:NI .820 CA:CE .818 CA:ND .799 NA:V .766 CA:LA .753 CA:NB .751 CA:ZR .723 CA:Y .713 NA:NI .677 AL:CE .662 FE:CE .623 FE:ND .613 AL:ND .610 CA:ZN .601 AL:LA .595 CA:V .594 AL:ZR .585 AL:NB .576 P:CU .576 FE:ZR .567 FE:LA .565 FE:NB .547 CA:NI .544 SI:CE .537 TI:CE .537 AL:Y .536 FE:Y .533 TI:ZR .531 TI:NB .526 NA:CR .501 MN:CE .500 SI:ND .497 TI:CR .492 TI:LA .489 MN:NB .481 TI:ND .473 NA:ND .466 SI:LA .449 MN:CO .448 SI:CR .446 TI:CO .444 MN:ND .439 MN:LA .433 P:ZN .431 FE:CR .424 SI:NB .418 FE:CO .416 MG:V .415 TI:Y .415 SI:ZR .411 MN:ZR .384 MN:Y .364 AL:CR .363 NA:CE .362 NA:NB .350 NA:LA .337 P:Y .320 FE:ZN .313 AL:ZN .311 MN:CR .308 SI:Y .301 P:ZR .267 MG:NI .264 MG:CO .256 P:SR .236 NA:ZR .204 AL:CO .185 MN:ZN .169 NA:Y .150 TI:ZN .113 SI:CO .077
DOMINION GROUP PORPHYRIES	P:NI .904 SI:NI .859 CA:LA .836 CA:CE .817 AL:NI .811 TI:NI .808 K:NI .793 P:CO .734 P:V .718 MG:NB .714 MG:LA .693 MG:CE .684 MN:LA .655 MG:ZR .649 FE:CE .644 P:CR .636 MG:ND .635 MN:CE .632 FE:ZR .605 FE:LA .602 SI:CO .602 FE:ND .583 AL:ZR .573 FE:NB .546 SI:CR .536 K:CR .524 CA:ND .519 AL:NB .517 MN:ZR .508 MN:NB .486 MN:ND .486 TI:CO .452 TI:V .436 SI:V .409 FE:NI .407 TI:ZR .380 TI:NB .311 AL:CO .309 SI:ZR .298 AL:CR .286 TI:CR .260 AL:ND .258 FE:Y .242 SI:NB .225 MN:NI .225 AL:V .211 MG:Y .209 SI:LA .195 AL:CE .147 CA:ZR .121 AL:Y .115 K:CO .093 SI:CE .091 MN:Y .084 K:V .032	P:NI .892 SI:NI .863 AL:NI .812 TI:NI .808 CA:CE .735 P:V .728 P:CO .725 K:NI .688 CA:ZR .671 CA:LA .662 FE:CE .657 FE:ZR .650 TI:ZR .643 CA:NB .642 CA:ND .641 FE:ND .630 MG:LA .620 MG:CE .614 AL:ZR .609 MG:ZR .593 FE:LA .582 MG:ND .560 TI:NB .546 MN:CE .533 FE:NB .533 MG:NB .512 SI:CO .509 MN:LA .497 AL:NB .492 SI:V .480 P:CR .449 MN:NB .446 FE:NI .412 SI:CR .389 MN:ZR .386 MN:ND .367 TI:V .355 AL:ND .317 CA:Y .313 AL:V .302 SI:ZR .291 NA:ND .289 TI:CO .288 FE:Y .282 TI:ND .257 NA:CE .243 MN:NI .231 NA:LA .221 AL:CE .221 MG:Y .206 AL:CO .199 NA:ZR .191 TI:Y .167 NA:NB .150 TI:CE .133 AL:Y .122 SI:CE .116 SI:NB .115 K:V .050 AL:CR .044 P:ZR .041 SI:LA .035 K:CR .033 MN:Y .032 K:CO .003 TI:CR .002
DOMINION GROUP BASICS		

Table 4.7c continued

	ALBERTON FORMATION	CROWN FORMATION	DOMINION GROUP PORPHYRIES
CROWN FORMATION	P:V .961 P:NI .960 P:CR .950 MG:CE .893 MG:ND .891 TI:V .890 MG:LA .888 MN:V .886 FE:V .884 FE:NI .880 MG:Y .875 MG:ZR .865 MG:NB .864 AL:V .863 SI:CR .863 TI:NI .857 MN:NI .850 TI:CR .848 FE:CR .847 MN:CR .843 MG:ZN .839 AL:CR .830 P:CU .826 AL:NI .824 NA:CR .824 NA:V .823 SI:V .823 P:CO .815 SI:NI .794 CA:CE .770 CA:LA .769 NA:NI .756 CA:ND .751 CA:Y .720 CA:NB .679 CA:ZR .675 CA:ZN .631 NA:CU .586 AL:ND .582 AL:CE .581 AL:LA .579 CA:V .545 FE:CE .540 SI:CU .537 AL:Y .534 AL:NB .527 AL:ZR .525 TI:CE .523 MN:CU .520 FE:ND .519 TI:LA .508 TI:ND .491 FE:CO .485 TI:NB .481 TI:ZR .480 CA:NI .480 FE:Y .471 TI:Y .471 FE:CU .468 SI:CE .465 FE:LA .460 SI:ND .452 TI:CO .437 TI:CU .429 FE:ZR .426 AL:ZN .426 SI:LA .421 FE:NB .420 CA:CR .417 SI:Y .376 SI:NB .349 MG:CO .338 MN:CE .336 MN:CO .333 FE:ZN .331 MN:LA .319 AL:CO .314 AL:CU .311 TI:ZN .305 P:ZN .297 MG:V .277 SI:ZR .269 MN:Y .232 MN:ND .212 MG:NI .206 SI:CO .195 SI:ZN .195 K:CR .161 MN:ZR .160 MG:CR .136 MN:NB .131 NA:CO .119 P:Y .089 MN:ZN .022		
DOMINION GROUP PORPHYRIES	P:NI .881 SI:CR .849 SI:NI .842 P:CR .820 AL:NI .801 TI:NI .766 K:NI .760 K:CR .753 AL:CR .746 TI:CR .702 CA:LA .685 CA:CE .664 P:CO .636 CA:ZR .613 TI:ZR .605 FE:CE .583 P:V .576 SI:CO .571 MG:LA .561 CA:ND .553 AL:ZR .552 MG:CE .547 FE:ND .541 CA:NB .538 FE:ZR .536 MG:ZR .521 MG:ND .509 TI:NB .504 FE:LA .481 FE:NI .465 SI:V .452 AL:NB .434 FE:NB .402 MN:LA .395 MN:CE .380 MG:NB .351 CA:Y .331 AL:CO .326 MN:CR .318 FE:CR .290 TI:ND .282 TI:CO .280 AL:ND .269 TI:Y .246 AL:V .244 TI:V .205 MN:NI .198 FE:Y .186 MG:Y .169 MN:ZR .163 MG:CR .128 SI:ZR .121 AL:Y .119 MN:ND .112 TI:CE .107 P:ZR .078 MN:NB .073 AL:CE .034 SI:NB .011 K:CO .001	P:V .557 P:ZR .473 P:NB .265 FE:V .252 TI:V .239 AL:Y .213 TI:ZR .198 MN:V .169 FE:ZR .083 P:RB .049	
DOMINION GROUP BASICS		P:V .915 FE:V .897 TI:V .890 MN:V .887 AL:V .855 NA:V .851 SI:V .806 CA:V .530 MG:ZN .529 MG:NB .423 MG:LA .373 TI:NB .344 MG:Y .329 FE:CO .308 MG:CE .307 TI:Y .258 MG:ZR .249 CA:CE .207 CA:LA .197 TI:ZR .180 TI:CE .177 TI:LA .169 P:CO .148 CA:Y .145 MG:ND .141 CA:ND .119 AL:CO .109 TI:ND .094 CA:NB .074 FE:Y .061 NA:CO .061 FE:NB .024 P:NI .018	SI:V .400 SI:CO .387 TI:ZR .377 TI:NB .373 TI:V .205 AL:V .201 AL:CO .125 P:V .067

TABLE 4.8a Ranges of major element ratios for each formation

	SIO2 :SIO2		TIO2 :SIO2		AL2O3:SIO2		FE2O3:SIO2		MNO :SIO2		MGO :SIO2		CAO :SIO2		NA2O :SIO2		K2O :SIO2		P2O5 :SIO2	
AR	1.000	1.000	.015	.025	.223	.311	.091	.286	.001	.004	.036	.112	.042	.261	.003	.077	.005	.082	.003	.005
PR	1.000	1.000	.019	.046	.213	.384	.106	.300	.001	.005	.037	.148	.047	.261	.019	.082	.002	.053	.008	.025
PM	1.000	1.000	.016	.031	.185	.338	.086	.219	.000	.003	.011	.087	.029	.120	.009	.093	.001	.125	.006	.113
KL	1.000	1.000	.008	.016	.163	.301	.178	.237	.002	.004	.075	.331	.014	.249	.003	.069	.002	.048	.001	.002
KO	1.000	1.000	.016	.021	.244	.305	.188	.276	.002	.003	.061	.121	.088	.200	.039	.130	.006	.054	.002	.003
KA	1.000	1.000	.017	.022	.243	.316	.174	.238	.002	.003	.073	.139	.090	.177	.012	.093	.007	.051	.002	.003
JC	1.000	1.000	.015	.033	.179	.390	.172	.374	.002	.005	.013	.032	.030	.065	.041	.084	.002	.032	.008	.017
DP	1.000	1.000	.007	.025	.138	.370	.024	.211	.000	.003	.004	.095	.005	.095	.003	.078	.014	.122	.002	.009
DB	1.000	1.000	.011	.036	.187	.417	.138	.343	.002	.005	.024	.219	.063	.219	.005	.089	.002	.063	.002	.014

	SIO2 :TIO2		TIO2 :TIO2		AL2O3:TIO2		FE2O3:TIO2		MNO :TIO2		MGO :TIO2		CAO :TIO2		NA2O :TIO2		K2O :TIO2		P2O5 :TIO2	
AR	40.594	65.589	1.000	1.000	10.704	16.128	3.850	12.956	.076	.189	1.528	5.039	1.727	11.089	.121	4.545	.242	3.472	.121	.237
PR	21.571	51.786	1.000	1.000	7.074	12.107	4.356	8.971	.048	.145	1.646	5.955	1.594	7.666	.717	3.457	.059	2.498	.394	.542
PM	31.770	64.182	1.000	1.000	10.729	12.579	4.815	11.045	.016	.128	.681	4.398	1.473	7.425	.371	5.351	.057	5.441	.397	.462
KL	63.235	132.078	1.000	1.000	16.298	36.650	13.645	30.425	.154	.465	4.761	43.650	1.466	29.780	.248	7.328	.275	4.032	.080	.204
KO	47.685	63.654	1.000	1.000	13.581	17.049	11.574	14.549	.119	.196	3.859	6.300	5.140	11.450	2.251	8.055	.365	3.066	.115	.151
KA	44.949	57.841	1.000	1.000	13.155	15.971	9.963	11.759	.099	.167	3.716	6.457	4.778	9.394	.644	4.697	.363	2.537	.130	.170
JC	30.072	64.810	1.000	1.000	11.459	12.946	10.030	12.140	.130	.166	.822	1.046	1.927	3.295	2.515	4.015	.144	1.368	.482	.520
DP	39.248	141.092	1.000	1.000	13.991	24.330	2.423	14.027	.020	.227	.327	4.944	.636	6.156	.303	6.015	.704	8.391	.144	.357
DB	27.543	93.682	1.000	1.000	6.098	25.721	6.526	18.723	.059	.268	.879	14.094	2.009	15.817	.172	5.970	.091	4.647	.112	.378

	SIO2 :AL2O3		TIO2 :AL2O3		AL2O3:AL2O3		FE2O3:AL2O3		MNO :AL2O3		MGO :AL2O3		CAO :AL2O3		NA2O :AL2O3		K2O :AL2O3		P2O5 :AL2O3	
AR	3.218	4.485	.062	.093	1.000	1.000	.328	1.059	.007	.016	.130	.397	.157	.944	.010	.293	.021	.296	.011	.020
PR	2.607	4.705	.083	.141	1.000	1.000	.397	1.086	.004	.020	.163	.682	.142	.793	.068	.286	.008	.222	.036	.074
PM	2.961	5.392	.080	.093	1.000	1.000	.405	.887	.001	.011	.059	.353	.126	.612	.033	.432	.005	.483	.033	.040
KL	3.321	6.148	.027	.061	1.000	1.000	.610	1.417	.009	.020	.289	2.033	.045	.938	.011	.270	.011	.164	.002	.009
KO	3.278	4.097	.059	.074	1.000	1.000	.702	.975	.007	.013	.226	.434	.328	.708	.159	.496	.023	.194	.007	.010
KA	3.167	4.114	.063	.076	1.000	1.000	.697	.894	.007	.012	.266	.490	.340	.692	.046	.316	.028	.185	.009	.012
JC	2.566	5.596	.077	.087	1.000	1.000	.856	1.059	.010	.014	.065	.091	.152	.264	.215	.341	.013	.148	.039	.044
DP	2.702	7.221	.041	.071	1.000	1.000	.151	.853	.001	.014	.020	.353	.038	.372	.018	.351	.050	.489	.010	.024
DB	2.400	5.357	.039	.164	1.000	1.000	.499	1.172	.007	.020	.130	.896	.152	.935	.025	.353	.006	.250	.007	.059

	SIO2 :FE2O3		TIO2 :FE2O3		AL2O3:FE2O3		FE2O3:FE2O3		MNO :FE2O3		MGO :FE2O3		CAO :FE2O3		NA2O :FE2O3		K2O :FE2O3		P2O5 :FE2O3	
AR	3.491	11.031	.077	.260	.944	3.051	1.000	1.000	.009	.049	.170	.554	.149	2.880	.031	.499	.025	.302	.010	.045
PR	3.331	9.445	.111	.230	.921	2.520	1.000	1.000	.008	.026	.270	.787	.193	1.387	.098	.631	.008	.354	.048	.104
PM	4.560	11.616	.091	.208	1.127	2.471	1.000	1.000	.003	.021	.115	.438	.153	1.235	.059	1.028	.011	.370	.041	.094
KL	4.217	5.623	.033	.073	.706	1.638	1.000	1.000	.011	.021	.349	1.435	.062	1.331	.013	.339	.009	.222	.003	.013
KO	3.618	5.319	.069	.086	1.025	1.425	1.000	1.000	.010	.015	.322	.467	.391	.905	.179	.598	.029	.228	.008	.012
KA	4.201	5.755	.085	.100	1.119	1.435	1.000	1.000	.009	.016	.358	.583	.434	.887	.061	.442	.031	.249	.011	.017
JC	2.998	5.814	.082	.100	.944	1.168	1.000	1.000	.011	.016	.072	.096	.174	.285	.215	.359	.012	.168	.040	.052
DP	4.748	42.398	.071	.413	1.172	6.630	1.000	1.000	.005	.021	.030	.453	.073	.765	.081	1.906	.065	2.287	.013	.143
DB	2.913	7.225	.053	.153	.854	2.005	1.000	1.000	.009	.026	.129	.908	.212	1.048	.025	.508	.006	.399	.010	.055

	SIO2 :MNO		TIO2 :MNO		AL2O3:MNO		FE2O3:MNO		MNO :MNO		MGO :MNO		CAO :MNO		NA2O :MNO		K2O :MNO		P2O5 :MNO	
AR	224.600	680.667	5.288	13.133	62.120	151.778	20.360	115.727	1.000	1.000	8.080	46.000	16.267	75.364	.640	42.222	1.875	26.515	.912	2.419
PR	201.038	879.857	6.892	20.629	51.154	226.429	38.083	119.167	1.000	1.000	16.786	65.833	19.250	116.286	7.385	56.714	.423	37.100	2.863	9.386
PM	398.533	3401.500	7.786	60.850	94.571	695.500	48.286	293.000	1.000	1.000	10.857	86.000	13.400	125.500	10.200	77.000	.778	234.100	3.300	25.850
KL	224.792	477.000	2.153	6.500	50.529	111.083	48.458	92.417	1.000	1.000	29.857	102.706	4.938	89.786	.882	28.846	.647	15.133	.220	.873
KO	285.889	535.273	5.106	8.409	79.556	143.364	68.611	100.636	1.000	1.000	27.938	41.214	33.294	82.000	14.500	44.250	2.615	19.333	.589	1.036
KA	327.882	520.818	5.971	10.127	84.471	142.000	62.294	105.455	1.000	1.000	27.412	52.071	42.563	72.000	4.786	37.182	2.533	18.467	.824	1.473
JC	193.154	497.538	6.035	7.677	70.235	99.385	64.423	88.154	1.000	1.000	5.059	6.462	12.250	25.154	16.000	28.077	.882	11.375	2.965	3.869
DP	379.889	3837.000	4.411	49.633	71.000	721.000	48.417	212.667	1.000	1.000	1.444	46.667	8.375	56.667	6.667	172.500	6.333	237.333	1.300	17.233
DB	199.172	611.200	3.738	16.840	50.276	138.727	39.138	116.846	1.000	1.000	9.636	65.615	15.450	106.700	2.900	34.067	.444	26.357	.756	6.370

	SIO2 :MGO		TIO2 :MGO		AL2O3:MGO		FE2O3:MGO		MNO :MGO		MGO :MGO		CAO :MGO		NA2O :MGO		K2O :MGO		P2O5 :MGO	
AR	8.955	27.797	.198	.654	2.517	7.698	1.806	5.868	.022	.124	1.000	1.000	.508	7.257	.079	1.878	.059	2.272	.037	.113
PR	6.745	26.987	.168	.608	1.466	6.120	1.271	3.703	.015	.060	1.000	1.000	.496	3.143	.143	1.533	.014	1.221	.076	.279
PM	11.452	90.461	.227	1.468	2.831	17.000	2.285	8.684	.012	.092	1.000	1.000	.385	7.481	.136	4.158	.042	6.026	.102	.615
KL	3.025	13.282	.023	.210	.492	3.455	.697	2.866	.010	.033	1.000	1.000	.157	1.859	.011	.813	.006	.434	.002	.028
KO	8.287	16.493	.159	.259	2.306	4.417	2.143	3.101	.024	.036	1.000	1.000	.978	2.221	.493	1.546	.071	.591	.018	.032
KA	7.210	13.696	.155	.269	2.040	3.766	1.716	2.792	.019	.036	1.000	1.000	.907	1.938	.119	1.036	.058	.575	.021	.039
JC	31.193	77.000	.956	1.216	10.954	15.381	10.404	13.860	.155	.198	1.000	1.000	2.025	3.919	2.495	4.884	.138	2.135	.470	.601
DP	10.474	263.000	.202	3.054	2.830	49.154	2.206	33.615	.021	.692	1.000	1.000	.494	7.308	.235	12.808	.142	13.115	.029	.900
DB	4.562	41.297	.071	1.138	1.116	7.709	1.101	7.736	.015	.104	1.000	1.000	.387	7.209	.184	1.868	.010	.921	.013	.430

	SIO2 :CAO		TIO2 :CAO		AL2O3:CAO		FE2O3:CAO		MNO :CAO		MGO :CAO		CAO :CAO		NA2O :CAO		K2O :CAO		P2O5 :CAO	
AR	3.830	23.868	.090	.579	1.059	6.357	.347	6.734	.013	.061	.138	1.967	1.000	1.000	.011	1.189	.044	1.136	.016	.079
PR	3.826	21.102	.130	.628	1.261	7.043	.721	5.181	.009	.052	.318	2.015	1.000	1.000	.136	1.334	.016	.953	.054	.271
PM	8.323	34.625	.135	.679	1.634	7.908	.810	6.522	.008	.075	.134	2.597	1.000	1.000	.209	3.216	.034	3.061	.057	.292
KL	4.020	73.063	.034	.682	1.066	22.000	.751	16.101	.011	.203	.538	6.367	1.000	1.000	.015	5.000	.014	2.101	.003	.054
KO	4.996	11.389	.087	.195	1.412	3.050	1.105	2.555	.012	.030	.450	1.023	1.000	1.000	.273	1.202	.032	.484	.012	.022
KA	5.663	11.060	.106	.209	1.445	2.943	1.128	2.306	.014	.023	.516	1.103	1.000	1.000	.069	.759	.040	.432	.015	.029
JC	15.405	33.459	.304	.519	3.785	6.571	3.505	5.755	.040	.082	.255	.494	1.000	1.000	.938	1.959	.052	.949	.153	.267
DP	10.513	187.929	.162	1.571	2.688	26.024	1.308	13.716	.018	.119	.137	2.024	1.000	1.000	.467	6.765	.143	12.714	.029	.508
DB	4.566	15.790	.063	.498	1.069	6.579	.954	4.725	.009	.065	.139	2.583	1.000	1.000	.027	.968	.007	.745	.011	.197

	SIO2 :NA2O		TIO2 :NA2O		AL2O3:NA2O		FE2O3:NA2O		MNO :NA2O		MGO :NA2O		CAO :NA2O		NA2O :NA2O		K2O :NA2O		P2O5 :NA2O	
AR	12.911	350.938	.220	8.263	3.407	97.062	2.002	31.813	.024	1.563	.533	12.625	.841	91.625	1.000	1.000	.073	28.698	.040	1.425
PR	12.229	51.362	.289	1.395	3.502	14.743	1.584	10.210	.018	.135	.652	7.010	.749	7.362	1.000	1.000	.037	1.512	.132	.639
PM	10.098	117.157	.187	2.692	2.316	30.353	.973	16.843	.013	.098	.241	7.373	.311	4.784	1.000	1.000	.011	14.647	.083	1.145
KL	14.543	363.333	.136	4.027	3.707	91.733	2.947	76.400	.035	1.133	1.229	91.895	.200	65.733	1.000	1.000	.073	11.667	.011	.473
KO	7.669	25.719	.124	.444	2.016	6.299	1.671	5.602	.023	.069	.647	2.027	.832	3.663	1.000	1.000	.117	1.134	.015	.059
KA	12.061	83.970	.213	1.552	3.168	21.552	2.265	16.448	.027	.209	.965	8.373	1.318	14.582	1.000	1.000	.130	1.358	.031	.215
JC	11.957	24.566	.249	.398	2.929	4.660	2.783	4.651	.036	.063	.205	.401	.510	1.066	1.000	1.000	.055	.495	.120	.207
DP	12.740	394.650	.166	3.300	2.846	54.650	.525	12.416	.006	.150	.078	4.250	.148	2.140	1.000	1.000	.173	26.700	.036	1.040
DB	11.262	210.759	.168	5.807	2.830	39.345	1.967	39.483	.029	.345	.535	5.438	1.033	36.793	1.000	1.000	.039	4.100	.037	2.197

	SIO2 :K2O		TIO2 :K2O		AL2O3:K2O		FE2O3:K2O		MNO :K2O		MGO :K2O		CAO :K2O		NA2O :K2O		K2O :K2O		P2O5 :K2O	
AR	12.233	194.433	.288	4.140	3.383	47.833	1.109	40.206	.038	.533	.440	17.000	.881	22.824	.035	13.733	1.000	1.000	.050	.690
PR	18.729	475.182	.400	17.091	4.503	120.909	2.872	131.273	.027	2.364	.819	70.455	1.049	64.364	.661	26.800	1.000	1.000	.175	8.973
PM	7.999	946.286	.184	17.514	2.072	217.000	1.150	91.143	.004	1.286	.166	23.714	.327	29.143	.068	93.714	1.000	1.000	.078	7.786
KL	20.984	480.091	.248	3.636	6.108	88.167	4.507	110.636	.066	1.545	2.304	158.727	.476	73.273	.086	13.667	1.000	1.000	.022	.355
KO	18.659	156.647	.326	2.738	5.155	44.265	4.392	34.647	.052	.382	1.693	14.118	2.066	31.353	.882	8.559	1.000	1.000	.042	.394
KA	19.794	141.868	.394	2.753	5.408	36.211	4.014	32.368	.054	.395	1.740	17.289	2.314	25.053	.736	7.690	1.000	1.000	.061	.366
JC	31.585	445.467	.535	6.947	6.779	79.600	5.937	84.333	.084	1.133	.468	7.267	1.032	19.333	2.021	18.133	1.000	1.000	.261	3.413
DP	8.208	73.592	.124	1.421	2.047	19.882	.437	15.500	.004	.158	.076	7.026	.079	7.000	.037	5.776	1.000	1.000	.039	.205
DB	15.935	652.625	.215	11.038	4.000	166.125	2.504	160.875	.038	2.250	1.085	96.375	1.341	136.500	.250	25.909	1.000	1.000	.059	2.388

	SIO2 :P2O5		TIO2 :P2O5		AL2O3:P2O5		FE2O3:P2O5		MNO :P2O5		MGO :P2O5		CAO :P2O5		NA2O :P2O5		K2O :P2O5		P2O5 :P2O5	
AR	193.502	356.341	4.213	8.263	50.142	90.702	22.325	96.082	.414	1.096	8.860	27.378	12.727	64.298	.702	24.695	1.449	20.132	1.000	1.000
PR	40.668	119.308	1.844	2.537	13.475	27.934	9.574	21.034	.107	.349	3.583	13.120	3.690	18.457	1.565	7.583	.111	5.699	1.000	1.000
PM	79.956	156.628	2.162	2.517	25.217	30.304	10.609	24.689	.039	.303	1.624	9.831	3.420	17.506	.873	12.037	.128	12.791	1.000	1.000
KL	433.740	1552.424	4.901	12.535	108.702	454.242	78.092	312.051	1.145	4.545	35.424	447.692	18.372	369.091	2.113	91.860	2.821	45.385	1.000	1.000
KO	356.853	516.491	6.632	8.717	97.852	142.453	83.116	126.132	.965	1.698	31.316	54.623	44.516	81.157	17.059	65.556	2.537	23.967	1.000	1.000
KA	302.131	424.307	5.880	7.714	81.530	109.929	58.579	88.489	.679	1.214	25.556	47.961	33.899	68.489	4.653	32.555	2.734	16.391	1.000	1.000
JC	57.791	132.218	1.922	2.075	22.520	25.968	19.275	24.707	.258	.337	1.663	2.129	3.751	6.518	4.833	8.333	.293	3.831	1.000	1.000
DP	113.037	589.200	2.803	6.923	41.838	101.600	6.988	75.513	.058	.769	1.111	34.231	1.969	34.103	.962	28.141	4.872	25.673	1.000	1.000
DB	73.496	481.743	2.644	8.946	16.817	133.486	17.869	101.959	.157	1.324	2.323	78.257	5.360	87.339	.455	27.156	.419	16.849	1.000	1.000

Table 4.8b Ranges of trace element ratios for each formation

	BA:BA		NB:BA		ZR:BA		Y:BA		SR:BA		RB:BA		ZN:BA		CU:BA		NI:BA		CO:BA		CR:BA		V:BA		LA:BA		CE:BA		ND:BA	
AR	1.000	1.000	.007	.088	.153	1.866	.024	.265	.100	2.959	.020	.382	.056	1.093	.007	1.412	.076	2.196	.051	.673	0.000	2.196	.184	2.289	.020	.202	.044	.519	.018	.227
PR	1.000	1.000	.011	.176	.190	3.602	.033	.547	.180	4.957	.014	.133	.059	1.590	.008	.229	.024	1.988	.022	.687	.016	6.578	.107	2.695	.035	.578	.084	1.470	.041	.747
PM	1.000	1.000	.013	1.384	.213	22.440	.028	3.068	.068	12.852	.026	.199	.043	3.960	.005	.400	.012	.680	.009	.800	.008	.840	.043	3.920	.037	4.280	.075	8.200	.034	3.760
KL	1.000	1.000	0.000	.075	.023	2.125	.011	.650	.152	2.796	.049	.475	.047	4.750	.042	2.688	.127	32.250	.038	5.500	.046	163.625	.161	11.125	0.000	.122	0.000	.500	0.000	.125
KO	1.000	1.000	.003	.032	.079	.711	.016	.173	.228	6.102	.048	.209	.080	.594	.064	.579	.106	1.117	.057	.492	.020	.383	.195	1.781	.009	.070	.022	.203	0.000	.634
KA	1.000	1.000	.004	.052	.104	.845	.020	.150	.297	2.349	.033	.197	.069	.619	.080	.677	.112	1.006	.054	.406	.082	1.722	.167	1.129	.011	.110	.024	.296	.014	.143
JC	1.000	1.000	.018	.129	.277	2.090	.056	.445	.251	1.590	.029	.104	.190	1.344	.021	.107	.014	.123	.029	.238	.007	.025	.020	.148	.049	.328	.046	.736	.047	.377
DP	1.000	1.000	.007	.046	.153	.932	.015	.102	.042	.876	.051	.277	.039	.426	.003	.230	.005	.032	.007	.065	0.000	.026	.027	.177	.019	.303	.050	.497	.022	.147
DB	1.000	1.000	.003	.168	.050	3.640	.008	.908	.121	15.440	.018	.243	.033	4.280	.021	2.320	.023	12.400	.018	2.720	0.000	53.760	.071	9.440	.006	.400	.016	1.160	.006	.540

	BA:NB		NB:NB		ZR:NB		Y:NB		SR:NB		RB:NB		ZN:NB		CU:NB		NI:NB		CO:NB		CR:NB		V:NB		LA:NB		CE:NB		ND:NB	
AR	11.304	140.000	1.000	1.000	15.614	30.909	1.941	5.036	5.579	191.169	.704	17.069	5.246	20.769	.410	21.667	2.389	40.000	3.852	12.182	0.000	32.000	12.049	35.455	1.176	4.306	3.109	9.036	1.513	5.091
PR	5.685	90.280	1.000	1.000	15.294	22.523	2.171	3.887	9.850	87.736	.151	4.749	3.033	10.435	.153	3.380	.751	14.966	.871	4.128	.511	63.673	4.745	17.744	2.237	4.074	5.075	8.747	2.523	4.962
PM	.723	75.447	1.000	1.000	14.671	19.661	2.025	2.771	3.742	124.703	.058	6.914	2.183	6.581	.263	1.186	.491	1.030	.474	1.065	.382	1.271	2.773	4.294	1.372	3.776	3.415	7.455	1.958	4.635
KL	13.333	2850.000	1.000	1.000	17.143	780.000	2.875	152.000	8.852	1680.000	3.629	419.000	17.143	610.000	5.278	740.000	30.000	1810.000	10.328	560.000	5.833	7740.000	36.885	2120.000	0.000	20.000	0.000	50.000	0.000	30.000
KO	31.228	302.000	1.000	1.000	14.848	33.448	3.515	7.655	36.316	251.935	3.516	26.444	14.091	32.414	3.902	34.138	21.321	47.931	9.706	21.724	3.478	20.345	31.471	77.586	1.176	4.103	2.727	4.347	0.000	4.443
KA	19.136	222.500	1.000	1.000	16.173	30.000	2.864	8.850	18.148	152.295	2.250	43.850	11.852	40.500	9.833	35.000	18.525	105.500	7.778	34.500	9.506	206.500	21.605	105.500	.940	5.500	3.770	4.500	1.634	[illegible]
JC	7.771	55.263	1.000	1.000	14.969	17.153	3.079	3.641	12.357	41.831	.274	4.149	9.627	11.389	.828	1.863	.764	.955	1.579	2.014	.191	.634	1.056	1.181	2.571	3.264	5.294	6.036	2.436	3.333
DP	21.597	150.000	1.000	1.000	15.714	23.846	1.649	2.405	2.316	41.544	2.471	13.167	1.614	15.641	.263	7.197	.444	1.241	.526	2.393	0.000	.930	1.149	8.217	.737	4.027	2.070	13.197	1.263	5.234
DB	5.952	376.986	1.000	1.000	17.547	37.500	3.016	10.417	10.848	211.000	.310	15.492	6.636	54.194	.727	30.800	1.273	185.833	3.212	36.250	0.000	629.167	18.602	107.043	1.321	5.417	2.830	11.250	2.075	4.000

	BA:ZR		NB:ZR		ZR:ZR		Y:ZR		SR:ZR		RB:ZR		ZN:ZR		CU:ZR		NI:ZR		CO:ZR		CR:ZR		V:ZR		LA:ZR		CE:ZR		ND:ZR	
AR	.536	6.553	.032	.064	1.000	1.000	.113	.176	.294	9.376	.030	.922	.332	.808	.026	.948	.117	1.294	.244	.438	0.000	1.177	.762	1.418	.075	.178	.170	.344	[illegible]	.173
PR	.278	5.269	.044	.065	1.000	1.000	.114	.216	.437	4.303	.008	.310	.135	.590	.009	.190	.033	.902	.039	.250	.023	3.836	.211	.996	.120	.243	.225	.502	.112	.241
PM	.045	4.687	.051	.068	1.000	1.000	.118	.148	.230	6.343	.004	.445	.140	.396	.018	.060	.030	.064	.028	.064	.023	.065	.162	.250	.083	.243	.207	.461	.114	.274
KL	.471	43.235	0.000	.058	1.000	1.000	.164	.543	.478	8.905	.100	2.971	.866	2.810	.196	3.690	1.113	15.176	.558	2.588	.216	77.000	1.991	7.571	0.000	.162	0.000	.375	0.000	.405
KO	1.407	12.583	.030	.067	1.000	1.000	.194	.243	1.791	8.582	.120	1.123	.698	1.248	.167	1.370	1.144	1.592	.490	.832	.165	.990	1.891	2.505	.073	.176	.155	.320	0.000	.170
KA	1.183	9.589	.033	.062	1.000	1.000	.164	.295	1.122	8.149	.095	1.462	.620	1.350	.431	1.167	.935	3.517	.431	1.150	.532	6.883	1.336	3.517	.042	.183	.189	.306	.082	.151
JC	.478	3.605	.058	.067	1.000	1.000	.189	.220	.761	2.528	.017	.277	.606	.687	.051	.124	.045	.059	.097	.120	.012	.039	.064	.075	.154	.190	.324	.347	.149	.200
DP	1.072	6.544	.042	.064	1.000	1.000	.091	.148	.171	2.040	.121	.644	.084	.656	.013	.456	.022	.074	.028	.102	0.000	.055	.069	.414	.039	.375	.158	.616	.066	.244
DB	.275	20.088	.027	.057	1.000	1.000	.138	.281	.510	8.671	.014	.658	.283	2.211	.034	.975	.054	5.514	.151	1.009	0.000	17.118	.925	3.326	.073	.184	.161	.402	.088	.213

	BA:Y		NB:Y		ZR:Y		Y:Y		SR:Y		RB:Y		ZN:Y		CU:Y		NI:Y		CO:Y		CR:Y		V:Y		LA:Y		CE:Y		ND:Y	
AR	3.768	41.067	.199	.515	5.679	8.880	1.000	1.000	2.387	53.723	.178	5.728	2.311	5.637	.162	5.816	1.042	8.802	1.694	3.243	0.000	8.802	5.857	10.000	.606	1.183	1.429	2.326	.725	1.115
PR	1.829	30.412	.257	.461	4.635	8.751	1.000	1.000	3.763	28.411	.054	1.910	1.179	3.104	.051	1.213	.292	4.846	.338	1.278	.198	20.617	1.844	4.930	.808	1.484	1.771	3.186	.978	1.555
PM	.326	36.250	.361	.494	6.748	8.485	1.000	1.000	1.820	45.000	.026	3.001	.948	3.233	.125	.428	.222	.495	.225	.523	.162	.459	1.213	2.121	.650	1.655	1.018	3.333	.939	2.159
KL	1.538	88.024	0.000	.348	1.842	6.087	1.000	1.000	1.923	31.418	.331	6.725	3.533	17.101	.852	22.464	4.843	49.615	2.601	8.696	.942	251.731	8.564	34.348	0.000	.641	0.000	1.368	0.000	.838
KO	5.792	61.633	.131	.285	4.118	5.164	1.000	1.000	8.118	38.115	.493	5.137	3.439	5.625	.838	6.171	4.868	7.559	2.461	3.750	.755	4.350	8.954	11.990	.323	.804	.654	1.462	0.000	.754
KA	6.681	49.469	.113	.349	3.390	6.116	1.000	1.000	6.336	42.036	.459	4.955	3.237	4.576	2.634	5.148	4.879	11.921	2.308	3.898	2.700	23.333	7.215	11.921	.233	.779	.960	1.557	.452	.826
JC	2.247	17.949	.275	.325	4.545	5.297	1.000	1.000	3.573	11.489	.079	1.282	2.975	3.419	.239	.576	.214	.276	.503	.564	.055	.192	.290	.373	.737	.914	1.657	1.917	.788	.934
DP	9.811	66.996	.416	.607	6.757	11.025	1.000	1.000	1.087	19.349	1.151	6.415	.758	6.655	.128	3.079	.232	.610	.247	1.018	0.000	.438	.478	3.668	.344	3.491	.972	5.741	.593	2.278
DB	1.101	118.112	.096	.332	3.560	7.268	1.000	1.000	3.290	45.179	.057	3.777	2.056	8.936	.195	4.503	.394	23.115	.964	4.231	0.000	69.202	5.805	16.807	.308	1.143	.661	2.353	.395	1.267

	BA:SR		NB:SR		ZR:SR		Y:SR		SR:SR		RB:SR		ZN:SR		CU:SR		NI:SR		CO:SR		CR:SR		V:SR		LA:SR		CE:SR		ND:SR	
AR	.338	9.958	.005	.179	.107	3.396	.019	.419	1.000	1.000	.010	.976	.064	2.189	.015	.795	.097	3.057	.041	1.358	0.000	.913	.120	3.717	.018	.264	.037	.774	.017	.277
PR	.202	5.565	.011	.102	.232	2.287	.035	.266	1.000	1.000	.004	.271	.080	.773	.011	.142	.043	.866	.030	.329	.052	3.051	.132	1.310	.045	.345	.096	.636	.049	[illegible]
PM	.078	14.779	.008	.267	.158	4.345	.022	.550	1.000	1.000	.008	1.400	.027	.876	.010	.106	.007	.265	.006	.204	.010	.230	.031	.867	.028	.646	.060	1.540	[illegible]	.717
KL	.358	6.563	0.000	.113	.112	2.093	.032	.520	1.000	1.000	.030	1.167	.141	3.800	.048	2.500	.247	25.800	.114	4.400	.053	130.900	.345	8.900	0.000	.278	0.000	.593	0.000	[illegible]
KO	.164	4.395	.004	.028	.117	.558	.026	.123	1.000	1.000	.014	.589	.092	.533	.022	.542	.173	.817	.065	.386	.039	.320	.258	1.253	.012	.064	.027	.146	[illegible]	[illegible]
KA	.426	3.368	.007	.055	.123	.891	.024	.158	1.000	1.000	.018	.313	.085	.653	.084	.714	.122	1.061	.055	.429	.109	1.475	.185	1.190	.010	.116	.025	.218	.011	[illegible]
JC	.629	3.981	.024	.081	.396	1.314	.087	.280	1.000	1.000	.022	.305	.271	.845	.039	.137	.022	.077	.044	.149	.015	.043	.025	.093	.071	.206	.146	.464	.079	.237
DP	1.142	23.558	.024	.432	.490	8.258	.052	.920	1.000	1.000	.059	3.491	.131	2.451	.018	.227	.019	.302	.032	.471	0.000	.222	.058	1.470	.083	2.314	.177	3.804	.076	1.519
DB	.065	8.240	.005	.092	.115	1.961	.022	.304	1.000	1.000	.003	.507	.046	1.017	.017	.455	.009	3.379	.021	.659	0.000	11.439	.144	2.008	.012	.240	.029	.492	.015	.291

	BA:RB		NB:RB		ZR:RB		Y:RB		SR:RB		RB:RB		ZN:RB		CU:RB		NI:RB		CO:RB		CR:RB		V:RB		LA:RB		CE:RB		ND:RB	
AR	2.620	48.972	.059	1.421	1.085	33.158	.175	5.614	1.025	97.018	1.000	1.000	.679	18.421	.067	16.667	.441	29.123	.296	12.105	0.000	19.541	1.067	36.491	.162	4.386	.348	8.772	[illegible]	4.737
PR	7.520	71.458	.211	6.625	3.221	120.313	.524	18.600	3.689	254.063	1.000	1.000	1.179	45.625	.146	9.688	.387	51.563	.379	17.813	.263	170.625	2.038	73.000	.552	19.333	1.273	43.438	[illegible]	23.667
PM	5.029	38.188	.145	17.300	2.248	280.500	.333	38.350	.714	132.568	1.000	1.000	.316	49.500	.055	5.000	.115	8.500	.077	10.000	.115	10.500	.465	49.000	.461	53.500	1.004	102.500	.435	47.000
KL	2.105	20.339	0.000	.276	.337	10.000	.149	3.024	.857	33.415	1.000	1.000	.683	27.805	.285	10.976	1.622	98.049	.554	18.637	.315	558.293	1.987	41.707	0.000	1.463	0.000	3.171	0.000	1.463
KO	4.780	21.045	.038	.284	.891	8.349	.195	2.028	1.698	71.651	1.000	1.000	.799	6.972	.724	5.963	1.019	13.119	.542	5.780	.147	4.495	1.974	20.917	.083	.826	.156	[illegible]	0.000	1.101
KA	5.074	29.874	.023	.444	.684	10.495	.202	2.178	3.193	56.040	1.000	1.000	.924	7.228	.798	10.792	1.751	22.376	.714	6.337	.760	41.089	2.143	19.208	.125	1.386	[illegible]	2.073	.041	1.386
JC	9.641	35.072	.241	3.651	3.608	59.302	.780	12.628	3.278	45.116	1.000	1.000	2.320	38.140	.396	3.023	.210	3.488	.432	6.744	.090	.698	.269	4.186	.644	9.302	1.317	20.930	.649	10.698
DP	3.610	19.730	.076	.405	1.552	8.244	.156	.869	.286	16.815	1.000	1.000	.225	3.387	.020	1.254	.054	.327	.067	.536	0.000	.241	.194	1.895	.103	1.765	[illegible]	[illegible]	.147	1.324
DB	4.114	55.246	.065	3.231	1.521	70.000	.265	17.462	1.974	296.923	1.000	1.000	1.269	82.308	.132	44.615	.217	238.462	.533	52.308	0.000	1033.846	3.070	181.538	.268	7.692	[illegible]	[illegible]	.197	13.077

	BA:ZN		NB:ZN		ZR:ZN		Y:ZN		SR:ZN		RB:ZN		ZN:ZN		CU:ZN		NI:ZN		CO:ZN		CR:ZN		V:ZN		LA:ZN		CE:ZN		ND:ZN	
AR	.915	17.769	.048	.191	1.237	3.016	.177	.433	.457	15.660	.054	1.474	1.000	1.000	.036	1.827	.185	2.133	.436	.942	0.000	2.788	1.348	3.596	.121	.404	[illegible]	[illegible]	.164	.327
PR	.629	16.830	.096	.330	1.694	7.426	.322	.849	1.293	12.455	.022	.848	1.000	1.000	.030	.756	.248	1.920	.224	.524	.168	7.610	1.154	2.453	.311	1.119	.731	[illegible]	[illegible]	[illegible]
PM	.253	23.257	.152	.458	2.525	7.122	.309	1.055	1.141	37.731	.020	3.168	1.000	1.000	.049	.359	.098	.365	.136	.290	.083	.385	.461	1.473	.284	1.730	.637	3.249	.249	1.375
KL	.211	21.304	0.000	.058	.356	1.155	.058	.283	.263	7.101	.036	1.464	1.000	1.000	.226	1.464	1.212	6.789	.508	1.158	.250	34.447	1.500	3.814	0.000	.143	0.000	.311	0.000	.205
KO	1.684	12.563	.031	.071	.802	1.433	.178	.291	1.876	10.866	.143	1.252	1.000	1.000	.239	1.593	1.231	1.882	.663	.829	.184	1.043	1.952	3.000	.075	.200	.175	.373	0.000	.143
KA	1.615	14.500	.025	.084	.741	1.612	.219	.309	1.531	11.759	.138	1.083	1.000	1.000	.621	1.493	1.402	3.096	.612	.877	.621	5.685	1.660	2.672	.059	.226	.210	.463	.099	.221
JC	.744	5.250	.088	.104	1.456	1.651	.293	.336	1.183	3.689	.026	.431	1.000	1.000	.079	.194	.067	.091	.150	.187	.018	.056	.093	.116	.244	.287	.506	.598	.246	.247
DP	2.350	25.325	.064	.620	1.525	11.848	.150	1.320	.408	7.635	.295	4.443	1.000	1.000	.055	.974	.060	.348	.153	.373	0.000	.225	.172	2.109	.219	1.020	.393	1.966	.186	.842
DB	.234	30.578	.018	.151	.452	3.534	.112	.486	.984	21.667	.012	.788	1.000	1.000	.036	1.147	.141	4.267	.258	.893	0.000	13.030	1.142	3.904	.052	.575	.107	1.041	.092	.599

Table 4.8b continued

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 BA:CU          NB:CU          ZR:CU          Y :CU          SR:CU          RB:CU          ZN:CU          CU:CU          NI:CU          CO:CU          CR:CU          V :CU          LA:CU          CE:CU          ND:CU
AR   .708 148.200 AR   .046   2.440 AR  1.055  38.600 AR   .172   6.160 AR  1.258  66.400 AR   .060  15.020 AR   .547  27.600 AR  1.000   1.000 AR   .585  45.200 AR   .390  16.400 AR  0.000  17.200 AR  1.134  50.400 AR   .115   4.000 AR   .291   8.800 AR   .152   4.000
PR  4.375 123.417 PR   .296   6.533 PR  5.271 112.000 PR   .824  19.767 PR  7.030  89.333 PR   .103   6.867 PR  1.323  33.333 PR  1.000   1.000 PR  1.282  64.000 PR   .694  17.000 PR  1.359 180.667 PR  2.565  66.333 PR   .903  16.333 PR  2.000  35.000 PR  1.000 [illegible]
PM  2.500 185.600 PM   .843   3.800 PM 16.571  56.500 PM  2.336   7.988 PM  9.417 105.107 PM   .200  18.031 PM  2.786  20.400 PM  1.000   1.000 PM   .786   2.533 PM   .679   3.300 PM  1.043   2.500 PM  3.214  13.250 PM  2.964  10.700 PM  6.296  20.500 PM  2.964 [illegible]
KL   .372  24.053 KL  0.000    .189 KL   .271   5.105 KL   .045   1.174 KL   .400  21.053 KL   .091   3.505 KL   .683   4.421 KL  1.000   1.000 KL   .923  12.000 KL   .387   3.053 KL  1.058  60.884 KL  1.529  11.632 KL  0.000    .632 KL  0.000   1.263 KL  0.000    .632
KO  1.728  15.688 KO   .029    .256 KO   .730   6.000 KO   .162   1.194 KO  1.845  45.500 KO   .168   1.381 KO   .628   4.188 KO  1.000   1.000 KO  1.066   7.875 KO   .467   2.938 KO   .176   1.813 KO  1.620  11.750 KO   .067    .625 KO   .151   1.563 KO  0.070    .750
KA  1.476  12.516 KA   .029    .102 KA   .857   2.322 KA   .194    .380 KA  1.400  11.910 KA   .093   1.253 KA   .670   1.610 KA  1.000   1.000 KA  1.312   3.014 KA   .516   1.000 KA   .525   5.900 KA  1.402   3.186 KA   .058    .220 KA   .243    .542 KA   .111    .216
JC  9.385  46.538 JC   .537   1.208 JC  8.033  19.615 JC  1.737   4.177 JC  7.300  25.826 JC   .331   2.523 JC  5.167  12.615 JC  1.000   1.000 JC   .467   1.154 JC   .967   2.231 JC   .200    .409 JC   .600   1.385 JC  1.433   3.077 JC  2.933   6.923 JC  1.533   3.516
DP  4.354 337.667 DP   .139   3.800 DP  2.195  77.667 DP   .325   7.800 DP  3.062  55.000 DP   .797  50.033 DP  1.027  18.143 DP  1.000   1.000 DP   .097   4.333 DP   .186   4.000 DP  0.000   3.000 DP   .177  16.667 DP   .372  14.750 DP   .735  24.250 DP   .336   4.625
DB   .431  46.644 DB   .032   1.375 DB  1.026  29.250 DB   .222   5.117 DB  2.200  59.265 DB   .022   7.558 DB   .872  27.667 DB  1.000   1.000 DB   .328  16.694 DB   .625  13.000 DB  0.000  38.583 DB  2.023  67.000 DB   .085   4.833 DB   .213  10.000 DB   .042 [illegible]

 BA:NI          NB:NI          ZR:NI          Y :NI          SR:NI          RB:NI          ZN:NI          CU:NI          NI:NI          CO:NI          CR:NI          V :NI          LA:NI          CE:NI          ND:NI
AR   .455  13.132 AR   .025    .419 AR   .773   8.519 AR   .114    .959 AR   .327  10.294 AR   .034   2.268 AR   .469   5.407 AR   .022   1.711 AR  1.000   1.000 AR   .300   2.519 AR  0.000   1.524 AR   .886   9.593 AR   .075    .667 AR   .195   1.444 AR   .102    .044
PR   .503  42.160 PR   .067   1.332 PR  1.109  30.000 PR   .206   3.428 PR  1.155  23.485 PR   .019   2.584 PR   .521   4.040 PR   .016    .780 PR  1.000   1.000 PR   .264   1.160 PR   .680   4.255 PR   .886   6.320 PR   .201   4.520 PR   .445   6.750 PR   .232   3.360
PM  1.471  80.680 PM   .971   2.035 PM 15.632  33.000 PM  2.021   4.512 PM  3.767 133.773 PM   .118   8.681 PM  2.741  10.200 PM   .395   1.273 PM  1.000   1.000 PM   .658   1.650 PM   .500   1.364 PM  3.158   5.765 PM  1.667   6.294 PM  4.148  12.059 PM  2.467   6.641
KL   .031   7.903 KL  0.000    .033 KL   .066    .898 KL   .070    .206 KL   .039   4.049 KL   .010    .617 KL   .147    .825 KL   .083   1.084 KL  1.000   1.000 KL   .171    .537 KL   .194   5.694 KL   .345   2.222 KL  0.000    .111 KL  0.000    .222 KL  0.000    .111
KO   .895   9.438 KO   .021    .047 KO   .628    .874 KO   .132    .205 KO  1.224   5.778 KO   .076    .981 KO   .531    .813 KO   .127    .938 KO  1.000   1.000 KO   .373    .568 KO   .144    .622 KO  1.292   2.000 KO   .049    .127 KO   .118    .274 KO  0.000    .133
KA   .994   8.904 KA   .009    .054 KA   .284   1.069 KA   .084    .205 KA   .942   8.221 KA   .045    .571 KA   .323    .713 KA   .332    .762 KA  1.000   1.000 KA   .283    .535 KA   .383   1.957 KA   .858   1.772 KA   .041    .129 KA   .041    .246 KA   .038    .138
JC  8.133  70.000 JC  1.047   1.309 JC 17.000  22.455 JC  3.620   4.673 JC 12.933  45.692 JC   .287   4.771 JC 10.933  14.909 JC   .867   2.143 JC  1.000   1.000 JC  1.933   2.636 JC   .200    .750 JC  1.154   1.545 JC  2.667   4.273 JC  6.091   8.909 JC  3.067   4.364
DP 31.100 201.167 DP   .806   2.250 DP 13.556  45.167 DP  1.639   4.314 DP  3.308  51.364 DP  3.055  18.667 DP  2.875  16.636 DP   .231  10.273 DP  1.000   1.000 DP   .769   2.714 DP  0.000   1.200 DP  1.417   8.833 DP  1.313  11.500 DP  3.644  19.400 DP  1.692   7.714
DB   .081  43.000 DB   .005    .786 DB   .181  18.429 DB   .043   2.536 DB   .296 106.053 DB   .004   4.617 DB   .234   7.095 DB   .060   3.048 DB  1.000   1.000 DB   .177   3.429 DB  0.000   4.335 DB   .448  25.211 DB   .013   3.000 DB   .047   5.429 DB   .021   3.071

 BA:CO          NB:CO          ZR:CO          Y :CO          SR:CO          RB:CO          ZN:CO          CU:CO          NI:CO          CO:CO          CR:CO          V :CO          LA:CO          CE:CO          ND:CO
AR  1.486  19.569 AR   .082    .260 AR  2.282   4.106 AR   .308    .590 AR   .736  24.533 AR   .083   3.380 AR  1.061   2.294 AR   .061   2.563 AR   .397   3.328 AR  1.000   1.000 AR  0.000   3.328 AR  2.562   4.095 AR   .194    .556 AR   .537   1.176 AR   .278    .608
PR  1.456  46.077 PR   .242   1.148 PR  4.000  25.862 PR   .783   2.955 PR  3.042  33.214 PR   .056   2.641 PR  1.907   4.462 PR   .059   1.442 PR   .862   3.793 PR  1.000   1.000 PR   .586  16.138 PR  3.362   6.057 PR   .732   3.897 PR  1.590   7.654 PR   .879   3.577
PM  1.250 111.360 PM   .939   2.111 PM 15.606  35.684 PM  1.912   4.453 PM  4.913 154.895 PM   .100  13.022 PM  3.448   7.368 PM   .303   1.474 PM   .606   1.520 PM  1.000   1.000 PM   .515   1.579 PM  2.848   7.053 PM  1.731   7.368 PM [illegible]  14.842 PM  1.848   9.789
KL   .182  26.250 KL  0.000    .097 KL   .386   1.794 KL   .115    .384 KL   .227   8.737 KL   .054   1.804 KL   .864   1.967 KL   .328   2.583 KL  1.862   5.864 KL  1.000   1.000 KL   .362  30.118 KL  2.023   4.407 KL  0.000    .238 KL  0.000    .506 KL  0.000    .270
KO  2.032  17.507 KO   .046    .103 KO  1.202   2.043 KO   .267    .406 KO  2.592  15.489 KO   .173   1.846 KO  1.206   1.507 KO   .340   2.141 KO  1.762   2.681 KO  1.000   1.000 KO   .271   1.366 KO  2.737   4.000 KO   .101    .254 KO   .234    .532 KO  0.000    .255
KA  2.460  18.578 KA   .029    .129 KA   .870   2.322 KA   .257    .433 KA  2.333  18.216 KA   .158   1.400 KA  1.141   1.635 KA  1.000   1.937 KA  1.870   3.531 KA  1.000   1.000 KA  1.016   6.484 KA  2.714   3.373 KA   .086    .306 KA   .246    .594 KA   .116    .293
JC  4.207  35.000 JC   .497    .633 JC  8.310  10.351 JC  1.772   1.988 JC  6.690  22.846 JC   .148   2.313 JC  5.345   6.667 JC   .448   1.034 JC   .379    .517 JC  1.000   1.000 JC   .103    .375 JC   .577    .730 JC  1.379   1.708 JC  3.034   3.379 JC  1.541   1.808
DP 15.357 134.111 DP   .418   1.900 DP  9.846  36.333 DP   .982   4.047 DP  2.125  31.389 DP  1.867  15.010 DP  2.682   6.536 DP   .250   5.381 DP   .368   1.300 DP  1.000   1.000 DP  0.000    .900 DP   .895   6.467 DP  1.400   5.644 DP  2.571  11.111 DP  1.214   5.000
DB   .368  55.040 DB   .028    .311 DB   .991   6.623 DB   .236   1.037 DB  1.517  46.860 DB   .019   1.876 DB  1.119   3.871 DB   .077   1.600 DB   .292   5.638 DB  1.000   1.000 DB  0.000  19.765 DB  2.445   7.484 DB   .073    .875 DB   .211   1.932 DB   .100   1.068

 BA:CR          NB:CR          ZR:CR          Y :CR          SR:CR          RB:CR          ZN:CR          CU:CR          NI:CR          CO:CR          CR:CR          V :CR          LA:CR          CE:CR          ND:CR
AR   .455  32.333 AR   .031   1.356 AR   .859  21.444 AR   .114   2.750 AR  1.095  79.455 AR   .051   8.344 AR   .359  11.500 AR   .058  11.800 AR   .656  11.000 AR   .300   6.200 AR  1.000   1.000 AR  1.042  16.400 AR   .075   2.727 AR   .225   5.500 AR   .103   2.500
PR   .152  42.000 PR   .014   1.959 PR   .261  44.118 PR   .049   5.041 PR   .328  19.294 PR   .006   3.800 PR   .131   5.941 PR   .006    .736 PR   .235   1.471 PR   .062   1.706 PR  1.000   1.000 PR   .208   9.294 PR   .047   6.647 PR   .105   9.941 PR   .154   4.941
PM  1.190 120.909 PM   .737   2.618 PM 15.467  43.455 PM  2.180   6.173 PM  4.346  98.100 PM   .095   8.681 PM  2.600  12.000 PM   .400    .958 PM   .733   2.000 PM   .633   1.941 PM  1.000   1.000 PM  3.000   8.727 PM  1.875   8.455 PM  4.667  17.364 PM  2.708 [illegible]
KL   .006  21.762 KL  0.000    .171 KL   .013   4.619 KL   .004   1.062 KL   .008  19.048 KL   .002   3.171 KL   .029   4.000 KL   .016    .945 KL   .176   5.143 KL   .033   2.762 KL  1.000   1.000 KL   .068  10.524 KL  0.000    .571 KL  0.000   1.143 KL  0.000    .571
KO  2.612  51.000 KO   .049    .288 KO  1.010   6.063 KO   .230   1.325 KO  3.124  25.688 KO   .222   6.806 KO   .959   5.438 KO   .552   5.688 KO  1.608   6.938 KO   .732   3.688 KO  1.000   1.000 KO  2.361  13.438 KO   .111    .615 KO   .258   1.438 KO  0.000    .438
KA   .591  12.133 KA   .005    .105 KA   .145   1.879 KA   .043    .370 KA   .679   9.188 KA   .024   1.315 KA   .176   1.609 KA   .169   1.906 KA   .511   2.609 KA   .154    .984 KA  1.000   1.000 KA   .467   2.818 KA   .027    .288 KA   .041    .311 KA   .019    .258
JC 40.667 151.250 JC  1.578   5.233 JC 25.889  85.000 JC  5.200  18.100 JC 23.444  66.000 JC  1.433  11.133 JC 17.778  54.667 JC  2.444   5.000 JC  1.333   5.000 JC  2.667   9.667 JC  1.000   1.000 JC  1.667   6.000 JC  4.556  13.333 JC  9.000  30.333 JC  4.556  15.333
DP 38.875 805.000 DP  1.375  15.100 DP 18.333 313.000 DP  2.283  39.200 DP  4.500 262.000 DP  4.144  68.133 DP  4.444  86.000 DP   .333  28.250 DP   .833   7.000 DP  1.111  19.000 DP  1.000   1.000 DP  1.583  59.000 DP  3.000  72.000 DP  5.667 124.000 DP  2.444  54.000
DB   .019 501.000 DB   .002   9.500 DB   .053 223.000 DB   .014  34.500 DB   .087 423.000 DB   .001  22.200 DB   .077 140.000 DB   .026  56.000 DB   .231  35.000 DB   .051  62.000 DB  1.000   1.000 DB   .170 372.000 DB   .005  31.000 DB   .312  69.000 DB   .337 [illegible]

 BA:V           NB:V           ZR:V           Y :V           SR:V           RB:V           ZN:V           CU:V           NI:V           CO:V           CR:V           V :V           LA:V           CE:V           ND:V
AR   .437   5.424 AR   .028    .083 AR   .705   1.313 AR   .100    .171 AR   .269   8.316 AR   .027    .937 AR   .278    .742 AR   .020    .882 AR   .104   1.128 AR   .244    .390 AR  0.000    .959 AR  1.000   1.000 AR   .069    .181 AR   .151    .347 AR [illegible]   .164
PR   .371   9.314 PR   .156    .211 PR  1.074   4.747 PR   .203    .542 PR   .763   7.582 PR   .014    .491 PR   .408    .866 PR   .015    .390 PR   .158   1.128 PR   .150    .297 PR   .108   4.300 PR  1.000   1.000 PR   .184    .715 PR   .431   1.312 PR   .226    .614
PM   .255  21.273 PM   .233    .361 PM  4.000   6.169 PM   .471    .825 PM  1.153  32.700 PM   .020   2.150 PM   .679   2.170 PM   .075    .311 PM   .173    .317 PM   .142    .351 PM   .115    .333 PM  1.000   1.000 PM   .417   1.174 PM  1.037   2.333 PM   .602   1.344
KL   .090   6.229 KL  0.000    .027 KL   .132    .502 KL   .029    .117 KL   .112   2.895 KL   .024    .503 KL   .262    .667 KL   .086    .654 KL   .450   2.899 KL   .227    .494 KL   .095  14.708 KL  1.000   1.000 KL  0.000    .067 KL  0.000    .142 KL  0.000    .276
KO   .561   5.140 KO   .013    .132 KO   .399    .529 KO   .083    .112 KO   .798   3.872 KO   .048    .507 KO   .333    .512 KO   .085    .617 KO   .500    .774 KO   .250    .365 KO   .074    .424 KO  1.000   1.000 KO   .031    .075 KO   .069    .144 KO  0.000    .172
KA   .886   5.975 KA   .003    .046 KA   .284    .744 KA   .094    .139 KA   .840   5.401 KA   .052    .467 KA   .374    .502 KA   .314    .713 KA   .564   1.165 KA   .297    .368 KA   .355   2.139 KA  1.000   1.000 KA   .026    .102 KA   .081    .133 KA   .035    .135
JC  6.778  49.412 JC   .847    .347 JC 13.389  15.667 JC  2.678   3.447 JC 10.778  39.600 JC   .239   3.711 JC  8.593  10.733 JC   .722   1.667 JC   .647    .867 JC  1.370   1.733 JC   .167    .600 JC  1.000   1.000 JC  2.185   2.800 JC  4.593   5.300 JC  2.111   7.133
DP  5.655  16.941 DP   .122    .371 DP  2.415  14.471 DP   .273   2.094 DP   .680  17.300 DP   .528   5.165 DP   .474   5.800 DP   .060   5.650 DP   .113    .706 DP   .155   1.118 DP  0.000    .632 DP  1.000   1.000 DP   .216   2.529 DP   .408   4.424 DP   .343   3.234
DB   .106  14.041 DB   .009    .054 DB   .301   1.081 DB   .059    .172 DB   .498   6.424 DB   .006    .326 DB   .256    .876 DB   .015    .494 DB   .040   2.234 DB   .134    .409 DB  0.000   5.875 DB  1.000   1.000 DB   .039    .147 DB   .064    .322 DB   .134    .174

 BA:LA          NB:LA          ZR:LA          Y :LA          SR:LA          RB:LA          ZN:LA          CU:LA          NI:LA          CO:LA          CR:LA          V :LA          LA:LA          CE:LA          ND:LA
AR  4.952  53.500 AR   .232    .850 AR  5.613  13.357 AR   .845   1.650 AR  3.786  56.615 AR   .228   6.157 AR  2.476   8.286 AR   .250   8.667 AR  1.500  13.313 AR  1.800   5.143 AR  0.000  13.313 AR  5.533  14.389 AR  1.000   1.000 AR  1.548   3.000 AR   .410   1.423
PR  1.729  28.689 PR   .245    .447 PR  4.117   9.133 PR   .674   1.237 PR  2.903  22.143 PR   .052   1.812 PR   .894   3.212 PR   .061   1.107 PR   .221   5.000 PR   .257   1.365 PR   .150  21.273 PR  1.399   5.442 PR  1.000   1.000 PR  1.496   2.442 PR   .743   1.176
PM   .234  26.769 PM   .265    .729 PM  4.117  12.000 PM   .604   1.538 PM  1.548  35.458 PM   .019   2.167 PM   .578   3.517 PM   .093    .337 PM   .159    .600 PM   .136    .578 PM   .118    .533 PM   .952   2.400 PM  1.000   1.000 PM  1.394   2.444 PM   .737   1.444
KL  8.167 367.500 KL  0.000   1.300 KL  6.182  43.000 KL  1.560  12.500 KL  3.609  99.609 KL   .683  25.250 KL  7.000  78.000 KL  1.583  52.000 KL  9.000 516.000 KL  4.200  88.000 KL  1.7502618.000 KL 15.000 178.000 KL  1.000   1.000 KL  0.000  13.000 KL  0.000   3.750
KO 14.222 109.818 KO   .244    .850 KO  5.688  13.625 KO  1.244   3.100 KO 15.563  86.778 KO  1.211  12.100 KO  5.000  13.375 KO  1.600  14.875 KO  7.975  20.375 KO  3.938   9.875 KO  1.625   9.000 KO 13.375  32.250 KO  1.000   1.000 KO  1.111   3.750 KO  0.000   1.875
KA  9.118  43.091 KA   .182   1.020 KA  5.455  23.800 KA  1.284   4.300 KA  8.647 103.222 KA   .721   7.973 KA  4.421  17.000 KA  4.538  17.200 KA  7.769  24.600 KA  3.263  11.600 KA  3.474  37.545 KA  9.789  38.400 KA  1.000   1.000 KA  1.545   5.600 KA   .714   3.400
JC  3.050  20.308 JC   .306    .347 JC  5.255   6.492 JC  1.094   1.358 JC  4.850  14.143 JC   .109   1.553 JC  3.489   4.100 JC   .325    .698 JC   .234    .375 JC   .585    .725 JC   .075    .220 JC   .357    .458 JC  1.000   1.000 JC  1.976   2.250 JC   .366   1.150
DP  3.305  53.381 DP   .125   1.357 DP  2.669  25.952 DP   .286   2.490 DP   .432  12.021 DP   .567   9.733 DP   .981   4.575 DP   .068   2.690 DP   .085    .762 DP   .184    .714 DP  0.000    .333 DP   .395   4.619 DP  1.000   1.000 DP  1.444   2.813 DP   .653   1.714
DB  2.500 141.882 DB   .185    .757 DB  5.429  13.625 DB   .845   3.250 DB  4.163  45.625 DB   .130   3.736 DB  1.738  19.375 DB   .207  11.933 DB   .333  75.125 DB  1.143  13.750 DB  0.000 134.286 DB  6.786  33.625 DB  1.000   1.000 DB  1.556   3.750 DB   .636   2.125

 BA:CE          NB:CE          ZR:CE          Y :CE          SR:CE          RB:CE          ZN:CE          CU:CE          NI:CE          CO:CE          CR:CE          V :CE          LA:CE          CE:CE          ND:CE
AR  1.926  22.537 AR   .104    .322 AR  2.907   5.497 AR   .430    .790 AR  1.293  27.250 AR   .114   2.873 AR  1.268   3.744 AR   .114   3.434 AR   .692   5.136 AR   .850   1.864 AR  0.000   4.438 AR  2.885   5.641 AR   .333    .646 AR  1.000   1.000 AR   .370    .613
PR   .680  11.844 PR   .114    .197 PR  1.994   4.618 PR   .314    .565 PR  1.572  10.410 PR   .023    .786 PR   .503   1.369 PR   .029    .500 PR   .148   2.245 PR   .131    .592 PR   .101   9.551 PR   .759   2.320 PR   .393    .669 PR  1.000   1.000 PR   .454    .569
PM   .122  13.385 PM   .134    .293 PM  2.169   4.821 PM   .300    .619 PM   .643  14.722 PM   .010    .996 PM   .305   1.545 PM   .049    .159 PM   .083    .241 PM   .067    .250 PM   .058    .214 PM   .434    .964 PM   .402    .527 PM  1.000   1.000 PM   .423    .660
KL  2.000 294.000 KL  0.000    .400 KL  2.667  32.000 KL   .731  16.700 KL  1.688 192.000 KL   .315  27.600 KL  3.217  59.000 KL   .792  75.000 KL  4.500 220.000 KL  1.969  55.000 KL   .8751119.000 KL  7.031 225.000 KL  0.000   5.000 KL  1.000   1.000 KL  0.000   4.000
KO  4.927  44.741 KO   .119    .367 KO  3.129   6.467 KO   .444   1.520 KO  6.871  17.278 KO   .419   6.347 KO  2.477   5.727 KO   .640   6.611 KO  3.581   8.444 KO  1.880   4.200 KO   .514   3.880 KO  6.935  14.400 KO   .267    .900 KO  1.000   1.000 KO  0.000    .750
KA  4.944  40.350 KA   .118    .265 KA  3.263   5.304 KA   .642   1.341 KA  4.594  40.331 KA   .374   5.159 KA  2.158   4.765 KA  1.844   4.118 KA  4.040  12.412 KA  1.684   4.059 KA  1.882  24.294 KA  5.029  12.412 KA   .179    .647 KA  1.000   1.000 KA   .375    .607
JC  1.356  10.370 JC   .147    .189 JC  2.521   3.088 JC   .526    .603 JC  2.155   6.828 JC   .048    .759 JC  1.673   1.975 JC   .144    .341 JC   .112    .167 JC   .296    .330 JC   .033    .111 JC   .172    .218 JC   .444    .506 JC  1.000   1.000 JC   .462    .540
DP  2.019  19.263 DP   .076    .483 DP  1.424   9.237 DP   .174   1.023 DP   .263   5.650 DP   .329   3.464 DP   .509   2.542 DP   .041   1.361 DP   .052    .271 DP   .090    .389 DP  0.000    .176 DP   .207   1.544 DP   .356    .604 DP  1.000   1.000 DP   .380    .619
DB   .862  44.300 DB   .049    .353 DB  2.495   6.200 DB   .425   1.313 DB  2.034  34.250 DB   .045   1.792 DB   .961   9.333 DB   .109   4.706 DB   .184  21.467 DB   .518   4.733 DB  0.000  86.000 DB  3.136  14.733 DB   .267    .643 DB  1.000   1.000 DB   .289    .424

 BA:ND          NB:ND          ZR:ND          Y :ND          SR:ND          RB:ND          ZN:ND          CU:ND          NI:ND          CO:ND          CR:ND          V :ND          LA:ND          CE:ND          ND:ND
AR  4.409  54.153 AR   .136    .661 AR  5.883  10.393 AR   .437   1.390 AR  2.650  58.990 AR   .211   5.561 AR  3.059   6.083 AR   .217   6.560 AR  1.125   9.826 AR  1.645   3.600 AR  0.000   9.682 AR  5.935  11.000 AR   .700   1.235 AR  1.615   2.790 AR  1.000   1.000
PR  1.339  24.581 PR   .202    .396 PR  3.833   8.929 PR   .643   1.122 PR  3.145  20.513 PR   .042   1.586 PR  1.075   2.609 PR   .052   1.000 PR   .298   4.314 PR   .280   1.137 PR   .202  18.353 PR  1.624   4.422 PR   .727   1.345 PR  1.759   2.203 PR  1.000   1.000
PM   .266  29.000 PM   .216    .508 PM  3.645   8.441 PM   .455   1.055 PM  1.395  35.458 PM   .021   2.298 PM   .725   3.344 PM   .091    .337 PM   .151    .415 PM   .102    .541 PM   .125    .369 PM   .720   1.662 PM   .692   1.255 PM  1.516   2.342 PM  1.000   1.000
KL  8.000 294.000 KL  0.000   1.167 KL  2.467  23.333 KL  1.193   8.159 KL  3.176  90.100 KL   .683  26.567 KL  4.967  39.333 KL  1.583  51.667 KL  9.000 258.000 KL  3.706  44.000 KL  1.7501309.000 KL 13.235 107.000 KL  0.000   2.000 KL  0.000   4.567 KL  1.000   1.000
KO 10.667  92.321 KO   .221    .771 KO  5.842  15.714 KO  1.327   3.043 KO 11.176  67.100 KO   .908  12.100 KO  5.184  15.000 KO  1.333  13.700 KO  7.533  23.000 KO  3.917  10.857 KO  1.588   9.571 KO 13.913  29.714 KO   .533   1.364 KO  1.333   3.444 KO  1.000   1.000
KA  9.688  73.143 KA   .253    .619 KA  4.632  12.211 KA  1.211   2.213 KA  9.188  32.400 KA   .721  10.963 KA  4.526  10.125 KA  4.632   9.000 KA  7.235  26.375 KA  3.412   8.625 KA  3.882  51.625 KA 10.579  26.375 KA   .294   1.400 KA  1.647   2.667 KA  1.000   1.000
JC  2.652  21.228 JC   .302    .411 JC  5.200   6.719 JC  1.071   1.268 JC  4.217  12.638 JC   .097   1.452 JC  3.370   4.070 JC   .283    .652 JC   .229    .326 JC   .551    .449 JC   .065    .220 JC   .314    .474 JC   .879   1.035 JC  1.951   2.175 JC  1.000   1.000
DP  5.765  46.345 DP   .141    .732 DP  4.091  15.139 DP   .439   1.686 DP   .662  13.140 DP   .756   6.323 DP  1.133   5.382 DP   .104   2.974 DP   .130    .591 DP   .200    .424 DP  0.000    .409 DP   .436   2.865 DP   .583   1.532 DP  1.639   2.629 DP  1.000   1.000
DB  1.471 119.652 DB   .125    .482 DB  4.684  11.429 DB   .780   2.529 DB  3.442  66.143 DB   .076   5.078 DB  1.498  12.143 DB   .222  10.957 DB   .326  48.625 DB   .936  10.000 DB  0.000 144.571 DB  5.617  29.143 DB   .471   1.571 DB  1.214   3.571 DB  1.000   1.000
```

Table 4.8c Ranges of major:trace element ratios for each formation

	SI:BA		TI:BA		AL:BA		FE:BA		MN:BA		MG:BA		CA:BA		NA:BA		K:BA		P:BA	
AR	262.97	2494.08	5.78	74.78	82.32	859.43	35.67	988.57	1.17	12.78	12.21	359.31	28.30	571.76	1.19	255.46	4.75	97.39	.77	10.30
PR	167.87	3183.39	5.21	107.34	46.04	939.35	34.85	976.63	.37	19.18	11.83	573.94	18.93	481.91	12.65	261.01	5.59	35.36	1.63	41.02
PM	100.31	12384.23	2.96	293.99	29.43	3216.03	20.98	1784.87	.09	27.88	2.30	400.39	6.26	583.20	1.36	1946.75	9.37	38.84	.92	95.14
KL	162.89	15427.12	1.91	149.88	52.71	2841.68	43.34	5319.81	.84	82.29	41.55	6580.24	26.38	3600.30	4.82	248.31	9.54	64.40	.14	10.64
KO	207.00	1944.82	4.56	43.60	66.16	622.34	77.41	643.67	1.08	7.87	27.00	226.13	36.74	595.21	19.71	240.95	11.06	44.49	.38	4.57
KA	225.92	1709.79	5.42	43.09	64.19	532.37	68.35	521.62	.78	5.50	23.43	164.39	38.29	282.32	4.85	192.42	7.38	46.07	.59	4.56
JC	193.99	2559.97	7.26	51.20	81.16	518.02	93.92	725.20	1.48	10.79	6.39	53.87	16.68	169.89	25.75	165.41	10.21	22.93	2.58	18.31
DP	195.43	1076.22	2.73	15.19	38.44	219.55	10.49	224.88	.13	2.18	1.60	68.08	2.96	80.38	1.46	101.62	13.34	69.33	.67	3.57
DB	99.87	9761.18	1.73	211.74	28.39	2813.76	23.48	3600.51	.39	55.76	10.65	1859.65	12.86	3121.81	3.92	495.59	9.85	44.38	.35	33.34

	SI:NB		TI:NB		AL:NB		FE:NB		MN:NB		MG:NB		CA:NB		NA:NB		K:NB		P:NB	
AR	23132.47	46043.15	615.62	1201.18	6387.18	12886.05	3524.70	15310.50	66.39	236.65	1206.00	5832.65	1543.25	11370.23	117.53	4552.57	239.48	3772.89	66.04	191.22
PR	7266.21	19918.16	300.11	741.04	2703.72	5826.00	2150.66	6492.26	22.59	117.08	536.00	3363.67	605.08	4648.24	385.64	1873.98	53.09	1531.92	86.10	267.42
PM	5605.74	13071.36	209.73	271.30	2115.54	2906.66	1208.99	2957.79	4.57	37.65	143.66	1015.37	400.93	2401.51	102.54	1406.61	16.80	1680.65	64.02	83.77
KL	41759.51	2394490.20	593.60	24519.55	11939.62	793420.70	13139.55	639951.00	189.67	11617.50	7001.50	549936.00	2352.55	870504.60	182.43	123897.30	761.02	88831.40	50.79	1440.12
KO	36567.18	98241.90	901.89	2034.17	11348.81	26684.02	12774.34	30025.97	176.02	400.60	4102.23	9668.79	6715.91	24576.46	2978.51	12506.31	910.54	5465.48	80.01	198.64
KA	32718.00	122832.72	824.50	3384.18	10187.39	39353.46	9981.56	43747.47	105.18	542.15	3082.00	21979.35	5214.66	29445.64	1014.43	7567.38	717.46	4441.57	87.28	331.66
JC	10031.12	21289.74	389.49	427.85	4025.38	4815.88	5006.39	5789.48	70.90	91.43	322.10	418.64	921.59	1672.60	1285.33	1935.39	79.32	1037.75	136.61	162.06
DP	9584.16	32361.30	211.45	409.04	4017.11	5766.09	937.71	5966.31	8.15	97.49	109.64	2000.01	263.31	2406.86	130.16	2530.51	391.90	4173.04	36.86	100.41
DB	16197.53	124328.40	652.06	2220.65	4221.57	36257.05	5931.35	39865.80	62.97	742.23	725.56	25537.05	1806.24	33805.31	174.92	11425.26	158.13	4257.44	93.88	352.76

	SI:ZR		TI:ZR		AL:ZR		FE:ZR		MN:ZR		MG:ZR		CA:ZR		NA:ZR		K:ZR		P:ZR	
AR	1165.65	1937.22	36.35	44.86	356.93	539.44	190.37	597.45	3.87	10.35	65.14	192.56	75.82	560.29	6.35	213.10	13.99	203.78	3.24	6.68
PR	336.00	1097.53	13.32	41.12	120.05	340.05	102.21	367.19	1.29	7.09	23.80	202.65	27.98	269.71	21.23	103.26	3.22	86.07	3.82	15.88
PM	343.24	696.96	12.80	14.35	131.26	159.38	73.25	178.04	.29	2.27	9.75	61.12	24.35	122.15	6.37	86.75	1.04	104.40	4.00	4.50
KL	2254.27	8551.75	32.04	87.57	644.53	2833.65	709.30	2503.44	11.06	41.49	259.85	3096.58	134.43	3108.95	9.85	697.74	24.30	432.19	2.74	7.62
KO	2232.60	2866.72	55.75	62.74	705.41	875.38	802.21	979.85	8.87	14.52	224.24	374.46	358.65	837.22	162.34	583.63	31.02	240.76	4.82	6.43
KA	1800.34	4094.42	50.29	112.81	615.52	1311.78	604.64	1458.25	6.50	18.07	190.57	732.65	305.73	981.52	43.99	306.38	29.76	191.64	5.01	11.06
JC	612.87	1315.54	24.50	26.17	247.84	292.59	305.87	346.96	4.28	5.46	21.00	25.78	60.12	99.45	79.14	129.29	4.88	67.70	8.76	9.90
DP	501.19	1583.34	11.63	19.88	210.07	275.48	46.71	280.40	.43	5.45	6.12	91.22	12.88	118.17	6.37	131.33	17.87	190.27	1.93	4.62
DB	761.42	3315.42	31.91	63.58	198.45	1002.32	277.93	1151.25	2.98	21.40	34.32	901.33	84.91	909.46	8.28	341.84	7.30	223.61	4.49	10.69

	SI:Y		TI:Y		AL:Y		FE:Y		MN:Y		MG:Y		CA:Y		NA:Y		K:Y		P:Y	
AR	7670.60	12522.68	214.70	349.71	2368.45	3526.28	1182.71	4436.73	24.89	65.03	404.67	1440.22	673.31	3480.90	39.44	1335.42	90.57	1265.99	28.81	46.74
PR	2480.40	6790.28	108.73	204.20	1050.57	1934.90	882.42	1847.09	9.73	35.08	208.27	1089.12	206.55	1528.23	150.97	638.86	15.91	529.55	33.46	75.55
PM	2753.65	4930.01	92.80	118.08	942.71	1239.79	524.77	1453.11	1.98	18.41	67.49	498.84	190.04	866.60	49.27	634.53	7.58	807.50	28.50	37.03
KL	10886.03	39099.03	147.03	468.31	3112.46	13332.22	3425.27	12893.29	46.24	179.59	1130.29	10123.44	818.28	5727.00	47.56	4247.11	80.34	1997.29	9.15	30.74
KO	9368.16	14408.65	236.67	302.28	3136.85	4370.19	3613.57	4770.91	43.78	71.13	1127.07	1781.31	1631.13	3447.38	715.98	2679.92	127.72	1037.75	20.67	28.00
KA	10503.09	13879.40	261.58	382.39	3128.08	4446.72	3187.43	4943.22	36.25	61.26	1076.04	2483.54	1674.88	3373.25	240.13	1598.49	143.40	942.48	27.57	37.48
JC	3246.59	6549.59	115.04	138.47	1163.88	1456.71	1550.31	1685.73	19.47	27.85	97.97	134.28	299.32	468.59	371.63	608.74	22.93	337.05	41.15	52.45
DP	4499.98	15765.76	125.13	197.11	1850.39	2754.96	514.60	2594.82	3.83	42.37	47.65	894.45	128.28	1121.00	63.41	1258.63	175.26	1894.56	18.91	48.56
DB	4912.86	14548.84	186.51	284.14	1280.44	4464.04	1795.54	4653.99	17.37	86.51	200.10	3643.66	547.85	4157.51	48.24	1542.68	29.26	1314.78	22.66	70.11

	SI:SR		TI:SR		AL:SR		FE:SR		MN:SR		MG:SR		CA:SR		NA:SR		K:SR		P:SR	
AR	181.47	5114.94	4.67	146.48	49.62	1477.05	54.45	1852.75	.63	19.00	15.73	543.84	31.32	421.30	2.95	389.15	3.44	371.84	.68	14.49
PR	195.87	1231.44	5.78	52.18	54.11	377.58	49.68	467.56	.72	9.32	18.28	216.35	33.86	338.15	16.70	107.13	1.53	90.89	1.99	19.94
PM	104.82	2686.52	2.18	59.53	23.31	654.36	15.26	482.15	.24	5.48	2.17	180.37	19.26	139.78	8.62	239.75	1.69	346.77	.67	17.80
KL	445.49	12341.70	6.96	119.90	128.41	2273.34	142.02	4255.85	2.18	65.83	63.01	5264.19	91.07	2880.24	20.61	526.90	7.27	271.11	.58	8.51
KO	318.74	1458.61	7.15	32.68	102.00	434.09	105.49	478.22	1.17	7.12	29.57	174.98	50.76	320.41	27.64	301.88	3.61	126.71	.68	2.83
KA	280.44	1802.83	6.55	45.43	81.82	561.35	79.73	550.00	1.42	5.80	30.25	169.82	69.47	287.34	9.80	202.89	5.57	69.27	.66	4.81
JC	481.99	1609.88	10.07	32.20	115.13	325.77	134.93	456.05	1.70	6.79	8.53	33.88	39.34	106.84	45.59	142.28	6.42	74.76	3.70	11.52
DP	590.00	3579.51	7.89	135.25	115.32	1734.66	74.15	1719.70	1.23	16.70	8.71	256.57	33.75	221.46	28.10	379.19	25.86	1030.99	1.86	34.18
DB	141.77	2089.78	4.82	69.53	29.97	671.03	39.74	733.50	.38	13.50	4.43	460.02	37.85	361.68	1.07	291.85	1.72	91.72	.92	18.97

	SI:RB		TI:RB		AL:RB		FE:RB		MN:RB		MG:RB		CA:RB		NA:RB		K:RB		P:RB	
AR	1522.30	46551.40	45.97	1205.31	476.80	14077.52	206.49	14000.27	11.23	190.23	70.65	5934.79	288.77	7071.77	6.89	4581.56	203.13	688.37	5.77	178.39
PR	2299.79	89553.84	95.02	3369.19	825.54	25565.19	691.70	25331.39	8.20	361.43	210.56	14886.56	191.51	14629.02	152.15	9320.12	140.50	639.95	28.45	1153.55
PM	1347.84	154802.88	31.13	3674.94	314.10	40200.34	174.85	22310.86	.66	348.53	41.35	5004.90	76.53	7289.94	18.26	24334.32	165.76	357.95	9.63	1189.19
KL	2370.78	61822.20	27.78	608.27	755.55	13658.52	630.84	18525.57	12.27	321.13	378.46	20987.34	121.68	13387.55	31.71	2967.60	120.16	413.92	1.99	48.82
KO	2260.14	22838.28	49.66	512.05	707.15	7308.22	741.79	7558.65	10.38	92.37	247.51	2655.41	382.58	6989.63	158.05	1980.67	200.50	281.74	4.72	53.65
KA	2801.20	24948.05	75.42	620.87	897.46	7211.06	896.01	8517.45	12.36	115.02	334.85	3922.49	527.79	6736.58	129.11	2828.10	101.29	411.55	7.56	60.06
JC	4514.47	72631.79	93.87	1452.74	974.61	14697.31	1223.95	20575.37	19.71	306.20	77.63	1528.53	252.40	4820.07	466.46	4692.95	180.21	382.61	32.93	519.62
DP	1336.34	9921.12	26.36	132.75	385.43	1939.19	113.03	1463.40	1.14	20.75	12.36	571.94	20.00	974.20	9.89	842.80	112.07	478.18	5.32	31.30
DB	2655.20	187715.03	71.64	4071.99	569.17	54110.75	881.16	69240.60	10.21	1072.38	130.03	35762.54	328.59	60034.80	56.77	13393.25	138.07	655.42	8.02	641.17

	SI:ZN		TI:ZN		AL:ZN		FE:ZN		MN:ZN		MG:ZN		CA:ZN		NA:ZN		K:ZN		P:ZN	
AR	1828.28	5252.86	47.56	119.06	562.29	1462.70	304.27	1090.80	7.16	20.85	104.11	520.67	119.44	955.22	10.15	577.83	21.66	448.83	5.11	15.48
PR	1361.37	3702.43	50.33	115.42	421.54	1118.59	454.38	852.93	5.34	18.59	141.71	433.56	113.37	906.24	60.39	392.71	5.47	244.34	15.67	42.07
PM	1369.67	4296.92	34.88	98.59	383.48	994.94	373.84	617.57	2.09	10.43	48.37	222.51	70.42	726.61	30.27	491.60	5.87	525.05	11.36	30.49
KL	2050.62	4276.71	21.88	62.66	491.23	1302.43	656.72	1215.79	10.50	24.14	257.04	1385.31	47.85	1522.67	10.50	361.31	8.74	254.67	1.59	7.73
KO	1920.42	4107.54	48.63	82.77	648.18	1245.83	785.44	1155.58	10.45	15.30	234.98	394.17	375.73	1002.46	170.17	648.48	37.14	250.97	4.45	7.69
KA	2416.87	4055.22	62.05	89.92	777.51	1116.27	805.80	1178.44	8.87	16.67	260.04	542.70	406.29	932.05	60.62	493.86	43.22	273.77	6.64	9.51
JC	1011.76	1945.59	37.16	43.15	385.36	446.48	493.08	539.48	6.25	8.68	31.46	41.85	87.55	149.86	123.05	201.03	7.59	98.59	13.53	16.35
DP	1823.88	9222.97	25.36	194.06	339.27	2488.86	248.22	970.04	3.04	17.00	19.12	346.24	26.17	442.34	37.10	527.00	67.84	1285.01	6.08	49.05
DB	1117.48	3970.34	28.76	117.44	329.49	1095.72	340.37	1178.44	5.49	17.97	88.80	673.75	108.69	954.84	23.13	399.06	6.21	340.38	3.87	29.89

Table 4.8c continued

	SI:CU		TI:CU		AL:CU		FE:CU		MN:CU		MG:CU		CA:CU		NA:CU		K:CU		P:CU	
AR	1352.89	56443.22	42.03	1556.30	476.08	17636.28	273.84	17596.90	4.68	263.33	93.70	6235.02	233.58	8004.64	9.13	5579.09	20.60	5744.98	5.27	242.54
PR	3827.84	75594.16	135.56	3305.24	1145.68	28211.69	1128.01	21308.39	13.90	619.60	400.45	14451.90	643.23	30207.99	380.22	8358.74	30.06	2166.07	42.65	999.36
PM	11017.29	39378.45	228.67	810.82	2449.90	9004.72	1603.62	9169.13	11.92	116.18	228.28	3147.66	939.32	3510.96	252.25	4866.86	58.11	4134.40	70.60	250.38
KL	1740.54	13657.92	20.85	277.03	573.62	3986.46	573.96	4409.90	7.56	57.07	195.68	2448.46	36.43	2922.75	16.13	1327.61	21.24	742.81	1.21	27.10
KO	1894.51	17200.32	43.37	346.59	539.35	5216.91	585.56	4838.97	7.91	53.25	227.52	1345.44	361.18	2309.37	143.51	1687.82	43.43	389.16	4.40	31.09
KA	2040.47	4180.46	52.97	119.29	656.42	1494.60	690.33	1449.77	8.11	21.00	237.75	627.98	402.27	841.30	58.48	429.72	28.94	277.20	5.57	12.72
JC	9028.01	24024.36	209.03	480.52	2170.13	4861.42	2725.33	6805.70	43.78	101.28	172.86	505.59	636.73	1594.33	1038.66	1552.28	95.79	716.99	73.32	171.87
DP	2799.44	122972.94	40.64	1318.90	600.97	19284.16	505.05	10963.10	7.54	154.90	26.68	3577.80	181.52	4945.72	288.22	5391.14	182.20	14777.56	8.03	302.57
DB	2861.84	38911.05	42.03	1317.90	864.74	15217.38	693.71	19991.18	10.81	271.08	182.78	5557.65	372.67	5669.95	63.28	3363.28	11.45	1044.67	7.10	282.93

	SI:NI		TI:NI		AL:NI		FE:NI		MN:NI		MG:NI		CA:NI		NA:NI		K:NI		P:NI	
AR	1116.38	9929.65	30.03	313.74	322.15	3040.53	353.23	4255.98	4.06	43.03	125.72	625.33	107.21	1378.62	15.62	796.86	13.25	501.40	4.69	27.64
PR	1181.16	10495.93	37.52	399.75	289.19	3601.36	332.94	3066.17	4.56	40.27	162.30	713.95	169.80	1146.38	65.08	1255.29	4.88	743.86	12.40	114.69
PM	6939.00	18363.32	216.61	432.35	2156.20	4729.45	1517.96	4584.57	5.74	58.09	185.72	1573.83	458.91	2576.17	99.57	2862.86	34.18	1632.00	67.06	139.90
KL	478.36	2402.78	4.65	48.74	88.11	701.32	164.96	775.82	2.55	11.25	183.90	396.33	39.48	610.24	2.73	233.56	1.77	130.68	.33	4.77
KO	1499.98	2343.32	38.93	48.77	476.72	696.67	549.46	769.34	6.76	11.16	170.85	272.76	245.04	532.78	110.78	434.10	19.74	196.71	3.27	5.35
KA	1114.94	2690.10	27.75	59.65	322.26	740.50	380.65	699.40	4.95	11.65	160.03	294.16	223.83	607.18	43.22	327.61	13.96	151.29	2.68	5.92
JC	13040.46	27657.33	416.45	559.17	4213.23	6226.49	5839.99	7578.95	77.45	119.70	370.41	539.35	1167.34	2189.58	1345.31	2434.78	83.02	1314.48	148.96	210.68
DP	17071.79	59780.46	254.45	763.08	3713.92	10586.00	1307.34	8770.48	14.52	154.90	174.20	3220.02	230.90	4237.15	114.14	4271.22	630.95	5728.38	49.70	188.38
DB	379.44	20702.48	10.34	612.35	155.23	4820.41	169.90	6144.73	2.58	118.21	80.07	1113.96	36.75	4013.60	29.68	1510.30	2.05	761.62	1.48	146.31

	SI:CO		TI:CO		AL:CO		FE:CO		MN:CO		MG:CO		CA:CO		NA:CO		K:CO		P:CO	
AR	3076.86	6004.60	90.43	162.12	995.49	1666.73	698.03	1689.87	12.00	37.97	214.94	552.54	241.21	2054.41	23.28	613.20	40.17	747.18	10.67	21.08
PR	3440.99	11400.96	142.33	344.61	991.51	3104.62	1253.43	2643.25	15.06	41.70	442.20	964.80	491.51	1776.94	169.35	1082.15	12.86	916.41	47.03	99.87
PM	8282.03	19931.69	215.64	486.23	2370.62	4699.63	2010.78	2834.41	8.61	54.22	241.20	953.84	435.32	2982.93	151.35	2433.43	29.06	2480.64	70.22	153.66
KL	2804.93	4742.44	27.25	90.75	516.67	1533.21	967.24	1482.73	14.52	28.60	434.58	1247.04	94.10	1633.41	16.02	488.42	10.38	336.53	1.93	10.21
KO	2890.63	5855.43	72.94	117.99	972.27	1775.97	1178.16	1647.31	13.90	21.37	352.47	558.90	512.05	1209.32	255.25	905.63	44.80	370.07	6.70	10.59
KA	3560.37	5108.41	95.63	119.31	1138.00	1494.60	1241.72	1452.28	13.11	25.82	396.26	637.08	592.65	1265.44	81.49	612.75	49.29	370.91	9.48	14.01
JC	6344.01	12771.71	212.10	270.59	2179.26	2840.58	2819.31	3287.18	38.73	54.42	178.82	262.39	583.67	898.87	695.85	1187.04	42.94	657.24	75.84	102.50
DP	11920.37	39853.64	165.72	595.10	2217.39	7632.51	1406.57	4846.43	15.49	63.37	71.26	1894.13	171.02	2236.59	148.38	2843.95	371.15	4433.27	38.44	150.41
DB	2073.13	7303.13	56.52	239.56	795.78	1941.21	928.29	1950.40	14.08	40.84	177.55	901.33	200.77	1773.45	50.04	653.64	9.77	612.69	7.67	64.65

	SI:CR		TI:CR		AL:CR		FE:CR		MN:CR		MG:CR		CA:CR		NA:CR		K:CR		P:CR	
AR	1135.80	31357.35	34.06	846.63	391.38	8704.04	391.18	8420.78	5.82	123.92	163.63	1971.81	256.01	5386.24	56.53	3056.63	13.25	3191.66	4.69	110.07
PR	278.64	15435.20	8.82	587.86	67.97	5296.11	89.59	4509.07	1.49	59.23	52.83	1049.93	50.85	1685.85	15.30	1846.02	1.39	1093.91	2.91	168.66
PM	6583.15	28430.67	213.42	594.05	2286.58	6370.85	1496.72	5393.61	5.74	98.57	213.06	1851.56	547.94	2153.63	140.14	2317.55	27.67	2686.83	65.90	183.29
KL	94.28	12357.17	.92	250.65	17.37	3606.80	32.51	3989.91	.50	51.63	37.59	1200.26	22.00	2644.39	.54	1201.17	.35	672.07	.07	24.52
KO	2642.98	16256.76	62.61	337.97	793.95	4826.55	948.88	5048.79	11.18	77.45	338.18	1684.63	443.56	3385.89	271.52	1500.76	57.61	1364.64	5.53	37.09
KA	594.83	4025.48	15.11	100.98	175.50	1285.21	207.29	1340.88	2.63	17.60	95.46	486.17	142.59	907.89	36.65	529.76	7.60	348.43	1.46	12.10
JC	29341.04	104105.56	664.78	2082.26	7574.87	21066.14	8765.81	29491.37	111.87	438.88	562.80	2190.90	1556.46	6908.77	3008.82	6726.56	415.10	2006.32	240.50	744.79
DP	26610.64	313999.32	338.72	5341.55	5050.40	70132.25	1888.38	46300.28	25.82	619.60	557.78	16100.10	333.53	29660.05	164.87	29898.57	1411.34	19703.41	67.28	1274.29
DB	161.55	264361.44	3.53	8470.93	45.85	78283.47	62.24	99734.44	1.02	1394.10	34.59	22130.10	15.90	63608.30	8.93	22331.19	.49	6724.62	.56	1501.22

	SI:V		TI:V		AL:V		FE:V		MN:V		MG:V		CA:V		NA:V		K:V		P:V	
AR	929.16	1919.84	27.91	51.83	314.91	532.90	193.48	568.54	3.21	10.52	65.19	164.51	67.33	569.43	6.45	190.39	12.71	207.10	2.88	6.74
PR	707.05	1963.08	38.32	63.25	248.75	569.84	239.09	485.15	2.95	9.34	74.28	253.57	77.97	455.40	36.57	198.62	3.23	157.79	12.02	20.14
PM	1635.30	3507.60	55.67	78.95	581.47	845.10	376.01	975.44	1.42	12.36	43.23	334.86	121.76	629.73	31.53	496.62	5.93	516.80	17.46	26.58
KL	948.10	1663.70	11.27	27.07	255.43	501.64	269.98	548.24	4.73	9.11	114.05	591.48	23.82	410.62	4.95	148.78	5.13	103.55	.68	3.14
KO	947.66	1463.86	23.44	30.95	307.04	443.99	361.36	452.93	4.42	6.31	114.51	168.68	156.79	334.15	76.98	262.63	12.38	101.55	1.97	3.04
KA	1164.29	1542.98	32.08	38.17	373.02	481.01	394.63	501.85	4.24	7.65	139.99	208.34	191.65	375.22	26.02	198.27	16.26	123.64	3.13	4.73
JC	8693.64	20154.29	347.04	398.87	3511.02	4559.04	4338.87	5343.42	67.12	77.45	288.10	365.15	824.01	1558.05	1121.09	1805.29	69.18	927.87	122.19	146.34
DP	2815.96	19072.67	48.02	264.13	636.16	3938.61	308.76	3246.69	2.40	55.76	44.67	545.77	60.03	1025.59	29.68	1750.01	106.94	1303.90	11.16	54.16
DB	563.81	1688.58	16.57	38.18	148.40	508.26	220.33	448.97	2.26	7.56	30.67	293.99	69.17	387.59	7.39	166.81	2.81	156.30	1.35	10.41

	SI:LA		TI:LA		AL:LA		FE:LA		MN:LA		MG:LA		CA:LA		NA:LA		K:LA		P:LA	
AR	7754.32	20662.42	237.48	554.54	2443.32	5591.68	1271.41	7013.98	28.40	77.45	435.02	2178.34	968.82	3741.97	42.39	1678.55	95.79	1885.74	30.26	68.58
PR	2322.11	5927.48	83.09	217.25	767.20	1851.37	609.15	1942.18	7.23	38.73	152.37	1123.77	219.17	1849.47	121.72	597.88	17.56	468.60	25.37	82.83
PM	2065.91	6617.35	57.00	166.39	575.20	1711.40	320.19	1580.89	1.21	20.65	52.76	542.70	134.77	682.84	36.38	471.52	5.43	596.31	17.63	52.17
KL	16982.20	248189.40	241.40	2919.57	4855.45	54782.55	5343.42	85116.98	87.78	1394.10	2100.45	105283.80	4627.68	59248.63	74.19	13725.15	166.04	4441.57	20.66	200.74
KO	14159.62	31117.16	332.35	822.06	4337.32	10281.65	5079.39	12641.66	60.24	174.26	1695.94	4680.79	2251.31	8772.94	1093.07	5582.80	313.63	2426.03	30.06	81.28
KA	13488.18	53349.04	344.55	1294.92	4173.11	15296.77	4093.33	16645.72	50.11	185.88	1468.48	6862.14	2411.17	7375.70	451.88	5490.06	225.34	1270.84	38.82	122.19
JC	3978.45	7807.92	130.87	169.69	1457.26	1755.66	1773.80	2211.85	23.97	34.13	110.34	164.55	341.66	556.45	504.49	724.65	31.13	384.73	48.00	64.28
DP	2535.84	13663.66	45.42	425.07	659.38	5451.79	258.35	2124.84	3.16	30.31	34.08	644.00	69.05	760.44	54.96	851.23	126.19	2814.77	10.49	107.44
DB	6215.33	41115.62	204.12	777.10	1579.96	13450.84	2013.14	12764.05	22.78	206.53	262.48	8391.75	693.09	11685.35	63.28	3635.31	66.42	1802.02	28.08	112.22

	SI:CE		TI:CE		AL:CE		FE:CE		MN:CE		MG:CE		CA:CE		NA:CE		K:CE		P:CE	
AR	4283.22	7818.21	109.11	217.20	1267.67	2104.99	593.32	2946.45	12.67	35.50	203.01	726.11	423.59	1746.25	19.78	732.85	45.28	755.92	15.86	27.57
PR	1208.56	2662.33	38.83	94.44	358.54	806.05	284.68	855.69	3.27	17.70	71.21	504.55	100.64	863.09	56.45	252.00	7.49	207.55	11.86	35.40
PM	976.21	2658.75	30.02	66.85	302.99	687.62	168.66	694.63	.64	8.80	24.18	238.46	66.91	322.02	18.19	237.41	2.83	298.15	9.28	20.96
KL	7960.41	236177.22	113.16	2535.89	2275.99	76060.41	2504.73	66862.64	41.15	1084.30	1050.23	61445.70	2147.21	89837.79	34.78	11425.26	76.63	5230.26	9.68	152.74
KO	8191.01	17156.70	174.44	360.90	2491.12	5155.38	2605.83	5590.54	32.48	77.45	861.08	1872.32	1478.00	3899.09	555.23	2233.12	108.56	1311.72	17.13	31.42
KA	7068.81	14450.91	169.44	398.14	2008.55	4629.82	2138.69	5146.76	24.46	63.78	733.12	2585.81	1167.34	3464.19	198.83	1323.55	116.84	676.37	18.49	39.02
JC	1892.97	3784.21	62.76	80.74	698.89	841.65	850.70	983.05	11.57	16.24	52.92	78.29	172.94	268.63	224.22	354.09	13.84	194.74	23.02	30.58
DP	1542.42	7233.70	27.63	151.30	401.07	1940.47	126.59	892.71	1.55	15.15	17.04	331.96	36.45	391.98	29.09	420.09	65.05	1001.87	5.74	38.24
DB	3037.04	16754.73	98.08	336.92	711.13	4813.69	876.31	5352.74	9.80	90.36	112.97	3827.04	338.67	4309.22	27.23	1696.48	22.90	712.43	14.38	52.37

	SI:ND		TI:ND		AL:ND		FE:ND		MN:ND		MG:ND		CA:ND		NA:ND		K:ND		P:ND	
AR	8207.54	16070.77	226.03	406.99	2531.19	4474.14	1148.37	5140.59	25.82	63.78	392.92	1679.36	726.61	3379.84	38.29	1767.47	99.62	1511.84	31.09	53.34
PR	2467.48	5272.46	83.09	176.10	767.20	1536.97	609.15	1644.28	6.69	32.05	152.37	969.53	205.48	1562.48	112.90	525.73	14.27	428.94	25.39	67.30
PM	1554.98	4632.76	49.67	116.66	480.07	1282.47	289.54	1503.14	1.52	19.05	54.62	516.01	101.44	682.84	39.41	517.75	6.18	646.00	15.70	37.99
KL	14984.29	123416.97	184.65	1364.86	4294.22	39723.97	4709.29	42558.49	77.45	658.33	2100.45	52641.90	1882.04	43560.97	65.46	9768.35	166.04	4649.12	11.93	144.01
KO	14877.07	37091.53	333.60	919.80	4654.73	11085.05	5306.70	13458.45	62.93	165.96	1741.61	4505.27	2518.27	7018.35	1300.51	4060.22	235.22	2426.03	31.06	77.31
KA	13650.54	30708.18	345.19	846.04	4351.40	9838.36	4270.02	10936.87	44.84	135.54	1560.26	5494.84	2027.49	7361.41	355.05	2908.25	225.34	1362.91	35.94	82.92
JC	4118.04	7476.12	127.30	175.64	1373.88	1817.26	1705.35	2055.25	21.42	35.33	107.77	170.32	341.66	504.95	438.69	694.85	27.07	384.73	46.70	66.53
DP	3886.10	16769.04	69.60	247.96	1010.48	3180.21	281.31	1961.65	3.44	39.83	42.88	766.67	81.00	905.29	67.45	924.20	150.23	2015.12	14.36	52.67
DB	5139.60	35956.41	193.84	584.08	1162.42	10880.90	1584.81	11480.15	17.21	199.16	198.32	7287.69	573.13	10393.78	47.81	3153.08	39.07	1331.93	32.29	94.14

It has already been shown, however, that this problem can be overcome using discriminant analysis, or, if this is unavailable, there are several interelement discrimination plots which can be used. These are discussed in the following section.

4.5 Interelement Discrimination Plots

The relative importance of the various major and trace elements and selected ratios in discriminating between formations was shown quantitatively in Table 4.2 and discussed in section 4.2.1.2. Several interelement plots were constructed using the most important discriminating variables indicated by discriminant analysis and those suggested by orthogonal discrimination. The plots which were most successful in distinguishing between formations are:

Ti:Zr vs Ti:P (Figure 4.6)
Zr:P vs P:Ti (Figure 4.7)
TiO_2 vs Zr (Figure 4.8)

The dotted lines drawn on these plots are arbitrary and serve merely as convenient separators between the units. Figures 4.6 and 4.7 contain the entire sample population and provide very successful discrimination diagrams. The Rietgat and Goedgenoeg Formations plot as a single unit, as suggested by discriminant analysis, and, while the Klipriviersberg Group cannot be separated into its three separate chemical entities, it does, as a whole, lie apart from the other formations.

In order to distinguish between the individual formations of the Klipriviersberg Group a plot of TiO_2 vs Zr (Figure 4.8), is the most effective. Figure 4.8 shows the existence of a small, but consistent gap between which no samples fall. All samples with concentrations below this gap belong to the Loraine-Edenville Formations. Although two Loraine-Edenville samples plot above the Zr gap, one (KL-145) lies completely off the trend demarcated by the other samples of the set, while the other (KL-465) lies amongst the Orkney samples. This is the lowermost sample of the Loraine Formation in borehole JBF-1, and although the upper purple zone, which marks the top of the Orkney Formation, is present some metres below the position of sample KL-465, this probably implies uncertainty in the positioning of the Orkney-Loraine boundary, rather than inconsistent chemistry.

All Orkney samples lie within the range of 90 to 110 ppm Zr, while only three Alberton samples have Zr concentrations of less than 110 ppm. These are KA-346, which lies at some distance from the TiO_2-Zr trend, KA-347 and KA-452, which lie within the Orkney field, near the other Alberton samples.

Figure 4.6 Ti:Zr vs Ti:P discrimination plot for all groups
(See pages 62 & 72 for symbols)

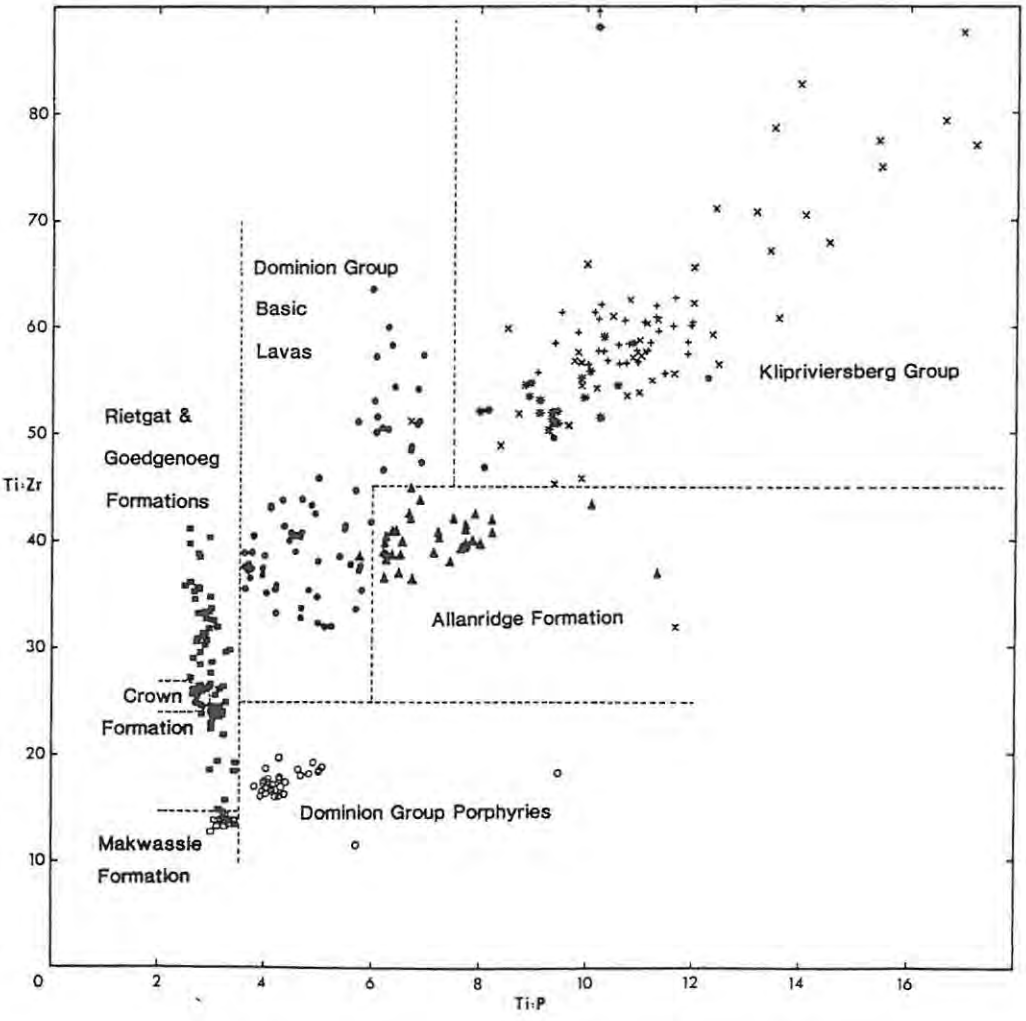


Figure 4.7 Zr:P vs P:Ti discrimination plot for all groups

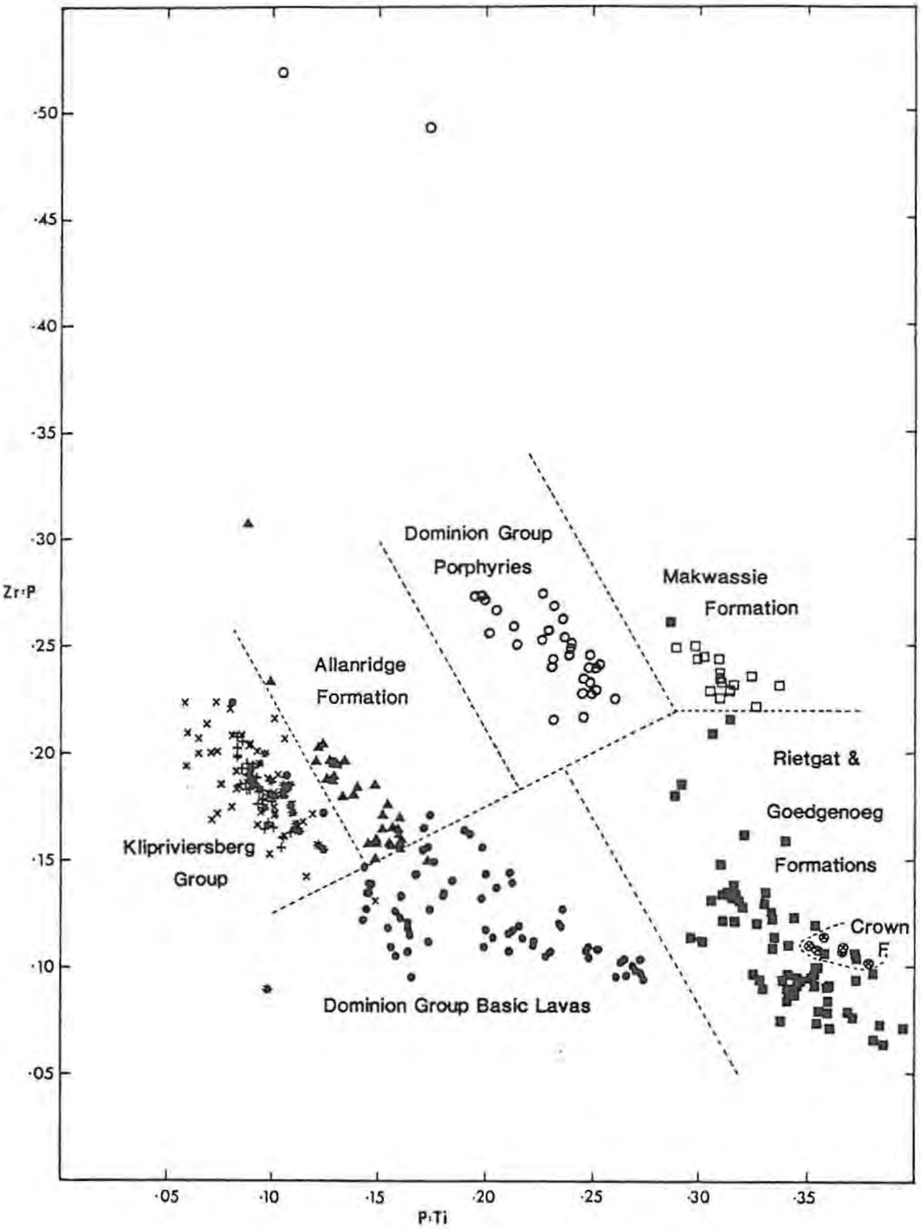
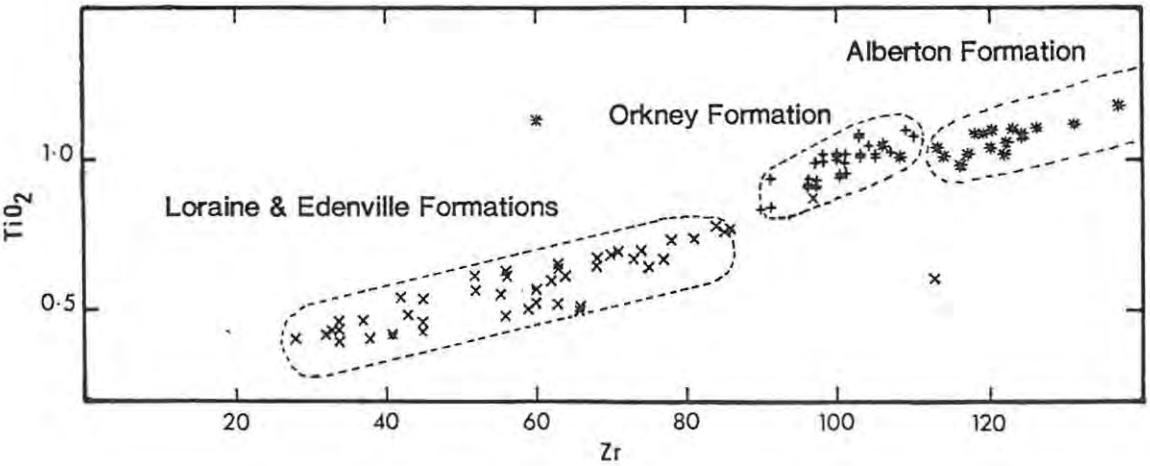


Figure 4.8 TiO_2 vs Zr discrimination plot for the Klipriviersberg Group



The major advantage of these three discrimination plots is that they require the analysis of only three elements, Ti, P and Zr. A large number of samples can thus be analysed within a short space of time in order to determine their stratigraphic affinities with reasonable confidence.

4.6 A Case Study of the Use of Various Discrimination Techniques

During 1981 a prospecting company drilled a borehole to the northwest of Klerksdorp. The volcanic rocks intersected were not able to be identified with any certainty and fourteen samples were sent to Rhodes University for identification. The analytical work and subsequent interpretation were carried out jointly by the author, T.B. Bowen, and her brother, M.P. Bowen.

Table 4.9 shows the list of samples together with the respective depths from surface at which they were taken.

Table 4.9 Unknown samples NL-781 to NL-794 showing depths from surface

NL-781	103 m
NL-782	226 m
NL-783	318.5 m
NL-784	377 m
NL-785	500 m
NL-786	627 m
NL-787	724 m
NL-788	782 m
NL-789	890 m
NL-790	891.5 m
NL-791	1106 m
NL-792	1155 m
NL-793	1230 m
NL-794	1250 m

The above samples were initially analysed for eleven major and five trace elements, viz. Nb, Zr, Y, Sr and Rb, upon the completion of which identification was possible. Analyses of a further ten trace elements were later done so that these samples could be added to the previously compiled data base.

The unique sample NL-789 consists of numerous light ocelli up to 2 cm in diameter set in a darker matrix. These fractions were separated and analysed individually (NL-789-O and NL-789-M). Thus it should be borne in mind that the whole rock analysis in the following diagrams lies somewhere along a mixing line joining the two fractions, which are labelled "O" and "M". The analyses are presented in Table 4.10.

Table 4.10 Major and trace element analyses for unknown samples NL-781 to NL-794. (Oxides and trace elements recalculated volatile-free, all Fe as Fe_2O_3, TOTAL is original total before recalculation).

SAMPLE:	NL-781	NL-782	NL-783	NL-784	NL-785	NL-786	NL-787	NL-788
SiO_2	53.43	53.08	53.43	52.77	53.02	53.85	52.79	54.72
TiO_2	0.444	0.353	0.473	0.419	0.388	0.579	0.613	0.583
Al_2O_3	11.41	11.01	12.24	11.29	10.28	13.52	13.47	13.14
Fe_2O_3	10.53	12.38	10.29	10.95	11.59	10.95	12.10	11.04
MnO	0.17	0.20	0.18	0.16	0.21	0.17	0.18	0.17
MgO	13.56	13.98	10.53	12.95	14.50	7.91	8.46	7.98
CaO	7.92	7.17	9.07	9.19	8.23	9.22	8.30	7.84
Na_2O	2.11	1.56	2.71	1.62	1.34	3.42	2.24	2.64
K_2O	0.38	0.23	1.02	0.60	0.39	0.32	1.77	1.80
P_2O_5	0.054	0.040	0.064	0.051	0.048	0.072	0.076	0.073
TOTAL:	99.59	99.29	99.68	100.04	100.04	99.43	99.81	99.67
LOI:	4.47	4.92	3.21	4.09	4.72	2.82	2.82	2.47
Ba	119	73	342	287	146	106	909	730
Nb	1.2*	1.4*	2.6	1.7*	0.7*	2.5	2.7	1.9*
Zr	49	36	55	47	39	62	65	59
Y	12.2	10.0	13.2	12.8	9.8	15.2	17.6	15.3
Sr	92	63	168	64	46	122	206	138
Rb	12.5	9.0	40.4	20.4	16.8	15.4	82.5	79.3
Zn	65	119	61	71	101	66	82	69
Cu	43	14	55	21	36	50	44	52
Ni	336	497	283	381	505	245	226	221
Co	72	87	66	78	85	67	69	67
Cr	1358	2754	883	1619	2308	470	453	425
V	160	155	178	170	164	206	206	199
La								
Ce								
Nd								

SAMPLE:	NL-789-O	NL-789-M	NL-790	NL-791	NL-792	NL-793	NL-794
SiO_2	57.92	42.09	53.75	54.19	53.16	55.45	54.60
TiO_2	0.577	0.571	0.537	0.977	1.057	1.274	1.277
Al_2O_3	12.62	14.70	11.64	15.07	16.10	14.08	16.45
Fe_2O_3	7.64	15.15	10.73	12.62	13.93	13.17	11.88
MnO	0.13	0.22	0.19	0.14	0.15	0.14	0.20
MgO	7.78	12.10	9.40	5.01	5.50	4.22	5.25
CaO	7.97	14.87	9.65	7.34	5.78	7.03	4.20
Na_2O	4.50	0.09	3.98	3.87	3.24	3.76	3.47
K_2O	0.75	0.16	0.06	0.67	0.93	0.69	2.46
P_2O_5	0.099	0.049	0.068	0.126	0.133	0.185	0.213
TOTAL:	99.67	100.39	99.12	98.38	99.27	99.87	98.46
LOI:	1.52	5.18	2.34	2.17	2.81	1.96	2.49
Ba	201	63	14*	276	370	281	1194
Nb	2.5	2.8	2.7	4.8	6.2	8.3	10.5
Zr	52	53	50	100	110	133	162
Y	9.0	22.8	14.1	21.4	20.7	26.6	28.0
Sr	174	32	60	258	211	172	237
Rb	31.2	7.4	4.3	29.4	41.1	29.8	94.5
Zn	43	93	56	97	101	100	110
Cu	22	59	37	65	71	70	110
Ni	206	388	324	169	194	191	147
Co	49	91	72	69	69	68	62
Cr	870	868	819	52	72	71	35
V	181	266	203	222	209	206	212
La							
Ce							
Nd							

* below LLD

Application of the criteria established during the study for the identification of lava types in the Klerksdorp area shows these fourteen samples to be unambiguously representative of an almost complete section through the Klipriviersberg Group. These conclusions are illustrated by means of the following diagrams:

Figure 4.9 shows the boundary lines only of Figure 4.6, a plot of Ti:Zr vs Ti:P. The NL samples have been plotted and lie very clearly within the Klipriviersberg field.

Figure 4.9 Unknown samples plotted on Ti:Zr vs Ti:P discrimination diagram

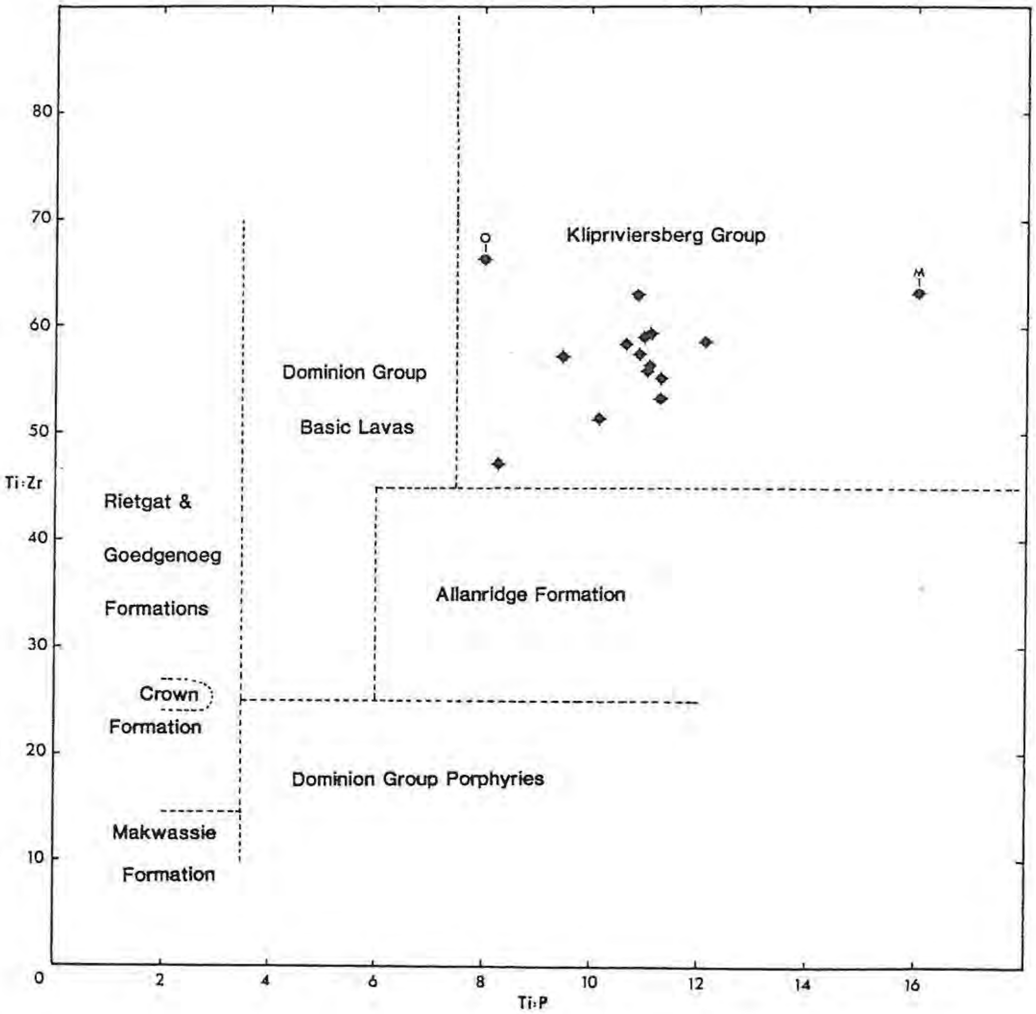
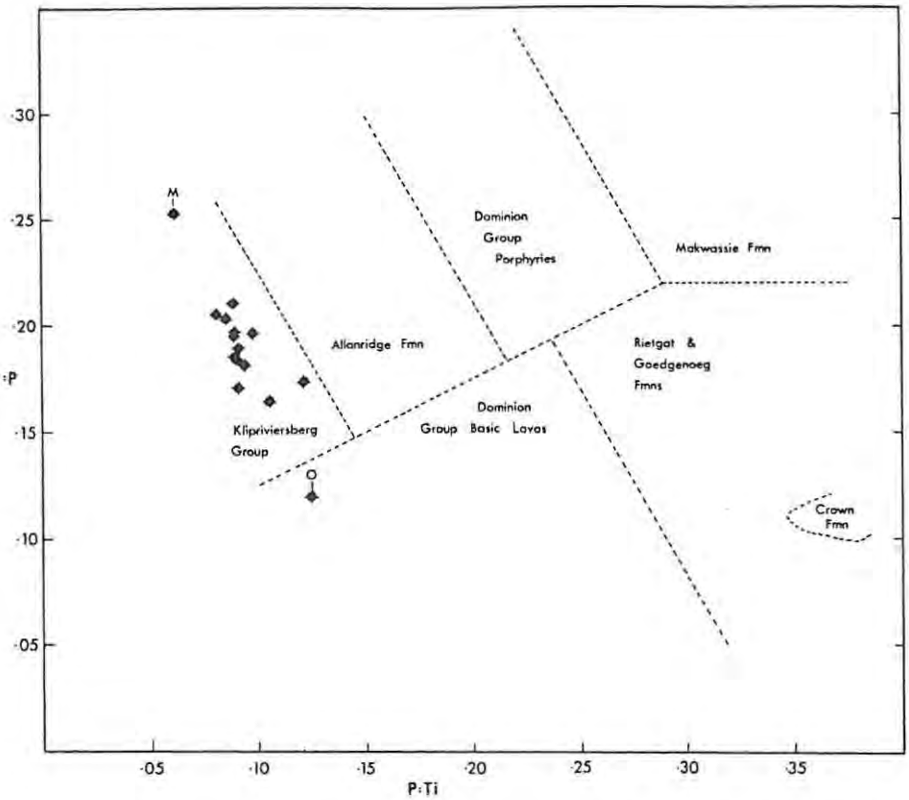


Figure 4.10 is a reproduction of the boundary lines only of Figure 4.7, which uses a different combination of the same variables. Again the NL samples alone have been shown and once more they plot within the Klipriviersberg field.

Figure 4.10 Unknown samples plotted on Zr:P vs P:Ti discrimination diagram



Having established that the NL samples have undoubted Klipriviersberg affinities, a third graph was employed, in which TiO_2 is plotted against Zr. This enables samples from the three chemically distinct units constituting the Klipriviersberg Group to be differentiated from one another. Figure 4.11, showing the boundaries of the three sets of volcanics from Figure 4.8, enables the NL samples to be subdivided as follows: samples NL-781 to NL-790 are representative of the Loraine-Edenville formations, while samples NL-791 and NL-792 represent the Orkney, and NL-793 and NL-794 the Alberton Formation respectively.

Figure 4.12b demonstrates that major element variation of the NL samples is also consistent with that of the Klipriviersberg Group. Within the boundary lines from Figure 4.12a, samples NL-781 to NL-790 plot within the Loraine-Edenville field, which displays a large variation in MgO relative to Fe_2O_3, while samples NL-791 to NL-794 plot in the Alberton/Orkney field, in which the variation is in the opposite direction.

Figure 4.11 Unknown samples plotted on TiO_2 vs Zr discrimination diagram

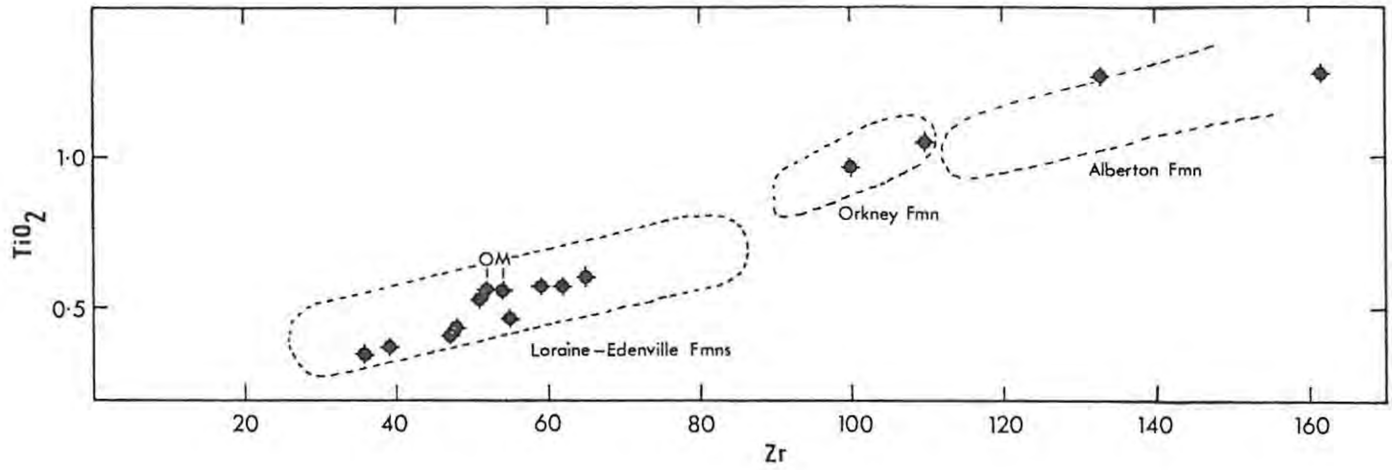
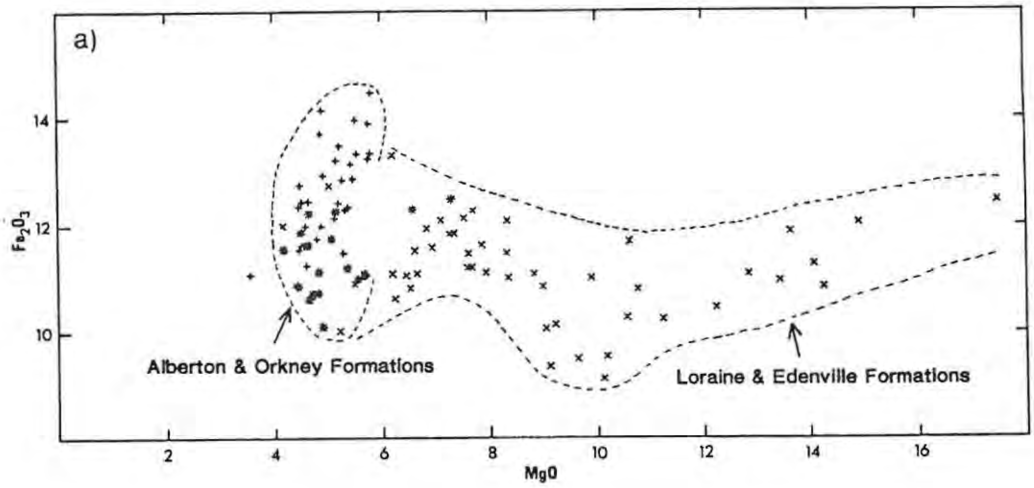
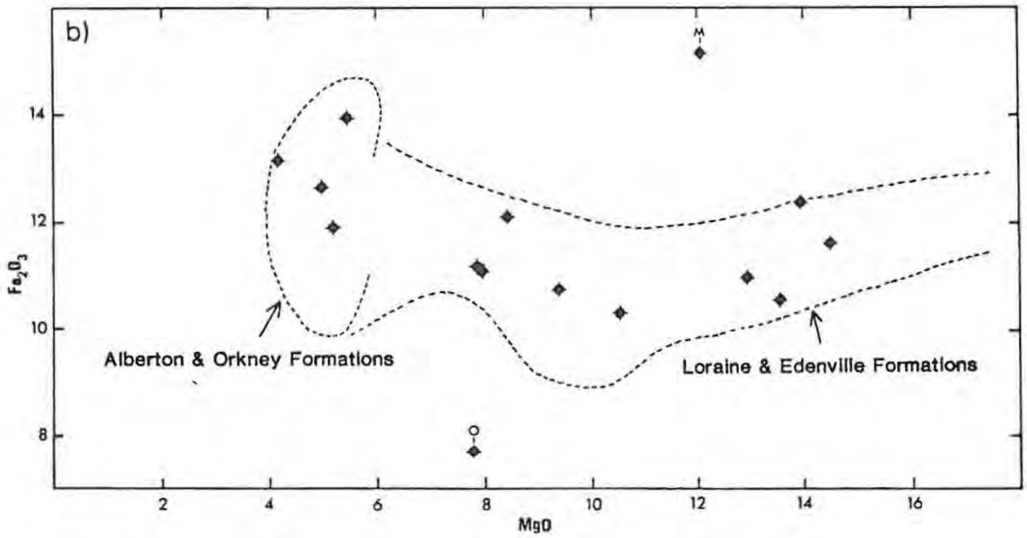


Figure 4.12 a) Fe_2O_3 vs MgO discrimination plot for Klipriviersberg Group
b) Unknown samples plotted on Fe_2O_3 vs MgO discrimination diagram.





The use of orthogonal discrimination enables classification of the NL samples to be achieved in a more quantified manner. It has been strongly indicated that they have clear Klipriviersberg affinities. Table 4.6 suggests an examination TiO_2 and P_2O_5 values as separators for formations within the Klipriviersberg Group. Table 3.2a shows that samples NL-781 to NL-790 do indeed lie within the TiO_2 range for the Loraine-Edenville Formations, i.e. between .400 and .878% TiO_2. NL-791 and NL-792 fall within the Orkney range - .940 to 1.020% TiO_2, while NL-793 and NL-794 have slightly higher values - 1.274 and 1.277% TiO_2 - than the Alberton Formation, whose upper limit for this study is 1.174% TiO_2. Similar conclusions are obtained from P_2O_5 values.

Amongst the trace elements, Zr is the most useful discriminator within the Klipriviersberg Group, as shown in Figure 4.8, although it is not listed in Table 4.6 due to the presence of a few stray samples which cause overlapping of the fields.

With major element ratios, separation is possible only between the Alberton and Loraine Formations, using TiO_2:Fe_2O_3, TiO_2:SiO_2, P_2O_5:SiO_2 or TiO_2:Al_2O_3 ratios. As these are not adjacent formations, these ratios will not be helpful in the current identification process.

The Alberton and Orkney Formations can, however, be separated using Ti:V and P:V ratios. As sample NL-792, which has thus far been identified as an Orkney sample, lies very close to the Alberton field in Figure 4.11, it is of interest to check whether this is indeed an Orkney member. The range for the ratio Ti:V within the Alberton Formation is 32.08 to 38.17 (from Table 4.8c), while that for the Orkney Formation is 23.44 to 30.95. Ti:V for sample NL-792 is 30.32, confirming its Orkney affinity. Similarly for P:V, NL-792, with a value of 2.78, lies within the Orkney range of 1.97 to 3.04, while the Alberton samples lie between 3.13 and 4.73.

It can therefore be concluded that, on the basis of data accumulated from the Klerksdorp area, the unknown samples may indisputably be identified as Klipriviersberg Group lavas, with samples NL-781 to 790 representing the Loraine-Edenville Formations, NL-791 and 792 the Orkney Formation, and NL-793 and 794 the Alberton Formation.

5. STATISTICAL EVALUATION OF DATA

5.1 Graphical Representation of Data

To analyse geochemical data, Koch and Link (1971) suggest one must first decide what an anomalous observation is. They say that current practice is to make an orientation survey, to calculate the mean and standard deviation of the observations, and then to define any observation more than two standard deviations above or below the mean as possibly anomalous and any one more than three standard deviations above or below the mean as certainly anomalous.

Normal probability graph paper is scaled so that if observations are normally distributed, their relative cumulative frequency in percent plots as a straight line. The mean of the observations is estimated by reading the fifty percent point on the straight line. The standard deviation of the observations is estimated by subtracting the sixteen percent point from the eighty four percent point and dividing the result by two (Koch and Link, 1970).

For fewer than 100 observations, they suggest it is desirable but not essential to replace the relative cumulative frequency (r.c.f.) by a plotting percentage obtained by the formula

$$\text{plotting percentage} = 100 \times \frac{3\,(\text{r.c.f.}) - 1}{3n + 1}$$

where n is the total number of observations. An example of the calculation is shown in Table 5.1. The graph of the plotting percentage plotted against the upper bound of the class interval is shown in Figure 5.1.

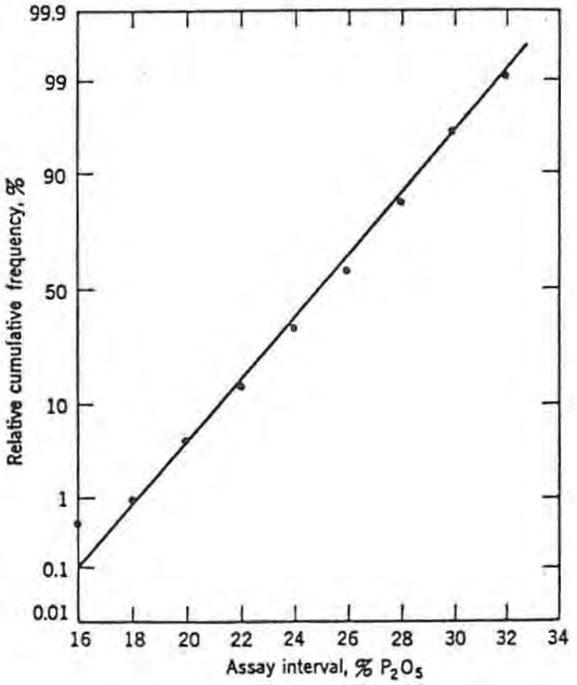
5.2 Probability Plots of Witwatersrand Triad Data

In order to examine the distribution of the chemical data of the Witwatersrand triad samples used in the current study, normal probability plots of the type discussed above were plotted using a program written by C. Beuthin for use on the Rhodes University ICL 1904S computer. The samples were first separated into their respective formations and then all major element analyses within each formation were tested for normality. The normal probabilty plots for major elements are shown in Figure 5.2a.

Table 5.1 Example of frequency distribution of 224 phosphate assays and plotting percentages (from Koch and Link, 1970)

Assay interval (% P_2O_5)	Interval midpoint, w	Frequency, f	Relative frequency (%)	Cumulative frequency, c.f.	Relative cumulative frequency, r.c.f. (%)	Plotting percentages
14–16	15	1	0.45	1	0.45	0.30
16–18	17	1	0.45	2	0.90	0.74
18–20	19	8	3.57	10	4.47	4.31
20–22	21	21	9.37	31	13.84	13.67
22–24	23	44	19.64	75	33.48	33.28
24–26	25	54	24.12	129	57.60	57.36
26–28	27	56	25.00	185	82.60	82.32
28–30	29	30	13.39	215	95.99	95.69
30–32	31	7	3.12	222	99.11	98.81
32–34	33	2	0.89	224	100.00	99.70

Figure 5.1 Plot on normal probability graph paper of phosphate data from Table 5.1 (from Koch and Link, 1970)



A similar procedure was adopted for the trace elements, the results of which are illustrated in Figure 5.2b. Each horizontal line of graphs represents a different formation, while each column corresponds with a different element.

The Y-axis has been modified to show the mean, given at 0.00, and one, two, three or four standard deviations shown by ± 1.00, ± 2.00, ± 3.00 and ± 4.00 respectively. Concentrations of major element oxides (in weight percent) and trace elements (in parts per million) are shown on the X-axis.

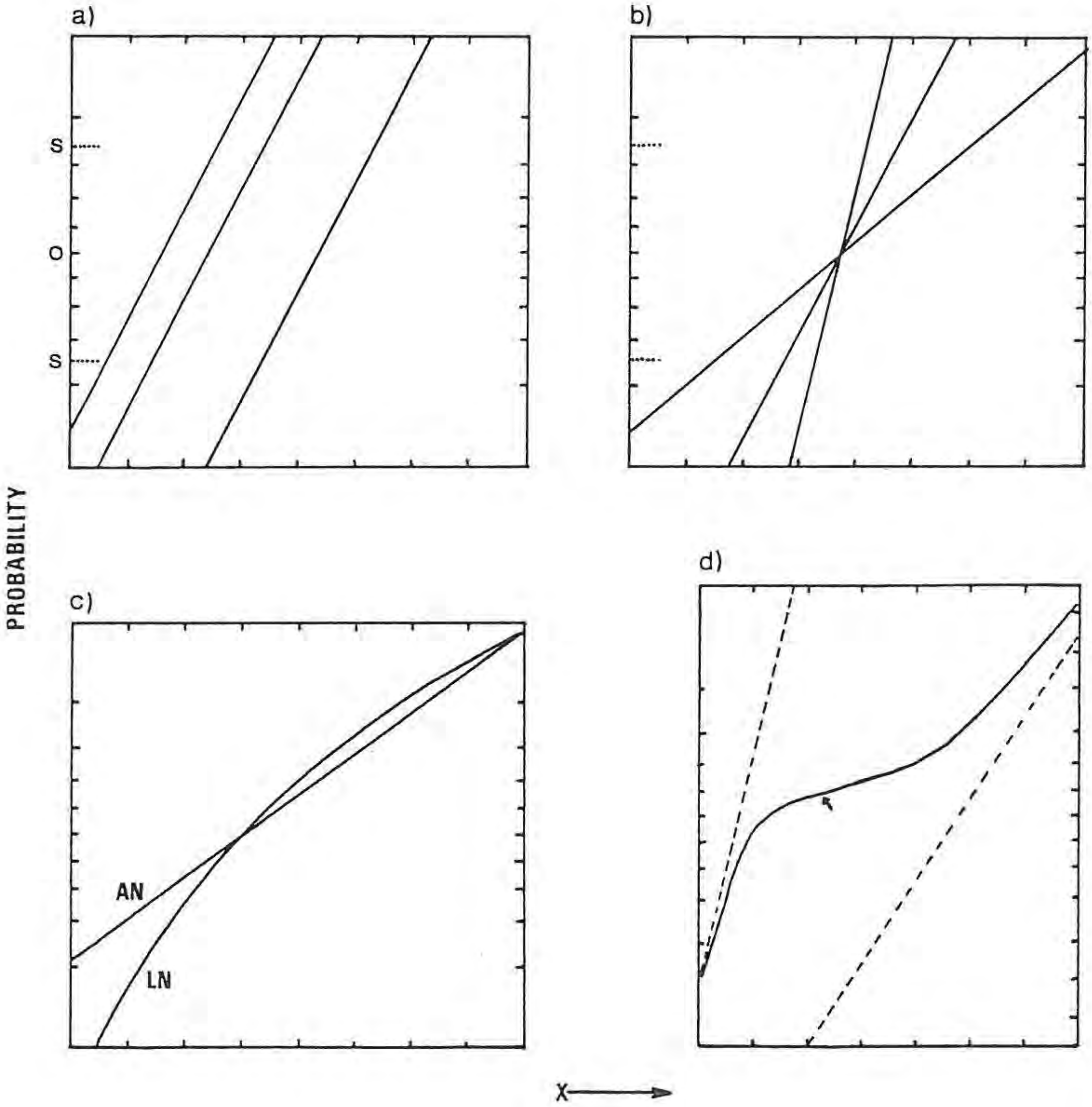
Figure 5.3 shows several hypothetical populations in order to illustrate some of the basic patterns which occur in Figures 5.2a and b. In Figure 5.3a, three lines are plotted, each with a different mean (read opposite the "0"), but the same standard deviations. Figure 5.3b show three lines, all with the same mean, but different standard deviations. The steeper the line, the smaller the standard deviation.

Figure 5.3c shows the difference between an arithmetic normal population, which plots as a straight line (AN), and a log normal population, which plots as a curved line (LN) on arithmetic probability paper. In general, concave-down graphs, such as LN, are skewed towards high values, i.e. the majority of points have low values, while the remainder tail off towards the higher end of the scale. The converse is also true.

Finally, Figure 5.3d shows how a combination of two normal populations produces a bimodal probability curve, which is recognised by the presence of an inflection point (marked with an arrow). Lognormal populations will produce similar patterns, with varying amounts of curvature. It is possible to separate the bimodal curve into its two constituent populations by means of a process called "partitioning". Details of the procedure are provided by Sinclair (1976), but this was not attempted in the current study.

The inflection point marks the cumulative percentile that represents the proportions of the two populations. Similarly, curves which have two inflection points indicate the presence of three populations, etc. The manifestation of more than one population may mean that that particular element is present in more than one mineral in differing degrees of concentration, for instance, or it may represent concentrations in the matrix and phenocrysts of a porphyritic rock, etc.

Figure 5.3 Hypothetical probability plots illustrating some basic patterns (after Sinclair, 1976)



Sinclair (ibid.) suggested that, although some authors recommend a minimum of 100 values in a probability plot, as few as 70 data points seem valid and useful. The only unit in the current study which fulfils this requirement, are the Dominion Group basic rocks (69 samples). Reasonably well-defined curves are, however, produced by the Loraine-Edenville, Allanridge, Rietgat, Goedgenoeg, Dominion porphyry

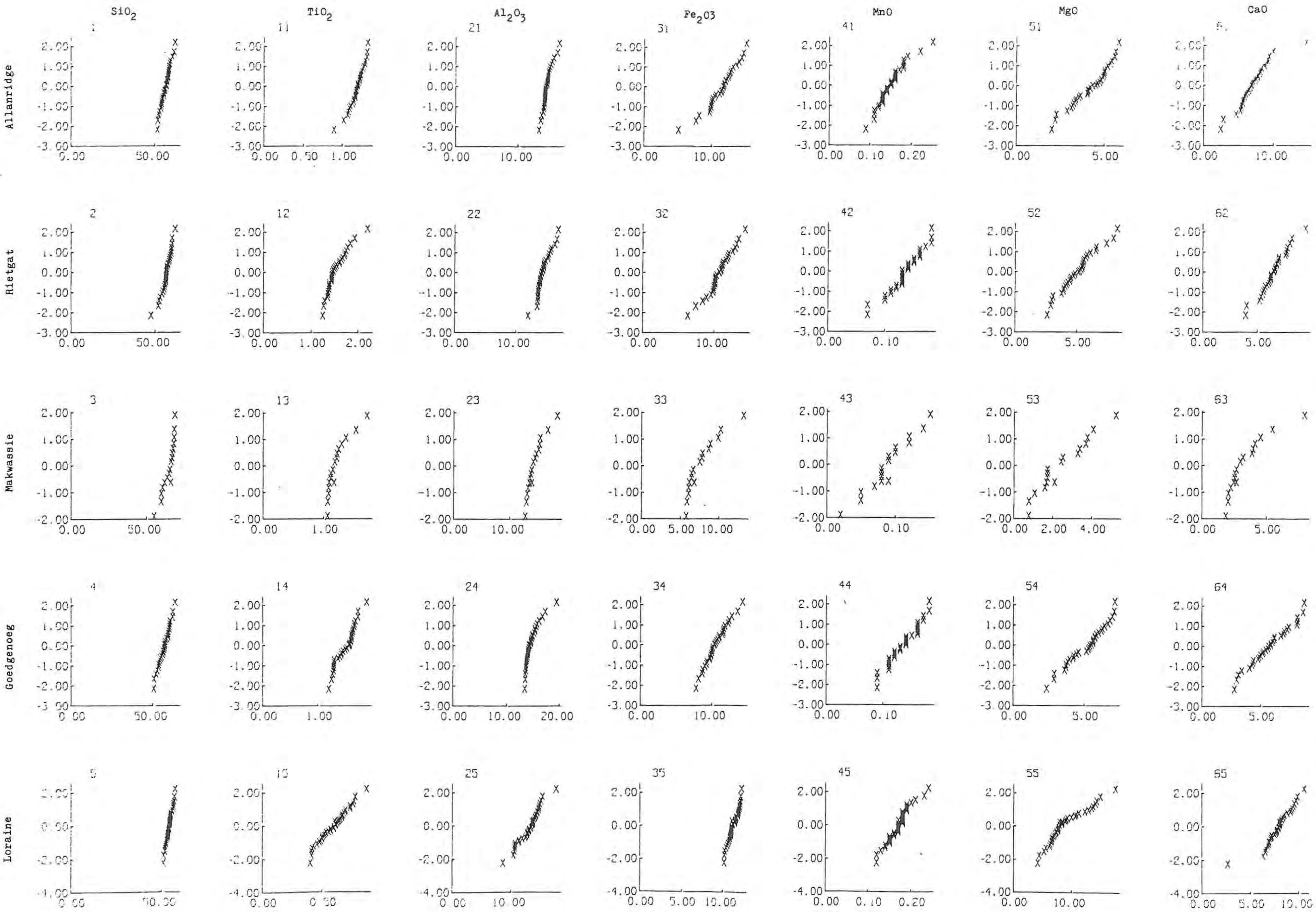


Figure 5.2a Normal probability plots of major elements for each formation

Figure 5.2a continued

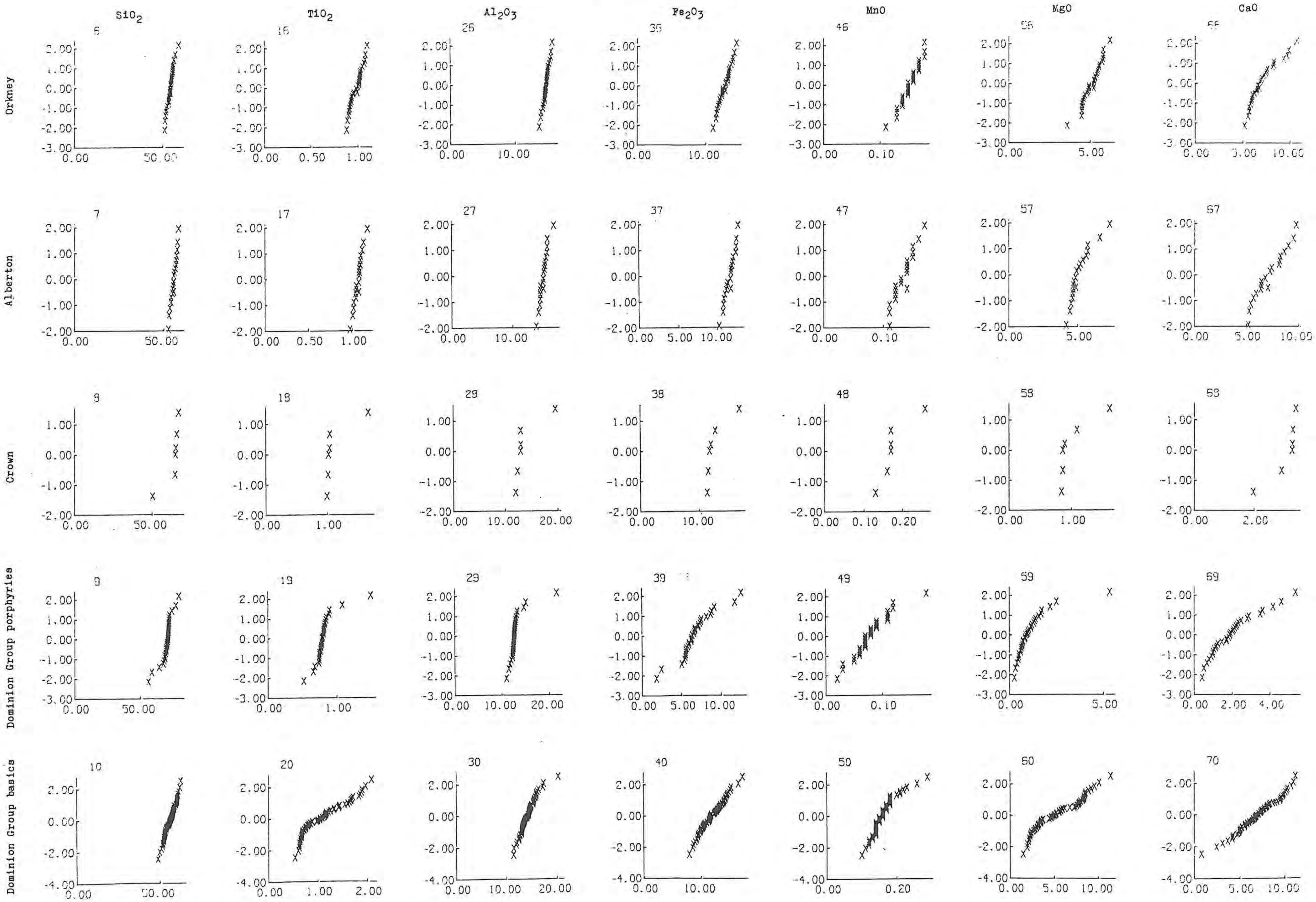


Figure 5.2a continued

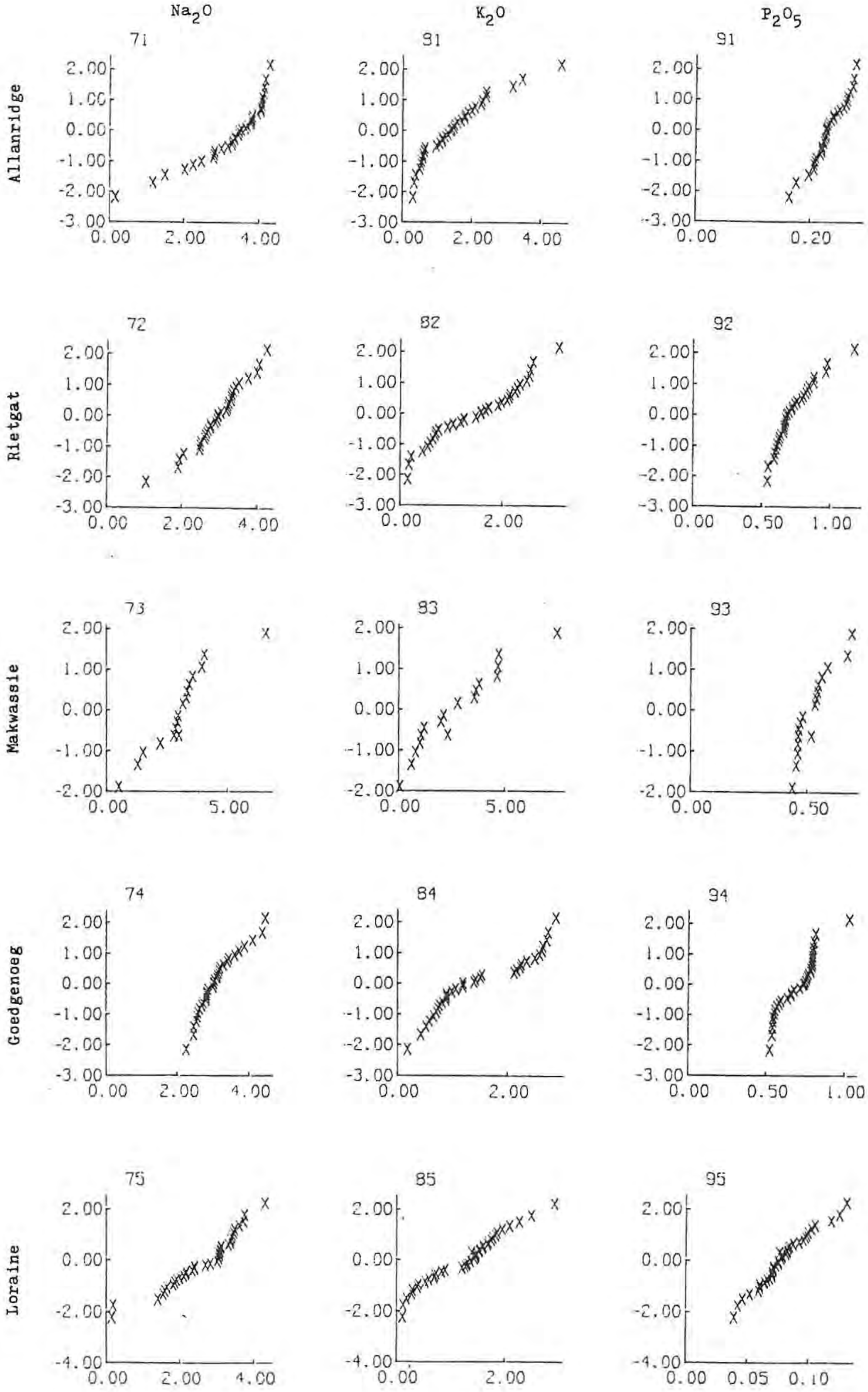


Figure 5.2a continued

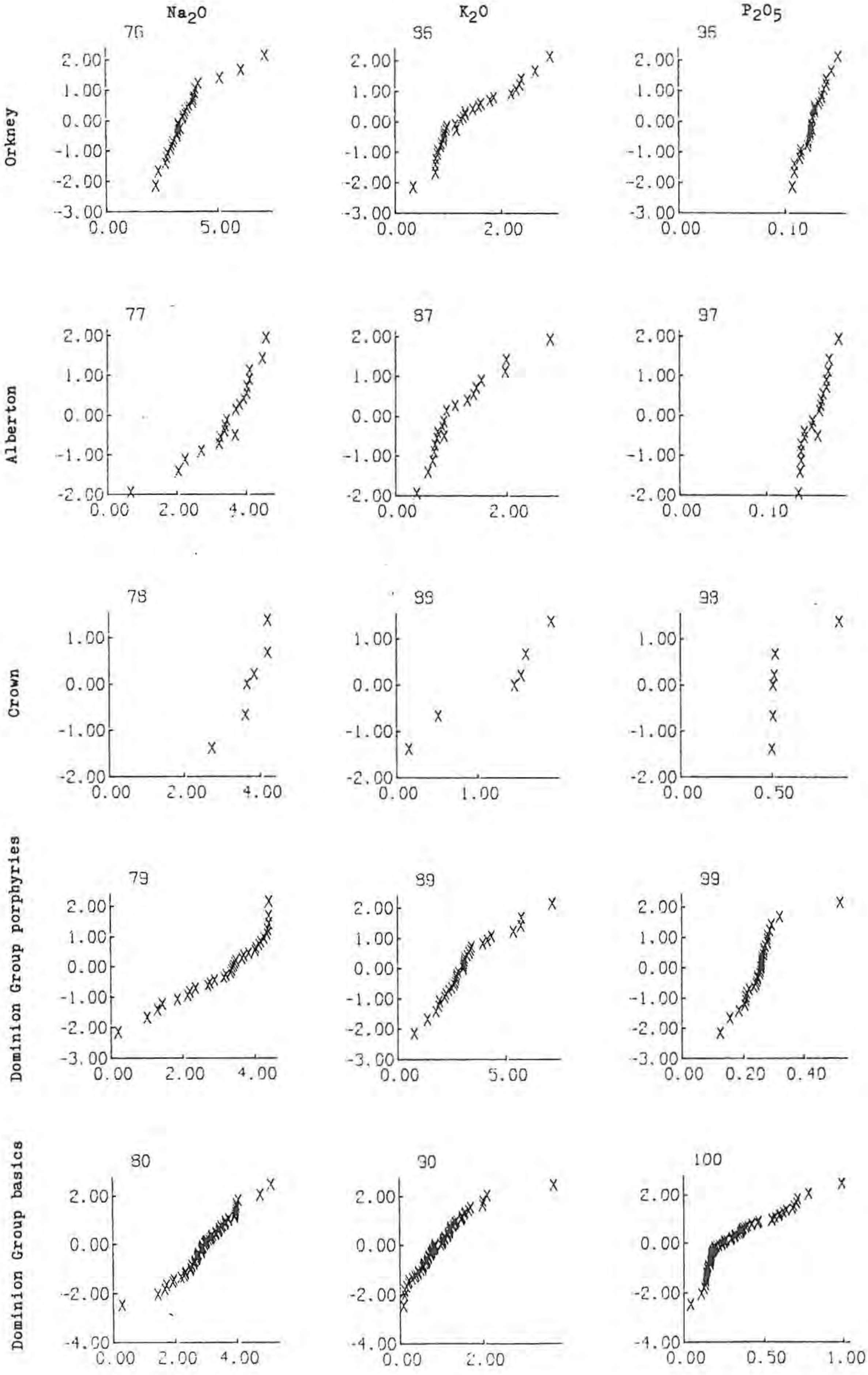


Figure 5.2b Normal probability plots of trace elements for each formation

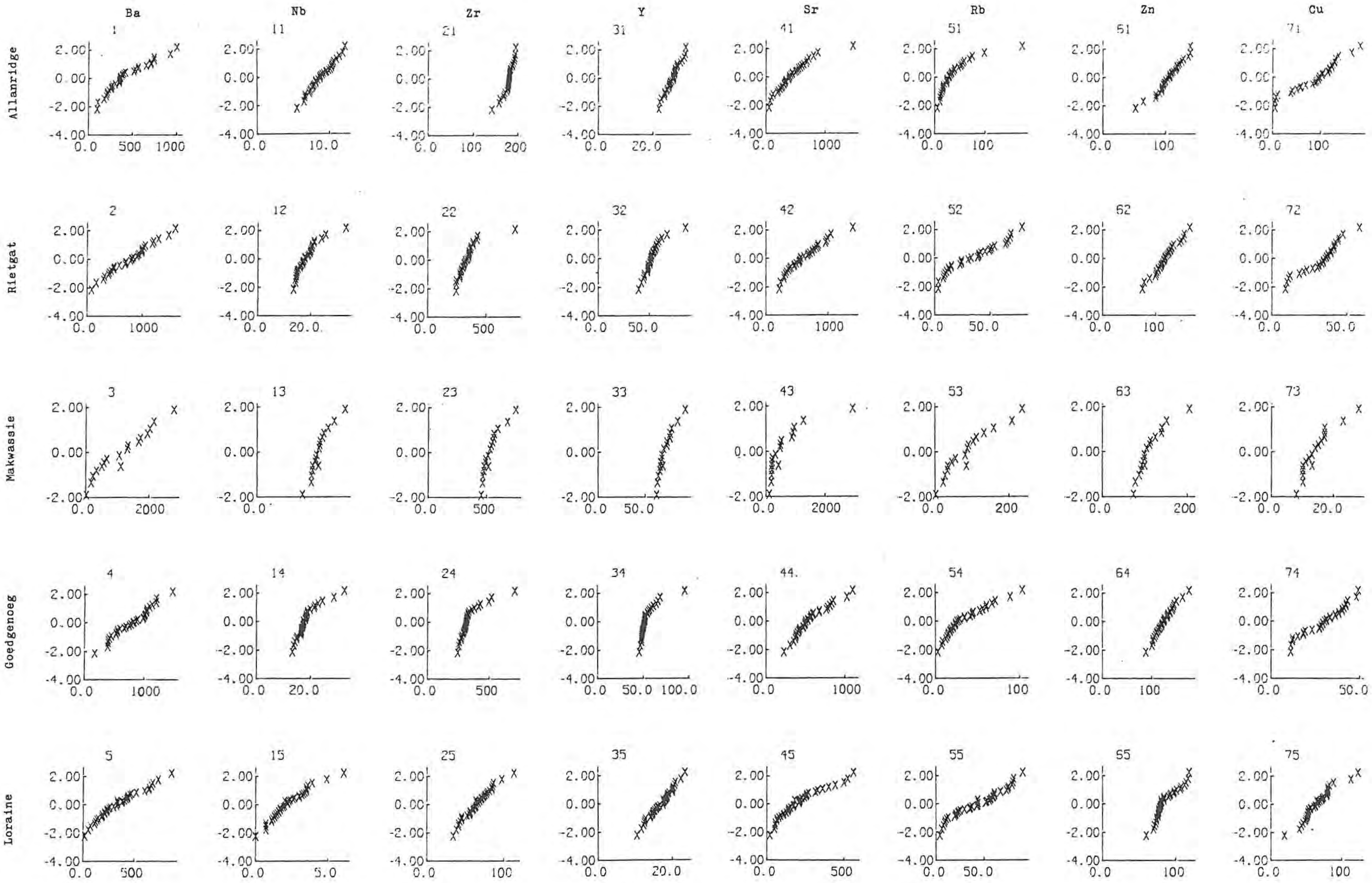


Figure 5.2b continued

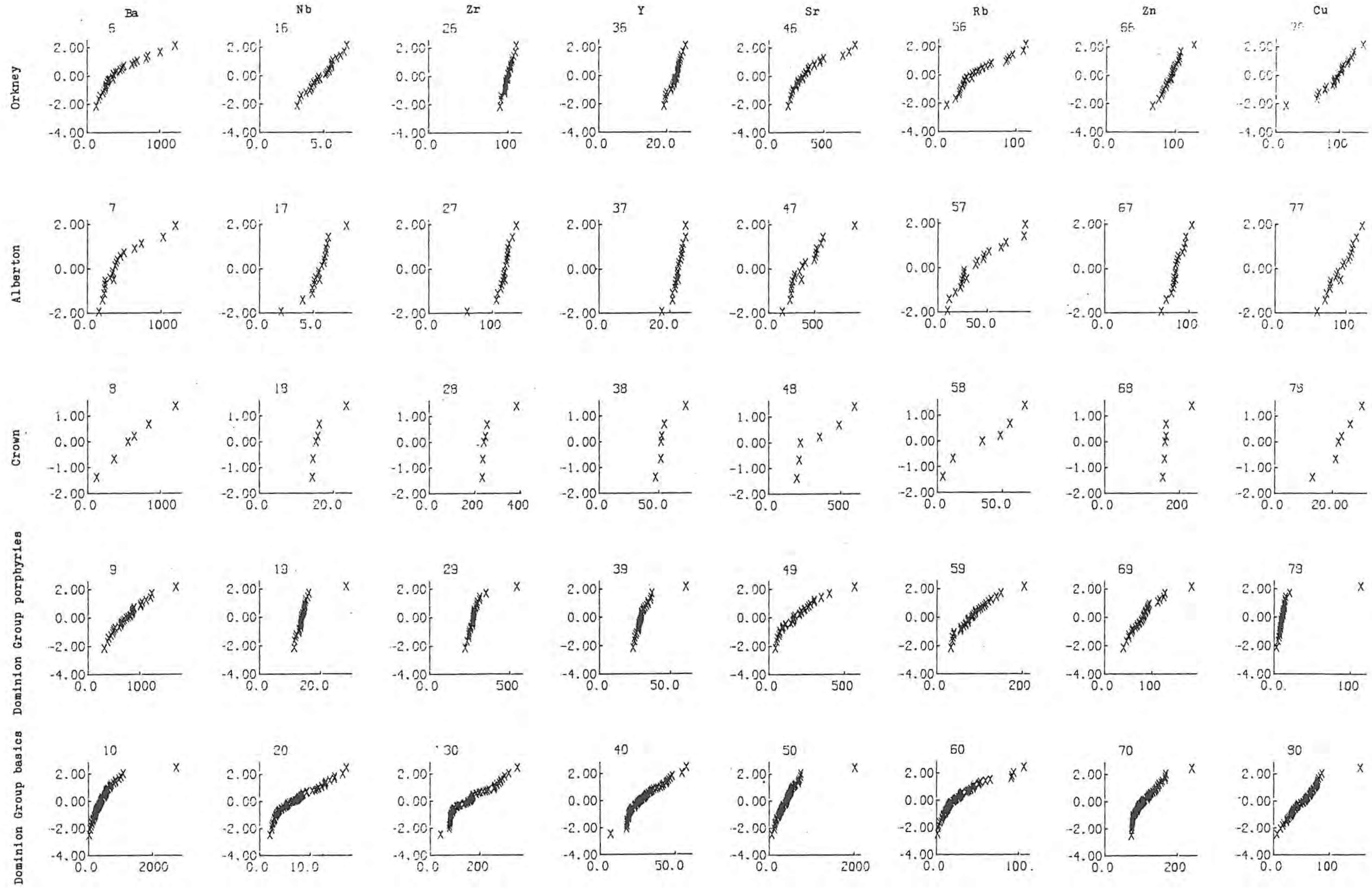


Figure 5.2b continued

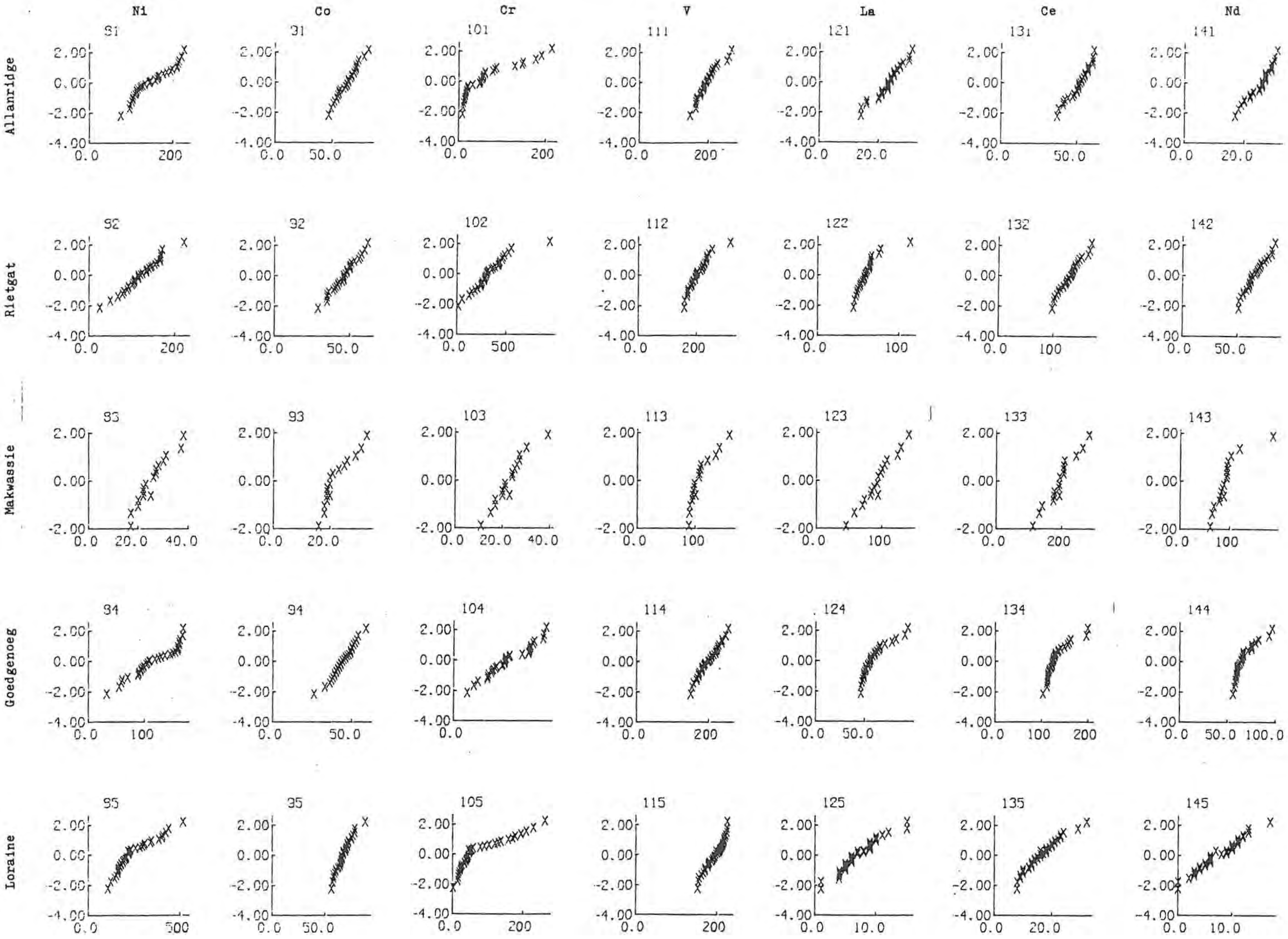
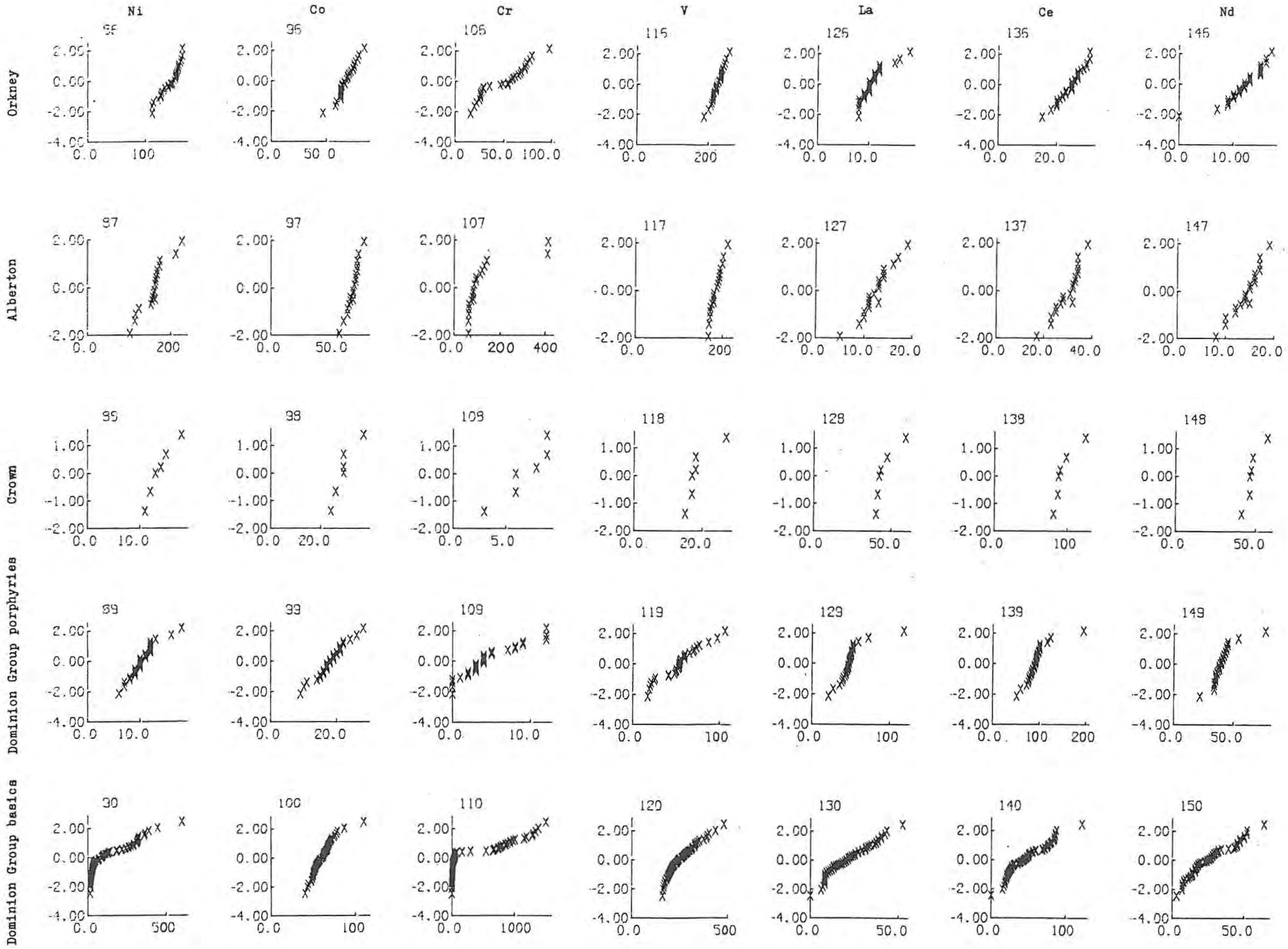


Figure 5.2b continued



and Orkney units, which have 46, 35, 34, 33, 32 and 31 data points respectively. It must be borne in mind in such cases that fluctuations in the probability curve may possibly be due to the low density of sample points, and this is certainly well-illustrated by the curves of the Alberton (19 points), Makwassie (17) and Crown (6) Formations.

One method of recognising "wild" samples is to plot confidence limits of a probability curve. This can be done graphically, but in the current study, the computer program which produced the probability plots also printed out a list of outliers for both the 90% and 98% confidence limits or intervals. An example of the output is shown in Figure 5.4. This isolates samples which plot away from the main curve, both at the tails and in between, so that they can be examined further.

Figure 5.4 Sample of output showing outlier samples for 90% and 98% confidence intervals

```
72  ELEMENT SI              FORMATION  JEPP
73 FOR THE 98% CI THE OUTLIERS ARE
74 FOR THE 90% CI THE OUTLIERS ARE
75                          AI-371
76
77
78  ELEMENT TI              FORMATION  LDOM
79 FOR THE 98% CI THE OUTLIERS ARE
80                          AI- 13
81 FOR THE 90% CI THE OUTLIERS ARE
82                          AI- 13
83                          AI- 69
84                          AI- 72
85                          AI- 73
86                          AI- 75
87                          AI- 91
88
89
90  ELEMENT TI              FORMATION  UDOM
91 FOR THE 98% CI THE OUTLIERS ARE
92                          AI- 33
93 FOR THE 90% CI THE OUTLIERS ARE
94                          AI- 33
95                          AI-263
96                          AI-276
```

In Table 5.2 different confidence limits are shown together with the standard deviation which corresponds to each limit (from Spiegel, 1961).

Table 5.2 Confidence limits with corresponding standard deviations.

Confidence limit (CL)	99.73%	99%	98%	96%	95.45%	95%	90%	80%	68.27%	50%
Std deviation (s)	3.00	2.58	2.33	2.05	2.00	1.96	1.645	1.28	1.00	.6745

Thus, a 90% confidence limit implies that 90% of the samples from a particular population should be found within the interval -1.645s to +1.645s. At the beginning of this chapter it was mentioned that Koch and Link (1971) suggested that samples which lay outside the 2s limit (or 95.45% CL) were possibly anomalous. By lowering this to the 90% CL, obviously a number of acceptable points would also be isolated, but it would ensure that all possibly anomalous values be scrutinised.

These normal probability plots were used in conjunction with the various methods described in Chapter 4 in attempting to classify samples into their correct formations. Naturally, some samples isolated using the probability plots were valid members of their particular group and simply represent extreme values. These were left unchanged, but certain samples were removed to other units, or left unclassified, as documented in Chapter 4.

To conclude, it is of interest to note some of the advantages and disadvantages of this simple graphical technique, as summarised by Sinclair (1976):

Advantages

1. A simple form of graphical representation of data.
2. Rapid, qualitative analysis of density distributions.
3. Rapid estimation of parameters of normal and lognormal distributions.
4. Compact graphical representation of several sets of data on a single diagram.
5. Recognition of polymodal distributions.
6. Partitioning of polymodal distributions.
7. Rapid recognition of certain abnormalities in data.

Disadvantages

1. Data might not approximate normal or lognormal density distributions.
2. Data might be too sparse for meaningful analysis on probability paper.
3. Tails of cumulative distributions are commonly not well-defined. This can cloud interpretation in the upper value range which is of particular interest in most mineral exploration data.

4. A small, but significant proportion of plots appears to be uninterpretable using the procedures outline in Sinclair (1976). This is particularly true if several populations are present with extensive overlap and/or different types of density distributions. Except in very special cases, four populations are about the maximum that can be treated successfully, and difficulties are not uncommon if three or four populations are present.
5. The lower the quality of data, the more ambiguous is the interpretation of the corresponding probability plot.

6. SUMMARY AND CONCLUSIONS

The volcanic rocks of the Witwatersrand triad were found to be primarily subalkaline tholeiitic rocks. The use of the word "andesite" for describing the majority of the basic volcanic rocks in the Witwatersrand triad in the past, is a misnomer, for two principal reasons. Firstly, the name "andesite" is generally confined to calc-alkaline rocks, associated with which are very specific tectonic regimes. The Witwatersrand triad volcanic rocks do not fit into this calc-alkaline association and M P Bowen (in prep.) has discussed this in some detail. Secondly, the Al_2O_3 content of the Witwatersrand triad volcanic rocks is too low for them to be called andesites.

The Dominion Group basic rocks, all the formations of the Klipriviersberg Group, and the Goedgenoeg-Rietgat Formations were classified as basalts, the latter formation having tholeiitic andesitic to andesitic tendencies in the non-genetic sense of Irvine and Baragar, (1971). About a third of the Loraine-Edenville samples were designated Mg-rich tholeiites. The Allanridge Formation rocks are basalts to tholeiitic andesites, while the Crown Formation samples are all tholeiitic andesites. The Makwassie Formation comprises predominantly tholeiitic andesites to andesites, but with a fair proportion of both basalts and dacites. The Dominion Group porphyries are mostly dacites, with an andesitic to tholeiitic andesitic tendency.

With regard to potassium content, the Crown Formation rocks are K-poor, the Alberton, K-poor to average. The Allanridge, Orkney and Dominion basalts are average, the Dominion porphyries are average to K-rich, and the Loraine-Edenville, Goedgenoeg-Rietgat and Makwassie Formations are K-rich to average. The Klipriviersberg Group becomes progressively more potassic upwards.

Major and trace element analyses have revealed that a clearly-defined geochemical stratigraphy exists within the Witwatersrand triad volcanic rocks. The Dominion Group consists of bimodal basaltic and dacitic lavas, both of which transgress the formal formational boundaries defined by SACS (1980). Within the overlying Witwatersrand Supergroup, the Jeppestown Amygdaloid or Crown Formation occurs in the study area, with distinctive chemistry, but the Bird amygdaloid marker is absent.

In the overlying Ventersdorp Supergroup, the lower Klipriviersberg Group, the middle Platberg Group and the upper Pniel sequence are each chemically distinctive units, with further subdivisions possible within each of these units. The lowermost Westonaria Formation of the Klipriviersberg Group is absent in the Klerksdorp area, being confined to only the deepest parts of the Witwatersrand basin, and the Jeannette Agglomerate Formation has not been recognised. Three chemically distinct units are present - the Alberton Formation, the Orkney Formation, and the Loraine and Edenville Formations together, which form a single geochemical entity.

The Platberg Group comprises three stratigraphic units, two of which, the Goedgenoeg and Rietgat Formations at the base and top respectively, have the same chemical signature, while the intervening Makwassie Formation is chemically distinct. This group is overlain by the Pniel sequence, the only volcanic unit of which, the Allanridge Formation, is also chemically distinctive.

Several techniques were used to distinguish between the 9 different geochemical units present. The simplest of these, orthogonal discrimination, assesses the range of each major and trace element, as well as that for each interelement ratio, for every geochemical unit. Discrimination is achieved when ranges are discrete, i.e. do not overlap. This method is successful in distinguishing all geochemical units from one another, except the Dominion Group basalts from the Allanridge, Loraine-Edenville, Orkney and Loraine basalts. The other techniques, however, do enable these distinctions to be made successfully.

The second discrimination technique involves the use of three discrimination plots, namely Ti:Zr vs Ti:P, Zr:P vs P:Ti, and TiO_2 vs Zr. The first two are able, with a minimum of overlap, to distinguish seven separate units, the three Klipriviersberg entities plotting together in one field. The third plot, TiO_2 vs Zr, enables these three Klipriviersberg units to be separated from one another.

The third and most sophisticated discrimination technique, discriminant analysis, requires the use of a computer, and has two main functions. Firstly, previously grouped data is assessed and an evaluation of the success of the parameters defining the groups is provided. In the current study, 99.07% of all the samples were correctly classified. The second function of discriminant analysis is to classify unknown samples. In this respect a number of intrusive samples from the current study were able to be assigned to various formations.

A useful test of the aforementioned discrimination techniques was afforded when fourteen samples from an unknown succession in the Klerksdorp area were acquired. They were positively identified as representative of a complete sequence through the Klipriviersberg Group, two of the samples being from the Alberton Formation, two from the Orkney Formation and ten from the Loraine-Edenville Formations.

Diagrams of major and trace element variation with depth show that, despite their having been subjected to low grade greenschist metamorphism, variation patterns are still reasonably clear. The greatest amount of scatter is shown by Na, K, Mn, Ba and Rb, and these elements should not be used for any petrogenetic deductions. In contrast, the immobile elements Ti, P, Nb, Zr and Y, together with the light rare earth elements La, Ce and Nd, appear to have been little affected by any post-extrusive processes.

Normal probability distributions of each major and trace element for each formation were plotted, enabling a qualitative estimation of the density distributions to be made. Confidence limits placed on these curves served to isolate "wild" samples, which were then examined further using discrimination techniques to clarify their true affinities.

With regard to the SACS (1980) nomenclature of the individual formations included in this study, several changes are recommended. It is proposed that the name "Rhenosterhoek Andesite Formation" be shortened to "Rhenosterhoek Formation", as the lava type present is primarily, but not exclusively, basaltic. For the same reason, the name "Allanridge Formation" is proposed in place of "Allanridge Andesite Formation".

The original purpose of this study, namely, to ascertain whether any geochemical criteria exist which may serve to discriminate between the various volcanic formations within the Witwatersrand triad, has been fulfilled with highly encouraging results. The successful identification of a sequence of unknown samples has demonstrated that the various techniques used have undoubted application in exploration and development in the Klerksdorp area. Chemical data from south of Johannesburg (Wyatt, 1976) appear to uphold these criteria in that region, and it remains for further analytical work to show whether these criteria can be extended to include areas further afield. In addition, closer sampling on either side of formational boundaries is required in order to resolve situations in which geochemical and visual delineation of boundaries does not concur.

7. ACKNOWLEDGEMENTS

The writer would like to thank the following people :

Professor H.V. Eales, who initiated this study and who, together with Dr Goonie Marsh, offered suggestions and criticisms during its progress;

Michael Bowen, for his brotherly cooperation;

Mr Meiring Strydom and the staff of Anglo American Prospecting Services, Klerksdorp, for providing access to borehole core and related information;

Anglo American, for the provision of a grant to finance this study, and the C.S.I.R. for a post-graduate bursary;

David Bowen, Mark Hannam and Julian Misiewitz, for help in the preparation of samples; Archie Cintso for making thin sections and Dennis Gouws and Johan Kruger, for their help with the spectrometer;

Craig Beuthin, Hugh Murrell and Pat Terry, for assistance with graph plotting;

Shirleen Reynolds and June McDougall, for typing this manuscript.

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APPENDIX I

HISTORY OF INVESTIGATION OF THE WITWATERSRAND TRIAD LAVAS

The literature review which follows is the result of an attempt to collect together as much published information as possible about the stratigraphic relationships, nomenclature, correlation and general descriptions of the volcanic rocks of the Witwatersrand triad. Much unpublished material has also been referenced, but this review has not exhausted all possible sources. The literature has been reviewed more or less in chronological order and the spelling of names, descriptions, terminology and views expressed are those of the original authors. The locality map in Figure A.1 shows the positions of places mentioned in the review.

The important contributions of the early writers, the most prolific of whom were Molengraaff (1903a, 1903b, 1904, 1905), Hatch (1903a, 1903b, 1903c, 1904a, 1904b), Corstorphine (1903), Holmes (1904, 1906), Rogers (1905, 1906, 1907, 1908) and du Toit (1906, 1907, 1908), were collated and consolidated in a book by Hatch and Corstorphine (1909). The next set of major contributions included those of Kynaston (1907, 1912, 1913), Humphrey (1909, 1910a, 1910b, 1911), Horwood (1910, 1912a, 1912b), Mellor (1911, 1912, 1913), McDonald (1911) and Rogers (1921, 1922, 1929). Rogers (1929) provided a comprehensive overview of the current state of knowledge of the Ventersdorp System to that date. Subsequently, more work was done by Nel (1927, 1933, 1934a, 1934b, 1935) and by Nel and others (1935, 1939), while Jacobsen (1943) produced a detailed thesis on the Ventersdorp System. Truter (1949) provided a detailed review in a comprehensive overview of all volcanism in South Africa. Further investigations by Von Backström (1952, 1962), Von Backström and others (1953), Matthysen (1953), Pienaar (1956), Coetzee (1960) and Winter (1963b, 1965b) provided additional detailed information, with the literature to that date being reviewed exhaustively by Winter (1965b). A very useful bibliography was provided by Simpson (1964). More recent studies included that of Whiteside (1970) and Wyatt (1976), while the reader is referred to SACS (1980) for the latest recommendations regarding nomenclature and correlation of stratigraphy.

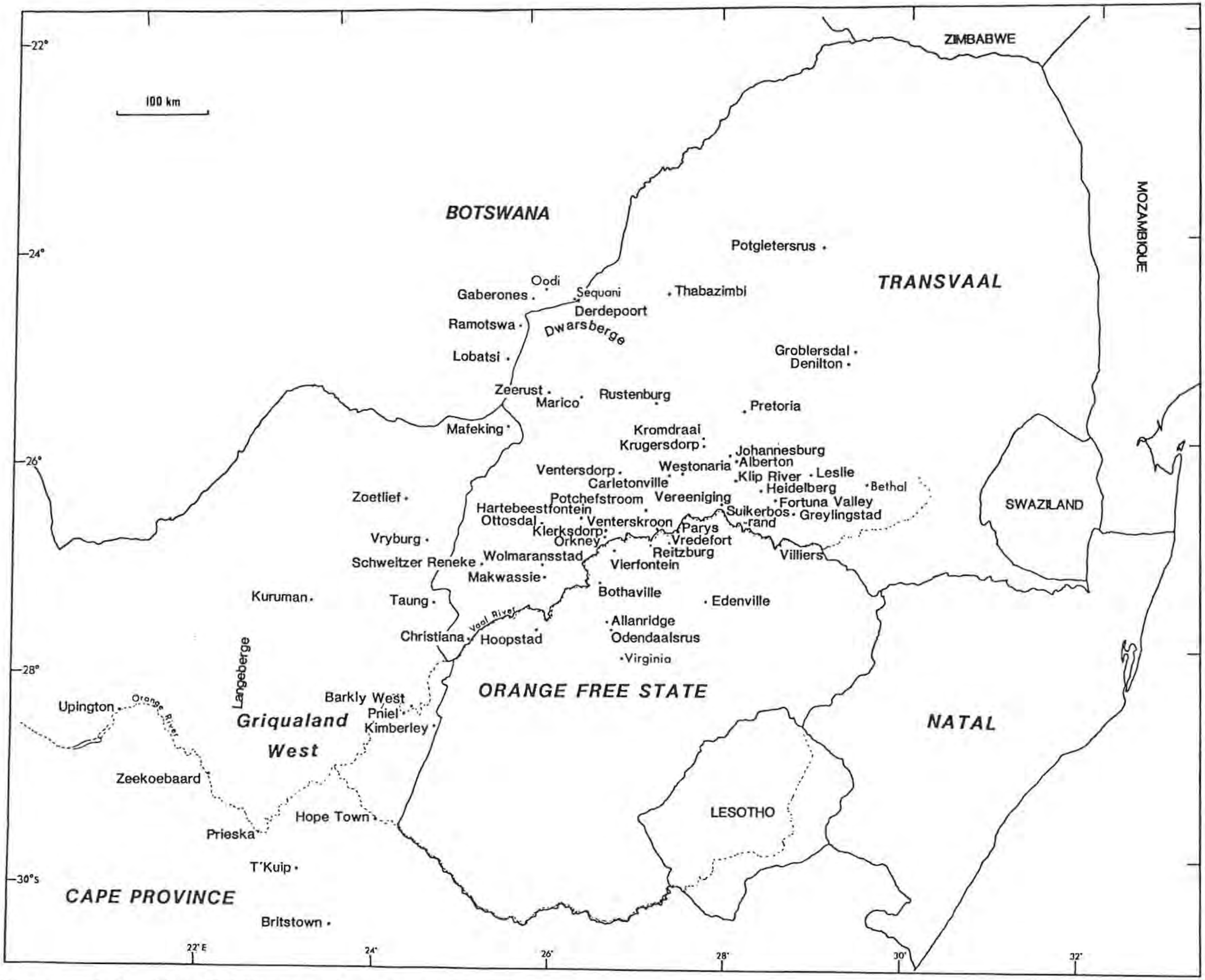

Figure A.1 Locality map for literature review

Before the turn of the century the amount of literature published on any of the Witwatersrand triad lavas was negligible. The earliest account of the Ventersdorp rocks was that of Wyley (1859), who wrote: "About five or six miles below Hope Town, the Orange River flows between rocky hills of greenstones, amygdaloid, claystone and other traps.". This was followed by Stow's (1874) map and description of the "amygdaloidal and associated rocks of Pniel", on the Vaal River near Barkly West.

Despite the occasional heretical statement from respected geologists such as Hans Merensky (1907), who emphatically announced that "amygdaloidal diabase, not kimberlite, is the source of river diamonds", the observational powers of the geologists of that time were acute and much of their original mapping and descriptions are still valid today.

The year 1903 heralded the beginning of an interest in these and associated rocks which lasted for about ten years, waned and then revived again during the 1930's. Molengraaff (1903a), in describing the strata circumscribing the central granite boss of the Vredefort Mountain-Land, reported the presence of "amygdaloidal diabase and diabase porphyrite merging gradually into one another" and that "these rocks bear a very close resemblance indeed to the amygdaloidal rocks of the Klipriversberg and the Suikerboschrand.".

Sawyer (1903), in a discussion about an unnamed amygdaloidal diabase formation near Heidelberg, recognised that in places its flows were conformable to the underlying Witwatersrand Beds, while in others the relationship was clearly unconformable. He also found that in some places the diabase overlies the Elsburg Reefs, but in others it overlies much older beds.

Hatch (1903a), describing two sections in the Potchefstroom District, observed "one great unconformity ... between the Upper Witwatersrand Beds and the Klipriversberg Amygdaloid", and probably another between the Black Reef and the Klipriversberg Amygdaloid. He deduced that, due to its vesicular structure, the amygdaloid was a flow which had spread over the Witwatersrand Beds after they had been tilted. He also noted the great disparity in thickness between the south-eastern and the north-western portions of the amygdaloid and added that this variability in thickness was characteristic of the Klipriversberg Amygdaloid in the Southern Transvaal, and concluded that the amygdaloid must be a series of flows.

Also in 1903, a hitherto unrecognised formation, younger than the Witwatersrand Beds, but older than the Black Reef Series, and comprising "shales, schists and shaly conglomerates, banded cherts, amygdaloidal diabase tufas, grits and very coarse conglomerates", was described by Molengraaff (1903b) from the south-western and southern Transvaal. He noted its unconformable relationship to both the underlying Witwatersrand Beds and the Black Reef Series above, but was unsure of its position regarding the "Klipriver Amygdaloid" and the "Vaal River Amygdaloid".

Hatch (1903b) wrote about a very thick, coarse conglomerate developed between the Black Reef and the Klipriversberg Amygdaloid near Reitzburg in the Orange River Colony, and correlated it with that referred to by Molengraaff (1903b).

His interest being revived by Molengraaff's earlier 1903 paper, Hatch (1903c) described a boulder bed containing boulders of various rock types (conglomerates and quartzites of the Upper Witwatersrand Beds, banded slates from the Lower Witwatersrand Beds, quartz, gabbro, diabase and quartz-porphyry) ranging up to several feet in diameter. This boulder bed, which occurs north-west of Ventersdorp, lies unconformably on the Lower Witwatersrand Beds. Hatch was convinced that this formation was the same as that described by both Dr Molengraaff and himself previously, and proposed for it the name "Ventersdorp Beds", and suggested that it include the underlying Klipriversberg Amygdaloid, which he showed was intimately related to it.

Dörffel (1903) wrote that "the Black Reef Formation on Kromdraai (NW of Pretoria) is deposited unconformably on a schistose conglomerate, belonging to the new formation described lately by Dr Molengraaff, Dr Hatch, and others, and for which Dr Hatch had suggested the name Ventersdorp Beds.".

Corstorphine (1903) described the same conglomerate in the Krugersdorp area and in the valley of the Suikerbosch Rand River, also associated with masses of diabase and having the same relationship to enclosing rocks. He was convinced that this diabase was a geological continuation of that of the Klipriversberg, and that this together with the amygdaloid, quartz-porphyries and quartzites of the Vaal River, Kimberley and Hopetown areas, constituted a major volcanic series.

Hatch (1904a) reported the presence of "Ventersdorp beds" north of the Dwarsberg in the Marico District, but noted that they rest immediately on the Basement Granite, not on Lower Witwatersrand Beds, as at Ventersdorp. In a supplement to this paper, Hatch (1904b) described a thin section of amygdaloidal diabase, "composed of lath-shaped crystals of plagioclose felspar, imbedded in a chloritic mass derived probably from the decomposition of augite; the amygdules consist of calcite and quartz.".

Hatch and Corstorphine (1904a) described the amygdaloidal diabase and diabase breccia occupying the Bezuidenhout Valley and postulated that it belonged to the Ventersdorp beds now called the Ventersdorp Series. They noted that quartz- and chalcedony-filled amygdales were abundant and that occasionally a porphyritic habit was observed in which the phenocrysts were stellate aggregates of feldspars. Microscopically, they described the diabase as a mass of minute felty laths of feldspars and augite with interstitial quartz, while the larger feldspars were sometimes orthoclase, sometimes plagioclase. The diabase breccia included mainly basic igneous fragments similar to the amygdaloidal diabase, but also pieces of quartzite. The breccia matrix was crystalline, containing mostly small feldspar crystals, with a kaolin cement.

To the north of the valley, the amygdaloid becomes slaty and is associated with slates, quartzites and conglomerates similar to those classified as part of the Ventersdorp Series in the Western Transvaal. From their observations, Hatch and Corstorphine inferred an episode of "long-continued volcanic activity, producing alternate outpourings of lava and the ejection of fragmental material, (accompanying) the deposition of the sediments.". In addition, they suggested "removing (the Elsburg Series) from their hitherto accepted position at the top of the Witwatersrand Series, and including them with the Ventersdorp Series.". Molengraaff (1904) seems to have also given support to this idea, and categorically stated that he recognised "the Klipriver Amygdaloid as representing a separate system - the Vaal River System - overlying the Witwatersrand Beds unconformably".

In a discussion on the paper by Hatch and Corstorphine (1904a), Frames (1904) suggested that the Elsberg Series and the diabase in the Bezuidenhout Valley had been inverted by localised thrust faulting from the south, which induced the slaty structure displayed at the bottom of the diabase. In two drill holes he found a "transition layer between the (diabase) sheet and the sedimentary beds composed of an intimate intermixing of grains of sand with igneous matter." In other instances they were abruptly separated by a "3 to 5 inch layer of quartzite". He accepted this as strong evidence that the ancient lava flow interrupted the deposition of the sedimentary strata, resulting in conformity between the Elsburg Series and the diabase. He concluded that the diabase was poured out as a lava, when the underlying beds were still horizontal, and was later tilted along with the Elsburg Series. Frames did not think it advisable to include the diabase and the Elsburg Series in the Ventersdorp Beds, until more evidence was collected, his reasoning being that the latter had characteristics not present in the Elsberg Series, viz. the Ventersdorp Beds were largely made up of fragments of pre-existing conglomerate, while the Elsburg Series of conglomerates were true and original pebble beds. In reply to Frames, Hatch and Corstorphine (1904b) reiterated their conviction that the Amygdaloidal Diabase was part of the Ventersdorp Series, but were not entirely sure whether the Elsburg Conglomerates were.

Holmes (1904) recognised amygdaloidal diabase and volcanic breccias belonging to the Ventersdorp Series near Vryburg. He found that to the west the diabase thins out to expose the underlying boulders of granite imbedded in the diabase. Further to the west he noted that the granite was penetrated by both acid and basic dykes, which appear to be older than the overlying Black Reef Formation.

Luttman-Johnson (1904) detailed the geology of the Fortuna Valley, Heidelberg, in which the Hospital Hill Quartzites of the Witwatersrand Series are unconformably covered by a great thickness of amygdaloidal diabase of the Ventersdorp Series, together with associated rocks, viz.

breccia, tuffs, conglomerates and quartzites. The coarse breccia is found interbedded with, and grading into, the fine tuffs. The Black Reef overlies the Ventersdorp Series unconformably.

Jorissen (1906) agreed with Hatch and Corstorphine (1904a) and Molengraaff (1904) in separating the Elsburg Series from the Witwatersrand System and placing it as the basal series of the Vaal River or Ventersdorp System.

The name "Dominion Reef Series" was given by Molengraaff (1905) to a series of reefs found in the Klerksdorp district. The reefs comprise sericite schists interbedded with gold-bearing conglomerates and quartzites, and are overlain by amygdaloidal diabase and porphyrites of what Molengraaff mistakenly called the Vaal River System, even though he saw clearly that they underlay conformably the Witwatersrand Beds. He later contradicted himself by saying that "the Dominion Reef Series and the Lower Witwatersrand Beds disappear under the overlying amygdaloidal diabase of the Vaal River System.". He evaded explaining this inconsistency by concluding that "a great diversity appears to exist in the sequence of the strata of the Vaal River System ...".

Two groups of amygdaloidal rocks, called the Beer Vley series and the Zeekoe Baard amygdaloid, found in the Prieska and Hope Town districts, were described by Rogers (1905). The Beer Vley group consists of andesitic amygdaloidal lavas, rhyolites and some agglomerates. He noted that this group is less altered than the Zeekoe Baard amygdaloids which are more basic and which he said contain very few recognisable original constituents. Rogers noted the similarity between the Zeekoe Baard amygdaloid and those in the Transvaal underlying the Black Reef Series. In the Prieska area, however, the correlation proved difficult and he suggested that these amygdaloids belonged to the same group as the "Boschveld volcanic rocks" of the Transvaal.

Samples of a number of igneous rocks from the Transvaal were collected by Rand (1905), who published descriptions of their petrographic features. The samples included two from the Klipriversberg Amygdaloid, six from the "eruptive occupying the floor of the Bezuidenhout Valley" and three from the vicinity of Klerksdorp.

Rogers (1906) mentioned the presence of the "Pniel Volcanic Series (Ventersdorp Beds)" between Barkly West and the Langeberge in the northern Cape. He stated that they undoubtedly underlie the Campbell Rand Group and the Black Reef Series. They consist of compact and amygdaloidal lavas, some of which are porphyritic, breccias and tuffs. He noted their resemblance to the lavas and breccias at T'Kuip, which have a lower basic portion, overlain by a thick group of porphyritic acid lavas.

In his survey of the Vryburg-Mafeking area, Du Toit (1906) detailed the occurrence of the Ventersdorp Series, consisting of lavas, breccias, conglomerates and other rocks of both sedimentary and igneous origin. In the Vryburg area he reported the presence of what he called the Zoetlief Beds, which unconformably underlie the Ventersdorp diabases and amygdaloids, but due to the similarity of rock types, he preferred to group the two formations together.

The Zoetlief Beds described by Du Toit consist of a lower portion of arkoses and quartzites, resting upon granite. This is followed by a middle portion consisting of acid and intermediate lavas: quartz porphyries, trachytes and allied rocks. The uppermost division comprises quartzites and flagstones, which grade into cherts. He noted that the quartz-porphyries and trachytes had been highly silicified.

The Ventersdorp Diabase formation contains compact and amygdaloidal diabases, volcanic tuffs and breccias, conglomerates, grits, sandstones and shales. Du Toit recognised finely developed flow-structures in the volcanic rocks, which are mostly andesitic and usually altered. In one area he detected a "pillowy-structure" in the lava, but he maintained that the greater portion of the volcanic material was laid down sub-aerially.

Hall and Humphrey (1906) reported the presence of Ventersdorp Beds (mainly conglomerates) north of Krugersdorp. These were covered by schists and various sedimentary rocks, which Hall and Humphrey decided were best included in the Swaziland Series. These in turn are overlain by the Black Reef Series.

Holmes (1906), in describing the geology of the south-western Transvaal, stated that the predominating rock of the Ventersdorp System in this area is amygdaloidal diabase, the nature of which had already been commented upon by previous authors. The second most important rocks are the acid quartz porphyries, well-exposed in the "Makuasiberg". They contain porphyritic crystals of feldspar and quartz and are highly resistant to weathering. South-west of Wolmaransstad he noted the occurrence of a porphyrite dyke, 23 metres wide, cutting through the quartzites underlying the diabase. He was unable to determine the exact relationship between the diabase and the porphyrite, but he postulated that the porphyrites occurred as intrusive dykes rather than interbedded lava sheets, and classed them together with the Ventersdorp System Rocks.

Holmes also recorded the presence of volcanic conglomerate containing fragments and boulders imbedded in a lava matrix, which is both overlain and underlain by amygdaloidal diabase. He concluded that "the sources of origin of the enormous masses of diabase which form the bulk of the Ventersdorp Beds are not apparent; they possibly belong to the class known as fissure eruptions, though anything of the nature of volcanic cones would have long ago become unrecognisable in a formation so ancient.".

Du Toit (1907) in a survey of the eastern Griqualand West district found the same two volcanic formations as he had in the Vryburg-Mafeking area, i.e. the Zoetlief Beds and the Diabase Formation, which he now grouped with the Pniel Volcanic series of Stow, who in 1873 had given this name to the amygdaloidal and associated rocks of the Vaal River Valley. Again he found that the Zoetlief Beds were unconformably overlain by the diabase, which, at the contact, often contains angular fragments of the underlying rhyolite. He determined the presence of three zones in the Pniel series: a lower zone of porphyritic lavas (acid and basic), a zone of normal diabases, and an upper zone of quartzites and conglomerates. Tuffs, breccias and brecciated lavas occur in all three zones. Du Toit remarked on "the great proportion of brecciated igneous material in (the Pniel volcanics), which sometimes forms beds 25 to 50 feet in thickness". He was unable to find any vents or fissures from which the Pniel volcanics could have erupted, but he did note the presence of many veins or dykes of felsitic material, which he suggested marked the sites of fissures from which the higher-lying acid volcanics may have issued.

Kynaston (1907) described the presence of Ventersdorp sediments and diabase breccia in the area occupied by the Pretoria-Johannesburg Granite. The breccia extends south-westwards into the Bezuidenhout Valley, as described by Hatch and Corstorphine (1904).

Rogers (1907), working adjacent to that area surveyed by Du Toit (1906) reported the same lavas as had Du Toit, i.e. Pniel and Zoetlief Beds. He expressed doubts as to whether the Pniel lavas and overlying Black Reef Series ought to have been separated, as he found them to be "very intimately connected" in this area, shown by a certain degree of interbedding of the two series. It appeared to him that the great unconformity between the two groups in the Transvaal, did not seem to exist in the Vryburg area.

To the west of this region, Rogers (1908) encountered very little outcrop of the Ventersdorp or Vaal River System. Although the Koras rocks in this area differed in important respects from those of the Vaal River System, Rogers suggested that they may have been formed at about the same time, and therefore placed them as a distinct sub-group in the Vaal River System.

Du Toit (1908) reported the occurrence, in the Hopetown-Britstown-Prieska-Hay area, of the Zoetlief Series, consisting of an upper group of acid volcanics and a lower group of sediments with occasional lava flows. South of the T'Kuip Hills he found a possible volcanic neck. Succeeding the Zoetlief rhyolites with an inferred unconformity, is a group which du Toit called the Kuip Series. It comprises diabase and amygdaloid with some interbedded sediments, and is indistinguishable in handspecimen from those of the Pniel Series. It reached 457 metres in thickness in one area. Unconformably overlying this is the Pniel Series - a lower sedimentary group, mainly quartzite, and an upper volcanic one of "diabase amygdaloid" and breccia.

Humphrey (1909) found almost the whole of the country along the western Transvaal border to be occupied by rocks of the Ventersdorp System, i.e. mainly diabasic rocks with amygdaloids, porphyries and acid lavas with tuffs and breccias. He suggested that they all fell "within the limits of the Pniel Series as constituted in the Cape Colony", mapped by du Toit and Rogers in previous years.

Hatch and Corstorphine (1909), in their book on the geology of South Africa, mentioned sheets of amygdaloidal diabase which occur at different horizons in both the Lower and Upper Witwatersrand Beds, interbedded with slates and quartzites. They maintained that these "bursts of volcanic activity" were "a prelude ... to the violent volcanic outpourings which characterise a later period" i.e. the Ventersdorp lavas. They documented the Ventersdorp System in a fair amount of detail, consolidating all the information gathered until then. They described it as "a series of acid and basic lavas, tuffs, breccias, and conglomerates, which, being typically developed at Ventersdorp in the Western Transvaal, may be conveniently grouped together as the Ventersdorp System." They dismissed Molengraaff's name, the "Vaal River System", as ambiguous. They included within the Ventersdorp System the Elsburg Series, consisting of alternating conglomerates and quartzite. They wrote that "the basic lavas are well represented by the rocks of the Klip River Hills south of the Rand, where they have an aggregate thickness of some 5000 feet. The rock there exposed is a fine-grained amygdaloidal and porphyritic diabase, long known as the Klipriversberg amygdaloid. The amygdales consist chiefly of silica ..., calcite and chlorite.".

Furthermore they stated that "acid lavas are of less frequent occurrence in the Transvaal, but they have been observed in the Makwassie Hills in the Wolmaranstad district", and at Platberg, and between Kimberley and Mafeking. "These form the lower division of the system, and, like the upper basic flows, are associated with tuffs and breccias, conglomerates and quartzites.".

Hatch and Corstorphine wrote that, in the geological succession, the position of the fragmental rocks - breccias and conglomerates - had but recently been understood, as their connection with the "Klipriversberg amygdaloid" had not been recognised for a long time. At Ventersdorp clastic rocks of two distinct types are found: (1) volcanic breccias, grading into fine tuffs, and (2) boulder and pebble beds. The fact that the boulder beds are, to a large extent, made up of the debris of the Witwatersrand System points to a considerable denudation of the latter after its elevation above sea level and before the deposition of the Ventersdorp System.

They also noted "that the period to which the Ventersdorp System belongs was marked by great volcanic activity is shown in the enormous accumulation of lava, volcanic ash, and breccia. But this activity must have been to some extent localised, so that while lava and fragmental rocks were being ejected in one place, sand and gravel were simultaneously accumulating elsewhere: only in some such way can the great diversity of the beds grouped together as the Ventersdorp System be explained."

They mentioned the distribution of the Ventersdorp System in the Heidelberg district, in the Bezuidenhout Valley near Johannesburg, at Kromdraai north of Krugersdorp, in the Marico district, north of the East Rand, in the Venterskroon-Parys district, at Hoopstad, near Reitzburg, and at Ventersdorp. In the south-western area of its exposure, from Mafeking to the T'Kuip Hills, the Ventersdorp System had been grouped into two series, the Pniel and the underlying Zoetlief Series. They concluded by supporting the idea of Merensky (1907) that river diamonds were associated with the amygdaloids of the Ventersdorp System.

Rogers and Du Toit (1909) wrote a detailed account of the rocks of the Ventersdorp System in the Cape Colony. They included in their succession, as did Hatch and Corstorphine (1909), the Pniel Series, the Kuip Series and the Zoetlief Series. They also placed in this system the Koras Series, though admitting that its true position was not known.

In the Marico district of the western Transvaal Humphrey (1910a) found the following succession of Ventersdorp rocks: a basal sequence of shales and conglomerates, followed by acid lavas and porphyries. Overlying this is a second sequence of shales and conglomerates, succeeded by basic amygdaloid. He contended that the two sedimentary facies represent one period in the middle of which the acid rocks were erupted, as the whole succession appeared conformable. He also observed that the "close-grained diabase" which had previously been mapped as an intrusive, was simply "the central and lower portion of massive flows while the amygdaloidal rocks are those which consolidated more at the surface.".

The Ventersdorp System in the Klip River Valley was found by Humphrey (1910b) to consist of the Elsburg Series overlain by the Klipriversberg amygdaloid. The latter forms the Klipriversberg to the north of the valley and the Suikerboschrand to the south-east. It consists of basic igneous rocks, frequently amygdaloidal, but also "close-grained." Occasionally it becomes markedly porphyritic with large well-developed crystals of felspar, which are usually saussuritised.

In their description of the geology around Zeerust and Mafeking, Hall and Humphrey (1910) presented a report virtually identical to that given by Humphrey (1909).

Horwood (1910) gave a detailed description of the petrography of the Klipriversberg Amygdaloidal Diabase. In addition he presented four major element analyses.

Mellor (1911) recorded the similarity of the amygdaloidal diabase in the Bezuidenhout Valley, Johannesburg, to that of the Klipriviersberg, south of Johannesburg. He noted that it had been subjected to earth movements as shown by the intense shearing evident throughout the diabase mass.

Humphrey (1911) described the geology north of Zeerust, which appeared to be merely an extension of the rocks described by him in 1909 in the Marico district.

McDonald (1911), discussing the intrusive rocks of the Witwatersrand, noted the close resemblance of many of the dykes to the Klipriversberg volcanics: "The great similarity in mineralogical composition appears rather to indicate that the dykes are the hypabyssal equivalents of the lavas. The absence of volcanic necks, marking the centres from which the lavas could have flowed, indicates that the eruptions were of the fissure type, and the dykes may now fill the channels up which the mass of molten material flowed.".

The Ventersdorp System in the Rustenburg district was described by Kynaston (1912) as consisting of two divisions, a lower sedimentary sequence of quartzites, quartzitic sandstones, grits and conglomerates, and an upper volcanic series. The lower portion of the latter comprises fine-grained and frequently amygdaloidal basic rocks. These are overlain by acid lavas, showing characteristics such as banding (indicating flow structure), brecciation, nodular and spherulitic structures. However, after extending his work into the Marico district, Kynaston (1913) found that the volcanic rocks were intercalated with conglomerates, quartzites and shales, and there appeared to be no regular succession for the whole area.

A number of writers have recorded the fact that the Ventersdorp System underlies the Black Reef formation in some places with a well-marked unconformity, yet in others the relationship is apparently conformable (Sawyer (1903), Molengraaff (1903b), Hatch (1903b)). Horwood (1912a) believed that, although the Ventersdorp diabases had always been considered older than the Black Reef formation, at least some of the diabases are intrusive in the Black Reef formation. He supported this view by describing a number of occurrences in which diabase had forced its way up from below through vertical joints in the Black Reef quartzite and had spread out above it. He concluded that "it would appear, therefore, that the eruptive activity which characterised the Ventersdorp period did not entirely die out during the time that the Ventersdorp System was being laid down; but that it extended into that period to which the Black Reef Series belongs.". In a criticism of this paper, Mellor (1912) stated that Horwood's conclusions had been based on the misidentification of shale as shaly diabase, and that these conclusions were therefore erroneous. In reply to Mellor, Horwood (1912b) refuted Mellor's evidence and maintained his former stand.

Mellor (1913) observed that the Ventersdorp System in the western Witwatersrand was represented by the Klipriversberg Diabase. Instead of forming hills, as it does south of Johannesburg, it tends here to form the lower ground. Mellor explained that this was a function of a greater ease of weathering, which was a result of the somewhat less acid character of the local rock, sometimes associated with a coarser texture. The diabase was found as usual to be markedly amygdaloidal and occasionally porphyritic, with its base apparently lying conformably on the Elsburg Beds, but overlain unconformably by the Black Reef Series. Mellor preferred to retain the Elsburg Beds in the Witwatersrand System, until further elucidation of its relationships showed otherwise.

Kynaston and Humphrey (1920) incorporated the reports of Kynaston (1912) and Kynaston (1913).

In 1921 Rogers (1921) discovered a succession of coarse agglomerate and lava belonging to the Jeppestown Series in the Heidelberg neighbourhood. The agglomerate was found to be considerably altered and the lavas, which appeared to overlie them, were highly vesicular. No feeder or vent from which the lavas might have come was found. Referring to the transition from the Witwatersrand to the Ventersdorp System, Rogers found indications "that volcanic activity began whilst the small pebble conglomerate and grit taken as the top of the Kimberley-Elsburg Series in Heidelberg was being formed". Rogers suggested that eventually "the arenaceous deposits were outweighed by the volcanic", and that "it would be difficult to find better evidence of the conformable succession of volcanic rocks on sedimentary than that offered by the Elsburg-Ventersdorp passage beds in that part of Heidelberg". This transitional zone is followed by at least 1524 metres of amygdaloidal lavas of the Ventersdorp System, containing a "strikingly porphyritic amygdaloidal lava about 300 feet above the base", similar to that found in Bezuidenhout Valley.

In a further description of the Heidelberg area Rogers (1922) stated that the Ventersdorp System there was divisible into two groups. The lower group, mainly lavas, displays stratification, indicating a large number of flows. Tuffs were seen only in the lowest rocks, and have undergone more intense alteration than the lavas. The phenocrysts of the porphyritic lava, also mentioned by Rogers (1921), were found to be albite-oligoclase feldspars. The upper group contains conglomerates and finer grained sedimentary rocks with some interbedded lavas.

In the Vredefort area the transition from the Elsburg Series to the Ventersdorp amygdaloid is very abrupt, unlike that near Heidelberg (Nel, 1927). In both these areas, the relationship between the two formations is conformable, unlike that in the Western Transvaal. The Ventersdorp Amygdaloid is the only representative of the Ventersdorp System in the Vredefort area. A porphyritic lava, the phenocrysts of which were found to be albite, is located near the base (Nel, 1927). This is similar to that described from the Heidelberg district by Rogers (1921). Nel did not notice tuffs or volcanic breccias in the

Vredefort area. The thickness of the amygdaloid was calculated to be between 3353 and 4267 metres, indicating "a close proximity to the place of origin of the lavas".

Rogers (1929) summarised the state of knowledge of the Ventersdorp System to that date. He listed the areas in which it occurs, i.e. in the central, west and south-western Transvaal, northern Orange Free State, and northern Cape Province. No Ventersdorp Beds had been recognised in either the Eastern Transvaal or Natal. Rogers stated that "the time represented by the Witwatersrand and Ventersdorp beds was one of considerable earth movements and widespread volcanic activity in the southern and western Transvaal and northern districts of the Cape; elsewhere in the Union there is no evidence yet known bearing on the period.". In neither the south-western Transvaal nor the Cape had rocks been recognised as Witwatersrand beds, but Rogers said that "the latter may be represented in the Cape Province by the lavas and sediments of the Zoetlief and Kuip series which are unconformably overlain by the Pniel amygdaloidal diabase.". To Rogers it seemed certain that the Zoetlief Series was represented by some part of the Witwatersrand-Ventersdorp succession in the southern Transvaal, but exact correlation could not yet be drawn. He also gave a good resumé of the different types of Ventersdorp rocks which were prominent in the various areas mentioned.

The Ventersdorp System in the Kimberley area was described by Williams (1932). Here only rocks belonging to the Pniel and Zoetlief Series were found, which lay "between the bottom of the Karroo system and the top of the Swaziland system of schists, gneiss and intrusive granite.". The Zoetlief beds are represented at the base by the "Vaal River conglomerate" which rests directly on top of the Swaziland schists with an unconformity, followed by quartzite and then quartz porphyry. This is succeeded unconformably by rocks of the Pniel Series, which consists of a quartzite with an underlying conglomerate, followed by a melaphyre, "a basic porphyritic rock of highly altered character", or diabase, as it was more commonly called. Williams presented chemical analyses of five diabase samples and three quartz porphyries.

Nel (1933) discussed rocks of the Witwatersrand System outside the Rand. He mentioned the volcanic rocks occurring at the base of the

Witwatersrand System in the Parys-Vredefort and the Klerksdorp-Ventersdorp areas. These appear to be overlain conformably by the Orange Grove quartzites, and consist in the former area of basic amygdaloidal lavas, and in the latter of "lavas and light-grey bedded ashy-looking rocks", some of which are cherty and amygdaloidal. In addition, "dense quartz-porphyry" is intercalated with the amygdaloidal varieties.

Nel mentioned the volcanic group discovered higher up in the Witwatersrand succession by Rogers (1921) in the Jeppestown beds. It is described as consisting of "agglomerate and lava of rather acid composition" in the Heidelberg area. It was also reported from south-west of Greylingstad, while on the West Rand he said it assumes an amygdaloidal character.

Nel (1934a) described the Witwatersrand System and associated rocks in the Klerksdorp and Ventersdorp districts. He noted the presence of a marked unconformity at the base of the Ventersdorp System, as the Ventersdorp Beds were deposited on a surface of older formations that had a fair amount of relief, and can be found resting on any of the various horizons of the Witwatersrand System, even extending right across on to the Old Granite. He reported that they lie nearly flat, or are gently folded. Nel maintained that "the relation of the Ventersdorp to the Witwatersrand System and the deposition of the former on an old land surface of marked relief, are factors of great importance in the search for those horizons known on the Rand in the concealed bodies of Witwatersrand beds around Klerksdorp.".

Nel, in discussing the structure of the Witwatersrand, stated that "dislocations of the Witwatersrand System started in pre-Ventersdorp times, and were renewed at intervals until after the deposition of the Black Reef and Dolomite Series". These movements produced "a number of prominent N.E.-S.W. trending strike or oblique faults as well as dip-faults with a general N.W.-S.E. trend; and it seems very likely that the great Ventersdorp volcanic eruptions followed or were correlated with these fissures". He noted that "the general distribution of the volcanic agglomerates and boulder beds, rock types that could not have been formed far from the source of their constituents, along or close to some of these lines of fracture is significant". He also concluded that these faults "are responsible for several reduplications of the rocks across a wide stretch of country", and "have all the characteristics of step-faulting with the downthrow sides north-west of the lines of fracture.".

Twenty nine years after Molengraaff (1905) discovered the Dominion Reef beds and erroneously classified the associated lavas as Ventersdorp volcanics, Nel (1934a) carefully reviewed the information on hand. He realised that the two volcanic formations separating the Dominion Reef beds from the overlying Lower Witwatersrand beds formed a conformable succession with the Dominion Reef sedimentary groups and belonged to a sequence older than the Hospital Hill Series. He proposed the extension of "Molengraaff's term 'Dominion Reef Series' to embrace not only the quartzose sediments, but also the two volcanic groups following conformably above them, and to look upon the series as the lowest sub-division of the Witwatersrand System in the Klerksdorp-Ventersdorp area.".

Nel (1934a,b) described the Dominion Reef volcanics as "lavas and bedded light-grey, ashy-looking rocks." Some of the lavas are "curious cherty amygdaloidal rocks" and "appear to be acid igneous rocks partly or wholly silicified"; others are "darker amygdaloidal lavas that bear a close resemblance to the Ventersdorp amygdaloid." Intercalated with the lavas is a "dense dark porphyry", with phenocrysts of mainly plagioclase and a little quartz. The thickness of the whole series varies from about a metre near Ventersdorp to over nine hundred and fifteen metres south-west of Hartebeestfontein. These accounts were followed by extremely detailed descriptions of the Dominion Reef Series, the Witwatersrand and Ventersdorp Systems in the Potchefstroom, Klerksdorp and Ventersdorp areas by Nel (1935), Nel et al. (1935), and Nel et al. (1939).

As a result of the discovery of a second volcanic horizon in the Witwatersrand System, the first being the Bird Amygdaloid in the Bird-Main Reef Series, Kovaloff (1934) suggested a reinterpretation of the boundary between the Upper and Lower Witwatersrand. The presence of the new horizon, the Jeppestown Amygdaloid, allowed for a better correlation of Witwatersrand Beds than had previously been achieved.

Beetz (1936) mentioned the presence of magnetic lavas in the lower part of the Ventersdorp System in the Klerksdorp District. The magnetic rock is "a dark fine-grained diabase with a high amount of magnetite", and the horizon is found "between the Ventersdorp sediments and the lavas and tuffs of the lowest part of the Ventersdorp System.". Beetz concluded that "where they occur at the surface in the Klerksdorp district, the underlying contact with the Witwatersrand beds can confidently be expected at a reasonable depth, say, 2,500 to 3,000 feet.". He stated that "the stratigraphical succession of rocks forming the Ventersdorp System ... in the Klerksdorp district ... is regular save that any one of the rock groups may increase or decrease in thickness or may be missing altogether in places.". He attributed this variation to a number of factors: the Ventersdorp had been deposited on an uneven surface; overlapping had been caused by the spread of later beds across the edges of older ones; lava flows and sheets of fragmental material thrown out from vents and fissures had built great fans with the thickness greater next to the eruptive centres; warping and fracturing had formed horsts and grabens.

Frommurze (1937) documented the results of a survey on the water-bearing properties of the Ventersdorp System and other important formations.

Truter and Strauss (1941), after studying the pre-Transvaal rocks in the Taungs area, proved that they belonged to two distinct formations, separated by an unconformity. The upper formation was correlated with the Pniel series of the Ventersdorp System, while the lower formation was correlated with the Zoetlief Series, which "can very possibly be correlated with the Dominion Reef series.".

In a major consolidation of data Jacobsen (1943) described the stratigraphy and petrography of the Ventersdorp System in the southwestern Transvaal and northern Orange Free State in great detail. From boreholes drilled in the Buffelsdoorn area near Klerksdorp, he derived the following succession for the Ventersdorp System:

"Horizon Y : Dark green dense porphyrite with many small yellowish specks and occasional larger felspar phenocrysts.

Horizon A : Quartz porphyrite.
Horizon B : Green, dense to fine-grained porphyrite with small black specks.
Horizon C : Large to fine volcanic breccia, dark quartzite, fine-grained tuffs and tuffaceous shales.
Horizon C_1: Green porphyrite with numerous feathery greenish-black specks.
Horizon D : Mainly dense green-grey almost siliceous porphyrite. Characteristic are the numerous parallel white bands in the lower and middle portion of the lava flows.
Horizon E : Dark green to grey-green porphyrite with zones of numerous yellowish specks and often with small black groups of crystals.
Horizon F : Dark green porphyrite, very well distinguished by very large, white, stellar clusters or aggregates of plagioclase.
Horizon G : Detritus-agglomerate, sporadically developed."

These horizons were grouped together in the following manner :

Upper Ventersdorp System : Y
Middle Ventersdorp System : A, B, C
Lower Ventersdorp System : C_1, D, E, F, G

From his study Jacobsen showed that a "lava stratigraphy" can be evolved. He used this to discuss the Ventersdorp succession in the Klerksdorp area, the northern O.F.S., the Ventersdorp-Hartebeestfontein areas and the Wolmaransstad area. He rejected "the term Ventersdorp diabase, so firmly embedded into the South African literature" as incorrect, "as typical minerals of the diabase group are nowhere to be found. The absence of olivine especially is noted by all authors who describe the petrography of the Ventersdorp porphyrites.". He regarded the coarse Ventersdorp sediments to be of fanglomeratic origin, while the quartz porphyries he considered to be intrusive. He recognised the strong secondary alteration to which the Ventersdorp rocks have been subjected, ascribing it to "autohydrothermal and solfataric processes". Jacobsen included the Elsburg Series in his study as many previous authors had considered it to be part of the Ventersdorp succession. He concluded, however, from his work, that it belonged to the Witwatersrand System.

Van Eeden (1946) described a series of rocks in the Schweitzer Reneke district which had up till then been grouped with the Ventersdorp System. He realised that there were actually two groups of rocks separated by an unconformity and maintained that the lower group, the Zoetlief series and the Dominion Reef series all represent rocks of the same age in different areas. The upper group he correlated with the Pniel or Ventersdorp lavas.

By examining borehole cores, Baines (1949) compared the geology of the Odendaalsrus area with that of the Klerksdorp area, and deduced that they had much in common.

In a major review of all volcanism in South Africa, Truter (1949) suggested giving the Dominion Reef rocks "the independent status of a system" because of the "phenomenal thicknesses" sometimes attained and their unconformable relationships to overlying rocks. Apart from the type area west and north-east of the Dominion Reef mine, Truter listed the following correlatives: north of Ottosdal; in the Vredefort area; the Insuzi series in the south-eastern Transvaal; the Godwan beds along the escarpment; between Denilton and Groblersdal; east and north-east of Crocodile Pools to beyond Thabazimbi; south of Lobatsi to between Zeerust and Mafeking.

He stated that the Witwatersrand System "was interrupted twice by volcanic eruptions, the first time during the Jeppestown epoch and subsequently during the Main-Bird epoch" and noted that the Jeppestown amygdaloid was first found in the Heidelberg area, and subsequently near Klerksdorp, near Randfontein and in the West Witwatersrand area, but is absent on the Central Rand and in the Vredefort area. Referring to the Bird amygdaloid, he noted its absence from the Klerksdorp area and on the Central Rand, but its presence throughout the East Rand, Far East Rand, Heidelberg and Vredefort areas. Also, the suggested correlatives of the Witwatersrand - the Mozaan series in Swaziland and

Natal, the Uitkyk formation north-east of Potgietersrust and the Stinkfontein series in the Richtersveld - all appear to contain similar volcanic zones.

He described the Zoetlief period as being characterised by frequent and extensive outpouring of lava, often on a stupendous scale" and reported that outcrops extend from Zoetlief, north of Vryburg, past Taungs and Kimberley to the T'Kuip hills near Britstown. North west of Prieska and near Upington they are referred to as the Koras series and in South West Africa as the Kunjas and Sinclair series, (correlations which are not supported today). Truter also included the quartz porphyries north-east of Kimberley and north and north-east of "Maquassi" in this system, as well as those east of Wolmaransstad and Ottosdal.

Truter stated that surface exposures and deep drill-holes indicated that the Ventersdorp System extended from the T'Kuip Hills in the south to Lobatsi in the north and Kuruman in the West to Leslie in the East. For the area south and east of the Rand and in the Cape Province, Truter inferred from the minimum of pyroclastic material contained in the lavas, that the eruptions were mainly of the effusive, non-explosive type and "were piled up more or less uninterruptedly in successive highly mobile flows building typical lava plains or plateaux.". Between Potchefstroom and Delareyville, however, breccia- and agglomerate-filled pipes or diatremes occur and the lavas are frequently interspersed with pyroclasts or volcanic conglomerate. According to Truter, this proved that "the eruptions were partly of the effusive and partly of the explosive type and that there were long intervals of quiescence during which active erosion in some localities proceeded simultaneously with rapid accumulation in others.". The distribution of diatremes and pyroclasts along normal faults invited the conclusion that "the eruptions were causally connected with tensional features and were therefore mainly of the fissure type.". He furthermore suggested that the frequently ripple-marked character of the sedimentary tuffs indicates subaqueous accumulation and that the breccias and agglomerates are partly vent-fillings and in part possibly of nuée ardente origin.

Brock (1950) believed that, in the absence of volcanic necks or throats, dykes constituted the feeders for the Ventersdorp "plateau lava". He submitted that the constancy of markers of porphyritic lava, for instance, is evidence that the lava had been exceedingly liquid and had flowed for great distances horizontally. He declared: "The characteristic of plateau lava country is block faulting. This is a worldwide rule. Not only is there a potential void created by the vacating magma, but there is the additional weight of the lava on top of the crust. Gravity naturally is the major force concerned, and block faulting is the result. Examples of plateau lava country are the Deccan in India, Snake River in Washington-Oregon, etc. The structural aspect in such areas is the domination of block faulting. Lateral compression does not come into the picture.".

Truter (1950), referring to the statement by Brock (1950) regarding the absence of volcanic necks, noted that "although such necks are not abundant, they are fairly common in certain parts, especially in the Western Transvaal, and many more are undoubtedly concealed under lava flows.".

Von Backström (1952) presented a detailed description of the Dominion Reef Series between Wolmaransstad and Ottosdal. In addition he listed a number of chemical analyses, two andesites and one rhyolite from the Dominion Reef Series, and one quartz porphyry from the Ventersdorp System.

By 1953 the Zoetlief series had been tentatively correlated with the Dominion Reef series. Matthysen (1953) embarked on a project to accumulate evidence for or against this correlation, with reference to the Taungs-Christiana area. He divided the Ventersdorp System of Taungs into the Zoetlief and Pniel Series, while the Ventersdorp System of Christiana was correlated with the Pniel Series only. He found insufficient stratigraphic evidence to correlate the Zoetlief with the Dominion Reef Series.

He then embarked on a study of borehole cores in the Orange Free State from which Matthysen was able to divide the Ventersdorp System into three easily recognisable series :

Upper Ventersdorp or Pniel Series
Middle Ventersdorp or Zoetlief Series
Lower Ventersdorp or Klipriviersberg amygdaloid Series

He gave two reasons for placing the three series together as a system :

(1) All three are characterised by large masses of lava, while the sediments almost always contain large quantities of ash-like material.

(2) The system lies stratigraphically between two large lithologically different sedimentary systems.

From field and literature studies, it seemed to Matthysen that every known occurrence of Ventersdorp rocks could be accommodated in one of these divisions.

Matthysen then selected the Klerksdorp-Ventersdorp area as his prototype, as the Ventersdorp rocks attained their maximum development in this area. He drew attention to a number of features: a porphyritic andesitic marker bed in the Klerksdorp area; a time lapse between the deposition of the lowest lavas and the overlying pyroclastics; the existence on the Klerksdorp townlands of a younger group of andesitic lavas on top of the quartz porphyries, but indistinguishable in hand specimen from those below; a zone of large phenocrysts and the purple zone (in the Orange Free State), useful as markers in the Klipriviersberg amygdaloid, which he said occurred only in the Witwatersrand basin; and an unconformity below the Zoetlief Series everywhere except in the Klerksdorp and Le Roux Pan areas. He noted that, in handspecimen, rocks of the Pniel Series are very similar to those of the Klipriviersberg Series, but can, in certain instances, be distinguished by textures, size of amygdales and colour. He said the Zoetlief Series was folded, faulted and eroded in places before the deposition of the Pniel rocks, which lie disconformably on those of the Zoetlief Series.

Von Backström et al. (1953) documented the geology of the Lichtenburg area, the major part of which is underlain by rocks of the Ventersdorp System.

In the third edition of his book, "Geology of South Africa", published in 1954, Du Toit retained the Dominion Reef rocks as a series and relegated it to the base of the Witwatersrand System. He correlated these rocks with those in the Cape grouped as the Zoetlief series. In the Jeppestown series of the Witwatersrand System, the thin Jeppestown Amygdaloid at about the middle of the series was mentioned as a marker of great value in deep boring.

Du Toit also gave a general description of the Ventersdorp System and listed the usual correlatives, but also included the "Deweras Series" of Southern Rhodesia. He emphasised the presence of volcanic breccias which are very characteristic of the lavas. Although the Ventersdorp magma had long been presumed to have been poured out from fissures, Du Toit noted that "breccia-filled necks penetrate Witwatersrand Beds to the west of Ventersdorp and Klerksdorp and between Greylingstad and Villiers, while sporadic shattering of the lavas, areas of coarse breccias enclosing in places large broken masses of Witwatersrand beds, and long belts of thick breccias north of Klerksdorp, all suggest extrusion from vents aligned along south-west trending fractures.".

Although Holmes (1906) regarded the quartz porphyries of the Makwassie Hills as intrusive into the basic lavas, du Toit (1954), on the other hand, wrote that "just north of Makwassi Station the porphyry appears to be overlain unconformably by a quartzite body and that in turn by Ventersdorp lavas.". He postulated that the Ventersdorp Contact Reef forms the real stratigraphical base of the Ventersdorp System and that the relation to the Witwatersrand System may be a disconformable one in the Central and East Rand and Vredefort areas.

Another overview of the distribution, lithology and stratigraphy of the Dominion Reef, Witwatersrand and Ventersdorp Systems was published by Hamilton and Cooke (1954) in their book on South African geology.

The exploration of and opening of the Orange Free State Goldfield provided a wealth of data on the extension of the Ventersdorp System beneath the Karoo cover. Pienaar (1956), in a detailed stratigraphic and a preliminary structural study of the Ventersdorp System in the Orange Free State Goldfield, proposed the following succession:

Ventersdorp Upper Lava	- maximum	488 m
Ventersdorp Upper Sediments	- maximum	1676 m
Ventersdorp Lower Lava	- maximum	1829 m

All the flows of the Lower Lava (except in the northwest) dip towards the centre of the Witwatersrand basin, with distribution and thickness controlled by block faulting and erosion. He reported that the composition of the Lower Lava ranges from a diabase at the base to an augite andesite at the top. Pienaar also documented a number of marker zones occurring in this group - the upper and lower purple markers and the upper and lower altered zones. The Upper Lava is also andesitic but differs in certain respects from the Lower Lava. East of Odendaalsrus a conglomerate was found overlying the Ventersdorp Upper Lava. Pienaar realised that it may represent a still younger group, but described it with the Ventersdorp Upper Lava. Within these lavas he found three porphyritic zones which could be used as markers.

Nel and Jansen (1957) described the geology of the Vereeniging district. In this area the Dominion Reef System is restricted to one intercalation of lava between the Archaean Granite and the Orange Grove Quartzite. The Jeppestown Amygdaloid is well developed and described in detail, as is the Ventersdorp System.

In an interpretive review Visser (1957) described the Dominion Reef System in terms of a geosynclinal phase. He stated: "In the Transvaal, as well as in the northern Orange Free State and the northern Cape, the Dominion Reef System and its correlates, the Insuzi, Godwan, Uitkyk, Zoetlief and Koras Formations, are exposed along the margins of the great basins in which the Witwatersrand and the Transvaal Systems were deposited later. They rest with an unconformity on an uneven floor of Archaean granite and enclosed remnants of Archaeozoic Formations. It would appear, therefore, that during the Proterozoic the old Archaeozoic geosynclinal belt became active once more and a depression was created which was only slightly smaller than the Archaeozoic basin. At first sediments were deposited, followed by the eruption of volcanic rock.". They "suffered only a slight degree of tilting prior to the deposition on them of younger formations.".

Referring to the orogenic and first magmatic phases of the Witwatersrand-Ventersdorp Cycle, Visser said: "Whilst the floor of the geosyncline was gradually being depressed, the marginal areas were tilted and elevated relative to the central position, whereby the size of the basin was decreased and erosion ... took place. In the

Klerksdorp and Odendaalsrus areas ... contemporaneous faulting also took place. ... eventually failure had to take place by way of tension-fractures, along which the Ventersdorp lava poured out to cover the last sediments in the basin conformably and to transgress across the tilted, older sediments along the margin of the basin.".

A mineralogical aside was provided by Barbour, Bird and Gold (1957) who recorded the existence of axinite-bearing veins in Ventersdorp lavas from the Kinross area, Transvaal. They noted that, "apart from an occurrence in the greenstones of Southern Rhodesia, there is no published record of axinite from elsewhere in southern Africa.".

In Botswana Wright (1958) tentatively correlated the Lobatsi Volcanic Series, a succession of felsites and porphyries with interbedded tuffs and agglomerates, lying between the intrusive Gaberones granite and younger sediments of the Ventersdorp and Transvaal Systems, with the Dominion Reef System in South Africa. Sediments of the Mogobane Series occur in the Gaberones area and although no amygdaloidal lavas occur here, evidence found outside of this area suggested a correlation with the Ventersdorp System.

Boocock (1960), however, reported that the Lobatsi Volcanic Series was composed of rocks of two different age groups, and assigned the volcanic succession, mainly felsites, to the Dominion Reef System. The younger sedimentary and volcanic succession, which includes the Mogobane Series, he correlated with the Ventersdorp System. He also included in the Ventersdorp System a succession of basic lavas, sediments and acid lavas in the Sequani area. This correlation was confirmed by Jones (1963) who noted that the Sequani lavas formed the north-westerly continuation of a similar succession which is developed in the Derdepoort area of the Transvaal. He also mentioned rocks of the Dominion Reef Series in the neighbourhood of Oodi Hill and along the Transvaal border.

In a description of the petrology and mineralogy of the rocks of the Dominion Reef System near Klerksdorp, Malan (1959) described mainly the lower sedimentary groups, but briefly mentioned the overlying lavas. He described two sequences of lavas, the "Lower Volcanics" separated by a quartzite from the overlying "Dominion Reef Lavas". He found that the Lower Volcanics are amygdaloidal, porphyritic, andesites, while the

Dominion Reef succession comprises basic lavas at the base followed by an upper acid lava sequence. Malan studied only the lower hundred feet of the former, which he found to be highly altered amygdaloidal andesite, with a thin basal tuffaceous horizon.

In a comprehensive report of the geology of the Orange Free State gold fields, Coetzee (1960) described the Jeppestown amygdaloid as being about 107 metres thick and built up of several lava flows of andesitic composition. He noted that the amygdales are sometimes surrounded by a white mantle and when the cavity filling is chloritic, the appearance resembles birds' eyes. A concentric banding observed in some core samples suggests that it might be a pillow lava. A rounding of detrital grains in the tuff also suggests deposition in water. The Jeppestown amygdaloid is regarded as a valuable marker in correlating the Witwatersrand sediments in the area around Odendaalsrus and Virginia.

Coetzee discussed the Ventersdorp System in terms of three subdivisions: the Lower Volcanic Stage, the Sedimentary Stage and the Upper Volcanic Stage. He described the Lower Volcanic Stage as a succession of superimposed flows ranging from 7.5 to 92 metres thick, which follow each other without significant hiatus. He reported at the top of some flows "a brecciated zone composed of swirled blocks of amygdaloidal lava", followed by "a highly amygdaloidal zone grading into an essentially non-amygdaloidal phase lower down, and finally a chilled basal sector containing scattered amygdales.". Alteration in the form of dolomitisation and epidotisation were also observed.

Of note in the Lower Volcanic stage is the presence of four markers, first described in detail by Pienaar (1956) - the upper and lower "altered zones", and the upper and lower purple bands. The altered zones are variolitic lava flows, while the purple bands have a mottled appearance and usually contain dark, rounded chlorite-bearing amygdales. Boreholes may contain two, one or none of the bands, which vary from a few centimetres to several metres in thickness and occur 6 to 9 metres below the top of a lava flow. Both Coetzee and Pienaar said the colour of the purple lava cannot be related to any particular feature in the chemical analyses, but in thin section finely-disseminated reddish-brown iron oxide is seen. He described a major development of volcanic breccia, sometimes exceeding 200 metres in thickness, which has been found at both the top and the bottom of the Lower Volcanic Stage.

Coetzee described the Sedimentary Stage as consisting of "clastic sediments and, in places, detrital tuff". Where present, it is usually less than 305 metres thick, but can exceed 1067 metres and has been known to attain a thickness of 1981 metres. The tuff is black, aphanitic and not bedded and its chemical composition differs from that of the Lower Volcanic Stage.

The Upper Volcanic Stage reaches 488 metres in thickness in the area reported on by Coetzee, and in one part is overlain by later Ventersdorp sediment. One particular borehole displayed an interfingering of lava and sediment for almost 1830 metres. Like the Lower Volcanic Stage, this stage is comprised of augite andesite lavas, which also exhibit brecciated flow tops and amygdaloidal and non-amygdaloidal portions. It has, however, a darker green colour, porphyritic zones, epidotised bands and a coarser texture. Chemically it contains more normative quartz and the normative plagioclose is more albitic.

In 1961 the Economic Geology Research Unit at the University of the Witwatersrand decided to investigate the problem of correlation within the Ventersdorp System. Their motives for embarking on this study were very similar to those of the present author, and are quoted in Chapter 2. Annual progress reports were compiled by Winter (1961, 1962, 1963a, 1964 and 1965a), who consolidated the results of the investigation in his Ph.D thesis (1965b).

In 1962 a study of borehole data from the Klerksdorp-Bothaville area resulted in the compilation of a tentative table of stratigraphic subdivisions for this area. The various formation names were derived from localities in which well-developed outcrops are present or in which maximum thicknesses have been recorded in borehole cores. This table was amended in 1963, to include subdivisions of the Ventersdorp System in other localities. In the Vierfontein area a sequence of porphyritic and non-porphyritic lavas which could not be correlated with either the Makwassie or Rietgat Formation, was termed the Garfield Porphyry Facies. Features of note emerging from this compilation are the fact that rocks of the Godwan Formation, north of Potgietersrus, were found not to resemble members of the Ventersdorp System, and the recording of algal structures in sediments of the Middle Division, by Winter (1963b). These stromatolites occurred in impure dolomitic limestone post-dating the quartz porphyry, and "were probably deposited in shallow lakes in an area of low relief after eruptions of acid and basic volcanic rocks." Winter concluded that "the discovery provides a link between the accepted prevalence of biogenic processes 2,000 million years ago during the time of deposition of the Transvaal System and the problematic origin of oolitic structures in the Swaziland System formed more than 3,000 million year ago." He suggested that such biogenic processes might have played a part in the deposition of "carbon" in the form of seams and granules in the Witwatersrand System.

In 1964 chemical data showed that distinctions could be made between the Jeppestown Amygdaloid, the Bird Amygdaloid and lavas of the Ventersdorp System. It was not certain whether similar variations would be found between the lavas within the Ventersdorp System.

A revised correlation of the Ventersdorp System was presented by Winter (1964). In this revision the Lower Division was associated with the Witwatersrand System and the Upper with the Transvaal System, while the Middle Division was renamed the Zoetlief System, comprising three series, the New Kameeldoorns, Makwassie and Rietgat Series. The Lower Division was renamed the Klipriviersberg Series and the Upper Division was correlated again with the Godwan Formation.

In 1965 a revised stratigraphic table was compiled. The three primary subdivisions of the "alleged" Ventersdorp System were found to be identifiable throughout the Western Transvaal and Northeastern Cape Province and investigations showed that the conclusions drawn from the type-area remain valid.

The findings of the EGRU investigation were consolidated by Winter (1965b) in his Ph.D. thesis, in which he documented in detail the structure and stratigraphy of the Ventersdorp System in the Bothaville district and adjoining areas. He pointed out that, although previous authors had noted many of the key facts in their attempts at stratigraphic subdivision, this information does not appear in any one publication. With the aid of this previous literature and over two hundred borehole logs, Winter devised a stratigraphic column based on three primary subdivisions incorporating six formations, as shown in Table A.1. He selected the Bothaville area as his type area as it includes all the type boreholes, maximum thicknesses of most of the formations, and most of the geographical areas from which the formation names have been derived.

TABLE A.1 Stratigraphic column of the Ventersdorp System in the Bothaville type area (from Winter, 1965b)

Primary Subdivision	Formation		Representative Rocks
Upper	Allanridge (A)		Dark green amygdaloidal lavas
	Bothaville (B)		Quartzites, conglomerates, subordinate dark shales
Middle	Rietgat (R)	Garfield (GP)	Green-grey amygdaloidal and porphyritic lavas; minor intercalated tuffaceous, calcareous and cherty shales; impure limestones; quartzites; conglomerates
	Makwassie (M)		Quartz and felspar porphyries, green-grey amygdaloidal lavas, minor intercalated sediments
	New Kameeldoorns (N)		Conglomerates; quartzites; tuffaceous, calcareous and cherty shales, impure calcareous rocks
Lower	Langgeleven or Lower Volcanic (L)		Green-grey pyroclastics and amygdaloidal lavas

Winter constructed isopach maps and structure contour maps of each formation. He presented detailed descriptions of all lithological types present. He stated that a number of beds within the Langgeleven Formation may be tuffs, but because all gradations exist between a well-defined tuff and a lava flow in this formation, it is difficult to distinguish between them, especially when the tuffs are amygdaloidal. He provided a list of ten distinctive features by which tuffs might be distinguished from lavas. He suggested that both agglomerates and flow-top breccias, which are very similar in appearance, occur in the Langgeleven Formation.

Winter described in detail the type sections for each formation. He considered the first volcanic effusion to be the beginning of the Ventersdorp System. Although a major change in lithology occurs, Winter drew attention to Mellor's (1913) statement that there was no great time interval between the deposition of the last sediments of the Witwatersrand System and the first effusions of the Ventersdorp System, and that there are areas in which volcanic material and sediments are intimately admixed in a transitional zone. Winter suggested a possible origin for the purple bands as "manifestations of contemporaneous weathering acting variously on different kinds of lava". He noted their prevalence on updomed areas, suggesting that in basins the flows followed upon one another at shorter intervals, thus preventing most flows from being weathered. Winter subdivided the Langgeleven Formation into five zones characterised by the following features:

5. green chalcedony amygdales and clustered milky quartz amygdales
4. variolitic bands or "altered zones"
3. purple bands
2. porphyritic lava
1. talcose tuffs

The New Kameeldoorns Formation overlies the Langgeleven Formation with an extensive unconformity and its distribution bears no relation to the depositional basin of the Langgeleven Formation. The sequence consists of clastic wedges of immature sediments which accumulated in fault troughs when the bounding faults were active.

The Makwassie Formation overlies the New Kameeldoorns Formation without a break and consists of quartz porphyries with quartz-free porphyritic and non-porphyritic volcanic rocks and minor bodies of sediments. The lower limit of the formation was taken as the base of the first lava flow following upon New Kameeldoorns sediments. The upper limit is marked by the advent of quartz-free porphyritic and non-porphyritic lavas. Although not conclusively proved, Winter favoured an ash-flow mechanism of emplacement of the quartz porphyries. He introduced a facies designation - the Garfield Formation - to include one or both of the Makwassie and Rietgat Formations in areas where these two cannot be separated or where doubt exists as to which of the two is represented.

The Rietgat Formation consists predominantly of green-grey amygdaloidal porphyritic and non-porphyritic lavas, but contains subordinate sediments and pyroclastic rocks. Algal-bearing limestones occur in this formation. Winter claimed that the volcanic rocks of this formation cannot be distinguished from the basic lavas of the Makwassie Formation. The uppermost flows may be intensely altered to calcite, epidote, clayey minerals and iron oxides, an important criterion for distinguishing between Rietgat and Allanridge lavas.

The Bothaville Formation consists of sediments suggestive of a shelf facies - conglomerates, grading into quartzite and shale, and then again to conglomerate. The sediments are of a subgreywacke composition and define an unconformity.

The Allanridge Formation lies conformably upon the uppermost conglomerate of the Bothaville Formation. It consists exclusively of alternating porphyritic and non-porphyritic lava flows.

With reference to the geological history of the Ventersdorp rocks, Winter concluded that the volcanics of the Langgeleven Formation were extruded in rapid sequence as "fissure eruptions or at least lines of volcanoes along deep-seated fractures.". "The peculiar features of the purple bands and altered zones suggest subaerial effusion, as also does the association of purple bands with abundant agglomerates. No pillow structures were noticed.".

The Makwassie Formation covers a large area and its great thickness suggested to Winter a similarity to some of the rhyolitic provinces such as the Taupo-Rotorua district, New Zealand, and the Basin and Range Province of the United States of America. Winter submitted that the Makwassie volcanics exhibit characteristics much in common with these.

The close lithological and structural relationship between the Rietgat and Makwassie Formation suggested to Winter that the former could represent the waning phase of the Makwassie cycle of volcanism. Sedimentary beds are more numerous and the nature of the flows and the oxidation of their tops suggest a subaerial environment for both formations. Winter assumed that the acid Makwassie magma, probably formed during New Kameeldoorns times by anatexis or differentiation, had become depleted by Rietgat times, the younger magma coming from a source more common to that of the Langgeleven lavas.

The Allanridge Formation consists of andesitic plateau lavas, subaerially extruded and uninterrupted by sediments. Suspected feeder dykes have been found.

Winter stated that the three primary subdivisions of the Ventersdorp System behave as distinct structural entities. The Lower Ventersdorp System conforms structurally with that of the Upper Division of the Witwatersrand System, while the structure of the Middle Ventersdorp System is less complicated and deformation has occurred along different axes from those of the underlying sequences. There is also a difference in degree of warping between the Upper and Middle Ventersdorp System, leading to angular unconformities in elevated areas. Winter thus did not regard the Ventersdorp System as a unit. He pointed out that, lithologically, the only uniform factor within the System is the abundance of andesitic lavas in all three subdivisions. He therefore suggested that the Lower Ventersdorp System be included with the Upper Witwatersrand System as a major subdivision, to be named the Klipriviersberg Series. Similarly the Upper Ventersdorp System could be considered as the lowermost subdivision of the Transvaal System and could be called the Pniel Series. He proposed that the Middle Ventersdorp System is of sufficient importance to warrant classification as a separate system. He recommended that the term "Ventersdorp System" should be discarded to avoid confusion, and the name "Zoetlief System" be adopted.

A.B. Simpson was responsible for documenting the petrology and geochemistry of these rocks, but his results have unfortunately never been published, although a bibliography of the geology of the Ventersdorp rocks was (Simpson, 1964).

Nel and Verster (1962) described the geology of the area between Bothaville and Vredefort. They found the Dominion Reef System to form a narrow band between the Archaean rocks and those of the Witwatersrand System to the west of Vredefort. The Dominion Reef System consists of altered basic amygdaloidal lava with lenses of metamorphosed sediments. They noted the presence of the Jeppestown amygdaloid in this area, where it is about 90 metres thick and capped by a volcanic breccia. They found that much of the area is underlain by Ventersdorp rocks, which may reach 3050 metres in thickness. Quartz-feldspar porphyry occurs on different horizons. Near the base is a zone of large albite phenocrysts. Pyroclastics and tuffs are also present, as well as lenses of sediment.

The geology of the Ottosdal area in the Transvaal was described by Von Backström (1962), who found that rocks of the Dominion Reef System cover relatively large parts of this area and consist of a basal auriferous and uraniferous conglomerate with quartzite, followed first by andesitic lava which contains lenses of porphyry, then by rhyolite porphyry containing tuffaceous material. Microscope examination and the presence of cordierite indicates that these rocks have been subjected to intense metamorphism. Von Backström noted that the major part of the Ottosdal area is covered by Ventersdorp rocks, most of which are andesitic, with some porphyritic acid lavas. Chemical analyses are presented for most of the rock types.

An interpretation of a number of age measurements on Dominion Reef, Witwatersrand and Ventersdorp rocks and their supposed correlates was presented by Nicolaysen (1962). Age determinations on uraninite and monazite from the basal conglomerate of the Dominion Reef System resulted in an age of 3050 ± 100 my. Rb-Sr measurements on muscovite from the underlying basement granite indicate an age of 2900 ± 100 my. The monazite was known to be detrital and by inference, so was the uraninite, thus a maximum age of 3050 ± 100 my. for the Dominion Reef System was obtained. A tentative age of 2100 my. was assigned to the deposition of either the Witwatersrand or Ventersdorp rocks. Pegmatites underlying the Stinkfontein Series were dated at 950 my. Correlation of this series with the Witwatersrand System was thus no longer tenable. Similarly, the rocks underlying the Koras Series were dated at 950 my., invalidating their correlation with the Dominion Reef System.

These relations were later supported by Van Niekerk and Burger (1964) who dated zircon crystals from a quartz porphyry in the Ventersdorp System by the U-Pb isotope method. They obtained an age of 2300 ± 100 my for the lava.

Haughton (1963) noted that the Insuzi Series, the Godwan Formation and the Zoetlief Series were still correlated with the Dominion Reef System, and the Mozaan Series with the Witwatersrand System, while in the same year Winter (1963a) stated categorically that "there is no evidence in the area for believing that the former Pongola System (Mozaan plus Insuzi Series) can be correlated either with the Dominion Reef or Witwatersrand System.".

Pretorius (1963) gave a brief description of Ventersdorp rocks in the Central Rand. He also provided a number of chemical analyses of igneous rocks.

The geology of the Schweitzer-Reneke area was described by Van Eeden et al. (1963). In this account the series of quartz- and feldspar-porphyries and tuffs found there were correlated with the Zoetlief Series and the Dominion Reef System, all of which Van Eeden et al. stressed belonged to the same period of volcanicity. They furthermore found that the greater portion of the area is occupied by the rocks of the Ventersdorp System, consisting mainly of andesitic lava, but also more acidic rocks, with intercalated pyroclastic and clastic sediments, volcanic breccia and agglomerate and tuff. Boreholes revealed clearly the measure of variation in this system in respect of stratigraphic succession and thickness of the components, within comparatively short distances.

Describing the Ventersdorp System in the Loraine area Olivier (1965) indicated a preference for Winter's (1962) subdivision into a Lower, Middle and Upper Stage.

In a critical review of stratigraphic terminology in South Africa, Truswell (1967) commended Winter's (1965b) nomenclature of the six stratigraphic units of the Ventersdorp System, but felt that the use of "Lower Volcanics" as a formational name was confusing, preferring the term "Klipriviersberg Series".

Van Niekerk and Burger (1968) obtained an age of 2500-2700 my from Pb-isotope dating of acid lavas from the Zoetlief volcanics. The mean age was 2638 ± 105 my. In the following year an age of 2800 ± 60 my was obtained for Dominion Reef lavas (Van Niekerk and Burger, 1969). They suggested that the Zoetlief succession might be more appropriately accommodated in a separate stratigraphic system.

Haughton (1969) used the term "Witwatersrand Triad" as a chapter heading in his book on the geological history of southern Africa, in which he produced a very thorough literature review.

Whiteside (1970) described the extrusive rocks of the Witwatersrand triad, i.e. the Dominion Reef System, the Witwatersrand System and the Ventersdorp System, which comprise the three lowest members of the Proterozoic in South Africa. He listed the succession for the Dominion Reef System in the type locality, near Hartbeesfontein, as follows :

(a)	Upper or Acid Volcanic Formation	6700 ft
(b)	Lower or Basic Volcanic Formation	2100 ft
(c)	Basal Sedimentary Formation	120 ft

He described these rock types, as well as those from presumed correlatives. The Bird Amygdaloidal Diabase and the Jeppestown Amygdaloid are the only two lavas known within the Witwatersrand System and these are briefly described. Whiteside together with Strydom (1968, in Whiteside, 1970) suggested a modification of the Ventersdorp succession as proposed by Winter (1965b). This included the addition of the Vaal Bend Formation below the Langgeleven Formation and the relegation of the New Kameeldoorns Formation to a sub-stage of the Langgeleven.

Crockett (1971) described rocks in the Lobatse and Ramotswa areas of Botswana which he correlated with the Ventersdorp System. The succession is divided into three units: the Lower Volcanic Assemblage of Si- and K-rich igneous rocks, the Mogobane Assemblage of argillaceous sedimentary rocks, and the Upper Volcanic Assemblage of andesitic lavas. Crockett discussed the petrogenesis of the Lower Volcanic Assemblage in detail, and presented eight chemical analyses. In the past these rocks have been assigned to both the Dominion Reef and Ventersdorp Systems. A porphyry occurring in the Lower Volcanic Assemblage has been dated at 2215 ± 100 my, which corresponds well with the age of 2300 ± 100 my obtained from a quartz poprhyry in the Ventersdorp System by Van Niekerk and Burger (1964).

A major event in the development of a stratigraphic nomenclature of the Witwatersrand triad lavas occurred in 1971 when the South African Committee for Stratigraphy decided to follow international recommendations and to adopt a lithostratigraphic instead of a chronostratigraphic system of nomenclature.

Labuschagne (1974) made a study of the lower 850m of the Ventersdorp Group on the East Driefontein Mine east of Carletonville, where only the Klipriviersberg Formation is present. He distinguished two types of flows, aphanitic and phaneritic. A significant component of the aphanitic type are "petrabullae", large infilled cavities up to several metres in diameter. Pillow structures have been found in places and the occurrence of brecciated lava layers capping aphanitic lava flows was noted. From the mineral assemblages present, Labuschagne deduced that they represented the quartz-albite-epidote-biotite sub-facies of the greenschist facies of metamorphism. The dense, compact nature of the aphanitic rocks resulted in their being less markedly metamorphosed than the phaneritic lava. Labuschagne realised that petrographic classification of these rocks is virtually impossible because of their altered and fine-grained nature. He therefore applied various classifications based on their chemistry and settled on the name "basaltic trachyandesites". He offered an informal stratigraphic sub-division, comprising four units, based on lithology, petrology and chemistry. Labuschagne concluded that the rocks belong to the calc-alkaline or Pacific-suite type.

Visser et al. (1975) compiled the results of a large number of theses which were initiated for the purpose of elucidating the Ventersdorp rocks and their relationships in the northern Cape Province. They found that rocks correlated with the New Kameeldoorns, Makwassie, Rietgat, Bothaville and Allanridge Formations occurred. The equivalents of the Langgeleven Formation did not outcrop anywhere, giving credence to Winter's (1965b) assertion that this formation is restricted to the area of the Upper Witwatersrand Basin. They deduced from field relationships and age dating that the porphyries of the Zoetlief Formation in the Northern Cape were the equivalent of those of the Makwassie Formation of Winter (1965b). They furthermore concluded that "the stratigraphic nomenclature as proposed by Winter (1965b) for the area around Bothaville can be successfully adopted in the Northern Cape.".

Also working in the northern Cape, Grobler and Emslie (1975) found that the volcanic-sedimentary sequence of rocks at the T'Kuip Hills corresponded with the middle division of the Ventersdorp System in the Bothaville area, viz. the New Kameeldoorns, Makwassie and Rietgat Formations, and that these are followed by andesitic flows corresponding to the Allanridge Formation. They concluded that the Zoetlief Series, the Kuip Series and the Pniel Series are all part of the same cycle and should therefore be grouped with the "Ventersdorp Group".

The widespread occurrence of stromatolites in primary limestones of the T'Kuip Hills was described by Grobler and Emslie (1976). The rocks in this area correpsond to the New Kameeldoorns, Makwassie and Rietgat Formations and the stromatolitic beds form part of the latter. An isotopic age of 2310 my (error and method not stated) for a quartz porphyry in the acid lava zone confirms this correlation with the Ventersdorp Supergroup.

Wyatt (1976) investigated the nature of the Klipriviersberg volcanics south of Johannesburg from a stratigraphic, morphological and petrochemical point of view. Apart from a minor lithic tuff at the base, he found all the volcanics to be lavas, which overlie the Elsburg Formation with apparent conformity. He subdivided them into the Westonaria, Alberton, Orkney and Kibler Park Formations, based on the presence of distinctive lithologic units, including a porphyritic zone, amygdaloidal and breccia horizons. Wyatt concluded that the latter represent fragmented lava flow tops. This, together with the identification of pahoehoe flows, but no pillow lavas, suggested that the lavas were subaerially extruded. Wyatt analysed forty nine samples, to which he applied cluster analysis in order to group chemically similar samples together. He classified the three upper formations as alkali-rich oceanic tholeiites, the result of a partial melt of a wet Precambrian mantle, while a genetically unrelated, 100-metre thick MgO-rich basal unit, the Meredale Member, was possibly formed as a result of liquid immiscibility.

Winter (1976) updated a portion of his thesis of 1965, proposing a framework of lithostratigraphic subdivision of the Ventersdorp for consideration by SACS. He presented a review of some of the more recent literature on stratigraphic aspects. A subdivision founded on six formations was evolved. Winter described briefly the type stratigraphy of the Ventersdorp succession as elaborated upon in his thesis earlier (1965b), but made a number of changes. He shortened the name "New Kameeldoorns" to "Kameeldoorns". The Klipriviersberg Formation was elevated to group status and divided into six formations. He classified the group as "almost exclusively andesitic". Table A.2 shows the new subdivision. Of note is the fact

TABLE A.2 Subdivision of the Klipriviersberg Group (from Winter, 1976)

Formations	Marker beds	Distinctive Characteristics	Contacts in type borehole, Langgeleven No. 1	Thickness	Correlative Areas (List Incomplete)	Pienaar's (1965) Classification
Edenville		Green chalcedony and clusters of milky quartz amygdales. 1.	1 827 2 395	568	Allanridge, Klerksdorp, S. East Rand	Zone U
Loraine	AZ 1 AZ 2	Variolitic and spherulitic structures surrounded by whitish groundmass hence "altered zones"	AZ 1 flow 2 395-2 401 AZ 2 flows 2 492-2 535 2 612	217	O.F.S., Bothaville, Klerksdorp, East Rand	Zone M
Jeannette Agglomerate		Prominent thick agglomerate at top. Many agglomerate beds in contrast with above. 2.	2 709	97	O.F.S., Bothaville East Rand	
Orkney	PZ 1 PZ 2	Purple-topped ash-flow tuffs. 3. 4.	PZ 2 flow 2 945-2 965 3 189	480	O.F.S., Klerksdorp, Bothaville, Edenville	Zone L
Alberton Porphyry	Porphyritic Marker	Porphyritic lavas including "porphyritic marker". 6.	Porphyritic marker flow 3 352-3 360 3 360	171	South Vaal, Ventersburg (?), Edenville, West Rand, Klipriviersberg, East Rand, Vredefort, Evander, Greylingstad	
Westonaria		Dark green "talcose tuffs"	Absent		South Vaal, Westonaria Alberton, S.E. Rand, Greylingstad	Absent

1. Some variolitic zones noted by Winter [1965] from Allanridge area.
2. Some porphyritic lavas south of Orkney
3. Pienaar distinguishes PZ 1 and PZ 2 in Klerksdorp and O.F.S. areas from other purple tops by their round chlorite amygdales.
4. Pienaar discovered a zone of pink chalcedony amygdales in O.F.S. goldfield in this stratigraphic position.
5. At base, Pienaar recognised a flow containing characteristic almond-shaped amygdales.
6. The "Porphyritic Marker" contains phenocrysts of felspar longer than 50 mm and thicker than 7 mm and consists of 1-4 flows of lava.

that the subdivision follows that presented in Winter's thesis (1965b), with the subsequent insertion of an agglomerate zone between the purple bands and the altered zones. Also mentioned is a new formation - the Vaal Bend Formation - proposed by Strydom for a succession of sediments, acid and basic lavas underlying the Klipriviersberg Group west and southwest of Klerksdorp, and resting on Witwatersrand rocks with a major unconformity. Winter could not fit this formation into his stratigraphic scheme due to "paucity of facts". The former Garfield Formation is now called the Garfield Member and refers to a group of pale green-grey porphyritic lavas, distinguished only from some Makwassie quartz porphyries because they are not acid. The member may contain minor intercalations of sediments and non-porphyritic lavas and may be a member of either the Makwassie or Rietgat formations, as Winter states that "part or all of the Rietgat Formation can be contemporaneous with the Makwassie.". He noted that many occurrences previously allocated to the Zoetlief Series of the Ventersdorp System have subsequently been designated as Dominion Reef System. He therefore proposed that the Zoetlief Series, i.e. the Kameeldoorns, Makwassie and Rietgat Formations, be renamed the Platberg Group. The former Pniel Series was relegated to the informal term "Pniel Sequence", as Winter says there is no common lithology to bind the two formations covered by that term, the Bothaville and Allanridge. He advocated the abolition of the name "Ventersdorp Supergroup" because it obscures important structural relationships.

Potgieter and Lock (1978) described and named a new lithostratigraphic unit, the Ritchie Quartz Porphyry Formation, south of Kimberley. Originally mapped as equivalents of the Zoetlief Series by du Toit (1906), the quartz porphyry was found by these authors to grade upwards into a brecciated zone, the voids of which have been infilled by the overlying andesite of the Ventersdorp System. The authors correlated the andesite with the Allanridge Formation and suggested that the quartz porphyry was the equivalent of the Makwassie Quartz Porphyry Formation.

The Godwan Formation in the Eastern Transvaal had been correlated in the past with the Insuzi Series of the Pongola System, thought to be a Dominion Reef equivalent. Button (1978) reviewed its stratigraphical relationships and trends and suggested that it might be the easternmost exposure of the Upper Witwatersrand basin.

Van Niekerk and Burger (1978), with improved processing and analytical techniques, obtained a new age of 2643 ± 80 my for the Makwassie Quartz Porphyry Formation. This age supported Winter's (1976) correlation of the Makwassie with the acid lavas of the Zoetlief succession.

A petrological study of volcanic rocks at T'Kuip by Cornell (1978) showed that they had undergone burial metamorphism resulting in a mineral assemblage corresponding to the greenschist facies. This metamorphic and metasomatic event was dated at about 2000 my ago, and found to occur in a number of other Ventersdorp rocks in other areas. Cornell concluded that "future petrological and geochronological studies on Transvaal and pre-Transvaal formations should seek to evaluate the effects of metamorphism and associated metasomatism before postulating unusual magma compositions or rearranging stratigraphic correlations.".

Tyler (1979a) made a study of the Kanye Volcanic Group in the west-central Transvaal. It had originally been correlated with the Ventersdorp System and later with the Dominion Reef System. It has since been determined that rocks of this Group are older than 2750 my, which is the age of the intrusion of the Gaberones Granite into the volcanics. The group consists of a succession of felsites ranging compositionally from dacite to rhyolite. Variolitic structures similar to those seen in the basaltic komatiitic lavas of the Onverwacht Group have been observed. Evidence suggests that a distinct hiatus, during which the Kanye Volcanics weathered to form a palaeosoil unit, separated the consolidation of the felsites from the extrusion of the Ventersdorp lavas. Tyler suggested that the Kanye Volcanic Group constitutes the proto-basinal phase of deposition of the Ventersdorp Supergroup and therefore should be correlated with the Ventersdorp Supergroup.

East of the Botswana border, near Gaborone, is a sequence of sediments, basalts and rhyolites which have been correlated with the Ventersdorp Supergroup by Tyler (1979b). The succession is divided into three belts, the Tshwene-Tshwene, Seokongwana and Derdepoort belts, in which almost the full Ventersdorp succession is preserved. There is a basal, basaltic zone (correlated with the Klipriviersberg Group), a thick chaotic alluvial fan deposit (Kameeldoorns Formation), a zone of acid volcanics (Makwassie Quartz Porphyry Formation), and an upper meandering-stream-flood-plain sedimentary zone (Bothaville Formation). Tyler found that the basal volcanics have a major element geochemistry consistent with continental tholeiitic basalts, while the acid lavas correspond to rhyolites.

Watchorn (1980) published a review of sedimentation and volcanism in the Dominion Group. Although numerous attempts have been made to correlate the Dominion Group with other volcanic and volcano-sedimentary units in South Africa, present evidence implies that its development was restricted to the Western Transvaal, where it represents a precursor to the main Witwatersrand basin (Watchorn, ibid.). Stratigraphically, the group is divided into three formations :

(1) The Rhenosterspruit Formation at the base composed mainly of coarse arkosic sediments, lenticular grits and conglomerates;
(2) The Rhenosterhoek Andesite Formation consisting of intermediate lavas and tuffs; and
(3) The Syferfontein Porphyry Formation, consisting of porphyritic felsic lavas, with interbedded tuffs and cherty amygdaloidal volcanics.

Palaeocurrent data indicate that the basal sediments prograded in a westerly direction and a braided fluvial regime is postulated for their origin. The increased proportion of lenticular volcanic units towards the top of the Rhenosterspruit Formation indicates a period of coeval volcanism and sedimentation.

Because of their close spatial, structural and temporal association, the Dominion Reef, Witwatersrand and Ventersdorp Systems were grouped together conveniently as the "Witwatersrand Triad" (Hamilton and Cocke, 1960). The South African Committee for Stratigraphy (SACS)(1980) accepted the usefulness of this concept and termed the time span involved, thought to be some 240 Ma, the Randian Erathem. They recommended, however, that the word "triad" should not be capitalised, as the grouping of the three units is quite informal, because there is no overall unifying lithological association and, furthermore, such a large grouping of successions goes far beyond the scope of purely lithostratigraphic classification and nomenclature.

SACS (1980) changed the Dominion succession to the rank of group. From recent age determinations and more detailed geological mapping, it was concluded that development of the Dominion Group was restricted to the Western Transvaal between Ottosdal in the west and the Vredefort Dome in the east, as shown in Figure 1.3.

The following former correlates were assigned by SACS to other sequences:

(1) The Insuzi Series (now Nsuze Group) is part of the Pongola Sequence.

(2) The Godwan Formation is part of the Transvaal Sequence.

(3) The Uitkyk Formation is part of the Pietersburg Group.

(4) The succession between Groblersdal and Dennilton has been named the Groblersdal Group, as it has been found to be appreciably younger than the Dominion Group.

(5) The volcanics and associated rocks forming the strip running west from around Thabazimbi have been assigned provisionally to the Ventersdorp Supergroup.

(6) The so-called pre-Ventersdorp lavas between Mafeking and the Botswana border are probably Ventersdorp correlates.

A lithostratigraphic column of the Dominion Group, amended from SACS (1980), is shown in Figure 1.6. The group comprises three formations: the Rhenosterspruit Quartzite Formation at the base, succeeded conformably by the Rhenosterhoek Andesite Formation, which in turn is overlain by the Syferfontein Porphyry Formation. SACS (1980) has mistakenly called the two lower formations the Rhenosterhoek Quartzite Formation and the Rhenosterspruit Andesite Formation. In the type area around the old Dominion Mine, the group is 2250m thick. A probable age of approximately 2 800 Ma has been determined for the Dominion Group (Van Niekerk and Burger, 1969).

The new name given by SACS to the former Jeppestown Amygdaloid or Jeppestown Lava is the Crown Formation. It occurs in both the Central Rand and Klerksdorp areas in about the middle of the Jeppestown Subgroup, which is the uppermost of three subgroups within the West Rand Group (formerly the Lower Division of the Witwatersrand Supergroup). The distribution of the Witwatersrand Supergroup is shown in Figure 1.4. There are no radiometric age dates for the lavas of the Witwatersrand Supergroup.

SACS maintained the designation of the Ventersdorp succession as a Supergroup, consisting of a lower Klipriviersberg Group, a middle Platberg Group, and two formations, the Bothaville and the Allanridge Formations. As these two formations have no unifying lithological features, the former being sedimentary and the latter volcanic, they cannot be united as a group.

The distribution of outcrops of the Ventersdorp Supergroup is shown in Figure 1.5. Drilling has shown, however, that Ventersdorp rocks occur under cover as far south as a line from Bethal, past Virginia towards Hopetown. The Ventersdorp repositories were thus larger than that of the Witwatersrand Supergroup, though superimposed upon the latter. Maximum thicknesses intersected in the Bothaville area combined amount to about 5 100m of volcanics and 2 900m of sediments. In the northern Cape Province the thickness is much less, as the basal Klipriviersberg Group is not known to occur outside the Witwatersrand basin.

The SACS (1980) subdivision of the Klipriviersberg Group follows that of Winter (1976) as shown in Table A.2. At the base of this group the Ventersdorp Conglomerate Formation, which contains the Ventersdorp contact reef, is not included in either contiguous Supergroup. The subdivision of the Platberg Group into the Kameeldoorns, the Makwassie Quartz Porphyry and the Rietgat Formations, basically also follows that of Winter (1965b, 1976), with the porphyritic Garfield Member being a part of either of the latter two formations. Overlying the Platberg Group, the Bothaville Formation is followed by the Allanridge Andesite Formation. The Vaal Bend formation of Strydom and Whiteside (Whiteside, 1970) was retained as an informal unit, as its relationship to contiguous units is still uncertain.

McIver et al. (1982) proposed that the Ventersdorp Supergroup represents the youngest komatiitic sequence in South Africa. Their proposal is based on the presence of high MgO rocks at the base of the Klipriviersberg Group south of Johannesburg, described by Wyatt (1976). Geochemical data compare favourably with known komatiites, but TiO_2 values in the Ventersdorp rocks are higher. To explain this McIver et al. suggested that, if two liquids were produced, one at higher pressure by smaller degrees of melting than the other, the MgO contents could be comparable but the TiO_2 content of the higher pressure melt would be higher.

Grobler et al. (1982) found they were able to distinguish between lavas of the Allanridge and Rietgat Formations in the Northern Cape and Western Transvaal using visual criteria if a relatively complete succession is present, or by using major element values if not.

APPENDIX II - Analytical Procedures

element	kV	mA	counter	vacuum	crystal	collimator	tube	STANDARDS USED							
Mn	50	40	flow	on	LiF200	c	Cr	AGV-1	BCR-1	G-2	GSP-1	JG-1	NIM-N		
Fe	"	"	"	"	"	f	"	"	"	"	"	"	"		
Ti	"	"	"	"	"	"	"	"	"	"	"	"	"		
Ca	"	"	"	"	"	"	"	"	"	"	"	"	"		
K	"	"	"	"	"	"	"	"	"	"	"	"	"		
Si	"	"	"	"	PET	c	"	"	"	"	"	"	"		
Al	"	"	"	"	"	"	"	"	"	"	"	"	"		
Mg	"	"	"	"	TLAP	f	"	"	"	"	"	"	"		
P	"	"	"	"	Ge	c	"	"	"	"	"	"	"		
Ba	55	40	flow	on	LiF220	f	Cr	AGV-1	BCR-1	CAR-08	GSP-1	KRF-13	NIM-P	PRO-1	S-12
Nb Zr Y Sr Rb	"	"	scint	off	"	"	W	AGV-1	CAR-08	G-2	KRF-13	PRO-1	S-9	S-12	S-15
Zn Cu Ni	"	"	flow & scint	on	"	"	Mo	CAR-08	KRF-13	S-9	S-10	S-12	S-15		
Co Cr V	"	"	flow	"	"	"	W	KRF-13	PCC-1	PRO-1	S-9	S-12	S-15		
La Ce Nd	"	"	flow	"	"	"	"	AGV-1	BCR-1	G-2					
Na	"	"	"	"	TLAP	f	Cr	AGV-1	BCR-1	G-2	GSP-1	JG-1	NIM-N		

Full corrections made for background, deadtime, instrumental drift, spectral and tube line interference

USGS standards: AGV-1, BCR-1, G-2, GSP-1, JG-1, PCC-1

NIM secondary reference standards: S-9, S-10, S-12, S-15

NIM primary standards: NIM-N, NIM-P

Rhodes University in-house standards: CAR-08, KRF-13, PRO-1

STANDARD CONCENTRATIONS - Trace elements

STD	Ba	Nb	Zr	Y	Sr	Rb	Zn	Cu	Ni	Co	Cr	V	La	Ce	Nd
AGV-1	1208												35.0	65.0	39.0
BCR-1	675												25.0	54.0	29.0
CAR-08	243	18.1	125.0	27.7	296.0	18.6	76.5	64.6	69.5						
G-2													96.0	165	55.0
GSP-1	1300														
JG-1															
KRF-13	205	5.4	100.5	30.7	205.0	10.1	75.0	59.5	51.4	45.5	293.0	259.0			
NIM-G															
NIM-P	40														
PCC-1										112.0	2730.0	30.0			
PRO-1	736									21.7	62.0	100.0			
S-09		8.0	137.0	17.2	54.3	56.7	73.0	43.2	111.0	16.9	114.0	137.0			
S-10							38.0	18.0	128.0						
S-12	29	113.0	406.0	89.0	4.0	11.2	267.0	6.1	15.0	8.5	385.0	427.0			
S-15										70.0	1995.0	17.0			

STANDARD CONCENTRATIONS - Major elements

STD	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
AGV-1	59.00	1.04	17.25	6.76	0.10	1.53	4.90	4.26	2.89	0.49	1.01
BCR-1	54.50	2.20	13.61	13.40	0.18	3.46	6.92	3.27	1.70	0.36	0.39
G-2	69.11	0.50	15.40	2.65	0.03	0.76	1.94	4.07	4.51	0.14	0.55
GSP-1	67.38	0.66	15.25	4.33	0.04	0.96	2.02	2.80	5.53	0.28	0.63
JG-1	72.24	0.26	14.21	2.21	0.06	0.73	2.18	3.39	3.96	0.10	0.45
NIM-N	52.43	0.19	16.64	9.00	0.17	7.43	11.55	2.44	0.26	0.04	0.07

APPENDIX III

Table A.3 CIPW weight percent norms for Witwatersrand triad samples

OL = FO + FA
OPX = HYEN + HYFS
CPX = DIEN + DIFS + DIWO
NCI = OL + CPX + CPX + MT + IL + HM
NPC = 100 AN/(AN + AB + 5/3NE)
(after Irvine & Baragar, 1971)

DI = Q + OR + AB + NE + LC + KS
(after Thornton & Tuttle, 1960)

CIPW WEIGHT PERCENT NORM

SAMPLE	DB- 1	DB- 2	DB- 3	DB- 4	DB- 5	DB- 6	DB- 7	DB- 8	DB- 9	DB- 10	DB- 11	DB- 12
AP	.59	.62	.54	.64	.66	.57	.45	.45	.43	.99	.92	1.49
IL	2.01	1.93	1.86	1.58	1.52	1.56	1.63	1.65	1.58	2.18	2.46	3.14
OR	5.47	15.05	14.74	24.45	35.67	35.75	.97	1.39	1.80	5.52	4.13	19.21
AB	51.69	47.68	49.82	59.39	54.25	45.57	32.74	50.94	58.30	70.34	64.97	6.70
AN	42.84	37.28	35.44	16.16	10.09	18.68	66.29	47.67	39.90	24.14	30.90	74.09
C	0.00	0.00	0.00	1.31	1.40	1.51	0.00	0.00	0.00	0.00	0.00	0.00
MT	2.93	2.97	3.03	1.90	1.46	1.74	3.32	3.54	2.97	2.60	3.28	2.96
DIEN	1.72	1.82	1.83	0.00	0.00	0.00	5.04	2.09	3.63	1.96	1.03	1.97
DIFS	3.12	3.27	3.76	0.00	0.00	0.00	4.79	1.63	2.49	2.15	1.37	7.90
DIWO	4.74	4.98	5.42	0.00	0.00	0.00	10.05	3.85	6.39	4.16	2.40	9.23
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	6.95	6.92	5.99	6.20	4.28	4.23	13.99	21.68	19.30	10.24	11.06	1.66
HYFS	12.61	12.44	12.35	9.83	7.32	8.82	13.31	16.90	13.21	11.25	14.71	6.66
Q	11.34	11.63	11.89	26.82	30.19	31.83	4.77	0.00	0.00	3.51	0.00	29.63
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.74	.39	0.00	.53	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.64	.29	0.00	.78	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.02	100.01	100.00	100.00	100.03	100.01	100.00	100.01	100.01	100.03	100.01	100.01
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.38	.68	0.00	1.31	0.00
OPX	19.56	19.37	18.34	16.03	11.60	13.05	27.30	38.58	32.51	21.49	25.77	8.33
CPX	9.57	10.06	11.01	0.00	0.00	0.00	19.88	7.57	12.51	8.28	4.80	19.10
NCI	34.1	34.3	34.2	19.5	14.6	16.4	52.1	52.7	50.2	34.5	37.6	33.5
NPC	45.3	43.9	41.6	21.4	15.7	29.1	66.9	48.3	40.6	25.5	32.2	91.7
DI	42.2	45.1	46.3	70.2	78.0	72.3	19.1	24.5	29.7	49.8	42.5	38.8

SAMPLE	DB- 13	DB- 14	DB- 15	DB- 16	DB- 17	DB- 18	DB- 19	DB- 20	DB- 21	DB- 22	DB- 23	DB- 24
AP	1.82	1.28	.45	.40	.40	.38	.36	.26	.38	.40	.45	1.09
IL	3.85	2.97	1.46	1.41	1.39	1.28	1.22	1.20	1.16	1.20	1.33	2.67
OR	16.12	8.25	11.66	7.82	2.48	7.77	6.13	6.82	10.38	8.42	9.91	14.30
AB	57.33	59.09	49.14	47.21	28.25	43.68	53.58	46.93	51.79	50.42	51.13	48.51
AN	26.54	32.66	39.20	44.98	69.27	48.55	40.29	46.24	37.83	41.16	38.95	37.19
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	3.81	2.83	2.93	2.99	3.60	2.71	2.54	2.70	2.45	2.38	2.58	3.18
DIEN	.10	1.37	3.69	5.42	4.83	4.92	3.38	5.12	3.36	2.59	2.34	.28
DIFS	.31	2.61	3.28	4.05	4.96	3.57	2.56	3.59	3.25	2.61	2.31	.95
DIWO	.38	3.89	7.16	9.84	9.96	8.84	6.17	9.08	6.75	5.29	4.74	1.15
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	5.88	6.00	14.17	13.90	14.47	15.08	6.31	11.86	10.46	10.24	11.80	4.50
HYFS	18.68	11.43	12.57	10.38	14.88	10.95	4.78	8.32	10.10	10.31	11.64	15.38
Q	10.60	16.11	0.00	0.00	2.70	0.00	0.00	0.00	3.47	6.77	1.41	21.66
FO	0.00	0.00	.03	1.78	0.00	.31	5.96	2.87	0.00	0.00	0.00	0.00
FA	0.00	0.00	.03	1.46	0.00	.25	4.98	2.21	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.04	100.03	100.00	100.02	100.02	100.01	100.01	100.02	100.02	100.02	100.00	100.04
OL	0.00	0.00	.05	3.24	0.00	.56	10.95	5.08	0.00	0.00	0.00	0.00
OPX	24.56	17.43	26.75	24.28	29.35	26.02	11.10	20.18	20.56	20.54	23.45	19.88
CPX	.79	7.87	14.12	19.31	19.75	17.34	12.11	17.78	13.36	10.49	9.40	2.38
NCI	33.0	31.1	45.3	51.2	54.1	47.9	37.9	46.9	37.5	34.6	36.8	28.1
NPC	31.6	35.6	44.4	48.8	71.0	52.6	42.9	49.6	42.2	44.9	43.2	43.4
DI	50.7	50.8	33.0	26.6	15.9	26.6	36.9	28.4	39.9	41.0	38.9	52.6

SAMPLE	DB- 25	DB- 26	DB- 27	DB- 28	DB- 29	DB -30	DB- 31	DB- 32	DB- 33	DB- 34	DB- 35	DB- 36
AP	.59	.43	.69	.40	1.07	.76	.71	.69	1.21	.76	.59	.66
IL	1.48	1.16	2.33	2.63	2.85	2.12	2.01	1.67	2.78	1.67	1.45	1.52
OR	21.69	18.69	6.52	12.12	9.23	7.51	8.23	23.53	72.41	60.33	47.83	31.30
AB	47.65	46.81	47.12	60.75	50.13	48.22	51.17	57.58	18.96	28.14	47.19	61.19
AN	30.66	34.50	46.36	27.13	40.64	44.27	40.60	18.89	8.73	11.53	4.98	7.52
C	0.00	0.00	0.00	5.73	2.35	0.00	0.00	0.00	9.87	8.31	5.13	1.35
MT	1.64	2.06	3.51	4.23	3.91	3.67	3.44	1.71	1.65	3.23	2.38	1.41
DIEN	.05	2.93	2.40	0.00	0.00	.30	1.51	.82	0.00	0.00	0.00	0.00
DIFS	.17	2.36	4.91	0.00	0.00	.72	3.00	2.47	0.00	0.00	0.00	0.00
DIWO	.21	5.47	7.10	0.00	0.00	.98	4.39	3.13	0.00	0.00	0.00	0.00
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	2.59	10.87	6.64	6.87	7.02	7.80	7.78	2.04	3.46	5.35	3.34	.97
HYFS	8.09	8.75	13.59	22.40	20.33	18.86	15.40	6.14	7.22	17.44	12.63	6.93
Q	34.23	3.09	5.36	17.79	18.93	12.89	7.21	22.56	15.96	33.17	41.51	30.33
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.01	100.01	100.03	100.03	100.02	100.03	100.01	100.01	100.02	100.01	100.01	100.01
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	10.68	19.62	20.23	29.28	27.36	26.65	23.17	8.18	10.68	22.79	15.97	7.90
CPX	.43	10.76	14.41	0.00	0.00	2.00	8.90	6.42	0.00	0.00	0.00	0.00
NCI	14.2	33.6	40.5	36.1	34.1	34.4	37.5	18.0	15.1	27.7	19.8	10.8
NPC	39.2	42.4	49.6	30.9	44.8	47.9	44.2	24.7	31.6	29.1	9.5	10.9
DI	69.6	44.3	34.1	46.9	44.8	41.8	39.6	70.2	68.8	59.8	72.9	82.9

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                                              CIPW WEIGHT PERCENT NORM

SAMPLE   DP- 37   DP- 38   DP- 39   DP- 40   DB- 41   KL- 42   KL- 43   KL -44   KL- 45   KL -46   DP- 47   DP- 48
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AP          .64      .66      .59      .62      .36      .09      .09      .07      .09      .09      .50      .50
IL         1.54     1.50     1.46     1.41     2.46      .99      .83      .79      .81      .86     1.39     1.43
OR        29.83    34.02    17.11    44.90     6.58    20.87    21.59     7.95     8.43     9.57    26.99    24.57
AB        57.98    51.22    76.93    53.57    46.93    71.25    17.74    27.63    24.85    27.24    58.19    62.09
AN        12.19    14.76     5.97     1.53    46.49     7.88    60.68    64.42    66.71    63.19    14.81    13.34
C           .00     0.00     3.38     1.52     0.00     7.66     0.00     0.00     0.00     0.00     0.00     0.00
MT         1.62     1.51     1.86      .48     3.89     3.29     2.65     2.48     2.46     2.61     1.96     2.12
DIEN       0.00      .04     0.00     0.00      .57     0.00     6.29     8.01     6.91     6.80      .00      .22
DIFS       0.00      .28     0.00     0.00     1.58     0.00     3.58     4.40     3.98     4.44      .00     2.01
DIWO       0.00      .30     0.00     0.00     2.05     0.00    10.43    13.15    11.49    11.78      .00     2.02
WO         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
HYEN       1.47     1.15     1.82      .80     6.88    12.40    12.44    11.56    14.97    13.14     1.72     1.00
HYFS       8.17     7.32     9.51     1.55    19.00    18.37     7.08     6.35     8.63     8.57    10.22     9.15
Q         26.16    29.91    34.76    39.18    14.75    10.75     0.00     0.00     0.00     0.00    26.22    22.16
FO         0.00     0.00     0.00     0.00     0.00     0.00     5.18     3.95     1.42     1.71     0.00     0.00
FA         0.00     0.00     0.00     0.00     0.00     0.00     3.25     2.39      .90     1.23     0.00     0.00
NE         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

TOTAL    100.01   100.01   100.01   100.03   100.02   100.00   100.01   100.00   100.00   100.00   100.01   100.01

OL         0.00     0.00     0.00     0.00     0.00     0.00     8.44     6.34     2.32     2.94     0.00     0.00
OPX        9.64     8.47    11.33     2.35    25.88    30.78    19.52    17.91    23.60    21.71    11.93    10.16
CPX        0.00      .63     0.00     0.00     4.20     0.00    20.30    25.56    22.37    23.02      .01     4.25
NCI        12.8     12.1     14.7      4.2     36.4     35.1     51.7     53.1     51.6     51.1     15.3     17.9
NPC        17.4     22.4      7.2      2.8     49.8     10.0     77.4     70.0     72.9     69.9     20.3     17.7
DI         79.2     78.8     78.6     92.8     40.7     53.5     18.9     16.7     16.1     18.0     75.6     73.6


SAMPLE   DP- 49   DB- 50   DP- 51   DB- 52   DB- 53   DB- 54   DB- 55   DB- 56   DB- 57   DB- 58   DP- 59   DB- 60
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AP          .54      .59      .62      .43      .85     1.44      .40      .33      .31      .73      .62      .76
IL         1.48     1.95     1.46     1.50     2.14     3.10     1.41     1.24     1.20     1.80     1.45     1.84
OR        35.81    12.33    26.12     4.58     8.71    18.53     8.60     7.16    14.01    10.66    63.20    14.69
AB        50.07    47.49    62.28    46.64    58.63    55.10    44.32    53.79    42.12    45.49    22.74    34.29
AN        14.12    40.17    11.60    48.78    32.67    26.37    47.08    39.05    43.86    43.84    14.06    51.02
C           .72     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     1.08     0.00
MT         2.26     2.25     1.62     3.23     3.02     3.16     2.64     2.32     2.48     2.65     1.45     2.70
DIEN       0.00     1.01      .19     3.41     2.59     1.85     5.93     4.84     5.31     2.44     0.00     1.81
DIFS       0.00     2.43      .64     2.16     3.56     5.41     4.57     3.98     3.86     3.95     0.00     3.02
DIWO       0.00     3.31      .78     5.84     6.14     6.90    10.88     9.10     9.54     6.30     0.00     4.75
WO         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
HYEN        .65     3.79     2.23    20.36     8.91     3.53    12.69    10.43    11.14     6.25     3.01     6.71
HYFS      12.11     9.10     7.61    12.88    12.24    10.37     9.77     8.58     8.11    10.10     7.21    11.18
Q         26.48    19.99    25.36     0.00     3.56    10.37     2.27     2.23     0.00    12.59    32.37    19.38
FO         0.00     0.00     0.00     2.96     0.00     0.00     0.00     0.00     1.56     0.00     0.00     0.00
FA         0.00     0.00     0.00     2.06     0.00     0.00     0.00     0.00     1.25     0.00     0.00     0.00
NE         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

TOTAL    100.01   100.02   100.01   100.01   100.02   100.03   100.01   100.00   100.00   100.01   100.01   100.02

OL         0.00     0.00     0.00     5.03     0.00     0.00     0.00     0.00     2.81     0.00     0.00     0.00
OPX       12.76    12.90     9.84    33.24    21.15    13.90    22.46    19.01    19.25    16.34    10.22    17.89
CPX        0.00     6.76     1.61    11.41    12.29    14.16    21.38    17.92    18.71    12.69     0.00     9.59
NCI        16.5     23.9     14.5     54.4     38.6     34.3     47.9     40.5     44.5     33.5     13.1     32.0
NPC        22.0     45.8     15.7     51.1     35.8     32.4     51.5     42.1     51.0     49.1     38.2     59.8
DI         74.4     53.2     78.0     23.1     41.9     50.1     28.4     36.9     31.0     42.5     77.8     42.8


SAMPLE   DB- 61   DB- 62   DB- 63   DP- 64   DP- 65   DB- 66   DB- 67   DB- 68   DB- 69   DB- 72   DB- 73   DB- 75
------   ------   ------   ------   ------   ------   ------   ------   ------   ------   ------   ------   ------
AP          .38      .99      .83      .59      .64      .83      .88      .78     1.66     1.59     1.63     1.61
IL         1.13     2.67     2.25     1.41     1.46     2.14     2.18     2.12     3.64     3.44     3.51     3.38
OR        12.39    12.58     6.81    31.33    27.91    11.93    14.39    10.98    14.22    26.07    18.21    12.67
AB        43.45    41.60    56.18    56.23    62.02    58.35    55.58    58.44    51.53    46.61    55.53    49.84
AN        44.16    45.82    37.01    12.44    10.06    29.72    30.03    30.58    34.25    27.33    26.26    37.49
C          0.00     0.00     0.00     0.00     0.00     0.00     2.15     0.00     0.00     0.00     0.00     0.00
MT         2.20     3.61     3.38     1.45     1.45     2.99     3.02     3.04     3.36     3.45     3.58     3.28
DIEN       3.59      .92     1.49      .26      .30     1.89     0.00     2.04      .57      .88      .67      .54
DIFS       3.03     2.71     5.14     1.26     1.36     2.61     0.00     2.81     1.67     2.68     2.28     1.52
DIWO       6.82     3.46     6.25     1.42     1.55     4.49     0.00     4.83     2.13     3.37     2.79     1.96
WO         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
HYEN      10.63     5.48     3.72     1.25     1.29     9.49    14.67     9.54     5.04     4.75     4.61     5.19
HYFS       8.96    16.14    12.82     5.98     5.85    13.08    15.85    13.16    14.85    14.54    15.60    14.67
Q          6.00    17.06     5.11    29.07    27.04     4.07     9.55     4.65    20.16    17.97    15.37    19.86
FO         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
FA         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
NE         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

TOTAL     99.99   100.01   100.02   100.02   100.01   100.03   100.03   100.02   100.03   100.04   100.03   100.04

OL         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
OPX       19.59    21.62    16.54     7.23     7.14    22.57    30.51    22.71    19.88    19.29    20.21    19.86
CPX       13.44     7.09    12.87     2.94     3.21     9.00     0.00     9.67     4.37     6.93     5.75     4.01
NCI        36.4     35.0     35.0     13.0     13.3     36.7     35.7     37.5     31.3     33.1     33.0     30.5
NPC        50.4     52.4     39.7     18.1     14.0     33.7     35.1     34.4     39.9     37.0     32.1     42.9
DI         38.0     42.5     42.3     79.3     80.2     45.1     45.8     44.3     51.0     52.4     52.2     49.9
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CIPW WEIGHT PERCENT NORM

SAMPLE	DB- 76	DB- 77	DB- 78	DB- 79	DP- 80	DP- 81	DB- 82	DB- 83	DB- 85	KL- 86	KL- 87	DB- 88
AP	1.40	1.40	.47	.36	.57	.57	.31	.33	.52	.07	.14	.69
IL	3.17	3.04	1.91	1.35	1.39	1.39	1.28	1.26	1.48	.77	1.15	2.16
OR	14.19	14.32	10.49	15.33	57.06	21.97	3.78	4.62	35.63	12.56	9.26	18.11
AB	46.86	47.95	57.53	44.19	31.55	38.29	40.45	47.32	35.16	27.89	38.78	43.85
AN	38.96	37.73	31.98	40.47	11.39	39.73	55.77	48.06	29.21	59.56	51.96	38.04
C	0.00	0.00	9.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.91
MT	3.36	2.75	3.77	2.58	1.44	1.55	2.97	2.84	2.39	2.36	2.90	3.58
DIEN	.34	1.28	0.00	1.84	.07	.21	5.39	5.74	1.03	7.42	4.95	0.00
DIFS	.72	2.58	0.00	1.25	.23	.81	4.22	4.33	1.10	4.37	4.18	0.00
DIWO	1.02	3.76	0.00	3.23	.28	.96	9.96	10.45	2.17	12.44	9.41	0.00
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	7.56	5.44	19.65	13.19	2.10	1.85	15.48	14.96	10.97	10.93	14.03	10.91
HYFS	16.24	10.96	20.43	8.96	6.96	7.12	12.13	11.30	11.67	6.44	11.86	19.14
Q	18.72	18.86	1.07	0.00	28.25	38.47	2.88	.18	7.81	0.00	.97	13.01
FO	0.00	0.00	0.00	3.86	0.00	0.00	0.00	0.00	0.00	2.93	0.00	0.00
FA	0.00	0.00	0.00	2.89	0.00	0.00	0.00	0.00	0.00	1.90	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.02	100.02	100.02	100.01	100.00	100.00	100.00	100.02	100.02	100.00	99.99	100.02
OL	0.00	0.00	0.00	6.76	0.00	0.00	0.00	0.00	0.00	4.83	0.00	0.00
OPX	23.80	16.40	40.08	22.15	9.06	8.97	27.60	26.26	22.64	17.37	25.89	30.05
CPX	2.08	7.63	0.00	6.31	.58	1.99	19.57	20.52	4.30	24.24	18.55	0.00
NCI	32.4	29.8	45.8	39.2	12.5	13.9	51.4	50.9	30.8	49.6	48.5	35.8
NPC	45.4	44.0	35.7	47.8	26.5	50.9	58.0	50.4	45.4	68.1	57.3	46.5
DI	47.7	50.0	30.6	36.0	80.3	66.8	23.0	25.4	50.9	20.4	25.2	43.1

SAMPLE	DP- 89	KL- 90	PR- 91	DB- 92	DB- 93	DB- 94	DB- 95	DP- 96	DB- 97	DP- 98	DP- 99	KA-100
AP	.62	.12	2.32	1.28	.40	.31	.59	.62	.33	.47	.43	.33
IL	1.56	.86	3.49	2.97	1.43	1.26	1.60	1.52	2.07	1.43	1.26	1.93
OR	31.57	19.18	1.49	10.13	7.19	8.83	12.96	41.66	2.58	52.22	32.37	11.99
AB	63.97	29.26	36.74	47.35	44.79	50.26	48.90	51.11	49.67	40.50	57.72	12.78
AN	4.46	51.55	61.78	42.52	48.02	40.91	38.14	7.23	47.74	7.27	9.92	75.24
C	2.75	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	2.73	3.02	0.00
MT	1.71	2.36	3.73	3.74	3.19	2.68	2.97	1.55	3.67	1.86	2.29	2.86
DIEN	0.00	6.63	.27	1.28	5.28	5.80	.85	0.00	1.23	0.00	0.00	2.71
DIFS	0.00	3.48	.26	2.95	4.10	4.06	1.06	0.00	2.22	0.00	0.00	2.94
DIWO	0.00	10.74	.54	4.08	9.72	10.28	1.92	0.00	3.38	0.00	0.00	5.73
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	2.89	8.75	18.81	7.11	13.83	11.66	12.05	2.49	9.67	1.79	3.21	11.13
HYFS	8.62	4.60	18.68	16.40	10.74	8.16	14.99	7.69	17.44	9.56	12.23	12.08
Q	33.22	0.00	8.21	11.81	0.00	0.00	5.14	29.59	11.97	33.27	37.39	15.92
FO	0.00	6.77	0.00	0.00	2.42	2.43	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	3.92	0.00	0.00	2.07	1.87	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.02	100.00	100.06	100.03	100.03	100.01	100.00	100.02	100.02	100.00	100.00	100.01
OL	0.00	10.69	0.00	0.00	4.50	4.30	0.00	0.00	0.00	0.00	0.00	0.00
OPX	11.50	13.35	37.49	23.51	24.57	19.82	27.04	10.18	27.12	11.36	15.45	23.21
CPX	0.00	20.86	1.07	8.31	19.10	20.13	3.84	0.00	6.84	0.00	0.00	11.39
NCI	14.8	48.1	45.8	38.5	52.8	48.2	35.4	13.3	39.7	14.6	19.0	39.4
NPC	6.5	63.8	62.7	47.3	51.7	44.9	43.8	12.4	49.0	15.2	14.7	85.5
DI	79.7	25.1	24.9	39.6	24.4	30.4	41.5	81.0	37.1	78.6	73.6	26.9

SAMPLE	KA-101	KA-102	KA-103	KA-104	KA-105	KA-106	KA-107	KO-108	KO-109	KO-110	KO-111	KO-112
AP	.33	.38	.36	.43	.40	.40	.38	.28	.31	.28	.28	.28
IL	2.01	2.03	1.93	2.01	2.05	1.90	2.07	1.91	2.01	1.93	2.03	1.86
OR	7.22	7.22	6.82	14.91	14.21	13.12	6.79	7.47	12.39	8.01	9.26	8.34
AB	55.81	56.73	59.94	55.38	46.68	49.15	56.24	57.07	50.25	56.90	54.30	42.33
AN	36.97	36.05	33.24	29.71	39.12	37.73	36.96	35.47	37.36	35.09	36.44	49.34
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	3.07	3.00	2.90	2.77	3.00	2.75	2.99	3.32	3.60	3.41	3.73	3.29
DIEN	.74	.70	1.50	3.11	3.29	3.21	.96	2.17	1.09	1.89	.89	3.45
DIFS	.86	.79	1.73	3.77	4.57	4.01	1.48	2.97	1.55	2.70	1.25	5.52
DIWO	1.62	1.51	3.26	6.92	7.82	7.25	2.42	5.13	2.63	4.56	2.13	8.85
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	13.30	13.34	11.70	8.87	8.07	8.42	9.25	10.81	12.53	10.91	9.35	7.61
HYFS	15.36	14.95	13.49	10.76	11.20	10.51	14.18	14.76	17.77	15.59	13.14	12.17
Q	7.07	2.76	5.98	.73	1.81	3.88	6.26	0.00	1.29	1.17	0.00	3.80
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.03	0.00	0.00	2.83	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.04	0.00	0.00	4.38	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.00	100.02	100.01	100.02	100.02	100.01	100.00	100.00	100.01	100.00	99.99	100.00
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.07	0.00	0.00	7.21	0.00
OPX	28.66	28.29	25.19	19.63	19.27	18.93	23.43	25.57	30.30	26.51	22.49	19.77
CPX	3.22	3.00	6.48	13.80	15.68	14.48	4.86	10.27	5.26	9.15	4.26	17.83
NCI	37.0	36.3	36.5	38.2	40.0	38.1	33.3	41.1	41.2	41.0	39.7	42.7
NPC	39.8	38.9	35.7	34.9	45.6	43.4	39.7	38.3	42.6	38.1	40.2	53.8
DI	42.1	41.5	44.1	43.4	37.0	39.8	44.1	37.8	37.1	38.5	38.1	30.7

CIPW WEIGHT PERCENT NORM

SAMPLE	KO-113	KO-114	KO-115	KO-116	KO-117	KO-118	KO-119	KO-120	KO-121	KO-122	KO-123	KO-124
AP	.36	.31	.33	.28	.28	.31	.33	.33	.36	.28	.26	.26
IL	1.90	1.90	1.84	1.90	1.88	1.73	1.99	1.90	1.75	1.75	1.63	1.65
OR	9.43	13.13	24.92	7.98	11.89	3.78	13.34	8.65	4.62	15.12	8.50	21.41
AB	43.55	42.68	40.30	57.57	52.57	45.99	49.59	75.14	4.29	46.87	84.31	62.08
AN	47.02	44.19	34.77	34.45	35.53	50.23	37.07	16.20	91.10	38.01	7.19	16.52
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	3.20	3.65	2.97	3.42	3.39	3.04	3.58	3.44	2.60	3.19	3.06	3.00
DIEN	3.90	2.35	3.15	1.31	1.54	4.38	3.09	4.03	5.75	2.04	4.07	4.24
DIFS	5.19	3.83	3.81	1.69	2.09	6.03	4.22	4.88	13.61	2.64	5.94	6.16
DIWO	9.08	6.09	7.00	3.01	3.61	10.37	7.29	8.97	18.64	4.68	9.94	10.33
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.23	0.00	0.00	0.00
HYEN	8.98	9.06	9.90	12.91	11.89	7.48	3.46	0.00	0.00	11.26	0.00	0.00
HYFS	11.96	14.77	11.96	16.63	16.15	10.30	4.72	0.00	0.00	14.56	0.00	0.00
Q	2.80	0.00	4.04	1.12	2.54	3.23	0.00	0.00	6.71	2.93	0.00	0.00
FO	0.00	.49	0.00	0.00	0.00	0.00	5.32	7.89	0.00	0.00	5.07	4.81
FA	0.00	.87	0.00	0.00	0.00	0.00	7.99	10.52	0.00	0.00	8.17	7.72
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.05	0.00	0.00	8.54	4.94
TOTAL	100.01	100.01	100.01	100.02	100.02	100.03	100.01	100.01	100.00	100.01	100.03	100.01
OL	0.00	1.36	0.00	0.00	0.00	0.00	13.31	18.41	0.00	0.00	13.24	12.53
OPX	20.94	23.83	21.86	29.53	28.04	17.78	8.18	0.00	0.00	25.82	0.00	0.00
CPX	18.16	12.26	13.96	6.01	7.24	20.77	14.61	17.89	38.00	9.35	19.95	20.73
NCI	44.2	43.0	40.6	40.9	40.5	43.3	41.7	41.6	42.3	40.1	37.9	37.9
NPC	51.9	50.9	46.3	37.4	40.3	52.2	42.8	17.7	95.5	44.8	7.9	21.0
DI	30.7	31.6	39.9	39.0	39.1	29.7	36.5	48.6	10.9	38.1	57.4	51.6

SAMPLE	KO-125	KO-126	KO-127	KO-128	KO-129	KO-130	KL-131	KL-132	KL-133	KL-134	KL-135	KL-136
AP	.26	.29	.28	.26	.31	.31	.24	.21	.21	.19	.12	.17
IL	1.69	1.73	1.69	1.67	1.88	1.67	1.43	1.43	1.45	1.20	.90	1.22
OR	11.15	18.23	17.81	23.78	9.27	27.39	21.06	4.05	9.96	8.69	2.97	15.61
AB	55.38	45.50	52.72	43.62	46.90	34.56	53.75	58.29	55.40	54.17	43.28	35.87
AN	33.47	36.26	29.47	32.60	43.83	38.05	25.18	37.66	34.65	37.14	53.74	48.51
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	3.10	3.32	3.22	3.10	3.54	2.99	2.97	2.86	2.87	2.77	3.07	3.06
DIEN	1.99	3.25	2.36	2.64	3.18	2.56	4.05	2.87	3.02	5.58	5.51	4.79
DIFS	2.74	4.33	3.68	3.89	5.09	3.74	4.04	2.78	3.07	5.28	2.83	4.50
DIWO	4.71	7.57	5.97	6.48	8.16	6.26	8.24	5.77	6.20	11.11	8.86	9.50
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	10.11	4.14	8.79	8.69	5.27	8.47	5.53	13.14	12.24	10.56	28.09	13.17
HYFS	13.90	5.51	13.68	12.82	8.43	12.34	5.51	12.72	12.44	10.00	14.43	12.37
Q	2.68	0.00	1.59	2.07	0.00	5.36	0.00	4.24	6.26	5.05	.41	2.43
FO	0.00	4.28	0.00	0.00	2.45	0.00	4.74	0.00	0.00	0.00	0.00	0.00
FA	0.00	6.27	0.00	0.00	4.32	0.00	5.20	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.01	100.01	100.01	100.01	100.00	100.00	100.02	100.01	100.00	100.00	99.99	100.01
OL	0.00	10.55	0.00	0.00	6.77	0.00	9.94	0.00	0.00	0.00	0.00	0.00
OPX	24.01	9.66	22.48	21.51	13.70	20.81	11.03	25.86	24.68	20.56	42.51	25.54
CPX	9.44	15.16	12.01	13.01	16.43	12.56	16.34	11.41	12.29	21.97	17.20	18.78
NCI	38.2	40.4	39.4	39.3	42.3	38.0	41.7	41.6	41.3	46.5	63.7	48.6
NPC	37.7	44.3	35.9	42.8	48.3	52.4	31.9	39.2	38.5	40.7	55.4	57.5
DI	41.8	37.8	43.0	41.4	32.2	40.2	43.5	37.9	40.4	35.4	17.0	27.6

SAMPLE	KL-137	KL-138	KL-139	KL-140	KL-141	KL-142	KL-143	KL-144	KL-145	KL-146	KL-147	KL-148
AP	.24	.21	.24	.14	.19	.14	.17	.17	.17	.19	.19	.17
IL	1.28	1.30	1.30	.99	1.07	1.16	1.15	1.15	1.13	.96	1.11	1.07
OR	6.84	14.66	7.68	23.96	22.83	7.84	15.19	19.71	23.93	20.04	17.38	14.07
AB	46.49	48.34	47.89	44.00	30.54	51.13	45.73	47.45	2.95	35.36	54.34	49.64
AN	46.67	37.00	44.44	32.03	46.63	41.03	39.08	32.84	73.11	44.60	28.27	36.29
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	3.18	3.09	3.15	2.84	3.02	3.12	2.96	2.90	2.96	2.87	3.00	2.87
DIEN	4.95	3.95	1.97	7.61	5.97	6.77	5.83	3.69	3.62	3.62	4.61	4.60
DIFS	4.56	3.98	1.83	4.95	3.83	5.69	4.66	3.16	3.15	1.83	4.00	3.74
DIWO	9.74	8.08	3.90	13.16	10.28	12.84	10.85	7.05	6.95	5.80	8.85	8.61
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	10.28	3.43	16.65	10.39	18.50	2.44	11.66	13.86	15.26	17.24	8.63	13.55
HYFS	9.48	3.46	15.45	6.75	11.89	2.05	9.32	11.85	13.28	8.70	7.50	11.01
Q	0.00	0.00	1.64	0.00	0.00	0.00	0.00	0.00	10.53	0.00	0.00	0.00
FO	2.66	6.66	0.00	4.54	1.19	7.94	2.14	.82	0.00	7.65	4.30	1.00
FA	2.70	7.40	0.00	3.25	.84	7.36	1.89	.78	0.00	4.25	4.12	.89
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.03	100.02	100.02	100.01	100.01	100.00	100.01	99.99	100.01	100.01	100.02	100.01
OL	5.36	14.06	0.00	7.80	2.04	15.31	4.03	1.60	0.00	11.90	8.42	1.89
OPX	19.76	6.88	32.10	17.14	30.39	4.50	20.97	25.70	28.55	25.95	16.13	24.56
CPX	19.26	16.02	7.70	25.71	20.08	25.29	21.34	13.91	13.72	11.24	17.46	16.95
NCI	48.8	41.3	44.2	54.5	56.6	49.4	50.4	45.3	46.3	52.9	46.1	47.3
NPC	50.1	43.4	48.1	42.1	60.4	44.5	46.1	40.9	96.1	55.8	34.2	42.2
DI	27.2	36.8	31.6	30.8	23.1	29.8	30.1	36.6	22.1	26.0	38.5	33.4

CIPW WEIGHT PERCENT NORM

SAMPLE	KL-149	KL-150	KL-151	KL-152	KL-153	KL-154	KL-155	KL-156	KL-157	KL-158	KL-159	PG-160
AP	.17	.19	.31	.24	.24	.17	.19	.12	.09	.14	.17	1.23
IL	1.03	1.24	1.20	1.24	1.37	.88	.96	.77	.77	.84	.77	2.23
OR	19.31	14.88	22.72	12.37	23.57	18.82	17.50	4.67	2.00	6.13	4.74	17.43
AB	46.87	45.02	48.57	50.48	44.82	38.20	40.19	41.05	38.70	34.21	33.68	54.61
AN	33.81	40.11	28.71	37.15	31.61	42.98	42.32	54.28	59.29	59.66	61.58	27.96
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.13
MT	2.84	3.06	2.65	2.75	3.13	2.78	2.64	2.93	2.81	3.12	2.91	2.55
DIEN	4.81	4.02	3.18	3.60	2.21	4.30	2.88	5.34	4.43	4.85	4.53	0.00
DIFS	3.69	3.73	3.57	3.51	2.17	2.54	1.53	2.58	1.99	2.32	2.15	0.00
DIWO	8.82	7.93	6.82	7.26	4.46	7.21	4.67	8.45	6.89	7.65	7.13	0.00
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	8.54	7.38	9.75	11.86	4.08	20.77	24.84	27.80	30.80	22.99	30.18	14.42
HYFS	6.55	6.85	10.93	11.56	4.01	12.26	13.19	13.42	13.85	10.99	14.30	12.92
Q	0.00	0.00	3.08	1.15	0.00	0.00	.47	1.99	2.94	0.00	2.94	22.88
FO	5.09	4.73	0.00	0.00	7.88	1.02	0.00	0.00	0.00	6.24	0.00	0.00
FA	4.30	4.84	0.00	0.00	8.55	.66	0.00	0.00	0.00	3.29	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.00	99.98	100.02	100.00	100.01	100.00	100.00	99.99	100.00	100.00	100.01	100.03
OL	9.39	9.57	0.00	0.00	16.43	1.68	0.00	0.00	0.00	9.52	0.00	0.00
OPX	15.09	14.24	20.68	23.43	9.09	33.03	38.03	41.23	44.66	33.97	44.49	27.34
CPX	17.32	15.67	13.56	14.37	8.84	14.05	9.08	16.37	13.32	14.81	13.81	0.00
NCI	45.7	43.8	38.1	41.8	37.9	52.4	50.7	61.2	61.6	62.3	62.0	32.1
NPC	41.9	47.1	37.2	42.4	41.4	52.9	51.3	56.9	60.5	63.6	64.6	33.9
DI	35.8	33.5	44.8	36.9	42.3	27.0	28.5	18.8	17.4	15.2	16.4	51.5

SAMPLE	PG-161	PG-162	PG-163	PG-164	PG-165	PG-166	PG-167	PG-168	PG-169	PG-170	PG-171A	PG-171B
AP	1.28	1.26	1.87	1.92	1.78	1.75	1.87	1.87	1.73	1.89	1.87	1.80
IL	2.38	2.33	3.02	3.06	3.04	2.93	3.14	3.00	2.93	3.10	3.10	3.00
OR	27.64	29.64	11.56	16.97	13.56	6.67	2.02	12.23	5.73	10.31	21.55	15.23
AB	47.61	43.64	41.45	39.00	46.31	55.21	54.44	46.80	50.72	52.24	47.61	46.57
AN	24.75	26.72	47.00	44.03	40.12	38.12	43.54	40.97	43.55	37.46	30.84	38.21
C	0.00	2.75	0.00	0.00	0.00	0.00	.23	1.32	0.00	2.56	0.00	0.00
MT	2.33	2.51	2.97	3.00	3.31	3.02	2.80	3.18	2.73	2.68	2.51	2.60
DIEN	1.12	0.00	.09	3.02	1.62	1.59	0.00	0.00	2.68	0.00	2.00	2.50
DIFS	1.23	0.00	.08	2.63	1.55	1.57	0.00	0.00	3.94	0.00	2.63	3.54
DIWO	2.38	0.00	.17	5.81	3.23	3.23	0.00	0.00	6.57	0.00	4.63	6.02
WO	0.00	0.00	0.00	0.00	0.00	0.00.	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	9.39	13.27	16.70	14.16	15.87	13.70	13.05	17.58	6.48	13.85	7.16	6.41
HYFS	10.38	12.66	14.70	12.32	15.21	13.53	13.73	16.09	9.53	12.99	9.41	9.08
Q	11.61	15.99	10.84	1.20	3.47	1.99	12.70	6.76	11.89	13.09	3.12	10.77
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.04	100.01	100.04	100.05	100.03	100.02	100.05	100.05	100.03	100.05	100.05	100.05
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	19.77	25.94	31.40	26.48	31.08	27.23	26.78	33.67	16.01	26.83	16.57	15.49
CPX	4.73	0.00	.33	11.46	6.40	6.39	0.00	0.00	13.20	0.00	9.26	12.07
NCI	29.2	30.8	37.7	44.0	43.8	39.6	32.7	39.9	34.9	32.6	31.4	33.2
NPC	34.2	38.0	53.1	53.0	46.4	40.8	44.4	46.7	46.2	41.8	39.3	45.1
DI	55.2	52.1	37.1	30.8	34.0	37.1	42.4	36.4	41.0	44.3	47.1	44.3

SAMPLE	PG-172	PG-173	PG-174	PG-175	PG-176	PG-177	PM-178	PM-179	PM-180	PR-181	PR-182	PR-183
AP	1.87	1.68	1.87	1.54	1.54	.09	1.09	1.28	1.33	1.61	1.42	1.73
IL	2.98	2.72	3.21	2.67	2.61	.47	2.08	2.20	2.42	2.67	2.38	2.68
OR	20.16	22.68	9.82	23.76	14.61	18.79	59.50	8.30	12.60	5.11	12.84	23.51
AB	47.23	47.59	42.99	47.87	45.65	5.91	23.56	59.83	45.41	51.05	53.10	44.49
AN	32.61	29.73	47.19	28.38	39.74	75.31	16.94	31.87	41.98	43.84	34.07	32.00
C	0.00	0.00	2.72	1.51	0.00	1.72	3.76	0.00	.59	1.87	0.00	0.00
MT	2.39	2.02	3.52	2.38	2.23	2.35	2.02	1.49	2.29	2.77	2.55	2.29
DIEN	2.13	1.65	0.00	0.00	2.28	0.00	0.00	.11	0.00	0.00	2.21	1.65
DIFS	2.59	2.18	0.00	0.00	3.51	0.00	0.00	.15	0.00	0.00	1.98	1.79
DIWO	4.75	3.83	0.00	0.00	5.73	0.00	0.00	.27	0.00	0.00	4.29	3.49
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	7.33	5.47	15.42	10.43	4.79	9.54	8.37	5.04	9.11	16.09	12.09	8.58
HYFS	8.88	7.26	17.85	11.62	7.36	13.34	9.99	6.72	11.27	13.95	10.83	9.33
Q	5.86	17.22	3.10	14.90	14.58	59.61	26.03	25.79	17.68	11.37	8.41	5.16
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.05	100.05	100.03	100.01	100.05	100.01	100.01	100.04	100.03	100.05	100.02	100.04
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	16.21	12.74	33.26	22.05	12.15	22.88	18.36	11.76	20.39	30.04	22.92	17.91
CPX	9.47	7.66	0.00	0.00	11.52	0.00	0.00	.53	0.00	0.00	8.47	6.93
NCI	31.1	25.1	40.0	27.1	28.5	25.7	22.5	16.0	25.1	35.5	36.3	29.8
NPC	40.8	38.5	52.3	37.2	46.5	92.7	41.8	34.8	48.0	46.2	39.1	41.9
DI	47.1	56.6	30.7	54.3	48.0	62.8	64.8	64.6	49.8	39.3	43.9	48.2

CIPW WEIGHT PERCENT NORM

SAMPLE	PR-184	PR-185	PR-186	PR-187	PR-188	PR-189	PR-190	PR-191	PR-192	PR-193	PR-194	AR-195
AP	2.75	2.27	2.30	1.94	2.06	1.97	1.85	1.92	1.54	1.59	1.56	.47
IL	4.09	3.40	3.57	3.19	3.19	3.06	2.98	2.97	2.70	2.57	2.72	2.31
OR	2.05	6.88	7.04	21.71	5.94	1.59	23.39	9.76	14.73	8.08	17.14	3.17
AB	46.76	45.25	43.39	46.26	46.87	60.55	48.24	49.89	52.72	43.09	17.48	61.79
AN	51.19	47.87	49.57	32.03	47.18	37.86	28.38	40.35	32.55	48.83	65.38	35.04
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.14	0.00	.74	0.00	0.00
MT	3.68	3.33	3.23	2.87	2.90	2.81	2.61	3.38	1.64	3.07	2.77	3.12
DIEN	1.59	.17	1.37	.80	.27	1.15	1.73	0.00	2.97	0.00	.18	1.22
DIFS	2.14	.18	1.55	1.03	.35	1.18	2.11	0.00	3.33	0.00	.14	2.45
DIWO	3.72	.35	2.94	1.83	.62	2.37	3.86	0.00	6.37	0.00	.33	3.56
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	6.44	15.82	12.63	10.13	10.83	12.30	8.73	13.55	3.45	13.35	18.00	6.85
HYFS	8.70	16.48	14.30	13.02	13.86	12.70	10.63	17.22	3.87	15.82	13.75	13.79
Q	0.00	9.07	6.10	7.79	13.25	6.75	8.18	3.75	10.76	12.42	10.25	10.37
FO	3.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	5.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.06	100.05	100.05	100.03	100.06	100.03	100.03	100.03	100.02	100.04	100.03	100.01
OL	9.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	15.14	32.30	26.93	23.15	24.70	25.00	19.36	30.77	7.32	29.17	31.75	20.65
CPX	7.45	.70	5.86	3.65	1.25	4.70	7.70	0.00	12.67	0.00	.64	7.23
NCI	39.6	39.7	39.6	32.9	32.0	35.6	32.6	37.1	24.3	34.8	37.9	33.3
NPC	52.3	51.4	53.3	40.9	50.2	38.5	37.0	44.7	38.2	53.1	78.9	36.2
DI	28.2	34.6	32.4	46.8	41.1	41.4	49.3	36.6	53.5	38.2	27.7	46.7

SAMPLE	AR-196	AR-197	AR-198	AR-199	KA-200	KO-201	KO-202	KL-203	KL-204	KL-205	PG-206	PG-207
AP	.52	.47	.50	.54	.38	.31	.31	.17	.17	.14	1.33	1.85
IL	2.29	2.16	2.20	2.14	1.99	1.82	1.88	1.26	.94	.79	2.38	2.97
OR	6.23	5.68	13.67	14.41	15.80	24.23	10.23	15.04	18.22	8.04	23.69	8.59
AB	60.10	48.97	57.20	59.11	41.95	35.17	48.50	47.48	42.35	42.46	43.04	50.03
AN	33.67	45.35	29.13	26.48	42.26	40.61	41.27	37.47	39.43	49.50	33.27	41.38
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	3.06	3.90	2.60	2.96	3.00	3.20	3.44	2.99	2.64	2.70	2.62	3.06
DIEN	2.15	.06	1.30	2.53	1.32	1.80	1.85	3.52	4.90	6.38	.91	2.88
DIFS	6.29	.13	2.18	3.79	1.83	2.80	2.59	3.38	3.15	3.22	.95	2.80
DIWO	8.02	.19	3.42	6.26	3.13	4.55	4.42	7.05	8.44	10.22	1.89	5.80
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	3.31	9.92	6.62	7.78	10.07	9.25	11.35	13.59	17.89	23.82	11.82	12.96
HYFS	9.69	20.77	11.10	11.68	14.00	14.35	15.88	13.07	11.51	12.00	12.37	12.57
Q	6.82	8.34	14.34	4.93	10.43	9.26	2.83	1.16	3.03	3.26	10.12	4.26
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.01	100.03	100.00	100.01	100.00	100.03	100.02	99.99	100.02	100.00	100.02	100.03
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	13.00	30.69	17.72	19.46	24.07	23.60	27.23	26.66	29.40	35.82	24.18	25.52
CPX	16.46	.39	6.89	12.58	6.28	9.15	8.86	13.95	16.49	19.82	3.75	11.47
NCI	34.8	37.1	29.4	37.1	35.3	37.8	41.4	44.9	49.5	59.1	32.9	43.0
NPC	35.9	48.1	33.7	30.9	50.2	53.6	46.0	44.1	48.2	53.8	43.6	45.3
DI	45.2	37.9	53.9	47.1	41.5	40.5	35.4	34.8	31.7	22.2	47.2	34.1

SAMPLE	PG-208	PM-209	PM-210	PM-212	PM-213	PM-217	PM-219	PM-222	PM-228	PM-231	PM-233	PR-234
AP	2.42	1.37	1.02	1.28	1.21	1.11	1.26	1.09	1.07	1.56	1.26	1.49
IL	3.53	2.55	1.99	2.29	2.27	2.14	2.33	2.03	1.99	2.87	2.20	2.52
OR	4.35	77.89	44.83	.66	55.57	23.38	28.09	11.21	7.02	30.67	18.90	8.08
AB	56.92	7.51	40.85	88.82	26.12	51.52	58.28	59.90	56.99	52.85	60.40	50.41
AN	38.74	14.60	14.31	10.52	18.31	25.10	13.62	28.89	35.99	16.49	20.71	41.51
C	1.07	3.52	0.00	1.90	2.97	0.00	5.59	.02	0.00	5.14	7.56	0.00
MT	3.20	2.23	1.57	1.65	1.52	1.93	2.55	1.57	1.67	2.00	3.39	2.57
DIEN	0.00	0.00	.14	0.00	0.00	.33	0.00	0.00	1.94	0.00	0.00	1.23
DIFS	0.00	0.00	.56	0.00	0.00	.74	0.00	0.00	6.00	0.00	0.00	1.36
DIWO	0.00	0.00	.66	0.00	0.00	1.03	0.00	0.00	7.53	0.00	0.00	2.62
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	14.15	9.31	1.77	4.11	4.26	3.90	8.09	4.21	.67	6.20	12.85	10.42
HYFS	15.75	10.73	6.89	7.75	6.86	8.74	12.93	7.49	2.07	9.20	17.91	11.51
Q	2.86	14.02	24.54	18.84	31.39	21.95	26.03	28.24	26.61	20.06	23.90	12.95
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.05	100.04	100.02	100.02	100.03	100.02	100.01	100.02	100.02	100.03	100.03	100.04
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	29.90	20.05	8.66	11.85	11.12	12.64	21.02	11.70	2.74	15.40	30.76	21.94
CPX	0.00	0.00	1.36	0.00	0.00	2.11	0.00	0.00	15.47	0.00	0.00	5.21
NCI	36.6	24.8	13.6	15.8	14.9	18.8	25.9	15.3	21.9	20.3	36.3	32.2
NPC	40.5	66.0	25.9	10.6	41.2	32.8	18.9	32.5	38.7	23.8	25.5	45.2
DI	37.8	62.1	76.7	74.5	71.9	65.5	61.6	67.6	58.9	64.3	48.5	44.2

CIPW WEIGHT PERCENT NORM

SAMPLE	AR-236	AR-238	AR-241	AR-244	DB-247	DB-251	DB-254	DB-257	DB-259	DP-261	DP-263	DP-265
AP	.54	.50	.54	.59	1.33	.38	.33	.33	.85	.66	.36	.50
IL	2.48	2.22	2.33	2.27	3.08	1.24	1.28	1.16	2.44	1.58	2.01	1.24
OR	47.92	5.53	11.57	6.48	15.89	10.25	4.56	11.79	9.12	20.69	7.34	92.91
AB	2.40	61.97	53.22	47.98	32.77	53.49	52.18	38.38	47.28	67.30	60.99	4.99
AN	49.68	32.50	35.21	45.54	51.34	36.26	43.27	49.83	43.61	12.01	31.67	2.10
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.15	1.49	0.00	4.55
MT	1.32	2.62	3.22	3.73	3.31	2.45	3.19	2.44	4.41	1.75	3.04	.64
DIEN	5.03	2.64	1.71	3.28	.89	2.92	3.55	5.34	0.00	0.00	1.13	0.00
DIFS	5.96	6.31	3.31	4.95	1.91	2.33	3.23	3.52	0.00	0.00	1.38	0.00
DIWO	11.07	8.62	4.89	8.15	2.72	5.43	6.95	9.28	0.00	0.00	2.53	0.00
WO	6.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	0.00	2.98	7.03	9.97	6.95	11.28	9.51	14.93	13.57	3.88	12.04	2.12
HYFS	0.00	7.13	13.58	15.02	14.85	9.02	8.64	9.84	23.73	8.89	14.68	2.63
Q	10.41	9.23	5.68	.03	21.10	0.00	0.00	2.03	2.89	27.19	2.48	54.45
FO	0.00	0.00	0.00	0.00	0.00	1.74	4.43	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	1.54	4.43	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.03	100.01	100.00	100.01	100.02	100.01	100.01	100.01	100.01	100.02	100.00	100.02
OL	0.00	0.00	0.00	0.00	0.00	3.28	8.86	0.00	0.00	0.00	0.00	0.00
OPX	0.00	10.12	20.61	24.99	21.80	20.30	18.14	24.77	37.31	12.77	26.72	4.75
CPX	22.06	17.58	9.91	16.38	5.52	10.68	13.72	18.14	0.00	0.00	5.04	0.00
NCI	25.9	32.5	36.1	47.4	33.7	37.9	45.2	46.5	44.2	16.1	36.8	6.6
NPC	95.4	34.4	39.8	48.7	61.0	40.4	45.3	56.5	48.0	15.1	34.2	29.6
DI	38.8	48.2	43.1	28.4	42.5	39.3	30.9	27.7	29.9	75.2	43.7	87.6

SAMPLE	DP-269	DB-273	DP-276	DB-278	DB-281	DB-285	DB-286	DP-288	KA-291	KO-295	AR-300	AR-304
AP	.52	.40	.28	.90	.36	.57	.81	.62	.33	.28	.52	.54
IL	1.46	2.14	.98	2.33	1.26	1.52	2.63	1.52	1.95	1.99	2.27	2.37
OR	34.84	22.57	37.31	8.02	6.33	14.60	9.03	28.90	7.29	9.51	34.18	31.48
AB	47.50	36.89	54.30	55.34	41.80	45.49	46.36	50.99	55.47	50.48	43.21	47.04
AN	17.66	40.54	8.39	36.64	51.87	39.91	44.61	20.11	37.24	40.01	22.61	21.48
C	0.00	0.00	2.70	.16	0.00	0.00	0.00	0.00	0.00	0.00	1.71	0.00
MT	1.93	3.41	1.30	2.91	2.75	2.55	3.68	1.65	3.03	3.48	2.52	1.99
DIEN	.11	.08	0.00	0.00	4.90	2.68	.50	.41	.51	.72	0.00	2.18
DIFS	.95	.23	0.00	0.00	3.59	2.85	1.21	1.47	.65	1.04	0.00	2.95
DIWO	.97	.29	0.00	0.00	8.83	5.60	1.64	1.76	1.17	1.74	0.00	5.12
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	1.11	5.83	1.67	14.64	15.72	10.17	7.40	1.93	11.99	12.16	8.99	4.94
HYFS	9.15	17.89	6.85	15.15	11.49	10.81	18.07	6.96	15.38	17.55	12.83	6.67
Q	26.98	17.92	37.59	3.52	.72	3.74	11.72	28.27	5.80	5.73	16.53	8.69
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.00	100.01	99.99	100.00	100.01	100.01	100.03	100.00	100.00	100.00	100.01	100.02
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	10.25	23.71	8.52	29.79	27.20	20.99	25.47	8.89	27.37	29.71	21.82	11.61
CPX	2.03	.60	0.00	0.00	17.32	11.13	3.35	3.64	2.33	3.50	0.00	10.25
NCI	15.7	29.9	10.8	35.0	48.5	36.2	35.1	15.7	34.7	38.7	26.6	26.2
NPC	27.1	52.4	13.4	39.8	55.4	46.7	49.0	28.3	40.2	44.2	34.4	31.3
DI	73.8	48.7	82.1	41.8	25.0	39.5	40.7	72.5	42.9	38.9	58.8	59.4

SAMPLE	AR-305	AR-307	PG-312	PG-314	PG-316	PG-319	PG-322	PG-325	PG-328	PM-329	PM-332	PM-335
AP	.40	.62	1.30	1.75	1.28	1.30	1.28	1.78	1.40	1.61	1.09	1.11
IL	2.40	2.23	2.40	3.21	2.40	2.38	2.53	2.85	2.37	3.21	2.03	2.08
OR	21.41	15.54	11.20	31.26	30.01	27.70	9.30	6.50	7.24	37.37	35.20	38.14
AB	53.68	51.21	50.35	51.12	42.22	38.44	67.88	52.52	62.61	43.13	46.69	45.75
AN	24.91	33.25	38.45	17.62	27.77	33.86	22.82	40.98	30.15	19.51	18.11	16.11
C	4.44	0.00	2.26	8.35	0.00	0.00	3.20	0.00	.80	5.63	0.00	0.00
MT	3.62	2.60	3.00	3.68	2.10	2.58	2.55	2.84	2.25	2.64	1.75	1.71
DIEN	0.00	2.00	0.00	0.00	.84	2.19	0.00	.41	0.00	0.00	.10	.00
DIFS	0.00	2.17	0.00	0.00	1.50	2.94	0.00	.35	0.00	0.00	.23	.02
DIWO	0.00	4.22	0.00	0.00	2.30	5.12	0.00	.78	0.00	0.00	.32	.02
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	11.78	10.23	13.17	11.33	4.96	7.63	13.87	16.03	11.03	10.04	3.83	1.89
HYFS	19.03	11.13	15.48	18.73	8.80	10.26	12.85	13.87	11.13	12.66	8.40	8.20
Q	14.98	8.16	17.07	3.83	19.74	10.18	12.90	10.22	12.27	7.17	22.83	26.74
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.00	100.03	100.05	100.04	100.03	100.04	100.04	100.04	100.02	100.04	100.02	100.04
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	30.81	21.36	28.65	30.06	13.76	17.88	26.72	29.90	22.16	22.69	12.23	10.09
CPX	0.00	8.39	0.00	0.00	4.64	10.25	0.00	1.54	0.00	0.00	.65	.04
NCI	36.8	34.6	34.1	37.0	22.9	33.1	31.8	37.1	26.8	28.5	16.7	13.9
NPC	31.7	39.4	43.3	25.6	39.7	46.8	25.2	43.8	32.5	31.1	27.9	26.0
DI	47.5	46.0	45.0	44.3	60.3	46.9	52.2	40.3	53.3	53.1	71.5	75.6

CIPW WEIGHT PERCENT NORM

SAMPLE	PM-338	AR-339	AR-341	AR-343	AR-345	KA-346	KA-347	KA-348	KA-349	KA-350	KO-352	KO-355
AP	1.09	.52	.64	.57	.52	.36	.33	.38	.33	.40	.31	.24
IL	2.03	2.22	2.48	2.18	1.99	2.10	1.88	2.01	1.80	2.03	1.82	1.71
OR	23.63	27.82	9.88	6.70	5.86	12.20	5.95	8.71	7.94	25.68	13.52	16.28
AB	45.00	19.50	55.27	60.29	57.30	33.30	65.11	54.52	61.30	48.72	51.58	46.17
AN	31.37	52.68	34.85	33.01	36.84	54.50	28.94	36.78	30.77	25.60	34.90	37.55
C	.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	1.59	2.57	3.03	3.29	3.06	3.23	2.61	3.18	2.80	2.87	3.22	3.45
DIEN	0.00	1.87	2.36	4.44	.67	2.42	2.73	3.14	2.91	2.63	2.62	1.45
DIFS	0.00	3.00	3.70	6.38	.92	2.30	3.09	4.14	3.96	3.33	3.95	1.91
DIWO	0.00	4.81	5.99	10.75	1.58	4.82	5.88	7.28	6.85	5.97	6.51	3.36
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	6.00	6.40	7.57	3.33	11.21	15.56	9.35	8.39	7.92	7.05	8.83	12.82
HYFS	7.58	10.26	11.86	4.79	15.25	14.79	10.61	11.07	10.79	8.94	13.30	16.85
Q	28.78	17.61	4.98	0.00	7.37	3.12	5.97	0.00	0.00	0.00	2.20	.13
FO	0.00	0.00	0.00	3.04	0.00	0.00	0.00	.84	.04	1.56	0.00	0.00
FA	0.00	0.00	0.00	4.82	0.00	0.00	0.00	1.22	.06	2.18	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.04	100.00	100.03	100.00	100.01	100.02	100.02	100.00	100.00	100.01	100.01	100.00
OL	0.00	0.00	0.00	7.86	0.00	0.00	0.00	2.07	.11	3.74	0.00	0.00
OPX	13.58	16.66	19.44	8.12	26.46	30.36	19.97	19.46	18.71	15.99	22.13	29.67
CPX	0.00	9.68	12.05	21.57	3.17	9.53	11.70	14.56	13.72	11.93	13.08	6.72
NCI	17.2	31.1	37.0	43.0	34.7	45.2	36.2	41.3	37.1	36.6	40.3	41.5
NPC	41.1	73.0	38.7	35.4	39.1	62.1	30.8	40.3	33.4	34.4	40.4	44.9
DI	64.6	41.6	42.4	37.8	43.7	26.5	46.9	36.9	43.3	46.9	39.5	36.4

SAMPLE	KO-356	AR-359	AR-360	AR-361	AR-362	AR-363	AR-364	AR-365	JC-366	JC-367	JC-368	JC-369
AP	.26	.50	.52	.66	.62	.57	.59	.54	1.18	1.18	1.21	1.21
IL	1.73	2.31	2.31	2.46	2.20	2.05	2.12	2.03	1.86	1.95	1.93	1.91
OR	7.39	20.87	11.10	19.32	11.45	16.08	21.94	19.54	17.15	15.64	2.39	6.49
AB	51.61	49.23	57.23	43.05	50.43	52.20	55.84	53.12	58.31	65.16	66.07	65.09
AN	41.00	29.90	31.67	37.63	38.12	31.72	22.22	27.33	24.54	19.20	31.54	28.42
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.52	0.00	3.23	1.56
MT	2.86	2.57	3.39	3.33	3.04	3.12	2.51	2.71	2.96	3.02	3.26	3.07
DIEN	.07	3.00	1.48	1.67	3.20	4.51	3.69	2.39	0.00	.12	0.00	0.00
DIFS	.11	5.09	2.15	2.49	4.14	5.66	4.43	4.05	0.00	.95	0.00	0.00
DIWO	.18	7.96	3.60	4.13	7.34	10.20	8.17	6.33	0.00	.98	0.00	0.00
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	8.75	4.72	10.48	9.93	9.08	8.61	6.99	5.93	2.09	1.99	2.66	2.12
HYFS	15.11	7.99	15.24	14.82	11.75	10.81	8.40	10.07	15.73	15.11	17.49	16.42
Q	11.75	7.29	0.00	6.08	4.47	.85	2.50	6.37	23.31	20.70	35.65	27.32
FO	0.00	0.00	.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.99	100.03	100.01	100.03	100.03	100.02	100.02	99.99	100.03	100.02	100.02	100.03
OL	0.00	0.00	.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	23.86	12.71	25.72	24.76	20.83	19.42	15.40	16.00	17.82	17.10	20.16	18.54
CPX	.35	16.05	7.23	8.29	14.67	20.37	16.30	12.77	0.00	2.05	0.00	0.00
NCI	28.8	33.6	39.3	38.8	40.7	45.0	36.3	33.5	22.6	24.1	25.4	23.5
NPC	44.3	37.8	35.6	46.6	43.1	37.8	28.5	34.0	29.6	22.8	32.3	30.4
DI	46.7	48.4	41.1	40.0	38.0	37.5	49.6	49.7	62.8	64.3	59.3	60.5

SAMPLE	JC-370	JC-371	KA-373	KA-376	KL-382	KL-392	PR-395	PR-398	AR-400	AR-403	PG-406	PG-417
AP	1.16	2.04	.33	.40	.17	.17	1.61	1.68	.64	.52	1.35	1.59
IL	1.90	3.10	1.90	2.18	.94	.94	3.08	2.85	2.18	2.16	2.65	2.80
OR	22.32	16.95	9.26	17.97	23.49	14.45	5.35	18.42	20.59	14.71	29.29	17.02
AB	64.77	64.14	52.39	44.33	36.93	46.29	46.13	39.17	31.69	25.98	36.70	45.79
AN	12.91	18.92	38.35	37.71	39.57	39.26	48.53	42.41	47.72	59.31	34.00	37.19
C	2.10	6.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.85	0.00
MT	2.91	4.32	2.74	3.16	2.81	2.87	2.36	2.89	2.99	3.80	2.61	2.86
DIEN	0.00	0.00	4.13	1.41	4.64	2.71	7.55	1.39	3.78	.54	0.00	1.41
DIFS	0.00	0.00	5.20	2.04	3.28	1.99	4.87	1.59	5.26	.80	0.00	1.37
DIWO	0.00	0.00	9.37	3.42	8.26	4.89	13.03	3.01	9.01	1.32	0.00	2.84
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	2.19	3.96	7.37	7.83	17.60	15.07	0.00	11.19	7.52	13.16	14.19	13.38
HYFS	15.48	22.69	9.28	11.33	12.42	11.07	0.00	12.88	10.47	19.50	12.99	13.02
Q	24.50	2.24	4.79	0.00	1.12	0.00	0.00	9.64	4.76	10.02	13.76	9.04
FO	0.00	0.00	0.00	1.59	0.00	2.83	7.17	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	2.53	0.00	2.29	5.09	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	3.37	0.00	0.00	0.00	0.00	0.00
TOTAL	100.02	100.08	100.02	100.02	100.03	100.02	100.03	100.04	100.01	100.01	100.04	100.04
OL	0.00	0.00	0.00	4.13	0.00	5.11	12.26	0.00	0.00	0.00	0.00	0.00
OPX	17.67	26.65	16.65	19.15	30.02	26.14	0.00	24.07	18.00	32.66	27.19	26.41
CPX	0.00	0.00	18.70	6.86	16.17	9.59	25.45	5.99	18.05	2.65	0.00	5.61
NCI	22.5	34.1	40.0	35.5	49.9	44.6	43.1	35.8	41.2	41.3	32.4	37.7
NPC	16.6	22.8	42.3	46.0	51.7	45.9	51.3	52.0	60.1	69.5	48.1	44.8
DI	67.8	46.6	38.6	40.0	30.6	33.5	28.4	40.1	32.7	29.6	47.8	41.5

CIPW WEIGHT PERCENT NORM

SAMPLE	IN-419	PG-421	PG-426	PG-433	AR-442	AR-446	AR-451	KA-452	KA-455	KO-457	KO-460	KO-462
AP	.69	1.42	1.85	1.49	.66	.57	.38	.33	.38	.28	.28	.28
IL	3.40	2.61	3.00	2.95	2.40	2.01	1.67	1.95	2.01	1.88	1.76	1.76
OR	4.97	24.18	28.20	6.49	4.82	16.30	22.78	4.77	19.50	10.31	15.09	28.09
AB	50.88	51.26	39.18	59.64	52.39	55.91	54.86	39.73	45.49	51.08	56.63	41.19
AN	44.15	24.55	32.61	33.87	42.79	27.79	22.36	55.50	35.00	38.62	28.29	30.72
C	0.00	0.00	0.00	.79	.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	4.19	2.60	2.75	2.71	3.25	2.75	2.10	3.18	3.06	3.45	3.13	3.35
DIEN	1.34	1.79	1.26	0.00	0.00	.74	3.99	3.96	2.20	1.45	2.61	1.70
DIFS	1.81	2.20	1.26	0.00	0.00	1.08	3.92	4.13	3.20	1.96	3.44	2.53
DIWO	3.15	4.00	2.56	0.00	0.00	1.81	8.07	8.22	5.36	3.40	6.04	4.19
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	8.53	8.75	12.32	13.87	12.75	9.19	7.12	12.25	8.91	12.23	6.98	9.96
HYFS	11.52	10.78	12.39	13.23	16.97	13.33	7.00	12.79	12.98	16.59	9.20	14.83
Q	0.00	8.96	6.30	2.16	3.47	8.01	3.75	6.14	2.21	6.60	0.00	0.00
FO	4.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	.32
FA	6.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.22	.52
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.01	100.04	100.05	100.04	100.01	100.03	100.00	100.02	100.01	100.02	100.00	100.02
OL	10.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.44	.83
OPX	20.05	19.53	24.70	27.10	29.72	22.53	14.12	25.04	21.89	28.82	16.18	24.79
CPX	6.30	7.99	5.08	0.00	0.00	3.63	15.98	16.32	10.76	6.80	12.09	8.41
NCI	44.6	32.7	35.5	32.8	35.4	30.9	33.9	46.5	37.7	41.0	38.6	39.1
NPC	46.5	32.4	45.4	36.2	45.0	33.2	29.0	58.3	43.5	43.1	33.3	42.7
DI	30.6	51.9	44.3	43.7	37.8	51.7	51.9	27.1	41.0	38.6	43.8	42.0

SAMPLE	KL-465	KL-467	KL-468	KL-469	KL-471	PR-472	PR-474	PR-476	PR-477	PR-479	PR-480	PR-481
AP	.28	.19	.09	.19	.28	1.54	1.28	1.40	1.56	1.40	1.56	1.63
IL	1.63	1.37	.75	1.18	1.11	3.10	2.35	2.52	2.67	2.52	2.76	2.65
OR	17.41	8.91	2.43	15.20	26.13	20.49	26.94	24.73	7.36	19.42	19.19	2.49
AB	50.01	48.21	6.62	51.28	55.09	55.38	41.82	51.06	50.01	40.16	46.11	60.84
AN	32.58	42.88	90.94	33.52	18.78	24.13	31.24	24.21	42.63	40.42	34.70	36.67
C	0.00	0.00	0.00	0.00	2.94	1.90	0.00	0.00	0.00	0.00	0.00	4.22
MT	3.10	2.81	3.15	2.87	2.73	2.83	2.62	1.91	2.62	2.67	2.58	3.00
DIEN	3.04	2.98	4.74	2.46	0.00	0.00	2.82	1.28	.02	1.15	.85	0.00
DIFS	4.93	3.34	1.96	2.37	0.00	0.00	2.76	1.53	.02	1.21	1.00	0.00
DIWO	7.87	6.39	7.20	4.94	0.00	0.00	5.69	2.83	.04	2.39	1.86	0.00
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	7.27	10.67	38.32	13.03	10.81	7.32	10.88	6.24	11.91	11.68	9.98	19.50
HYFS	11.77	11.99	15.84	12.57	14.98	13.91	10.63	7.47	13.00	12.29	11.71	15.19
Q	3.09	6.55	3.67	0.00	1.59	5.39	6.17	13.21	14.40	12.71	7.35	13.53
FO	0.00	0.00	0.00	.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FA	0.00	0.00	0.00	.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.01	100.00	100.00	100.02	100.01	100.02	100.02	100.03	100.04	100.03	100.03	100.05
OL	0.00	0.00	0.00	1.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPX	19.04	22.66	54.17	25.60	25.79	21.24	21.51	13.71	24.91	23.96	21.70	34.69
CPX	15.84	12.70	13.90	9.77	0.00	0.00	11.27	5.64	.08	4.75	3.71	0.00
NCI	39.6	39.5	72.0	40.8	29.6	27.2	37.7	23.8	30.3	33.9	30.7	40.3
NPC	39.5	47.1	93.2	39.5	25.4	30.4	42.8	32.2	46.0	50.2	42.9	37.6
DI	41.5	37.2	5.9	39.3	54.9	54.0	43.9	59.9	45.3	43.7	46.8	39.1

SAMPLE	PR-483	PR-484	PR-485	PR-486	PR-487	PR-489	PR-491	PR-492	PR-494	AR-495	AR-496	AR-497
AP	1.28	1.54	1.68	1.47	1.78	1.42	1.47	1.87	2.06	.62	.62	.54
IL	2.31	2.74	2.82	2.55	2.68	2.57	2.57	3.25	3.30	2.37	2.23	2.25
OR	33.02	24.87	17.23	16.51	11.20	22.55	24.28	20.90	26.19	17.85	14.67	3.44
AB	31.27	31.43	45.37	37.01	54.57	40.56	43.91	43.23	37.50	32.24	37.26	49.45
AN	35.71	43.69	37.40	46.48	34.23	36.89	31.80	35.87	36.31	49.90	48.07	47.11
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	2.62	2.86	3.04	3.10	2.16	2.48	2.57	2.64	3.45	3.29	3.16	3.52
DIEN	1.82	2.36	1.83	1.88	2.72	1.22	.86	.88	2.11	1.06	2.70	1.79
DIFS	2.43	2.28	2.08	1.49	3.04	1.55	1.14	1.58	2.81	1.45	4.45	2.35
DIWO	4.24	4.74	3.95	3.49	5.82	2.77	2.00	2.42	4.92	2.50	7.05	4.14
WO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYEN	8.17	12.55	11.72	18.34	6.57	8.45	8.78	6.19	10.96	11.42	7.33	12.43
HYFS	10.92	12.09	13.34	14.48	7.35	10.74	11.70	11.06	14.56	15.67	12.09	16.32
Q	11.32	8.27	6.42	9.55	14.12	14.61	12.49	16.71	.82	3.39	5.20	0.00
FO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.02
FA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.03
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.03	100.04	100.04	100.01	100.04	100.04	100.03	100.03	100.05	100.01	100.02	100.03
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.04
OPX	19.09	24.65	25.06	32.82	13.92	19.19	20.48	17.25	25.52	27.09	19.42	28.75
CPX	8.48	9.38	7.87	6.85	11.58	5.53	4.00	4.88	9.84	5.01	14.20	8.28
NCI	32.5	39.6	38.8	45.3	30.3	29.8	29.6	28.0	42.1	37.8	39.0	42.9
NPC	53.3	58.2	45.2	55.7	38.5	47.6	42.0	45.3	49.2	60.7	56.3	48.8
DI	46.6	36.8	39.7	32.9	49.5	48.8	51.0	51.0	35.9	32.6	33.9	30.0

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CIPW WEIGHT PERCENT NORM

SAMPLE AR-498  AR-500
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AP        .54     .52
IL       2.14    1.90
OR       2.19   13.41
AB      29.53   27.58
AN      24.26   17.30
C        0.00    0.00
MT       2.94    2.89
DIEN      .39    1.86
DIFS      .43    2.34
DIWO      .82    4.21
WO       0.00    0.00
HYEN    13.46   10.37
HYFS    14.99   13.00
Q        8.33    4.64
FO       0.00    0.00
FA       0.00    0.00
NE       0.00    0.00

TOTAL  100.02  100.01

OL       0.00    0.00
OPX     28.45   23.37
CPX      1.64    8.41
NCI     35.2    36.6
NPC     45.1    38.5
DI      40.0    45.6
```