THE GEOLOGY AND GEOCHEMISTRY OF THE VOLCANIC ROCKS

OF THE PONGOLA SEQUENCE

IN SOUTHERN SWAZILAND

BY

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I, MBONGENI HENRY MABUZA, hereby declare that this thesis is my own original work, that all assistance and sources of information have been duly acknowledged, and this work has not been presented to any other university for the purpose of a higher degree.

ABSTRACT

The ~3.0 Ga Pongola Sequence, comprising a lower dominantly volcanic Nsuze Group and an upper largely sedimentary Mozaan Group, crops out in the Mahlangatsha and Kubuta areas of southern Swaziland. The Nsuze Group consists of basaltic, andesitic, dacitic and rhyolitic rocks with intercalations of ferruginous shale and pyrophyllitic schists. The Mozaan Group comprises quartzites, ferruginous shales, basalts and minor amounts of andalusite and sericitic schists.

In the study area in southern Swaziland the Pongola Sequence is represented by a northerly striking lens of metavolcanic basaltic rocks extending southwards to the Ngwavuma River valley. These lavas comprise basalts, basaltic andesites and very minor rhyolites that are amygdaloidal and vesicular in places. Hunter (1952) tentatively correlated these metabasaltic rocks with the Nsuze Group but the geochemistry indicates that an upper Mozaan correlation is more likely.

In the study area four stages of deformation have been deduced: a cleavage development (D_1); low angle thrusting and bedding-parallel thrust faulting (D_2); normal/oblique slip faulting (D_3) and fracturing/jointing (D_4). There has been duplication of strata by thrusting and normal faulting. Absence of marker beds prevents the determination of the degree of duplication.

It is clear from the geochemical analysis that there are two broad groups of data from the suite, one from the Sigwe Hills in the north and the other from south of the Ngwavuma River. The samples from south of the Ngwavuma River are enriched in TiO_2, Al_2O_3, CaO, Cr, Zr and Nb compared to the samples from Sigwe Hills. These volcanic rocks are tholeiitic in nature and indicate a within plate continental setting.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

PAGE

CHAPTER

TABLE OF CONTENTS (Continued)

PAGE

LIST OF FIGURES

PAGE

FIGURE

LIST OF FIGURES (Cont.)

PAGE

FIGURE

LIST OF FIGURES (Cont.)

FIGURE **PAGE**

LIST OF FIGURES (Cont.)

PAGE

FIGURE

LIST OF FIGURES (Cont.)

PAGE

FIGURE

LIST OF TABLES

PAGE

TABLE

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CHAPTER 1

INTRODUCTION

1.1 LOCATION OF THE STUDY AREA

The area to be discussed is about 95 km^2 in area and is located in the southeastern part of Swaziland (Figure 1.1). Access is from the Hlatikulu-Hluti and the Nhlangano-Hluti-Maloma roads (in the annexure Map 1). An additional number of tracks and farm roads also provide access to the study area from the main roads.

Outcrop is generally restricted to ridges, particularly the Sigwe Hills (Map 1). The lower lying areas have been cultivated extensively so that sporadic outcrops are confined to stream beds. Map 2 in the annexure shows the sample points. The terrain in the area is gently undulating except in the Sigwe Hills where there are very steep slopes in places.

1.2 PREVIOUS WORK

The Nsuze Group was first recorded in the Piet Retief and Paulpietersburg areas as consisting of a basal thick quartzitic succession overlain predominantly by andesitic lavas with rare occurrences of the more acid and more basic varieties (Humphrey and Krige (1931) in Armstrong (1980).

No detailed studies have been carried out, except for regional geological mapping undertaken during the 1950's. The presence of the dominantly volcanic rocks in the study area was reported first by Hunter (1952). At that stage large volumes of volcanic rocks were not recognized as being associated with the Mozaan Group and Hunter assigned the rocks under consideration to the Nsuze Group. Basaltic lavas were subsequently identified in the uppermost Mozaan Group near Mooihoek by Hunter (1963), (Figure 1.1). There has been no information on the chemistry of these lavas until the present study which represents the first detailed investigation, (two of the samples analyzed K1 and K2 are from Mooihoek). There is a direct correlation between the geochemistry of the volcanic rocks from the vicinity of Mooihoek (upper Mozaan Group) and that of the volcanic rocks from the study area. In

Figure 1.1 and other subsequent figures, the study area is thus shown as being part of the Mozaan Group stratigraphy.

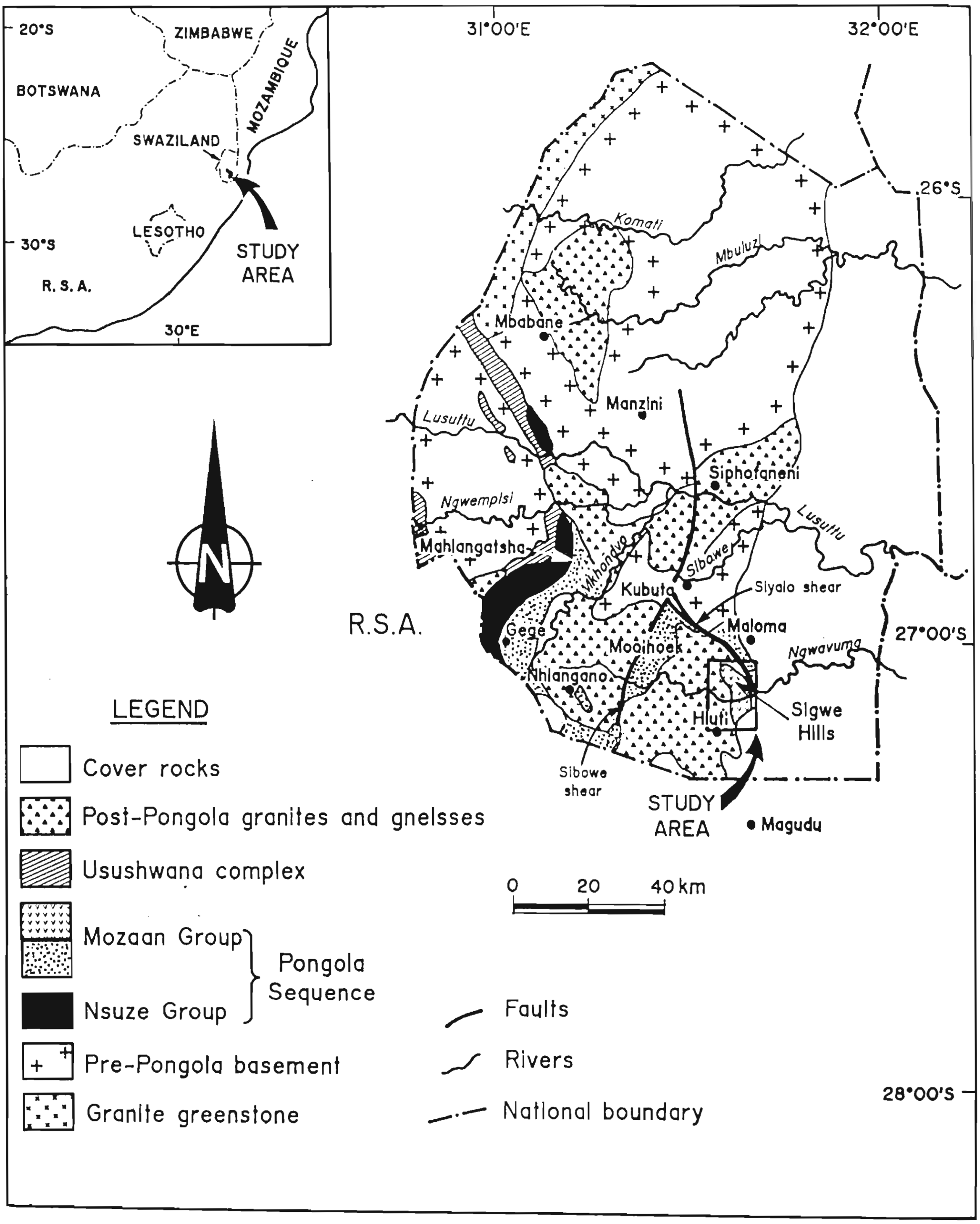

Figure 1.1: Map showing the location of the study area and the distribution of the Pongola Sequence in southern Swaziland.

Regional stratigraphical correlations within the Pongola basin have been complicated by lack of distinctive lithological sequences and the complex nature of the structure within the entire basin. In Swaziland and adjacent areas of northern KwaZulu-Natal and southeastern Transvaal, the Pongola Sequence is transected by shear zones striking north and northwest. This results in a series of fault-bound tectono-stratigraphic packages that are further disturbed by a number of granitoid intrusions.

This thesis is concerned with that part of the sequence preserved in the Sigwe Hills and extending to and beyond the Ngwavuma River (Map 1).

1.3. AIMS AND APPROACH

The present study has the following objectives

(i) to map and record the extent and relationships of the various volcanic and sedimentary lithologies;

(ii) to attempt to establish the environment(s) in which the volcanic rocks were extruded;

(iii) to establish the compositions of the volcanic rocks and to compare them with those in other parts of the Pongola basin;

(iv) to record structural data in order to attempt to unravel the deformational history and to relate this to the broader structural evolution of the Pongola basin;

(v) to undertake a petrographic study of the lithologies to ascertain mineralogical variations and to determine the metamorphic conditions to which the rocks have been subjected;

(vi) to establish the validity of these volcanic rocks being related to the Mozaan Group rather than the Nsuze Group in the stratigraphy.

Fieldwork involved mapping with the aid of 1 : 10 000 scale orthophoto sheets and 1 : 50 000 topocadastral sheets onto which data were transferred. Aerial photographs of 1 : 30 000 scale were also used. The final map has been compiled at a scale of 1 : 50 000 (Map 1).

A total of 47 samples of the volcanic rocks were analyzed for major and minor oxides together with trace elements Ba, Sr, Nb, Y, Rb, Zr, Sr, U, Th, Zn, Cu, Ni, Cr, V and La. Four additional samples of volcanic rocks collected from inliers of Mozaan volcanic rocks immediately south of the Swaziland border (Magudu district in northern KwaZulu-Natal), and from upper Mozaan outcrops in the vicinity of Mooihoek (Figure 1.1) were also analyzed.

CHAPTER 2

REGIONAL GEOLOGY

2.1 INTRODUCTION

The late Archaean Pongola Sequence (~2.94 Ga, Hegner *et al.*, 1984) crops out in southern Swaziland in two discrete areas, namely, Mahlangatsha-Gege and Kubuta-Sigwe Hills (Figure 1.1) where it rests unconformably on older granitic rocks, the ages of which range from about 3.64 Ga to about 3.25 Ga (Farrow *et al.*, 1990). The Nsuze Group, where it crops out to the west of Swaziland in the vicinity of Amsterdam, rests unconformably underlying Lochiel granite dated at 3.1 Ga (Barton *et al.*, 1983). This is therefore a maximum age for the Pongola Sequence.

Following the volcanism and sedimentation which produced the Pongola Sequence, the stratigraphically lowest formations in the in the Piet Retief area were intruded by magmas of dominantly mafic and ultramafic composition. These were first recognized by Hunter (1952) as a suite of gabbroic, dioritic and granophyric rocks which seemed to have their greatest development near the Usushwana river in southwestern Swaziland. Rocks of this Usushwana Complex have subsequently been identified in the area extending from east of Paulpietersburg in KwaZulu-Natal to west of Mbabane in Swaziland and also north of Amsterdam in the Transvaal (Figure 2.1). The Usushwana Complex (age ~2.87 Ga, Hegner *et al.,* 1984) is important in assessing the geological evolution of the region and will be described in a later section. Table 2.1 presents a stratigraphic column showing the position of the Pongola Sequence and other rock associations which are spatially related to it.

Various dominantly potassic granitoids intruded the Pongola Sequence in southern Swaziland and adjacent areas of southeastern Transvaal and northern KwaZulu-Natal. These were emplaced as gneiss domes, tabular granite batholiths (Hlatikulu granite) and a number of megacrystic discordant granitoid plutons. The most extensive is a megacrystic granodiorite building the Kwetta batholith. On its southern and western flanks are smaller intrusions of leucogranite, the Mooihoek and Mhlosheni plutons (Figure 2.2). The absolute ages of these intrusions are not known as Rb-Sr dating techniques have yielded only errochrons (D.R. Hunter *pers. comm.*, 1991).

Table 2.1: Stratigraphic column showing the chronological sequence of geologic units in relation to the Pongola Sequence.

POST-KAROO DOLERITE INTRUSIONS

KAROO SEQUENCE
- ECCA GROUP

GRANITOIDS < 2.87 Ga

USUSHWANA COMPLEX > 2.87 Ga

PONGOLA SEQUENCE
- MOZAAN GROUP
  - ii) upper volcano-sedimentary unit
  - i) lower sedimentary unit
- NSUZE GROUP
  - iii) upper volcaniclastic-sedimentary unit
  - ii) middle predominantly volcanic unit
  - i) lower sedimentary-volcanic unit

~~ UNCONFORMITY ~~

GRANITOID - GREENSTONE BASEMENT > 3.1 Ga

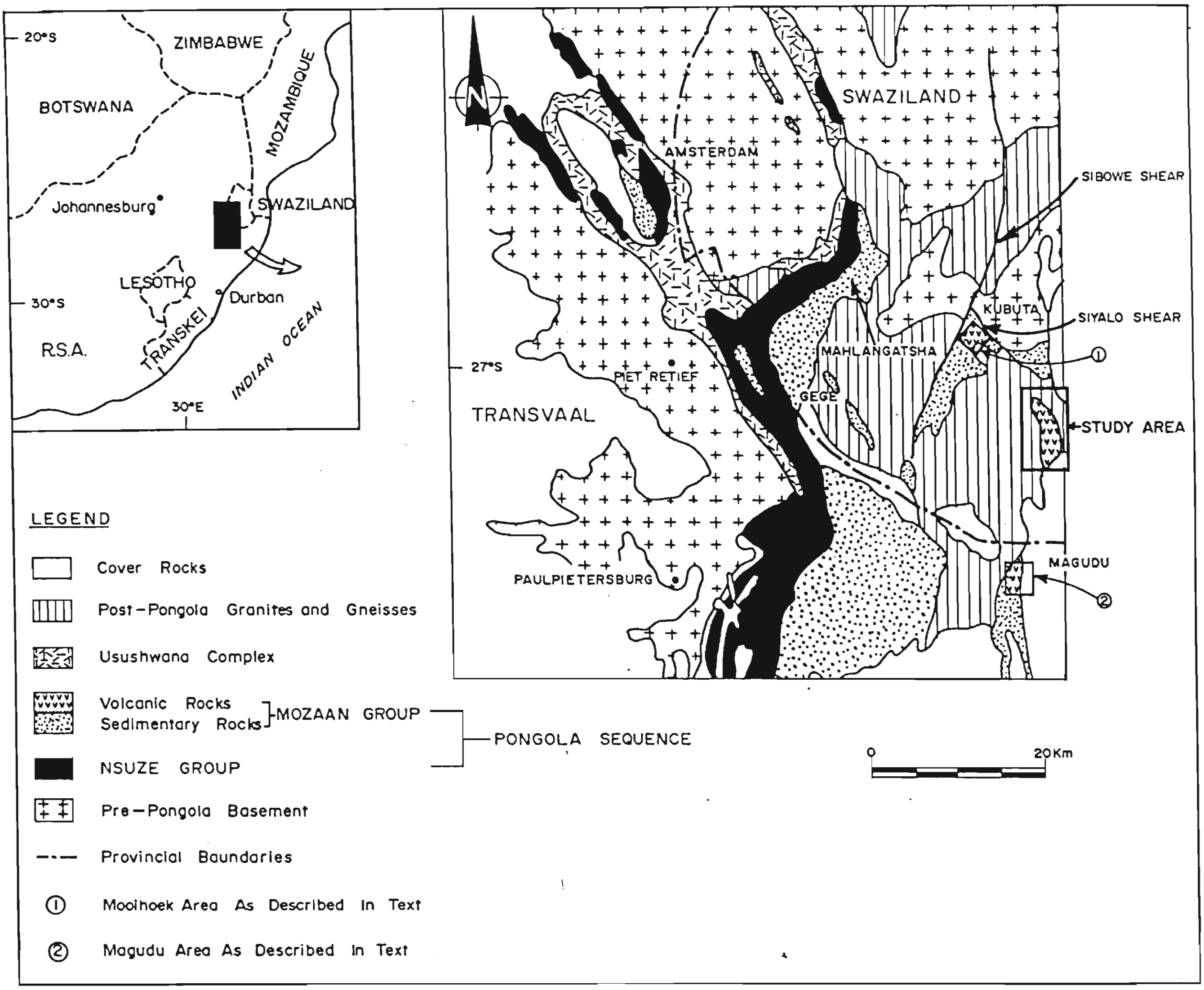

Figure 2.1: Map showing the distribution of the Archaean Pongola Sequence and associated intrusive rocks in southern Swaziland and southeastern Transvaal.

2.2 PRE-PONGOLA BASEMENT

2.2.1. Banded gneisses (Ancient Gneiss Complex)

The Pongola Sequence rests unconformably on banded gneisses in the type area of Amsterdam southeastern Transvaal (Hatfield, 1990), and the same unconformable relationship probably occurs in most areas where the Pongola rocks are developed. The dominantly tonalitic and trondhjemitic basement gneisses interlayered with amphibolites crop out north and northwest of the study area (Figure 1.1). They are medium to coarse grained, grey rocks composed of quartz, plagioclase, and biotite, with minor amounts of hornblende and potassium feldspar. Layers and lenses of amphibolite are composed of hornblende and plagioclase with minor quartz and biotite. The foliation in the tonalites results from the preferred orientation of the mafic minerals which may occur irregularly through the rock or be concentrated into thin layers varying from 1 to 10 cm in width. The strike of the subvertical foliation in these basement gneisses is generally northeasterly but, changes to northwest immediately south of the Swaziland Natal border.

Bimodal gneisses composed of alternating bands of leucotonalite and amphibolite are exposed in many parts of central and western Swaziland. The bands vary from 1 centimetre to several metres in width and are complexly folded and intruded by aplites and quartzo-feldspathic pegmatitic phases. The strike of the subvertical foliation in these gneisses is also northeasterly dips. These gneisses constitute part of the Ancient Gneiss Complex as described by Hunter (1970a).

The bimodal gneisses of the Ancient Gneiss Complex (AGC) in Swaziland have yielded ages ranging from 3.640 Ga to 3.250 Ga based on single zircon Pb-Pb studies (Compston & Kröner, 1988; Kröner *et al*, 1989, 1991). Gneisses (correlated with the AGC) forming the basement to the Pongola Sequence in the study area have not been dated but it is reasonable to assume a similar spectrum of ages for them.

2.2.2 Pre-Pongola Metavolcanic and Metasedimentary Sequences

The Archaean terrane (>2.6 Ga) in southeastern Transvaal and northern Natal contains a number of discrete metavolcanic and metasedimentary remnants which are enclosed in granitoids that either pre- or post-date these remnants (Figure 2.2). On-going studies on this granitoid terrane are likely to provide meaningful age constrains on the start of the Pongola deposition. These remnants include the Commondale supracrustals, the De Kraalen supracrustals, the Anhalt Granitoid Suite and the Mkhondvo Metamorphic Suite (Mkhondvo being the Siswati nomenclature as opposed to Mkhondo). Each of these remnants is composed of distinct rock types and has characteristic features.

(i) Commondale Supracrustal Suite

This remnant situated south of Piet Retief (Figure 2.2) is preserved in two major synformal keels separated by a shear zone trending north-northeast (Smith, 1987). A pile of mafic and ultramafic rocks with minor intercalations of metasedimentary and calc-silicate horizons are preserved in this supracrustal suite. Ultramafic rocks are serpentinized and retrogression to talc-chlorite schists occurs in zones of high strain (Hunter and Wilson, 1988). An alternating sequence of spinifex-textured and cumulate layers is preserved in the core of one of the synforms. These layers represent individual cooling units. Thinly bedded, ferruginous quartzites, talc schists, and amphibolites occur in the fold closure at the eastern end of the layered sequence. Pillows, flow-top breccias, and other textures diagnostic of lava flows are absent.

(ii) De Kraalen Supracrustal Suite

The De Kraalen remnant, located southeast of Piet Retief (Figure 2.2), consists predominantly of banded iron-formation and metaquartzite with minor amounts of calc-silicate rocks and amphibolites. These rocks crop out over an area of about 5 km^2. Immediately southeast of this remnant there is a medium-grained, layered tonalitic gneiss known as the De Kraalen Gneiss (Hunter *et al.*, 1992). These gneisses have impersistent quartzo-feldspathic layers which can be traced over strike lengths of up to 15 m. The gneisses are preserved in close spatial association with the De Kraalen metavolcanic rocks and layered amphibolites although temporal relationships are not clear in the field (Hunter *et al.*, 1992).

(iii) Mkhondvo Metamorphic Suite

In the Mkhondvo (Siswati nomenclature) valley in southern Swaziland are bimodal layered gneisses labelled the Mkhondvo Metamorphic Suite (MMS in Figure 2.2; Hunter *et al.*, 1978). Banded iron-formation, cummingtonite-anthophyllite-bearing gneisses and amphibolites occur in close association with quartzites. These rocks have a minimum age of ~3.4 Ga (Kröner *et al.*, 1991), this age being obtained for a trondhjemite intrusive into this suite.

Some quartzites in the suite have in the past been correlated with the Mozaan Group because of their association with the banded iron-formation, which is a common feature of the Mozaan quartzites (D.R. Hunter, *pers. comm.*, 1992).

2.2.3 Pre-Pongola Tabular Batholiths

This granitoid body underlies much of the country south of Piet Retief towards Paulpietersburg and is most extensive in the southeastern Transvaal (Figure 2.2). It is not found in Swaziland. The three main subdivisions to this suite are:(i) a tabular, multiphase batholith, (ii); a hornblende granodiorite, and (iii); a cataclastic gneiss that may be tabular (Witrivier Gneiss). The tabular batholith comprises three distinct types: (i) a light coloured, coarse grained leucotonalite / trondhjemite occurring west of Piet Retief and enclosing the Commondale remnant; (ii) a granodiorite, granite and trondhjemite facies; and (iii) a unit which has discontinuous, contorted lenses of biotite, grading into a uniform coarse grained leucotonalite. This batholith is recognised as intrusive into the Commondale supracrustals owing to the common presence of supracrustal xenoliths in some of the members of the suite (Hunter *et al.*, 1992). The Anhalt Granitoid Suite is dated at ~3.25 Ga (Matthews *et al.*, 1989; Farrow *et al.*, 1990) and it is emplaced between the overlying supracrustal sequences and the underlying layered gneisses (Talbot *et al.*, 1987).

2.3 THE PONGOLA SEQUENCE

The Pongola Sequence comprises a lower, dominantly volcanic Nsuze Group and an upper dominantly sedimentary Mozaan Group. The former crops out in the Mahlangatsha-Gege area and represents a northern extension of the Nsuze Group occurring in the adjacent areas of the Republic of South Africa (Figure 2.1).

In eastern South Africa, the Pongola Sequence consists of the lower, predominantly volcanic Nsuze Group overlain by the Mozaan Group which is mainly composed of sedimentary rocks. A "paleosaprolite" is developed in the basal sediments of the Nsuze Group which rest unconformably on the underlying Archaean granitoid basement (Mathews and Scharrer, 1968; Armstrong, 1980). These authors refer to the term paleosaprolite as a structureless, hard, medium-to coarse grained, highly micaceous cohesive rock which grades into the underlying granite basement. This clearly represents a period of intense weathering and exposure of the basement rocks prior to the deposition of the Pongola Sequence in this area.

The Nsuze Group comprises a basal sedimentary-volcanic unit overlain by a thick sequence of basalts, basaltic andesites, andesites, dacites and rhyolites, up to a maximum thickness of 8,500 m. There are minor volcaniclastic and sedimentary rocks intercalated with the lavas. The Mozaan-Nsuze boundary is locally transitional but generally marked by an andalusite slate and elsewhere it is unconformity bounded. The Mozaan Group contains fluvial, shallow marine, deltaic and shelf sediments with minor volcanic intercalations (Armstrong, 1980).

2.3.1 The Nsuze Group

Generally, east of Piet-Retief in the south eastern Transvaal, the Nsuze Group comprises a basal arenaceous sedimentary unit overlain by a succession of felsic volcanics with intercalations of tuffaceous beds commonly interbedded with clastic sedimentary layers. Overlying the felsic rocks is a thin persistent pyroclastic-volcanosedimentary unit which is in turn overlain by a sequence of intermediate volcanics, andesite being the main rock type. At the top of the succession the Nsuze Group comprises a thin sequence of amygdaloidal intermediate and mafic lavas, agglomerates, tuffs, argillites and minor arenaceous sediments, all of which are present in varying proportions (Hatfield, 1990).

The Nsuze Group has a lower basal sedimentary-volcanic unit (± 800 m thick) composed of sandstones with intercalated lenses of acid and intermediate lavas, volcaniclastics and volcanogenic sediments underlain mostly by non-intrusive granitoids. This unit is overlain by a middle, predominantly volcanic unit (± 7,500 m thick) consisting mainly of basic, intermediate and acid lavas with minor intercalated volcaniclastic-sedimentary rocks. An upper volcaniclastic-sedimentary unit (± 500 m thick) comprising complexly interfingering volcaniclastic, sedimentary and volcanic assemblages overlies the middle volcanic unit (Armstrong, 1980). Towards the southwestern border of Swaziland, east of Piet Retief, (Figure 2.1), the basal sedimentary unit is highly discontinuous in outcrop because it has been disrupted by the intrusion of the Usushwana Complex. A continuation of the upper volcaniclastic-sedimentary unit into southwestern Swaziland contains a much higher proportion of the sedimentary lithologies (Hatfield, 1990). In Swaziland, there is a greater proportion of argillaceous sedimentary rock varieties, with an absence of coarse - grained pyroclastics. This means that a more lengthy period of quiescence prevailed in this part of the Pongola basin (Hatfield, 1990).

2.3.2 The Mozaan Group

The Mozaan Group consists of a succession of arenaceous and argillaceous sediments, overlying the predominantly volcanic Nsuze Group. In southern Swaziland the Mozaan Group crops out in two distinct areas (Figure 2.1). The western or Mahlangatsha-Gege locality has quartzites and conglomerates with minor intercalations of shale resting on the Nsuze Group, and the eastern or Kubuta area which is essentially argillaceous in character with subordinate quartzites (Hunter, 1963).

The Mozaan Group occurrences in the Mahlangatsha area are a continuation of those from the type area south and south-east of Piet Retief (Figure 2.1). In both the Mahlangatsha and Kubuta areas the Mozaan Group is well exposed with the quartzites building outstanding outcrops with sparse vegetation cover. In the Mahlangatsha area the Mozaan Group builds a spectacular plateau standing at a high elevation of about 1400 m above sea level.

In the southwestern border of Swaziland, the Mozaan Group has a northwesterly strike, and occurs in a faulted synclinal structure (Hunter, 1963). This strike changes at Gege (Figure 2.1) to become northeast and then gradually swinging northwards to almost due north, but the broad syncline is still well preserved. At Mahlangatsha, the basal succession of the Mozaan is a thick sandstone with conglomerate and thin shaly argillaceous beds directly resting on the felsic rocks of the Nsuze Group with a tectonic contact (Hunter and Gold, 1993). The basal quartzite which dips gently towards the southeast and east is in turn overlain by an alternating sequence of quartzites, shales and phyllites with andalusite schists making up a total thickness of about 1100 m. The andalusite schist is not found in the higher horizons in contrast to the type area east of Piet Retief where the succession comprises a thin sandstone overlain by a thick pile of andalusite schists. At the Kubuta locality, the Nsuze Group lavas are absent and a thick basal sandstone with conglomerate beds rests unconformably on granitoid gneisses (Figure 2.1). This sandstone is overlain by a thick sequence of shales in which two prominent iron formations occur, constituting a maximum thickness of about 3000 m. A major northwest striking, dextral shear (Siyalo shear; Figure 2.1 and Figure 2.2) truncates the basal sandstone southeast of Kubuta and the Siyalo shear itself is truncated by the northerly striking Sibowe shear (Figure 2.2). West of Siyalo shear the sandstone unit dips subvertically and is disrupted by this fault. A thick sequence of ferruginous shales overlies this sandstone but iron formation horizons are absent. The eastern strike of the Mozaan is terminated by numerous normal faults of Karoo age. At this Kubuta occurrence, the Mozaan Group is preserved in a syncline (referred to here as the Mooihoek syncline) which plunges to the southeast.

This thesis is concerned with that part of the sequence preserved in the Sigwe Hills and extending southwards, to and beyond the Ngwavuma River (Map 1 and Figure 1.1). The dominantly volcanic lithologies located in the area defined by the Sigwe Hills in the north and the Ngwavuma River in the south were originally assigned to the Nsuze Group by Hunter (1952) who first recorded their existence. At that time, volcanic rocks were known to occur in the Pongola Sequence only in the Nsuze Group. Subsequently basaltic lavas were identified in the uppermost Mozaan Group in the Kubuta area (Mooihoek area) (Hunter, 1963). Basaltic lavas are preserved and represent higher stratigraphy of the Mozaan Group in the Kubuta outcrop. The preservation is facilitated by these lavas occurring in the axis of the syncline.

These lavas, described by Hunter (1952), are dense, fine grained, dark rocks commonly with amygdales of feldspar and quartz. This is one of two known occurrences in the Pongola Sequence where volcanic rocks unequivocally overlie the Mozaan sedimentary succession. The other occurrence where basaltic lava overlies Mozaan sediments is found in the core of the Tobolsk syncline in the vicinity of Magudu (Figure 2.2). Structurally and lithologically

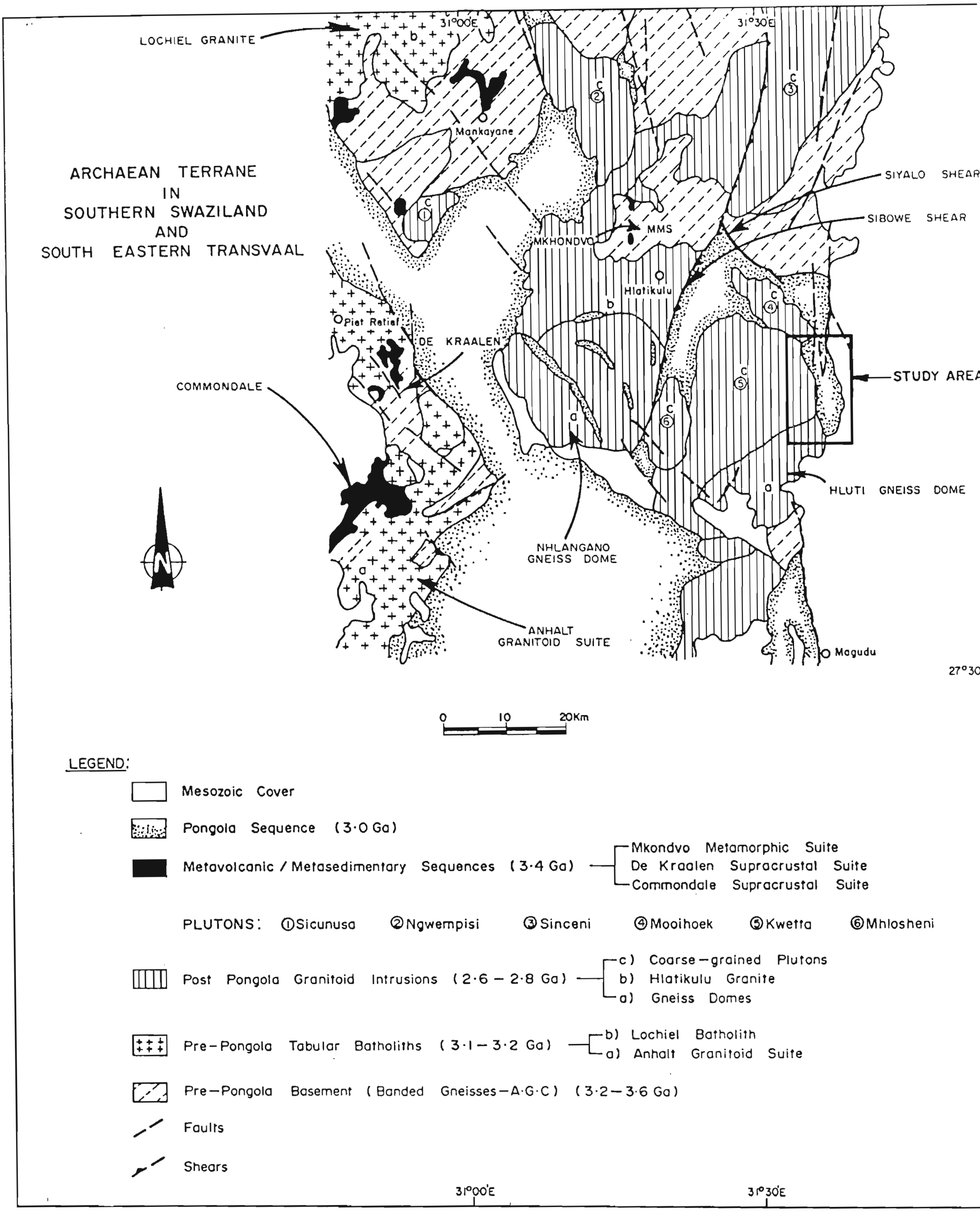

Figure 2.2: Simplified geological map of the Archaean terrain in southern Swaziland and southeastern Transvaal. International and provincial boundaries have been omitted for clarity. (After Hunter *et al.*, 1992).

these two occurrences are similar and present important evidence that volcanism was a terminating phase in the Pongola succession in this area.

The volcanic rocks investigated in this study are situated some 20 km southeast of the Mooihoek syncline. These volcanic rocks do not overlie Mozaan sediments, with the southern occurrence in contact with Mozaan quartzite, and in the north the substrate is not present because of intrusion of later granite. One of the prime questions to be addressed in this thesis is the possibility that the volcanic rocks maybe correlated with the Mozaan Group as identified in the areas close to Kubuta and Magudu.

Correlating the two basalts shows that the basal sandstones and shales of the Mozaan Group, south of Kubuta, represent a higher stratigraphic section than those situated far west in the main Pongola basin. The combined effects of faulting and intrusion of the Mooihoek pluton preclude the possibility of determining the exact stratigraphic position of the sandstone-shale-iron-formation succession east of the Siyalo shear (Figure 2.1).

Hunter and Gold (1993) concluded that deformation coupled with internal disconformities and northward overlap of the Mozaan Group militates against simplistic correlations until more detailed structural and sedimentological studies have been undertaken, particularly in the Mahlangatsha area. The eastern limit of the Mozaan Group is overlain unconformably by gently eastward dipping strata of the Mesozoic Karoo Sequence, which is also in faulted contact with the Mozaan Group.

A detailed geochemical study of the Nsuze Group volcanic rocks between the Bivane and White rivers immediately south of the Swaziland border, provided information on the nature of Nsuze volcanism (Armstrong 1980) and will be discussed on a comparative basis with the geochemical data set presented in this study.

2.3.3 THE PONGOLA BASIN AND PROBLEMS RELATING TO ITS INTERPRETATION

The Pongola Sequence is an assemblage of volcanic and sedimentary formations that were deposited about 3.0 Ga ago in the south-eastern region of the Kaapvaal Craton in southern Africa (Figure 2.3). Throughout this region the Pongola strata rest unconformably on a granitic-greenstone basement. The Pongola Sequence is exposed in several extensive but isolated areas within a belt about 100 km wide extending southwards from southern Swaziland to northern Natal, a distance of about 270 km (Figure 2.4).

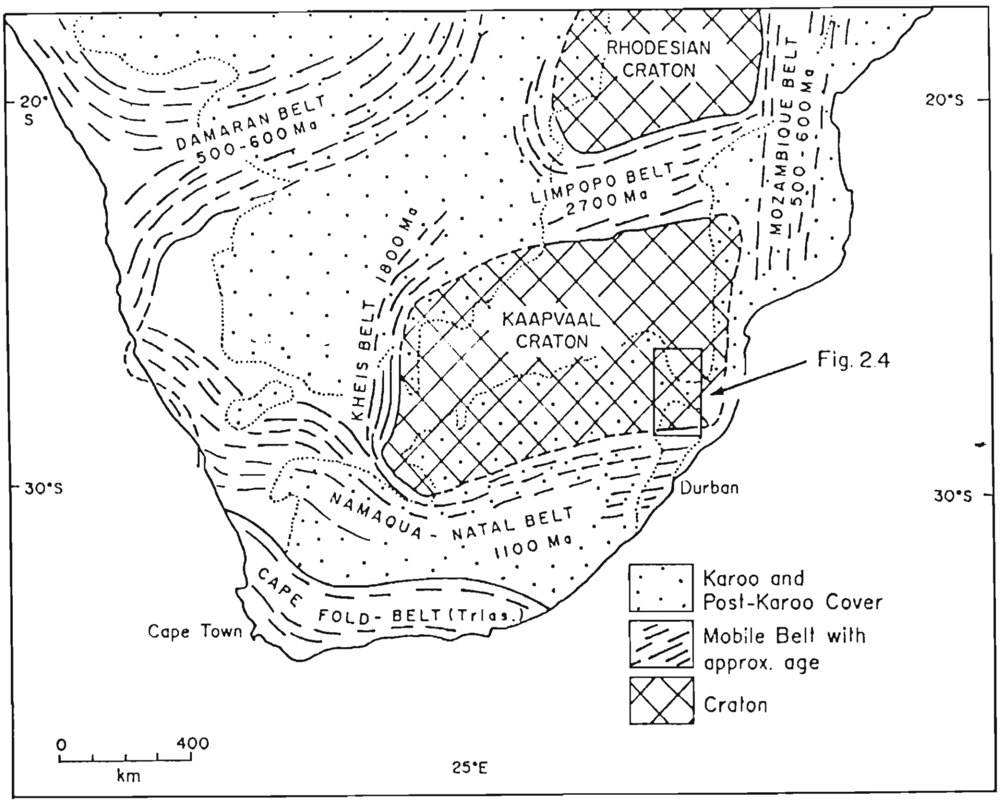

Figure 2.3: Distribution of Archaean Cratons and peripheral mobile belts in southern Africa (based on the work of Matthews, 1990).

This Late Archaean Sequence is of special geological interest because it possibly represents the oldest intracratonic sequence in the world (Matthews, 1990).

The Pongola Sequence outcrops in a semi-continuous linear belt in South Africa and Swaziland. A geologic map of the Pongola structure is presented by Figure 2.5 together with stratigraphic thicknesses for the Nsuze and Mozaan sections. The belt is marked by variations in stratigraphic thicknesses of the Pongola Sequence accompanied by a large proportion of volcanic rocks. These features have been interpreted by Burke *et al.*, (1985) to indicate deposition of the Pongola Sequence in a continental rift setting. Figure 2.6 shows the peculiar shape of the Pongola rift (after Burke *et al.*, 1985). According to Matthews (1990), regional structural features of the Pongola Sequence define three extensive but contrasting structural domains. According to Burke *et al.*, (1985), the Pongola Sequence shares many features that are typical and diagnostic of rocks deposited in continental rifts. If this interpretation is correct, its age of between 3.0 to 3.1 Ga makes it the world's oldest, well-preserved continental rift.

Hunter (1991) argues that by the age of 3.1 Ga, because of the emplacement of tabular multiphase batholiths, a stable high standing sialic crust capable of sustaining a series of basins had formed. In these extensive basins, thick sedimentary sequences with intercalations of low MgO volcanics accumulated. One of these basins is of course the Pongola basin.

A northern domain, centred on the Pongola-Mozaan basin is situated in the Piet Retief and Vryheid districts (Figure 2.4). The western margin of this basin has not been disturbed but the eastern and northeastern margins have been deformed extensively and disrupted by the intrusion of a number of granitoid plutons. The central domain is exposed within a group of erosional inliers (Figure 2.4). It is characterised by repetitive northwest-trending outcrops of basement overlain unconformably by northeast dipping Pongola strata. This structural pattern indicates extensive block faulting. The southern domain, in contrast to the general north to northwest structural trends in the other domains, is characterised by eastwest trending folds and faults. They are associated with zones of thrust faulting related to the Natal Thrust Front at the boundary between the Kaapvaal craton and the ~1.0 Ga old Natal tectono-thermal Province.

2.4 THE USUSHWANA INTRUSIVE COMPLEX

Although not present in the study area this complex is important as it provides information on a suite of magmas which may be of a similar origin to those of the Pongola Sequence. Intrusive into the Pongola Sequence, the Usushwana Complex (~2.87 Ga; Hegner *et al.*, 1984) of southeastern Transvaal and western Swaziland (Figure 2.1) consists of gabbros, quartz gabbros, quartz diorites, granodiorites and micrograntes. The Usushwana Complex in Swaziland occurs as a northwest striking dyke complex that parallels major faults in the granitic basement. This dyke complex is linked to a second northwest striking large dyke complex in southeastern Transvaal by a sheetlike mass that extends along the base of the Pongola Sequence (Hunter 1970b). This second dyke complex is also paralleled by major faults in the basement. Both the dyke complexes and the sheet contain xenoliths of Pongola rocks.

At Embo in western central Swaziland, known outcrops of the Usushwana Complex exhibit a spectacular localized preservation of crude inward layering which suggests that the mafic magmas differentiated in situ. A postulated evolution of the Usushwana Complex is that magmas seem to have preferentially intruded along faults that were formed during an initial rifting episode (Hunter, 1970b).

2.5 POST - PONGOLA GRANITOIDS

There are three main groups which can be considered in this group of granitoids which are largely intrusive into the Pongola Sequence in southern Swaziland. These are (i) gneiss domes; (ii) the tabular Hlatikulu batholith; and (iii) discordant plutons. Each of these has distinguishing features, as outlined below.

(i) Gneiss domes

In southern Swaziland (south of Hlatikulu), multiple, elongate gneiss domes of the Nhlangano gneiss are aligned in a northwest direction (Figure 2.2). There are septa of the Pongola Sequence between the domes. In the Nhlangano gneiss dome these septa are Mozaan Group quartzite and banded iron- formation metamorphosed to amphibolite facies grade, implying that the Nhlangano gneiss post dates the Pongola Sequence. The northeast trending Hluti gneiss dome occurs southeast of Hlatikulu (Figure 2.2). Contacts of this gneiss with the Pongola Sequence are not exposed due to the poor nature of outcrop but in the southwestern corner of the study area (Map 1) the gneiss is in faulted contact with quartzite, presumably of the Mozaan Group. The contact is a thrust fault marked by a quartz-sericite-muscovite schist. The extent of displacement on this fault cannot be determined. The Hluti gneisses which are foliated and medium-grained have quartz, microcline, plagioclase and biotite as dominant minerals. Compositionally the gneisses range from granitic to granodioritic because of their varying amounts of K-feldspar and plagioclase. These domal gneisses have a maximum age of 2.8 Ga (Hunter *et al.*, 1992). Xenoliths of metavolcanic material are found in the main body of the Hluti granite gneiss which suggests that the gneisses are younger than the volcanic lavas of the Pongola Sequence. A problem is brought about by the extent to which the Hluti gneiss has been deformed ("gneissified") whilst the Pongola lava rocks are weakly foliated with a lower metamorphic grade. This could suggest that the "gneissification" in the Hluti gneiss is a result of a preferred orientation of the minerals rather than a metamorphic effect.

(ii) The tabular Hlatikulu batholith

This is a grey, medium- to coarse-grained granite that post-dates the Nhlangano gneiss domes. Porphyritic phases are developed locally. The sheet-like character of this batholith is seen on the western side of the Mkhondvo valley (Figure 2.2) where the floor to this sheet is constituted by ortho- and paragneisses of the Mkhondvo Metamorphic Suite (Hunter *et al.*, 1978). Mozaan Group quartzites define the high ground overlooking the valley. This Hlatikulu batholith is located at the interface between the underlying gneisses and the overlying sedimentary rocks. It has a maximum thickness of about 500 m.
This tabular granite is intrusive into the Mozaan Group, a relationship that is clearly demonstrated southwest of Hlatikulu. The Pongola strata in the Kubuta area are in faulted contact with this granite along the Sibowe shear zone (Hunter, 1961; Figure 2.1, 2.2). Xenoliths of Mozaan quartzite are found scattered throughout the granite mainly in the area between Hlatikulu and Nhlangano, west of this major zone.

Quartz, microcline and plagioclase are the major minerals in the granite, and biotite is a minor phase. Accessory minerals include zircon, apatite and allanite. Pegmatites occur as intersecting veinlets ($\sim$50 cm) wide in the granite.

(iii) Coarse - grained plutons

Several discordant granite plutons intrude the Pongola Sequence both in southern Swaziland and adjacent areas of South Africa (labelled 1-8 in Figure 2.2). They are lithologically variable. Only those occurring in southern Swaziland will be described below.

The Kwetta granodioritic pluton, which is the most extensive, is located southeast of Hlatikulu and intrudes the upper Mozaan Group basalts in the area of Sigwe Hills. It is distinguished by the existence of randomly distributed microcline megacrysts in a coarse grained matrix of quartz, feldspar, biotite and hornblende (Hunter *et al.*, 1992). Plagioclase rims locally surround the megacrysts of microcline. In the north, the pluton makes up the high ground and in this area it is medium-grained. The Kwetta pluton has sharply defined contacts with the Mozaan sediments east of Hlatikulu. The pelitic rocks are metamorphosed in a narrow contact aureole in which biotite and garnet are evident (Hunter *et al.*, 1992). The Mhlosheni and Mooihoek are two small plutons (Figure 2.1) characterized in the field by prominent boulders on high standing hills. They are granitic in composition, coarse-grained, and pale in colour since mafic minerals are subordinate. Quartz and feldspar are the main constituents and biotite is minor (Hunter *et al.*, 1992). Pegmatites are rare or absent. The Mooihoek pluton effectively separates the stratigraphically highest basalts of the Pongola Sequence dipping steeply eastward in the Sigwe Hills from the gently southward dipping lower Mozaan sedimentary rocks south of Sithobela (north of study area).

2.6 KAROO SUPERGROUP

2.6.1 ECCA GROUP

Ecca Group sediments are confined to the eastern flat-lying part of the study area. They consist of grey-black carbonaceous shales and sandstones with horizontal laminations. The sedimentary rocks of the Ecca Group either rest unconformably on the Pongola Sequence or are in faulted contact with this sequence.

2.6.2 KAROO DOLERITES

These dolerites occur either as dykes, which may vary in width from 1 m to greater than 50 m, or as extensive sills. They form a prominent feature of the landscape around Hlatikulu to the west and in the Hluti area immediately south of the study area. The Karoo sediments have been extensively invaded by the sheets and dykes. Dolerite sheets are common in the study area where they intrude the Pongola Sequence.

The dolerites weather into spheroidal boulders scattered over the land surface and produce a reddish-brown coloured soil. Texturally these dolerites vary from medium to coarse grained, with porphyritic varieties. They are composed of plagioclase, clinopyroxene and hornblende. Olivine may be present but is rare. Some varieties contain quartz. Magnetite is a very common accessory with ilmenite and more rarely chloritized biotite (Hunter, 1961).

2.7 CONCLUSIONS ON THE REGIONAL GEOLOGICAL SETTING

The Pongola Sequence (2.94 Ga) comprising the Nsuze and Mozaan Groups, rests unconformably on older granitic rocks in southern Swaziland, southeastern Transvaal and northern Natal. Intrusive into this late Archaean Pongola Sequence is the Usushwana Complex (gabbroic, dioritic and granophyric rocks) and various potassic granitoids.

The Karoo Supergroup (Ecca Group) rests unconformably on the Pongola Sequence rocks in southeastern Swaziland and dolerites of Karoo age are intrusive into these lithologies.

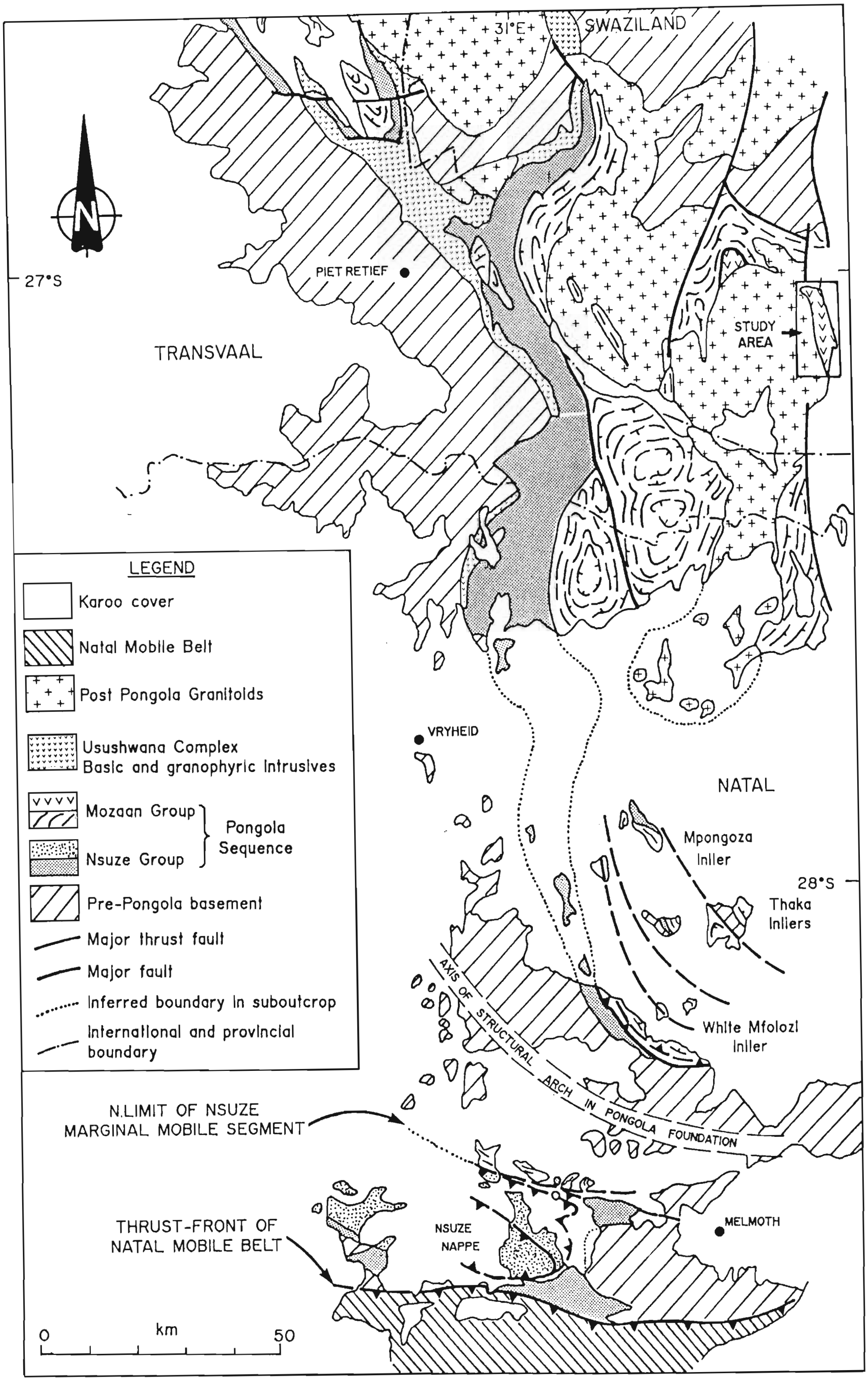

Figure 2.4: Regional distribution and geologic setting of the Late Archaean Pongola Sequence, based partly on the work of Matthews (1990).

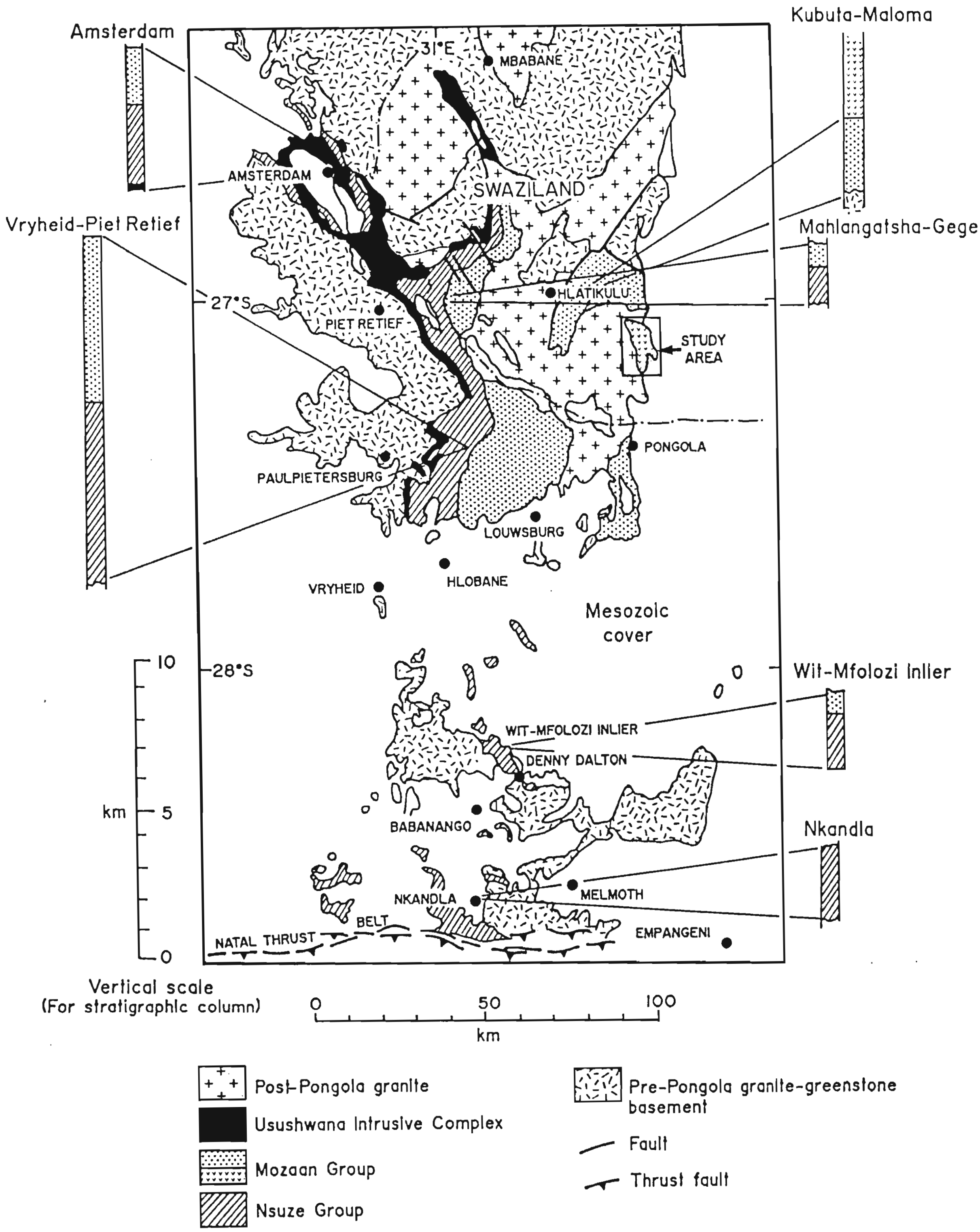

Figure 2.5: Geologic map of the Pongola structure with stratigraphic sections from various localities. The Pongola rift is bounded by thrusts in the south and splits in two around basement horsts in the north. Map based on the work of Button (1981) and Burke *et al.*, (1985).

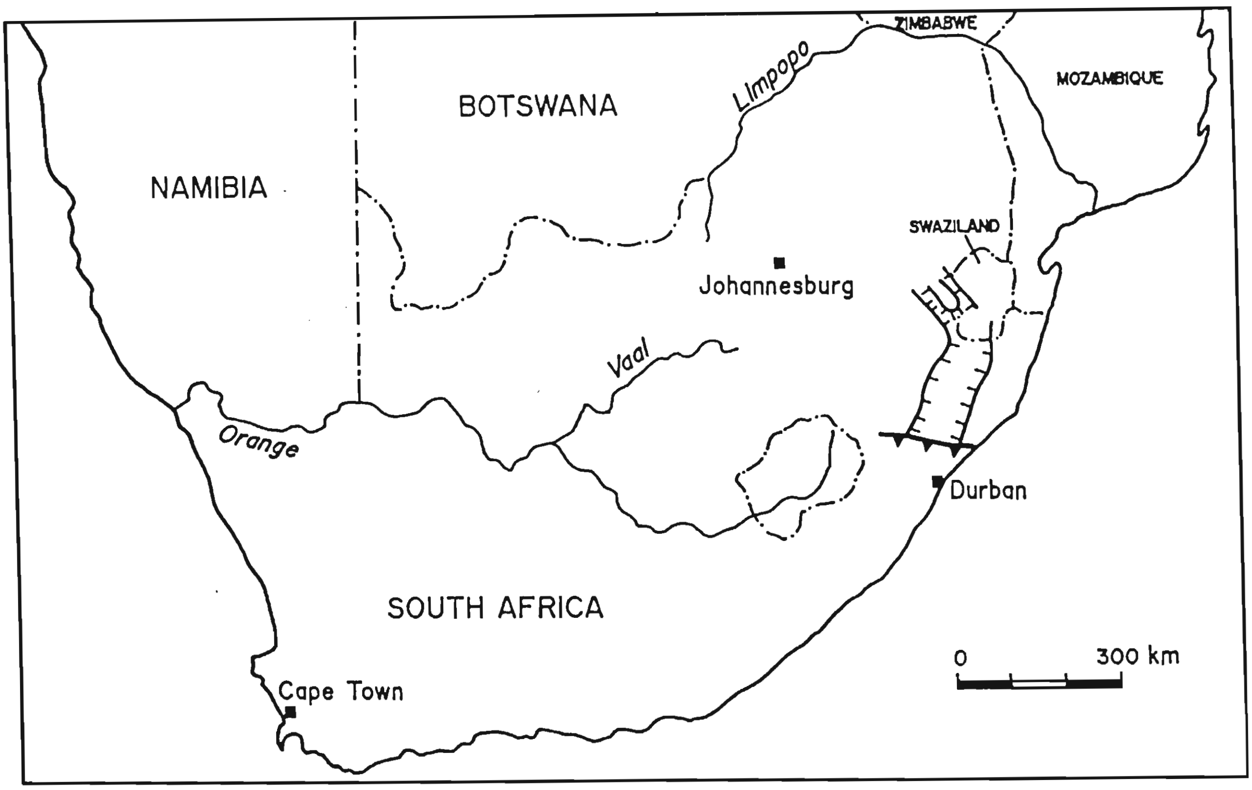

Figure 2.6: Regional map showing the shape of the Pongola Rift, suggested by Burke *et al.*, (1985).

CHAPTER 3

FIELD RELATIONS AND LITHOLOGIES

The study area is dominated by the upper Pongola Sequence into which various granitoids have intruded. Rocks of Karoo age overlie this Archaean basement in the east. Various dolerite intrusions are also found.

3.1 THE PONGOLA SEQUENCE

(i) Field relations and rock types

Basaltic metavolcanic rocks with lenses of meta-quartzite and more rarely phyllite represent the Pongola Sequence in the study area. The lavas are either dark greyish, fine- to medium-grained or light grey greenish rocks with a similar variation in grain size. Amygdales ranging in size from less than 1 mm to 3 cm that are flattened and elongated with their longer axis oriented northsouth are common (Figure 3.1). Although common, the amygdales are not considerably developed throughout this volcanic pile (see Map 1). These rocks strike typically northsouth from south of the Ngwavuma river to the Sigwe Hills in the north. There is an obvious weak foliation in the lavas south of the Ngwavuma River which dips moderately (53^0) eastward. Estimating the thickness of these Pongola volcanic rocks is hampered by the duplication of strata by thrusting as evident from the Sigwe Hills road cutting (discussed in Chapter 5). A thickness 800 m must be regarded as a maximum for these volcanic rocks. Generally these volcanic rocks are basaltic in nature with very minor local variations and geological contacts between the variations are not sharply defined. No flow contacts and flow top breccias were identified in these volcanic rocks. Where there are high concentrations of amygdales and vesicles, these units are considered to be flow tops and are planar features.

There are numerous quartz veins within the pile of metavolcanic rocks. South of the Ngwavuma valley these veins are mostly oriented in a northwest-southeast direction with a lesser number striking eastwest (Map 1). They consist of coarse-grained, dark grey, lustrous quartz with white patches of a highly siliceous and recrystallized rock. Quartz veins are typically between 2 to 10 m in width. In the Sigwe Hills, vein-like recrystallized areas are mainly oriented in the general northsouth and northwest-southeast directions, and commonly mark the sites of faults (Map 1). Three samples that were collected from the Sigwe Hills, RM 02, RM 03, and RM 04, are anomalously rich in silica, which is also seen in their chemistry (discussed in Chapter 6). Reasons for this enrichment could not be established in the field because of the limited and poor nature of outcrop. Sample sites are shown in Map 1.

Intercalated within the volcanic rocks are metaquartzites which are lensoid or lenticular in plan and are typically parallel to the general northsouth strike. They may be up to 500 m thick over strike lengths of up to 3 km. Bedding, where observed, dips steeply (60^0) eastward. There are four major quartzite lenses with minor intercalations of phyllite. One of these quartzites has been rotated from a northsouth to an eastwest strike possibly as a result of the intrusion of the Kwetta granite and/or the dolerite intrusions. In the eastwest striking quartzites, the bedding dips shallowly to the south (see Map 1). These quartzite septa outcrop in the granite as koppies.

The largest of these quartzite lenses is about 3 km long and about 0.5 km wide with a minimum thickness of about 300 m. It is in faulted contact with the granite gneiss (Hluti gneiss dome) south of the Ngwavuma River (Map 1). The contact is marked by a quartz-sericite-muscovite schist reflecting a fault contact even though the extent of displacement cannot be determined due to the lack of marker horizons. This fault however is considered to be a thrust with the downthrow to the east due to the absence of strata which may be considered lower in the Pongola Sequence.

The quartzites are hard, white to grey, highly recrystallized rocks, commonly well jointed with planar cross bedding (Figure 3.2). In some cases the rocks are friable where sericite is abundant. The flakes of sericite are wrapped around quartz grains. Trough cross bedding is common. Paleocurrent directions could not be determined as the blocks of quartzite are typically not in situ, but in two localities where the rocks are in place, the transport direction was to the south. Figure 3.3 displays some of the well exposed cross beds.
Highly recrystallized quartzite crops out north of the Sigwe Hills. Two north trending parallel faults which are also silicified pass through this outcrop. It could not be established whether the outcrop is part of the Mozaan quartzite or was vein quartz related to faulting. West of this outcrop is another sliver of quartzite in contact with the Mooihoek granite. This body is considered to be part of the Mozaan Group.

Sandy phyllites and sandstones are found interbedded in the quartzites. In one of the quartzite lenses (south of Map 1), the phyllite is a ferruginous, schistose, olive green rock that weathers to a reddish brown and is weakly magnetic. This outcrop is only about 5-10 m wide and about 100 m long.

Phyllites and/phyllitic shales occur within the metabasalts in the northern extreme of the Sigwe Hills and here they appear to be associated with small zones of faulting which are oriented north-northwest and north-northeast (Map 1). These small phyllitic horizons within the metabasalts may represent sites of localized movement during shearing along the small quartz-filled faults with which they are associated.

In a small stream south of the Ngwavuma River valley, andalusite schist is exposed (see Map 1).

(ii) Petrography

In thin section, the lavas comprise tremolite-actinolite, quartz, feldspar, epidote, chlorite, chloritoid, zoisite and opaque minerals (commonly ilmenite altering to leucoxene); (Figure 3.4).

The lavas cropping out the Sigwe Hills are considerably altered. Thin section study shows that the feldspar is extremely saussuritized. Quartz occurs as small grains in the groundmass but more usually as large grains in amygdales and also along ubiquitous veinlets (Figure 3.5). Epidote, chlorite and zoisite occur in close association in the amygdales, groundmass and in veinlets. Carbonate is observed in one thin section (RM 02) associated with chlorite, epidote and zoisite in an amygdale. In another thin section (RM 13), euhedral sphene grains were found to be prominent. (Figure 3.6).

In thin section the andalusite schist shows knots of andalusite about which micaceous foliation is wrapped (Figure 3.7).

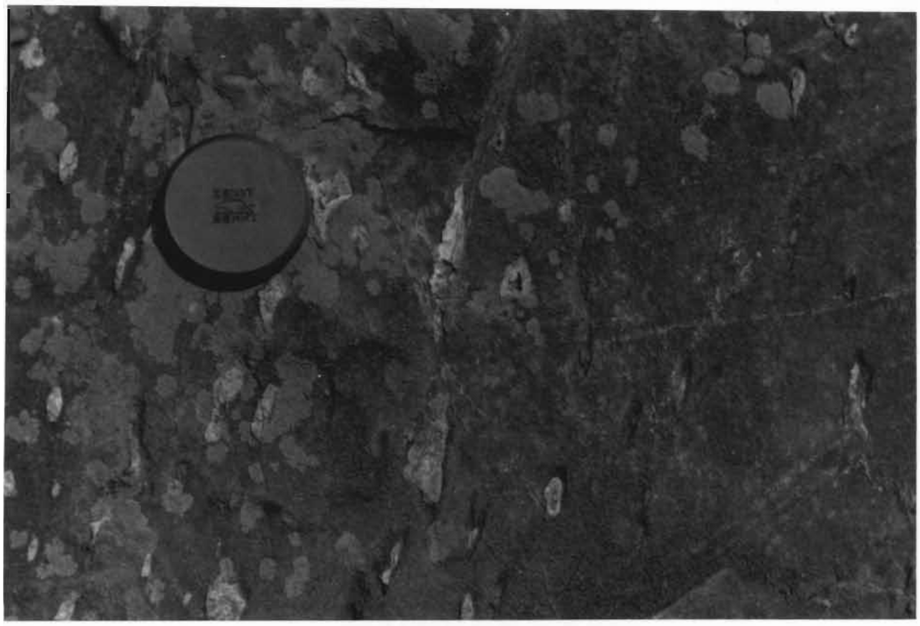

Figure 3.1: Flattened quartz amygdales in basalt from south of the Ngwavuma River. (Lens cap is 5 cm).

Figure 3.2: Jointing and planar cross bedding in quartzite from Sigwe Hills in the study area.(The hammer handle is 30 cm long).

Figure 3.3: Trough cross bedding in the quartzites in the study area (Sigwe Hills; Pencil is 14.5 cm long).

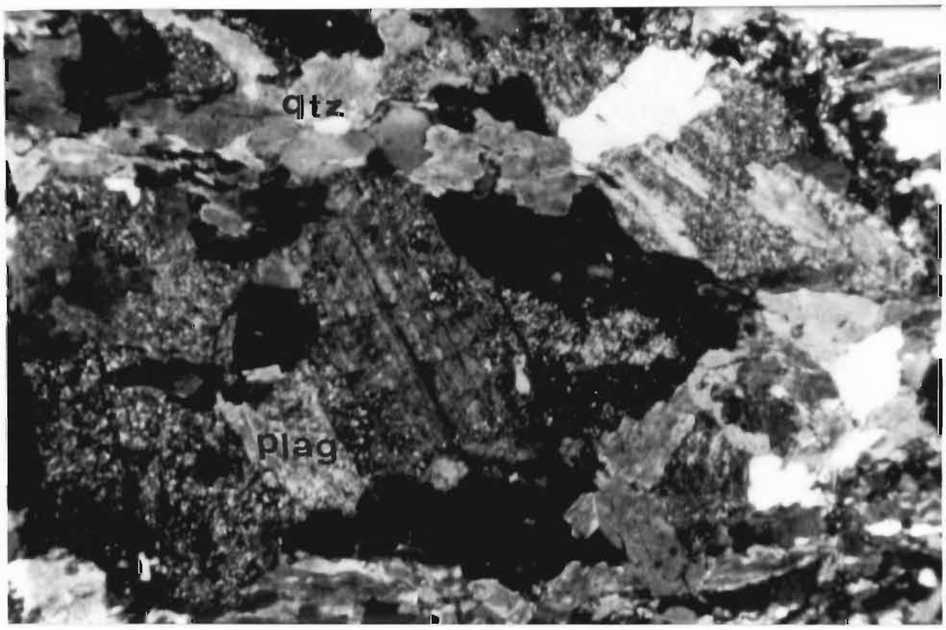

Figure 3.4: Photomicrograph showing altered basaltic lava south of Ngwavuma River area, (magnification is x 10, crossed nicols).

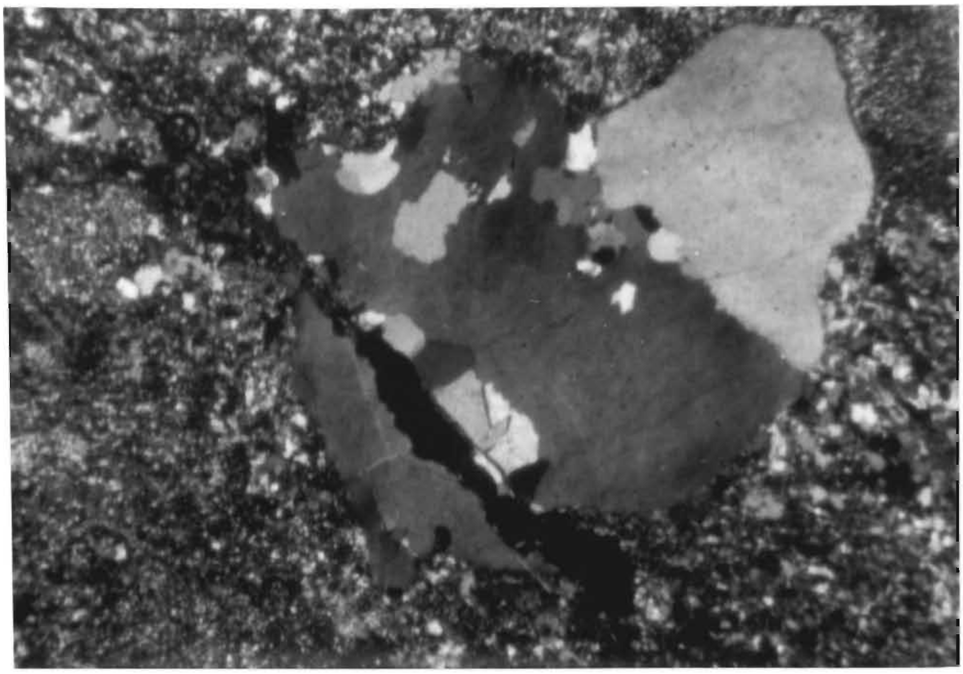

Figure 3.5: Photomicrograph of basalt from south of the Ngwavuma River showing quartz grains in groundmass, amygdale and in veinlets, (magnification is x 25, crossed nicols).

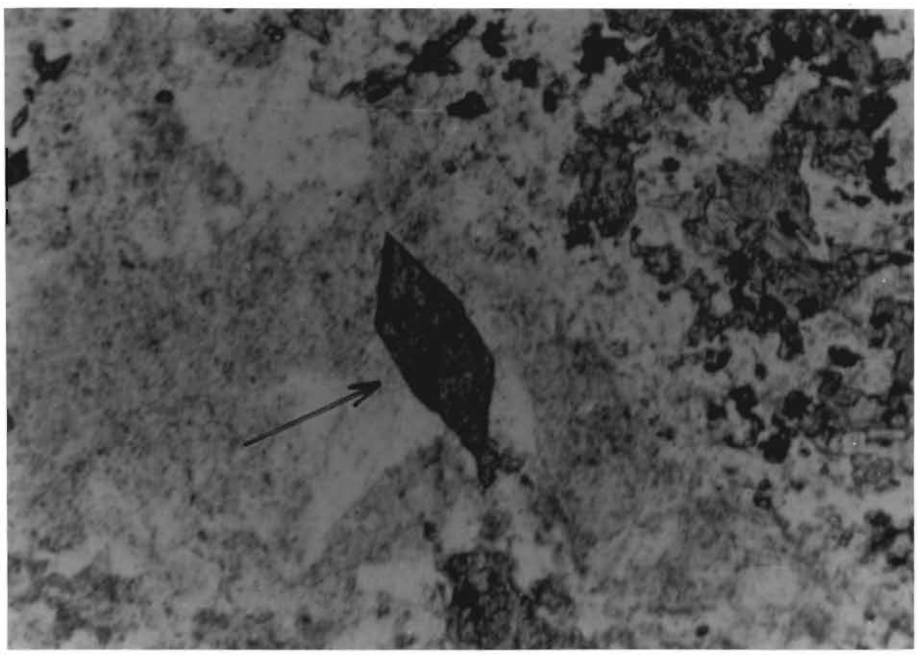

Figure 3.6: Sphene grain in basalt from south of the Ngwavuma River, magnification is x 63, crossed nicols).

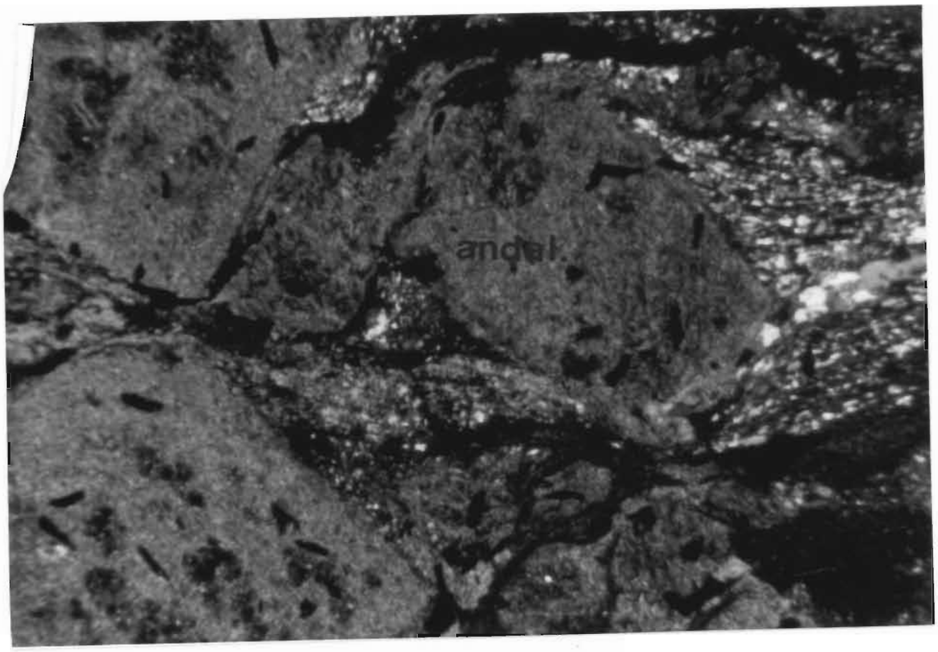

Figure 3.7: Photomicrograph of andalusite schist (south of Ngwavuma River) showing andalusite grains forming knots about which the foliation is wrapped, (magnification is x 10, crossed nicols).

3.2 POST-PONGOLA INTRUSIONS

The Pongola Sequence rocks in the study area have been intruded by a number of intrusive rock bodies that have already been described. In this section their field relations here are discussed further.

(i) Hluti Gneiss Dome

Part of this granite gneiss dome occurs in the southwest corner of the study area in faulted contact with quartzites of the Pongola Sequence (Map 1). Along the contact there is a soft schistose rock comprising quartz, muscovite and sericite. It appears that the contact is a fault with a downthrow of the Pongola rocks.

(ii) Kwetta Granite

This granite constitutes the western boundary of the study and intrudes the metavolcanic rocks in the Sigwe Hills and Ngwavuma River valley. This granite is intrusive into the Pongola lithologies because xenoliths of metaquartzites are found in this granite (Map 1). The contact of the Kwetta granite and the Pongola metabasalts is poorly exposed, but further to the west xenoliths of metavolcanic rocks are found. Scattered boulders of the Kwetta granite are found due north at two sites along the main road towards Maloma, (Map 1). This granite is also in contact with the Hluti gneiss dome just south of the Ngwavuma River towards the southwestern boundary of the study area (Map 1). The nature of this contact could not be established because of extensive cultivation in the Ngwavuma River valley.

(iii) Mooihoek Pluton

This pluton separates the stratigraphically highest basalts of the Pongola Sequence at Sigwe Hills from the known lower Mozaan sedimentary rocks. The contact between the Mooihoek granite and the Pongola strata is not exposed but it is clear that the contact is faulted between the small north-northwest trending faults. The faults are more numerous closer to the northern limit of the study area (Map 1). At Sigwe Hills the granite does crop out in two localities within the pile of volcanic rocks. In one locality, the granite body is not exposed but boulders are spread over the land surface, and in the other locality, outcrop of the intrusion is controlled by two faults (one trending north-northwest and the other northeast). In this part of the pluton, xenoliths of metabasalt are found.

3.3 KAROO SEQUENCE

3.3.1 ECCA GROUP

The Pongola Sequence is unconformably overlain by shales and sandstones of the Ecca Group to the east (Map 1). Towards the extreme north of the study area, the contact between the Pongola Sequence and the Ecca Group beds is faulted. The shales are black or grey in colour, thinly laminated and breaks unevenly into irregular fragments. Khaki (ochre) and brownish shale varieties are also present. A cross-bedded gritty sandstone with iron staining (limonite) is found with shales in an outcrop just across the Ngwavuma River along the Pongola-Maloma main road towards Maloma in the north.

3.3.2 Karoo Dolerite

The study area has been intruded by large volumes of Karoo dolerite. Sheets of this rock body form a prominent feature of the landscape particularly in the vicinity of Hluti to the southwest. South of the Ngwavuma River patches of Ecca shales are often preserved overlying or underlying the dolerite sheets.

The Karoo sedimentary rocks have been extensively invaded by dolerite sheets and dykes, while the basalts to the north of the Ngwavuma valley have been intruded by dyke swarms usually parallel to the strike of the volcanic rocks. The dolerites weather into spheroidal boulders which lie scattered over the surface.

3.4 CONCLUSION OF THE FIELD RELATIONS AND LITHOLOGIES

In the study area the late Archaean Pongola Sequence is intruded into by the Hluti granite gneiss, the Kwetta granite and the Mooihoek granite. Ecca Group shales and sandstones of the Karoo Sequence overlie unconformably the rocks of the Pongola Sequence and intrusive into all these lithologies are the Karoo dolerite sills and dykes.

CHAPTER 4

METAMORPHISM

The Pongola Sequence has been subjected to low-grade regional metamorphism with localized areas showing effects of dynamic and contact metamorphism. The mineralogy of the volcanic and sedimentary rocks is typical of low-temperature, low-pressure metamorphic conditions in which hydrated mineral assemblages are characteristic. The metamorphic mineral assemblage amphibole (tremolite-actinolite)-feldspar-chlorite-zoisite-epidote-quartz with minor amounts of calcite, sphene, leucoxene and hematite is dominant in the basalts (Figure 4.1). These minerals are indicative of greenschist to low grade amphibolite facies metamorphism.

Primary igneous minerals are rare in the basalts although relicts may be preserved in some cases. Tremolite-actinolite is the dominant amphibole, but in many cases it appears to be transitional in optical properties to hornblende. The tremolite-actinolite is light brown to pale green with localised fracturing in some grains in thin section. The greener variety (actinolite) is strongly pleochroic from pale green to a darker green. This amphibole forms columnar to fibrous aggregates (Figure 4.2). Chlorite occurs as fibrous or flake-like crystals with weak pleochroism from colourless to pale green. Under crossed nicols the chlorite shows the anomalous dark blue colour characteristic of penninite. The chlorite is probably an alteration product from the amphiboles because some of the amphiboles are zoned showing the anomalous buff blue colour of penninite in the core and the yellow-orange colours of the amphiboles in the outer rims.

Dense aggregates of chlorite are also found filling amygdales together with quartz, epidote, zoisite and calcite. Plagioclase is saussuritized and appears cloudy preventing the determination of its optical properties. However, in some remnant plagioclase crystals albite twinning can be observed and extinction angles indicate a composition of about An_{30} (oligoclase). This composition is too sodic for normal basalts and is indicative of later re-crystallization under metamorphic conditions. The plagioclase grains usually retain their lath shaped form but are clouded by a dusting of small epidote grains. The epidote is in many cases zoned with a highly birefringent nucleus and outer rims of zoisite (low birefringence).

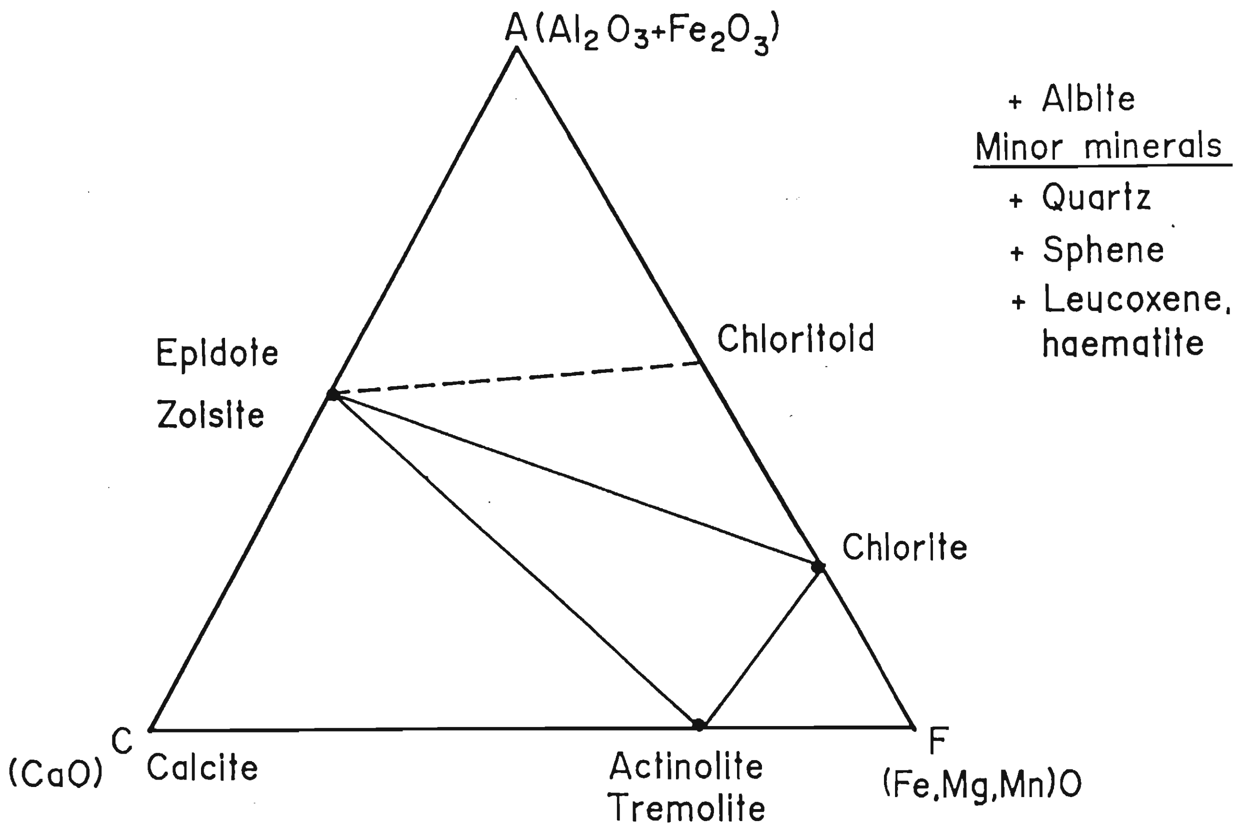

Figure 4.1: Some mafic rock characteristics of the albite-actinolite-chlorite zone of the lower temperature part of low-grade metamorphism (Winkler, 1974).

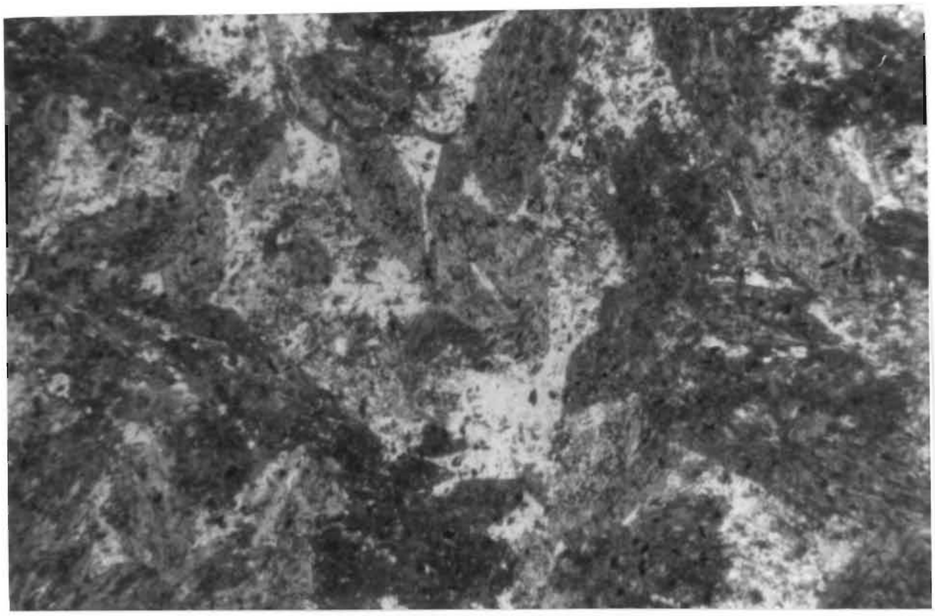

Figure 4.2: Columnar aggregates of actinolite (dark, elongate patches) with altered feldspars (lighter patches) in basalt from south of the Ngwavuma River, (magnification is x 25, crossed nicols).

Quartz forms small granular crystals in the groundmass and also builds veinlets. When present in amygdales, the quartz may be granoblastic. Carbonate, sphene, leucoxene and hematite are accessory minerals. Leucoxene locally forms alteration mantles on relict ilmenite crystals.

The arenaceous rocks consist of detrital quartz with rare muscovite flakes and opaque oxides. The quartz is detrital because it shows rounded edges due to transportation prior to deposition. These metamorphic mineral assemblages are not in themselves diagnostic but would be consistent with the low P/T part of low grade regional metamorphism (Winkler 1974).

A ferruginous schistose rock interlayered within the quartzites south of the Ngwavuma River has the assemblage: amphibole- (grunerite or cummingtonite)-epidote-quartz and minor amounts of magnetite. This assemblage of metamorphic minerals is indicative of upper greenschist-lower amphibolite facies metamorphism. There are two generations of amphibole development: a colourless, non-pleochroic amphibole (grunerite) which breaks down to a pale green/brown pleochroic amphibole with high order birefringence colours. This second generation of amphibole is elongate and aligned with a distinct fabric, whereas the earlier grunerite displays no preferred orientation. A decussate texture is observed whereby the needlelike, elongate crystals of amphibole (possibly cummingtonite), are wrapped around earlier formed quartz grains. The epidote which transgresses the foliation represents retrogression. Magnetite appears as small euhedral crystals.

Aluminous schists interbedded with quartzite consist of the mineral assemblage andalusite - chloritoid - zoisite with minor quartz. This paragenesis is also consistent with low grade amphibolite or greenschist facies metamorphism.

In conclusion, the Pongola rocks in the study area have been subjected to low-grade regional metamorphism. The observed mineral assemblages from the volcanic and sedimentary rocks are typical of low-temperature, low-pressure metamorphic conditions in which hydrous minerals are a feature. The rocks are therefore metamorphosed to low grade amphibolite facies.

CHAPTER 5

STRUCTURE

5.1 REGIONAL OVERVIEW

Throughout the northern Pongola basin there are two dominant structural trends, namely the northwest-southeast and the north-south (Figure 5.1). In the main outcrop area of the Pongola basin (west of Magudu in northern KwaZulu-Natal), the Piensrand and the Toboslk synclines are situated. The Tobolsk syncline trends northwest-southeast whilst the Piensrand syncline trends north-south (Figure 5.1). They are separated from each other by a broad zone of shearing known as the Delft shear which strikes northwest (Hatfield, 1990). Towards the northwest the Delft shear is presumed to link up with the Mahamba shear which was mapped by Hatfield (1990) to the east of Piet Retief, near the southwestern border of Swaziland. He interpreted the Mahamba shear as a transpressional structure in which both dextral and sinistral senses of movement are represented. To the west of the Mahamba shear is an intensely deformed, ~ 15 km wide zone which constitutes the pyroclastic volcano-sedimentary unit of the Nsuze Group (Hatfield, 1990). This zone, trending northwest with a sinistral sense of movement and transport of some 40 km, was speculated by Hatfield (1990) to have been created simultaneously with the deformational episode that gave rise to the Mahamba shear zone (his D_1 event). The southeastward extension of this zone to the Delft shear coincides with the sudden change of strike direction together, with a major thinning of the Pongola Sequence, in particular of the Nsuze Group (Hunter and Wilson, 1988). The regional northeast to north-northeast strike of the Pongola Sequence swings suddenly to the northwest in this zone in which the dips are steeper than elsewhere (D.J.C. Gold, *pers. comm.*, 1992). The early Archaean greenstone-granitoid basement within this zone is often mylonitized affected by faulting and refolded (Hunter and Wilson 1988; Verbeek, 1991).

The Usushwana intrusive suite is believed to have intruded into pull-apart grabens that most probably formed during this deformation (Hunter and Wilson, 1988). This suite is itself deformed by the last tectonic movements which constitute the northwest and north-trending shears.

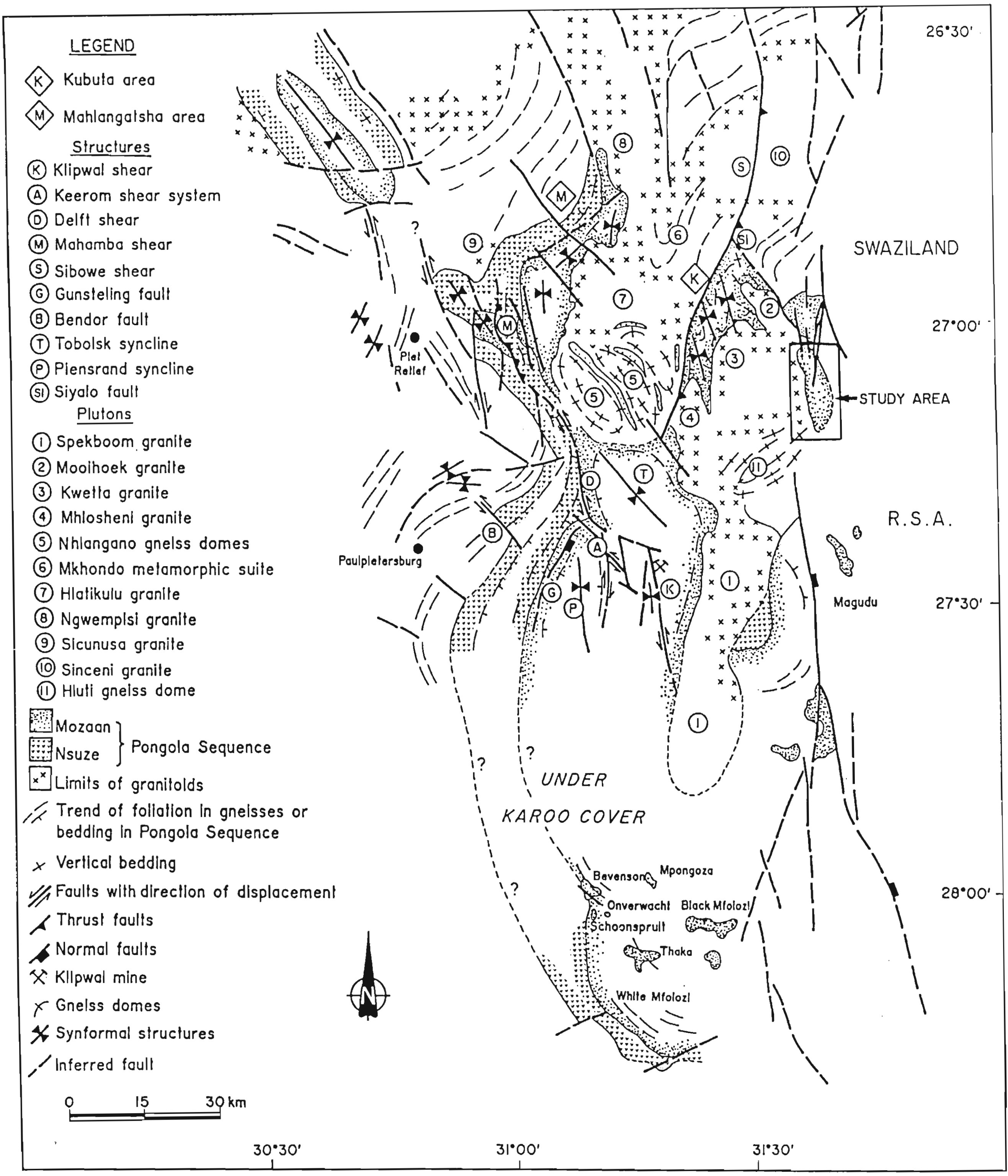

Figure 5.1: Map showing the main Pongola basin and the structures encountered within the basin. International and provincial boundaries have been omitted for clarity, (based in part on the work of Hunter and Gold, 1993).

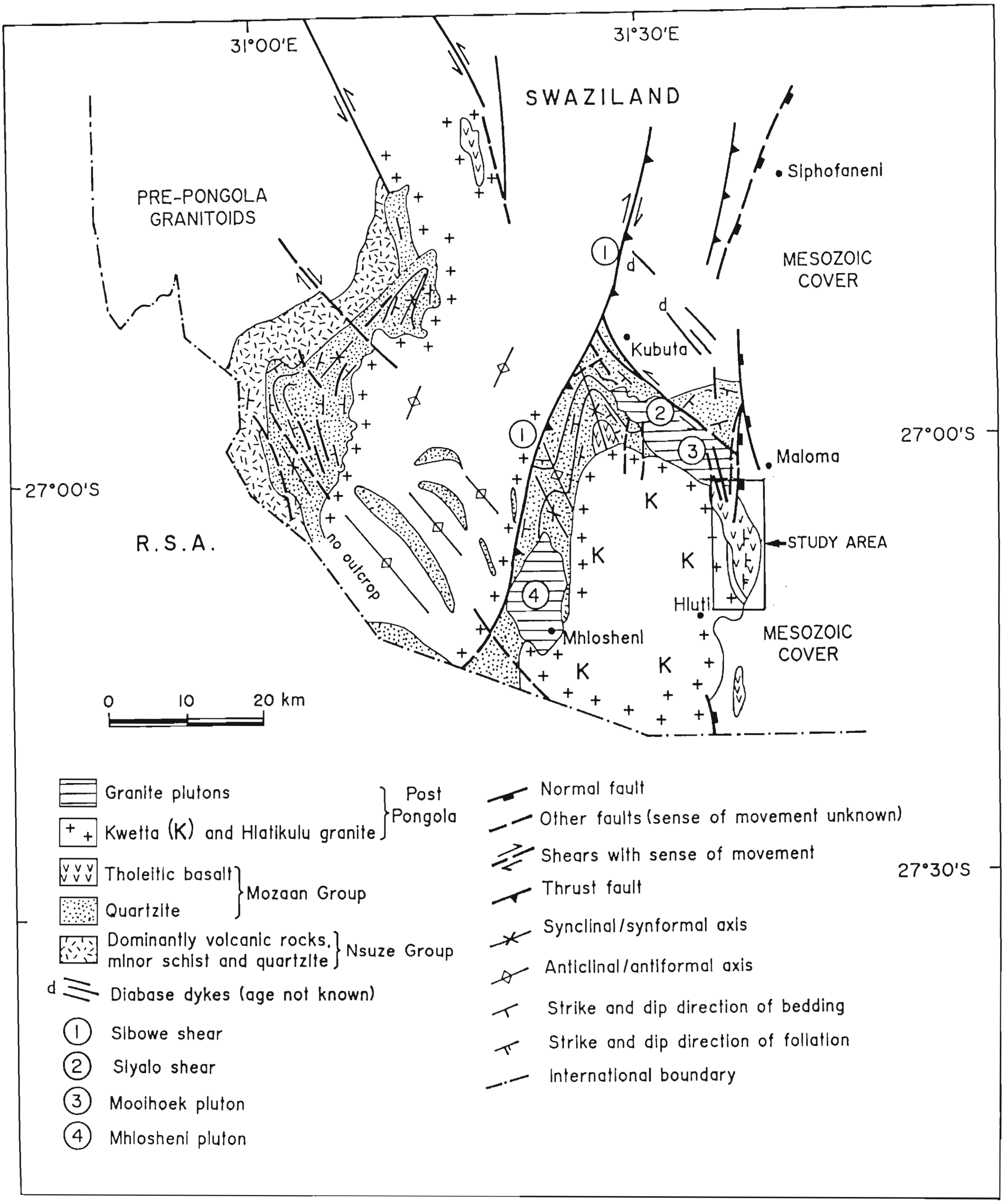

Figure 5.2: Mozaan Group rocks in southern Swaziland in a syncline between the Sibowe and the Siyalo shears, (modified after Hunter, unpub., 1992).

Northerly aligned structures are found within the broad northwestern zone of faulting affecting the Pongola Sequence (Geol. Surv. Swaziland, 1968, 1980; Hatfield, 1990) and in the pre-Pongola basement (Hunter, 1970b; Hepworth, 1973; Smith, 1987; Talbot *et al.*, 1987; Verbeek 1991). These are subparallel and they have the same sense of shear displacement.

The eastern limit of the Pongola basin is marked by a major northward trending fault (Figure 5.1 and Figure 5.2). It is not clear when this faulting event began but the last normal movement resulted in the preservation of the upper basaltic units in a series of inliers to the east of the fault. They are juxtaposed against the stratigraphically lower sedimentary divisions west of the fault (Linström, 1987).

In southern Swaziland (near Kubuta) the Mozaan Group sandstones occupy the nose of a syncline which plunges to the southeast (Hunter, 1961; Figure 5.2). The fold has been modified as a result of the intrusion of the Mooihoek pluton into its eastern limb (see Figure 5.1). Intrusion of the Mooihoek granite was accompanied by detachment faulting along incompetent horizons. Northwesterly trending structures are commonly developed in Swaziland, but in adjacent areas of the Transvaal the most intense deformation is displayed by the northerly trending shears (D.J.C. Gold, *pers. comm.*, 1992). Most of these are dextral shear zones with a steep easterly dip. The Sibowe shear is the best developed of these in Swaziland. It truncates the Mozaan Group rocks in the Kubuta area (Hunter, 1952, 1991; Hepworth, 1973, Geol. Surv., Swaziland geological map sheets, 1968, 1980; Figure 5.2). The Sibowe shear strikes north-northeast truncating the basement gneissic rocks and the Mozaan Group metasediments. The shear is a broad mylonitized zone with lineations and fold axes plunging towards the southeast (Hepworth, 1973).

The Mozaan Group is deformed by large amplitude folds to the east of the Sibowe shear, whose axes also plunge to the southeast. Hepworth (1973) suggests that the Sibowe shear was generated as a result of progressive deformation. Early lineations (L_1) plunge towards the northeast and were reoriented into a southeast direction. These lineations are consistent with a maximum compressive stress from the northeast which is supported by the presence of small scale folds as well as regional scale folds associated with this episode of deformation (Hunter 1963, 1968; Geol. Surv. Swaziland geological map sheets; 1968, 1980, 1982).

East of the Sibowe shear, Mozaan Group quartzites are preserved in a broad synclinal structure whose northeastern limb is truncated by the sinistral Siyalo shear (Hunter and Gold, 1993) which has a northeasterly strike and sub-horizontal lineations. The Siyalo shear is truncated by the Sibowe shear west of Kubuta. At this locality the Siyalo shear splits into a number of splays that give rise to a series of lenses of basal Mozaan quartzite (Figure 5.2). The Siyalo shear lies at the contact between the Mozaan Group and the Ancient Gneiss Complex southeast of Kubuta (Figure 5.2) (Hunter and Gold, 1993). Further southeast, the shear defines the contact between the gently Mozaan Group to the northeast and the Mooihoek pluton to the southwest (Figure 5.2). The Mozaan rocks east of the Siyalo shear cannot be correlated with those to the west of the shear with any confidence. The synclinal structure located between the Sibowe and Siyalo shears, has a sub-vertical northeastern limb. Hunter (1961) proposed that intrusion of a granite plug in the northeastern limb had caused thrusting and overturning of the Mozaan stratigraphy, but this assumption could not be confirmed because of the poor nature of outcrop. The intrusion of the Mooihoek pluton caused bedding-parallel slip in the nearby Mozaan shales (Hunter, 1968). The southwestern contact of the Mooihoek granite pluton with the Mozaan Group is semi-conformable to the strike of bedding but swings north at one locality before resuming its regional northeasterly trend (Figure 5.2). Although no fault has been identified at this locality, a right-lateral fault offset could be inferred. This is in agreement with the displacements observed in north-striking faults elsewhere (D.J.C. Gold, *pers. comm.*, 1992). Bedding-parallel faulting exists in the Mozaan strata east of the Siyalo shear. There is uncertainty as to whether low angle thrust faulting has duplicated the strata in this area.

The intrusion of the Mhlosheni and Mooihoek plutons seem to have been structurally controlled because, the latter has its longer axis oriented northwesterly, whereas the former has its longer axis aligned northerly (Figure 5.1 and Figure 5.2). This structural control is inferred, because as mentioned earlier, throughout the northern Pongola basin two dominant structural trends are observed and these two plutons are aligned along each of these trends. This means that these two granite bodies were intruded in zones of weakness which were aligned in the two observed directions.

5.2 STRUCTURE IN THE STUDY AREA

The study area has poor outcrop which inhibits the possibility of collecting and analyzing representative structural data for the whole area. The only significant exposure is a major east-northeast striking road cutting through Sigwe Hills (Figure 5.3).

The basaltic volcanic rocks and interbedded quartzitic and phyllitic rocks generally dip steeply to the east or southeast, although one quartzite lens north of the Ngwavuma River has an eastwest strike (Map 1-western central portion) and bedding dips moderately to the south. A weak foliation in the lavas is also aligned north-south and has a steep dip to the east.

5.3 THE SIGWE HILLS ROAD CUTTING

5.3.1 Introduction

In order to facilitate description, the Sigwe Hills road cutting has been divided into six domains separated by faults (Section X-Y, Figure 5.3). The faults numbered Fl_1-Fl_6 displace four stratigraphic horizons in a normal sense. These domains are described from right to left. Observations at the road cutting were taken looking in directions between 150° and 170°. The four lithological units comprise a phyllite (Ph_1), a quartzite (Qz), a phyllite schist (Ph_2) and a silicified metavolcanic unit (Sv). The basal phyllite is a very weathered reddish-brown, crumbly, soft, fine grained rock with an average thickness of 9 m. The overlying quartzite is hard, greyish-white and coarse-grained. It is recrystallized and bedded but bedding is poorly preserved. The unit is on average about 1.8 m thick. A phyllitic schist overlies the quartzite and is greenish grey in colour and fine-grained. It has an average thickness of about 5 m. The upper silicified metavolcanic unit is a hard, medium-to-coarse grained, greenish-grey rock with patches of whitish grey quartz vein material. It is massive or foliated. This unit has an average thickness of about 12 m. Throughout the road cutting, there are localised zones of fracturing and jointing (Figure 5.3). The most dominant fabric in the Sigwe Hills' road cutting is a penetrative foliation (s_1). Bedding (s_0) is only readily apparent in some quartzite horizons.

5.3.2 Domain 1

In domain 1 there are three minor bedding parallel faults that are cut by the Fl_1 fault and a late fracture cutting across Fl_1. The s_1 has been dragged slightly in a normal sense. Some of the faults post-date the Fl_1 fault because they are not deflected by it but they also do not to displace it. The fracturing and jointing postdate the foliation, bedding parallel faults and the fault Fl_1. The dip-slip displacement along Fl_1 is about 9 m (Figure 5.3).

5.3.3 Domain 2

In this domain both bedding (s_0) and foliation (s_1) have been dragged extensively by Fl_2. A fault bounded sliver containing Ph_2 is preserved in the fault zone. The dip-slip displacement of this fault is about 13 m. A brecciated quartz vein occurs in the Ph_2 unit above Fl_1 (Figure 5.3). The brecciation in this vein is parallel to s_1 but cuts across Fl_1 into domain 1 without apparently displacing it. A thrust fault at the base of the Qz unit cuts s_0 and s_1 in its footwall and in places interleaves the Ph_1 and Qz units.

5.3.4 Domain 3

The Sv, Ph_2, Qz and Ph_1 units are present in domain 3. The intensity of foliation development and orientation in the silicified volcanic unit is very variable in this domain. Foliation dips vary from shallow to steep. Small scale displacements occur along minor faults, particularly in the Ph_1 towards the eastern margin of domain 3.

5.3.5 Domain 4

The Sv unit is not represented in this domain bounded by Fl_3, Fl_4 and of Fl_5. The Qz and Ph_2 units are duplicated by thrust faulting which may also explain thickening of the Ph_2 unit. The upper quartzite pinches out eastward. The lower quartzite is also partly duplicated by a thrust fault that rises through the unit from west to east. Drag folding associated with movement of Fl_4 caused the footwall ramp to be folded into a tight anticline and an adjacent syncline. The fold axes have a trend/plunge of 136° /74°. The fault Fl_4 can be matched with a thrust fault at a higher stratigraphic level in the footwall.

Figure 5.4 represents a possible sequential reconstruction of the thrust faulting which duplicates the strata in domain 4. The thrusts (marked by * in Figure 5.4), formed prior to the normal faults Fl_3 and Fl_4 due to compression from the west. Thrusting developed at a high angle to the bedding planes leading to the development of small horse structures and continuous compression caused the beds to climb on top of one another causing further duplication of the stratigraphy. In stage 2, Fl_3 and Fl_4 developed and displaced the existing thrust faults (Figure 5.4). Fl_5 then developed, cutting across the upper parts of Fl_4. Drag along the footwall of Fl_4 caused folding of the beds and the foliation in the Qz and the Ph_2 units.

5.3.6 Domain 5

The domain bounded by Fl_4 and Fl_5 contains Qz, Ph_2, and Sv stratigraphic units. The lowermost phyllite is possibly a repetition of Ph_2, as in domain 4. The Fl_4 fault cuts through the upper quartzite in domain 4. The presence of the lower Ph_2 unit in its footwall is due to drag. Fault Fl_4 itself has been dragged by normal movement on the Fl_5 fault.

5.3.7 Domain 6

This domain lies above the Fl_5 fault. A splaying of Fl_5 occurs towards the western limit of the road cutting to produce Fl_6. In this domain only the Sv unit is exposed. It is unfoliated and massive with a small zone of fracturing to the west.

5.4 DEFORMATIONAL HISTORY

Four deformational events, D_1-D_4, can be identified mainly on the evidence from the Sigwe Hills road cutting.

5.4.1 D_1 Event

The most conspicuous D_1 structure is the s_1 foliation which is a relatively intense cleavage typically dipping north-northeast. At Sigwe Hills s_0 is tilted towards the north (average strike and dip is 280°/34° NE; Figure 5.5) and has been affected by folding. The foliation at Sigwe Hills dips steeper than the bedding (average strike and dip is 288°/59° NE; Figure 5.6) which suggests that bedding has not been overturned if the foliation is axial planar (Figure 5.7).

Figure 5.3 The Sigwe Hill road cutting section showing the observed structures as explained in the text.

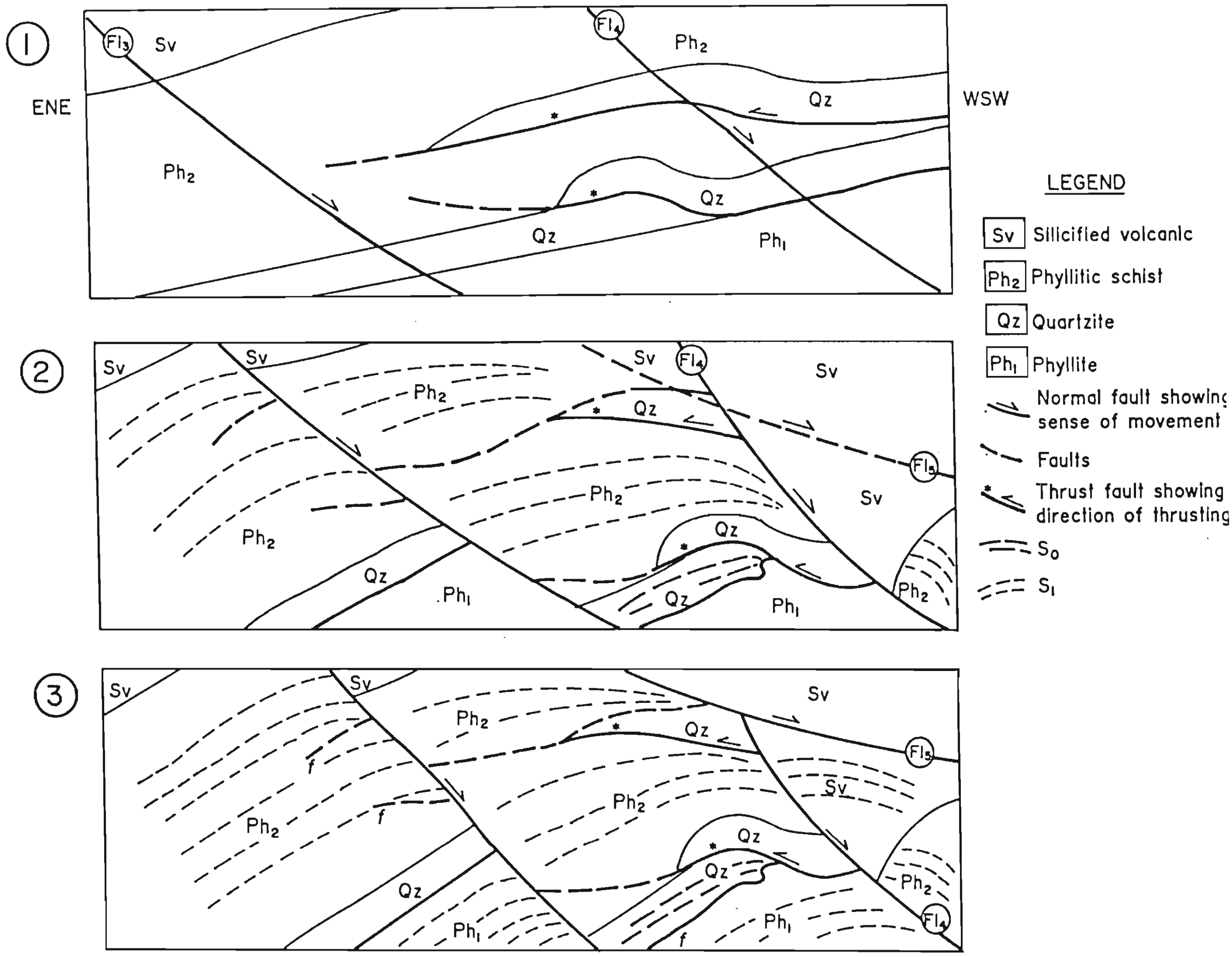

Figure 5.4: Reconstruction of part of domain 4 showing the history of the duplication of some horizons. Lateral extent shown is 10 metres with no vertical exaggeration.

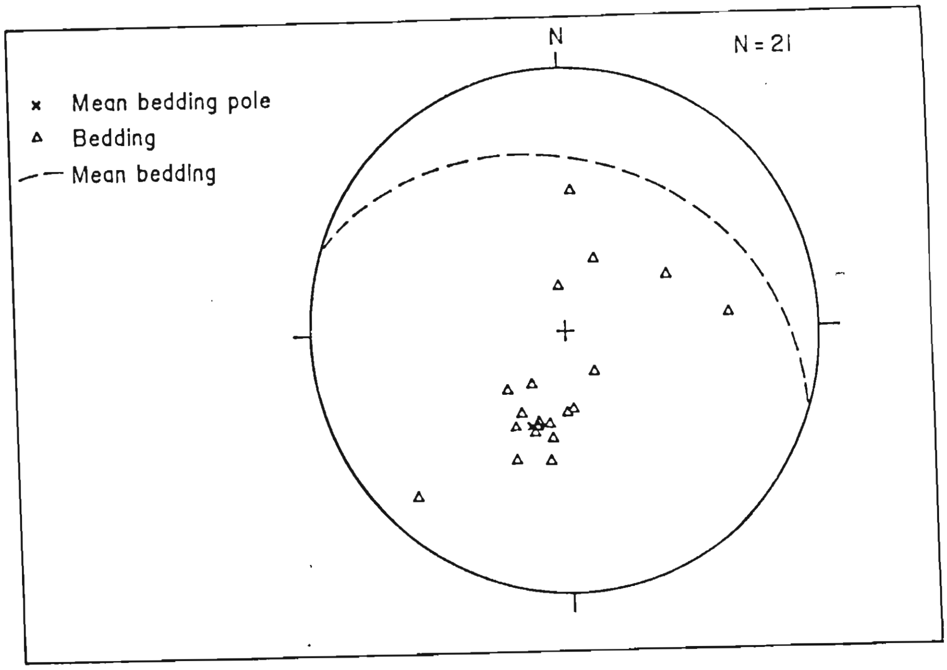

Figure 5.5: Stereographic projection showing poles to bedding for the Sigwe road cutting. Hatched line shows the average bedding plane orientation.

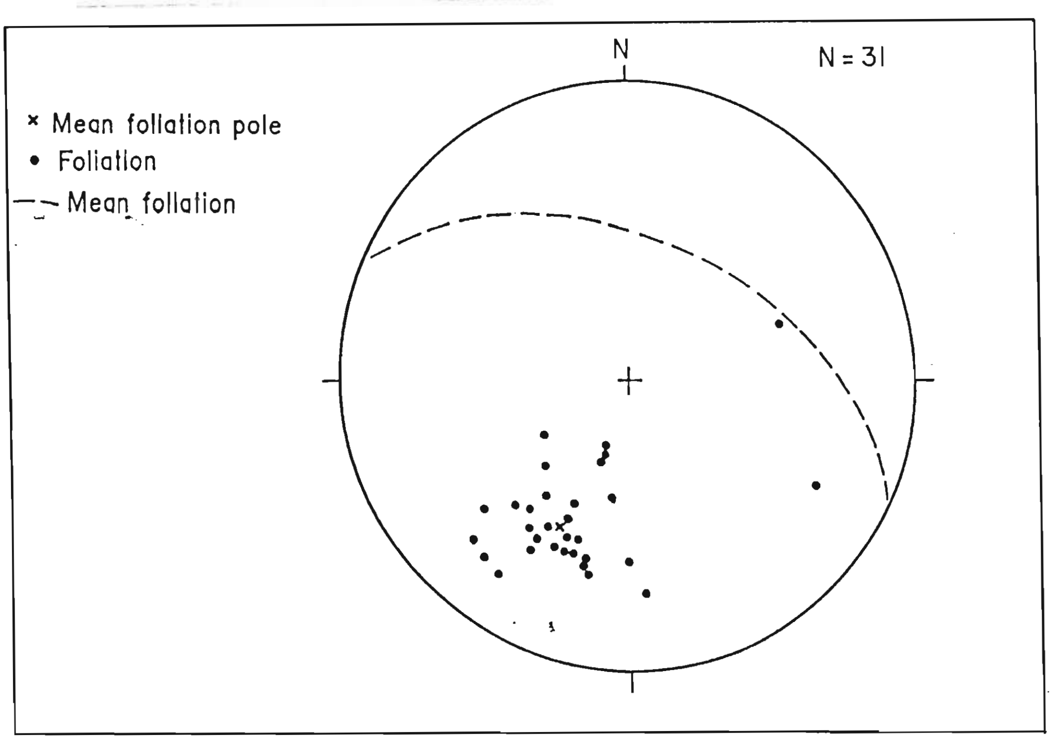

Figure 5.6: Stereographic projection showing poles to foliation surfaces at the Sigwe road cutting. Broken line gives the average foliation orientation.

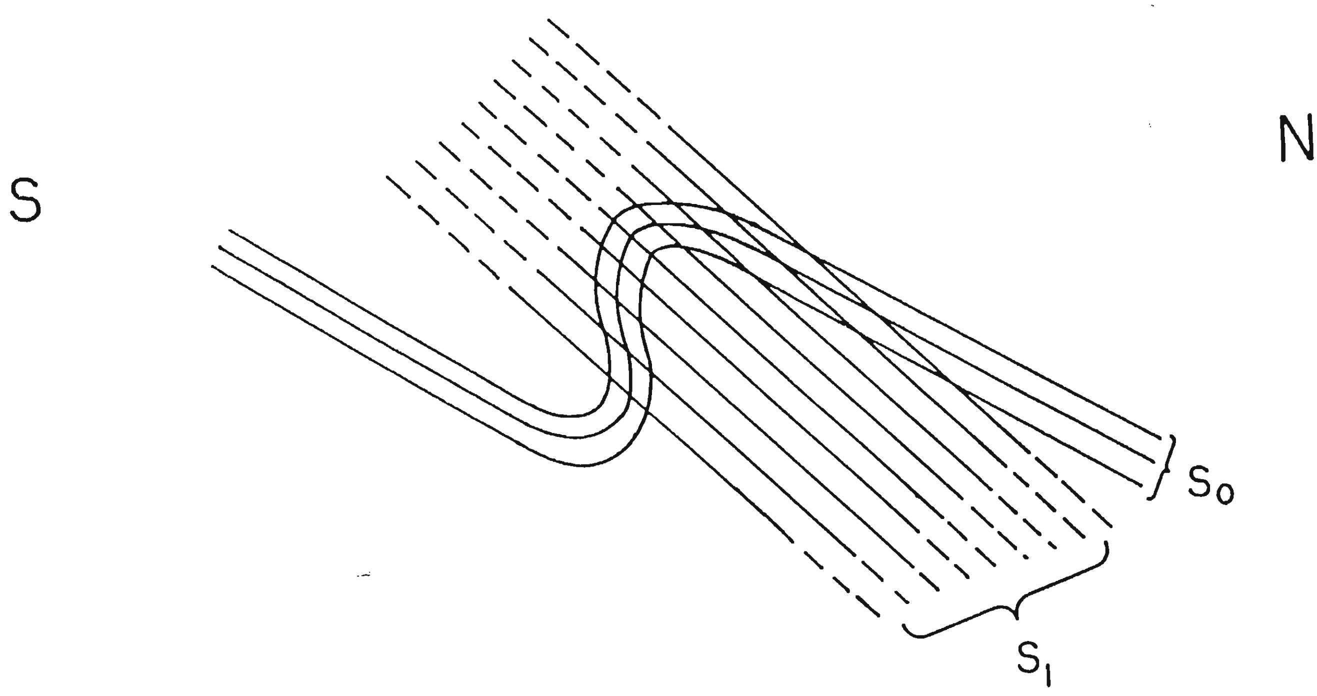

Figure 5:7: Schematic diagram showing the relationship of axial planar foliation (s_1) to bedding (s_0) at Sigwe Hills.

The mean bedding and mean foliation poles were calculated using the Eigenvector statistics method in the computer program ORIENT by M. von Veh at the University of Natal, Pietermaritzburg (M. von Veh, *pers. comm.*, 1993). Appendix 3 at the back of text shows some parameters used in the description of structural data obtained from the Sigwe Hills road cutting section.

5.4.2 D_2 Event

This event is represented by detachment and low angle thrust faulting. Mineral stretching lineations on fault planes are weakly developed and plunge down-dip (Figure 5.8). The sense of movement on these faults is difficult to identify and vergence indicators are inconsistent. The Sigwe Hills thrusts cut up-section towards the north (domain 4, looking at an oblique view to the southeast) while rotated and faulted clasts showing bookshelf sliding (Figure 5.9) point to a northerly movement direction of thrusting (Figure 5.9).

5.4.3 D_3 Event

The D_3 event is characterised by normal or oblique-slip faulting with possible inversion of some of the thrusts. Most of the normal faults in the Sigwe Hills road cutting dip towards the south and southwest (Figure 5.10). Faint lineations defined by slickenside striations are visible on fault plane and lineations indicate that movement varied from down-dip to strike parallel with a sinistral component of slip (Figure 5.10). Because of the northeast dip direction of bedding in the Sigwe road cutting, the lithological units have been repeated from east to west across the various D_3 faults at this locality. Foliation and bedding in the footwall of the faults have undergone varying degrees of drag proportional to the amount of displacement along the faults.

5.4.4 D_4 Event

Several joint and fracture assigned to a to a late brittle D_4 event. These discontinuities cross-cut s_1 and the earlier formed faults and have variable orientations (Figure 5.11).

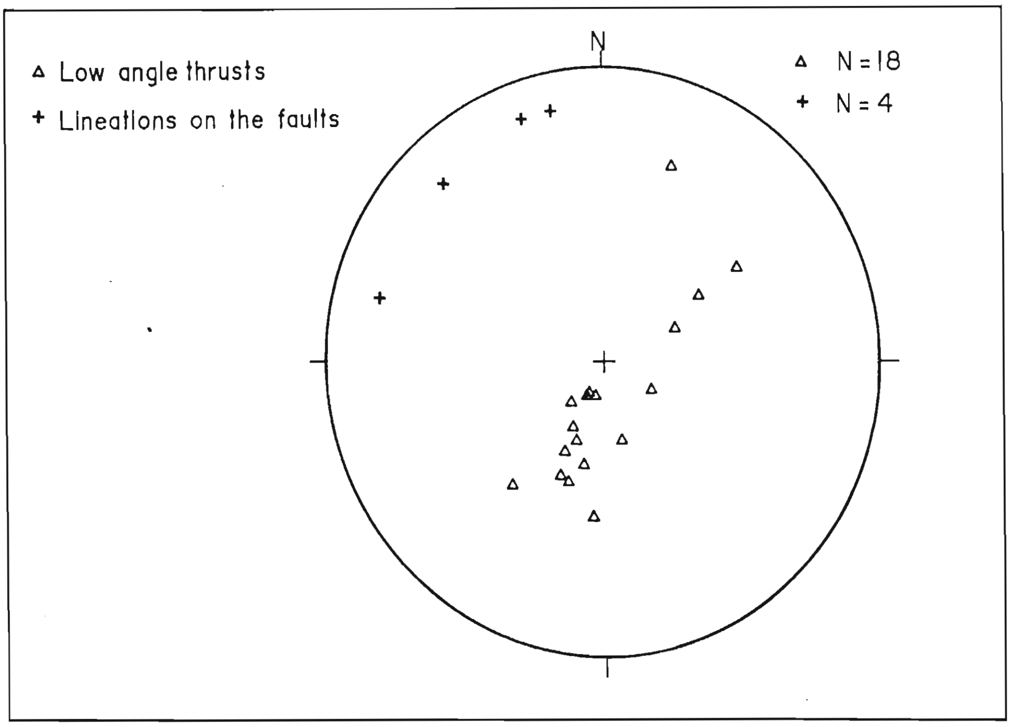

Figure 5.8 : Stereographic projection of poles to low angle thrusts (▵)and lineations (+) on the thrust planes at the Sigwe road cutting.

Figure 5.9: Bookshelf sliding in a clast within phyllitic horizons in the Sigwe road cut exposure. Coin = 30mm in diameter, direction of view south-southeast.

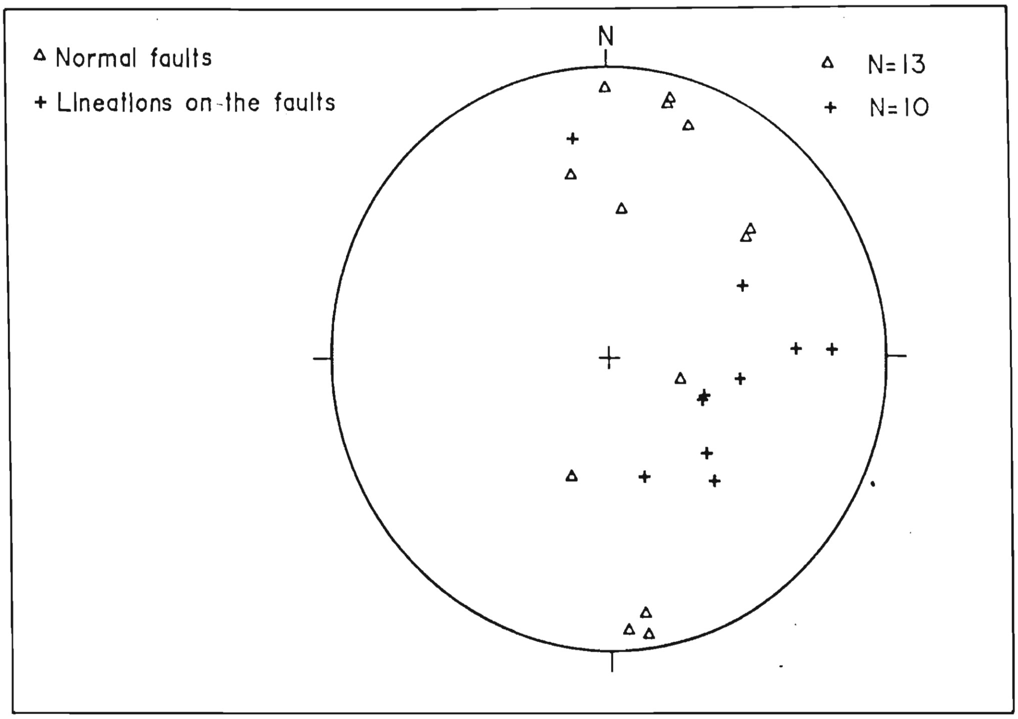

Figure 5.10: Stereographic projection of poles to normal fault surfaces and plunges of lineations on them at Sigwe Hills road cutting.

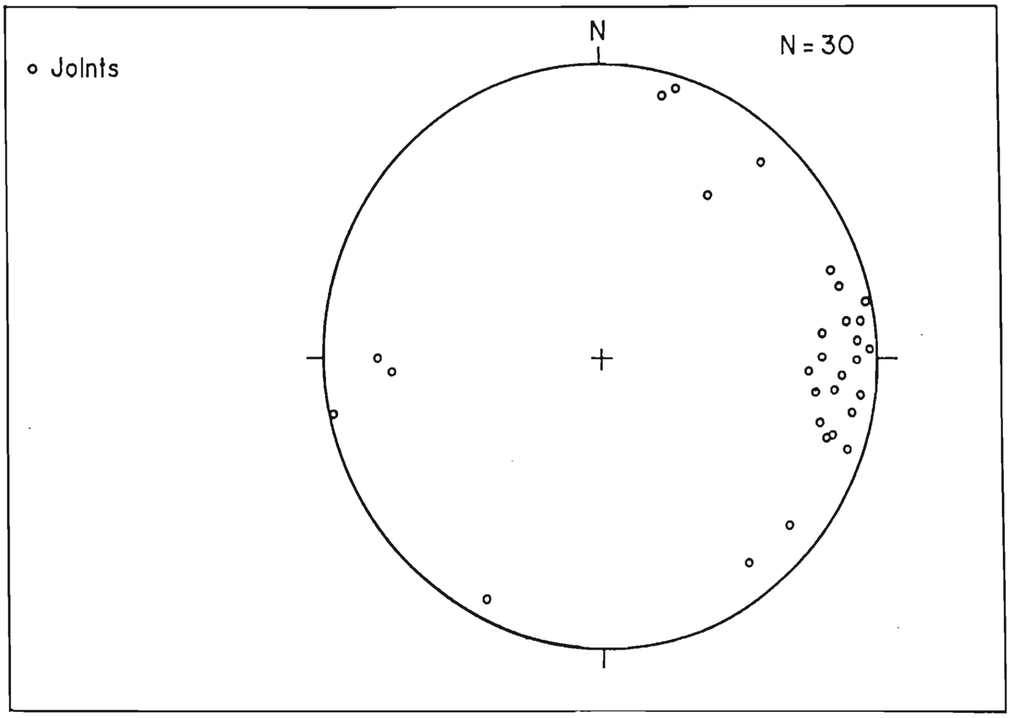

Figure 5.11: Stereographic projection of poles to joint sets at the Sigwe Hills road cutting.

5.5 SUMMARY OF DEFORMATIONAL EVENTS

There are four distinct stages in the deformation history of the study area as deduced mainly from the Sigwe Hills road cutting. These can be summarised as follows:

(i) Cleavage development;
(ii) Low angle thrusting and bedding parallel thrust faulting;
(iii) Normal/oblique slip faulting;
(iv) Fracturing and jointing.

Outcrop did not permit extrapolation away from the road cutting.

5.6 DISCUSSION

The Pongola Sequence in the study area is intruded in the west by a granite batholith known as the Kwetta granite. The intrusion of this batholith is evident because towards its western limits, the volcanic lavas are found as xenoliths in this granite. The forceful emplacement of this body may have been responsible for the development of the s_1 cleavage, the D_1 tilting of the strata towards the east in the south and north-northeast in the north, localised folding of bedding. Outward expansion of the pluton may have caused D_2 thrusting of Pongola strata, northwards at Sigwe Hills but possibly eastward further south.

Oblique slip faulting which appears to be confined to the Sigwe hills seems to be related to the sinistral strike-slip movement which gave rise to the Siyalo shear zone (possibly Riedel shears as these faults are subparallel to each other and are oblique to the main Siyalo shear) south of which the stratigraphically highest parts of the Mozaan Group are preserved. The intrusion of both the Mhlosheni and the Mooihoek granites appears also to be related to this event and to be structurally controlled because the former pluton is aligned northerly whereas the latter is oriented northwest (Figure 5.2), reflecting the two dominant structural trends in the Archaean greenstone-granitoid basement.

The D_4 event may be correlated with the Jurassic-Cretaceous magmatism and northsouth faulting in the region.

The interpretation of the volcanic rocks in the study area as belonging to the upper Mozaan Group implies the possible presence of a major fault between the Kwetta granite and the Pongola rocks. Although the granite is clearly an intrusion as it encloses xenoliths of the country rock, major contact metamorphic effects would be expected if the intrusion occured at the present level of exposure. In this case therefore, the deformation is likely to post date the magmatic emplacement and to say that the granite caused the deformation is untenable.

The lower Pongola stratigraphy could alternatively be absent due to a basement high in the Pongola basin. The Nsuze volcanism may have been confined to the western limit of the depository, with deposition of sediments of the Mozaan Group subsequently prograding eastward.

Many of the outcrops of the volcanic rocks in the Sigwe Hills-Ngwavuma valley area create the impression that they have been only moderately deformed. However, this study clearly reveals a much more complex history of deformation for this part of the Pongola Sequence in the area involving duplication of strata by both thrusting and normal faulting. The absence of marker beds precludes determination of the degree of duplication. This faulting needs to be taken into consideration when estimating stratigraphic thicknesses, attempting regional correlations and modelling the tectonic evolution of the Pongola basin.

CHAPTER 6

GEOCHEMISTRY OF THE LAVAS

Geochemical data for the rocks from the study area have not previously been reported. The main aim of this investigation is primarily to establish the geochemical characteristics of the volcanic rocks and to compare these data with those available from other parts of the Pongola Sequence.

6.1 SAMPLING AND ANALYSIS

Forty seven volcanic rocks from the study area were analyzed for major, minor and trace elements by X-Ray fluorescence spectrometry using the Philips PW 1404 spectrometer at the University of Natal, Pietermaritzburg. Details of sample preparation and analytical techniques are given in Appendix 1. Only those rocks which appeared unweathered in the field were sampled for analysis. However, petrographic examination revealed that all the samples have undergone some alteration because of the presence of chlorite and calcite. Field locations of the samples are marked in Map 1 in the pocket at the back of the volume. Where outcrop is good, the samples were collected at closely spaced intervals providing a fair representation of the rocks within the volcanic pile from south to north. The sampling was not done on a systematic grid basis but rather on the basis of outcrop availability in the field.

In addition, four basaltic lava rocks (MAG1, MAG2, K1 and K2) from known upper Mozaan Group, (this setting established by Hunter, 1963 and Hunter, *pers. comm.*, 1992) outcrops outside the study area were also analyzed for comparison with the main data set. Two of these samples are from Magudu, south of the study area (MAG1 and 2) (Figure 1.1) and the other two are from Mooihoek, north-west of the study area (K1 and 2) (Figure 1.1).

6.2 ANALYTICAL RESULTS

The analytical results are presented in Table 6.1. Major, minor and trace element concentrations are given together with loss on ignition (L.O.I) of the original powder. All major element compositions are given anhydrous. The C.I.P.W. petronorms and other parameters arising from the analyses are given in Appendix 4. The norms are given for comparative representation with previous data sets for Armstrong, (1980) and Preston, (1987). The petronorms were calculated using the computer program by B. Groenewald at the University of Natal, Pietermaritzburg (B. Groenewald, *pers. comm.*, 1993). Total iron is recorded as $*Fe_2O_3$ since the ratio of ferric to ferrous iron changes with oxidation state and alteration, and is therefore likely to be different in each sample reflecting variable degrees of alteration. The determination of FeO in each sample is therefore unwarranted. The allocation of Fe^{3+} is based on 10% of total Fe with the remainder being allocated as Fe^{2+}. Due to low grade metamorphism and alteration the Fe^{2+} and Fe^{3+} have been modified, therefore for consistency a constant ratio of these oxidations is used. For volcanic rocks similar to those compositions encountered in the study area on a worldwide basis, the proportion of Fe^{3+} to total Fe ranges from 0.002 to 0.2 (Le Maitre, 1976). The average for many volcanic rocks in a world wide basis is 0.1 and therefore this value has been used in this study except in calculations where the total Fe is calculated as Fe_2O_3 (shown as $*Fe_2O_3$ in variation diagrams).

6.3 GEOCHEMICAL VARIATIONS

The samples from the study area, together with the additional samples from Magudu and Mooihoek, when plotted in a total alkalis against silica diagram (Figure 6.1), reveal that they vary in composition from basalts and basaltic andesites through andesites to rhyolites. Some of the samples are depleted in alkalis causing these compositions to plot outside the designated fields in Figure 6.1. These samples are altered and their behaviour in Figure 6.1 reflect possible alkali element mobility during metamorphism and alteration.

Those samples that show depletion in alkalis do not necessarily show anomalous behaviour for other elements. Therefore the reason for this depletion should be treated with some caution. It is also possible that different elements will behave differently under various conditions of alteration and metamorphism and this may lead to general dispersion of data points on variation diagrams.

6.3.1 Major, Minor and Trace Element Variation Diagrams (range distribution of compositions)

Frequency distribution diagrams for the major and minor element oxides (Figure 6.2a) and trace elements (Figure 6.2b) summarize the chemical characteristics of the volcanic rocks. Table 6.2 shows statistical parameters required for an assessment of the distribution of all the major, minor and trace elements analyzed. In the following discussion major element contents are expressed in weight % and trace elements in ppm.

An analysis of the distribution of all data shown in Table 6.2 and plotted in Figure 6.2a and 6.2b is based on the following criteria:-

(i) If the median value is closer to that of the 1st quartile, the distribution is skewed to the right.

(ii) If the median value is closer to that of the 3rd quartile, the distribution is skewed to the left.

(iii) If the median value is midway between the two quartiles, then the distribution is symmetric.

Given that all elements will respond to fractionation processes (by depletion through crystallizing phases or by enrichment in residual liquid) then deviations from symmetrical distributions may be indicative of non-magmatic processes. The most significant of these is alteration.

Figure 6.2a shows that element oxides such as Al_2O_3, CaO and MnO have almost symmetric distributions; total alkalis, SiO_2, K_2O and P_2O_5 are skewed to the left; total Fe_2O_3 and MgO are skewed to the right. Titanium does not define a distinct pattern because of an inadequate number of samples covering the observed compositional range.

Figure 6.2b shows that most of the trace element distribution (Ni, La, Ba, Nb, U, Rb, Sr, Zr, and Th) are skewed to the left although most of the incompatible elements are close to a symmetrical distribution. For many elements two groups of population groups are observed. One controlled by the major population of mafic rock samples and a minor population controlled by the relatively few felsic rocks. The distribution plots for TiO_2 and Y indicate three population groups and for Cr, two well defined populations are observed.

There is no consistent pattern in the statistical distribution of data except that it may be significant that Al_2O_3 and the incompatible elements Y and Zr show almost symmetrical distributions. Mobile elements and particularly the alkalis are highly asymmetric.

6.3.2 Trends in major and minor element chemistry

The plot of Al_2O_3 against SiO_2 (Figure 6.3) demonstrates that with increase in the silica content, there is a significant decrease in alumina content. The range in Al_2O_3 is from 9.2 % to 18.0% with most of the samples having 12% - 15.5%. This plot depicts three groups of samples all showing the trend of decreasing Al_2O_3 with increasing SiO_2. The three samples with SiO_2 contents between 71% - 74% weight are felsic rocks (rhyolites) which do not plot in the same field as the more mafic groups of rocks with SiO_2 contents less than 60%. These three anomalous samples are also depleted in alkali contents.

Magnesium plotted against SiO_2 (Figure 6.4a) shows considerable scatter, but the lowest magnesian samples also have the highest silica content giving a poorly defined trend. The range in MgO content is small (from 2.5 to 6.8%) with the majority at about 5.0% affecting the overall normal distribution shown in the statistical plots. No meaningful trend can be deduced from this plot. There is however a clear distinction between the samples taken from south of the Ngwavuma River and the remaining samples in the suite. The samples from the south of the Ngwavuma River form a cluster towards the left margin of the diagram.

The plot of MnO against SiO_2 (Figure 6.4b) shows some scatter but a systematic decrease with increase of SiO_2 can be observed. Most of the samples have MnO contents between 0.13 and 0.20%. Manganese is easily mobilised during hydrothermal alteration and metamorphosed samples commonly show variability in Mn concentrations (Humphris and Thompson, 1978).

Table 6.1: Major and trace element analyses for representative samples from the volcanic rocks.

Sample	SiO2	Al2O3	+Fe2O3	+FeO	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	Total	L.O.I	•Fe2O3	Ti
MK001	52.36	14.94	1.26	10.23	0.19	5.82	10.12	2.9	0.22	1.4112	0.25	99.7	0.22	12.65	
MK002	49.93	16.61	1.42	11.5	0.18	4.58	11.42	1.99	0.26	1.5108	0.28	99.68	0.98	14.22	
MK003	52.13	15.03	1.32	10.7	0.19	6.21	9.98	2.37	0.22	1.377	0.24	99.77	0.27	13.23	
MK004	50.28	15.05	1.39	11.24	0.19	6.33	10.58	2.49	0.26	1.4223	0.25	99.48	0.51	11.9	
MK005	51.91	14.47	1.35	10.96	0.18	5.74	10.69	2.11	0.31	1.4477	0.26	99.43	0.9	13.55	
MK006	52.39	14.81	1.31	10.57	0.17	5.26	10.6	2.51	0.36	1.3548	0.23	99.56	0.49	13.07	
MK007	50.81	15.38	1.41	11.46	0.18	4.49	11.76	1.88	0.27	1.428	0.28	99.35	0.67	14.17	
MK008	51.2	15.03	1.35	10.97	0.18	5.43	11.16	2.34	0.18	1.4214	0.25	99.51	0.77	13.56	
MK009	49.81	16.19	1.35	10.95	0.19	3.41	12.22	2.91	0.51	1.8175	0.42	99.78	1.3	13.54	
MK010	52.07	15.14	1.33	10.76	0.18	6	9.5	2.82	0.2	1.3723	0.24	99.61	0.45	13.31	
MK011	49.67	16.14	1.41	11.38	0.2	3.81	11.31	2.73	0.69	1.5641	0.26	99.16	1.31	14.13	
MK012	51.88	14.64	1.33	10.8	0.18	5.83	10.45	2.29	0.24	1.3849	0.25	99.27	0.52	13.35	
MK013	55.73	13.98	1.01	8.17	0.11	2.76	11.41	0.2	4.94	1.2153	0.06	99.59	0.95	10.1	
MK014	53.39	14.39	1.25	10.11	0.18	5.75	9.87	3.09	0.36	1.3225	0.23	99.94	0.46	12.5	
MK015	50.27	17.21	1.46	11.82	0.17	5.4	11.08	0.11	0.08	1.8862	0.33	99.82	3.2	14.61	
MK016	50.81	14.82	1.5	12.11	0.19	4.65	9.02	4.12	0.27	1.7329	0.31	99.53	0.35	14.98	
RM01	52.62	13.78	1.35	10.91	0.23	6.69	9.58	2.61	0.66	0.8135	0.16	99.41	1.2	13.49	
RM02	72.12	12.12	0.52	4.17	0.07	0.8	3.67	1.98	3.4	0.4827	0.12	99.44	1.17	5.16	
RM03	72.45	11.86	0.48	3.86	0.06	0.78	4.44	1.32	3.85	0.4531	0.1	99.65	1.1	4.78	
RM04	73.33	11.57	0.43	3.46	0.05	0.69	4.88	1.2	3.5	0.4527	0.11	99.68	1	4.28	
RM5	52.08	15.29	1.13	9.12	0.16	3.78	14.28	0.95	1.67	0.9141	0.17	99.55	1.3	11.28	
RM06	50.97	17.97	1.03	8.3	0.11	2.67	17.85	0.05	0.03	0.4841	0.08	99.55	1.88	11.27	
RM07	55.4	14.51	1.05	8.53	0.14	4.4	10.89	2.75	0.58	0.8489	0.16	99.26	0.59	10.54	
RM08	54.5	14.53	1.16	9.43	0.18	5.39	9.04	3.46	0.7	0.963	0.19	99.53	1.19	11.66	
RM09	55.09	13.49	1.1	8.89	0.19	5.15	8.97	4.32	1	0.9858	0.2	99.38	0.84	11	
RM10	55.19	14.39	1.21	9.79	0.22	5.18	8.17	3.74	0.49	1.0143	0.21	99.61	1.16	12.11	
RM11	55.33	14.29	1.16	9.43	0.18	4.88	9.49	3.1	0.4	0.9908	0.21	99.45	0.72	11.06	
RM13	57.51	12.08	1.11	8.97	0.17	3.96	13.89	0.23	0.79	0.8558	0.15	99.71	1.08	11.09	1
RM14	56.05	12.78	1.2	9.7	0.18	5.43	8.21	4.36	1.24	0.8821	0.14	100.18	1.04	12	
RM15	63.93	9.31	1.03	8.37	0.13	4.14	10.67	0.88	0.65	0.7951	0.14	100.05	1.17	10.35	1
RM16	56.6	12.59	1.2	9.7	0.16	5.64	7.38	5.05	0.7	0.8659	0.13	100.01	1.01	12	5
RM17	57.43	13.15	1.19	9.66	0.13	4.95	8.67	2.46	1.42	0.8818	0.14	100.09	1.46	11.94	3
RM18	55.92	13.19	1.27	10.28	0.17	5.22	8.22	3.39	1.18	0.846	0.13	99.81	1.28	12.71	4
RM19	54.99	14.6	1.24	10.01	0.15	4.72	7.01	4.79	1.35	1.0415	0.18	100.08	1.27	12.38	3
RM20	59	12.69	1.17	9.48	0.15	5.06	6.65	3.78	1.11	0.8509	0.13	100.06	1.36	11.72	4
RM21	54.18	14.95	1.26	10.22	0.17	4.22	8.25	4.42	0.85	1.0915	0.18	99.79	1.1	12.64	6
RM22	55.19	13.86	1.28	10.36	0.2	5.76	8.08	3.09	0.69	1.0318	0.19	99.74	1.38	12.81	4
RM23	57.2	13.1	1.21	9.81	0.16	4.67	8.32	3.06	1.16	0.9013	0.15	99.74	1.22	12.13	5
RM24	57.23	13.14	1.21	9.77	0.17	5.15	7.09	4.05	1.57	0.8252	0.12	100.34	1.43	12.08	3
RM25	54.08	14.59	1.31	10.59	0.16	4.32	8.92	2.98	1.24	1.0632	0.18	99.44	1.27	13.1	4
RM26	58.43	13.74	1.12	9.07	0.16	4.55	6.67	4.43	0.91	0.9107	0.15	100.13	1.13	11.22	5
RM27	56.74	12.74	1.1	8.89	0.15	5.24	9.24	4.3	0.57	0.8112	0.14	99.93	0.78	11	4
RM28	55.31	13.44	1.24	10.05	0.17	5.73	8.81	3.1	1.03	0.855	0.14	99.87	1.37	12.43	4
RM29	56.85	13.06	1.17	9.44	0.16	5.74	8.54	3.48	0.71	0.8506	0.14	100.15	1.02	11.68	4
RM30	56.27	14.23	1.19	9.63	0.18	4.99	9.23	2.71	0.76	0.9287	0.16	100.26	1.24	11.91	3
RM31	56.27	14.26	1.18	9.57	0.17	4.96	9.53	2.51	0.56	0.9223	0.16	100.1	1.09	11.83	3
RM32	55.32	14.62	1.19	9.61	0.11	3.4	8.27	5.52	0.71	1.0406	0.17	99.97	0.7	11.89	6
MAG1	55.94	14.07	1.22	9.91	0.16	4.91	7.36	4.31	0.59	1.0226	0.19	99.68	1.7	12.23	
MAG2	56.3	14.53	1.2	9.69	0.14	4.79	6.93	4.09	1.14	0.9993	0.17	99.97	2.68	11.97	5
K1	56.76	13.96	1.17	9.44	0.16	4.75	7.07	4.81	0.4	0.9884	0.19	99.75	1.28	11.66	5
K2	56.43	13.72	1.2	9.69	0.16	4.87	7.58	4.07	0.73	0.9879	0.19	99.68	1.33	11.97	

•Fe2O3 = Fe2O3 = (FeO x 1.1113)

+ allocation of Fe^{3+} is based on 10% of total Fe.

Table 6.1 (continued).

Sample	Zr	Sr	Nb	Y	Rb	U	Th	Zn	Cu	Ni	Cr	V	La	Ba	Sc
MK001	167.2	231.1	8.4	37.5	5.1	0.2	1	101	86	112	204	262	27	72	34
MK002	177	340.1	8.7	39.8	8.4	0.7	3.8	101	95	110	210	265	18	36	36
MK003	163.2	210.9	7.3	35.7	3.7	0.5	2.5	95	112	113	196	254	20	79	31
MK004	169.8	237.6	7.2	36.6	4.8	0.6	3.8	101	109	111	201	267	23	59	34
MK005	171.3	254.5	9.4	38	9.2	0	0	99	102	108	182	266	22	35	32
MK006	165.6	302.6	8	35.7	7.6	1.9	0	98	77	108	189	245	20	75	34
MK007	166.6	262.2	8.5	37	4.2	0	0.8	98	103	105	193	254	18	50	35
MK008	164	302.8	7.6	37.3	2.3	0	6.3	98	93	108	197	257	18	37	34
MK009	202.2	160.7	11	43.6	11.7	0.2	3.2	114	155	111	215	285	16	99	36
MK010	164.8	302.2	7.5	35.6	3.7	0	0	95	86	110	205	253	24	81	33
MK011	180.9	257.1	9.3	38.2	17.8	0	0.4	93	52	120	208	273	18	280	36
MK012	161.9	253.6	7.2	36.5	4	0	0.1	95	109	111	192	248	15	87	34
MK013	142.9	396	6.9	17.4	50.7	0	1.2	56	62	65	134	165	8	992	24
MK014	161	294.7	7.1	35.5	7.3	0	0	93	67	106	187	240	14	99	31
MK015	223.7	225	10.4	47.6	2.5	0	0.8	127	65	103	248	316	27	58	34
MK016	191.3	266.3	8.5	40.5	5.5	0	1.8	109	114	50	143	316	27	66	40
RM01	130.6	191.9	6.2	34.6	29.5	0	2.8	113	3.5	390.4	66	212.1	25.4	145.6	31.4
RM02	404.5	197.7	21.3	73.1	69.9	4.1	24.6	42.2	135.3	9.4	23.9	33.7	108.8	721	11.2
RM03	365.5	303.3	19.4	69.3	84.6	2.1	18.6	35.7	103.1	9.3	15.5	43.7	95.7	734.8	9.3
RM04	385	311.9	20.5	71.6	78.9	4.2	23.2	28.3	3.1	10.4	12.2	41.4	98.1	783.8	9.9
RM05	149.2	804.1	7	33	47.6	2.1	3.8	88.7	25.7	92.5	53	204.5	36.5	187.8	26.3
RM06	70.9	742.1	3.5	18.2	1.7	0.3	0	44.9	0	61.6	43.5	236.6	6	13.5	16.7
RM07	139.6	326	6	34.6	10.7	2.3	4.8	61.8	0	89.4	50.2	208.9	24.3	387.9	25.5
RM08	153.1	352.6	5.7	33.4	26.7	0.8	3.9	101.3	61.3	107.7	74.1	241.5	21.6	231.4	30.9
RM09	158.9	201.2	5.5	33.7	29.3	0	3.4	99.9	50.8	112.4	63.2	219.9	21.7	199.4	32.9
RM10	160.1	216.1	5.7	33	24.5	0	3.4	101.8	68.9	101.9	59.5	241.5	30.2	166.4	29.8
RM11	158.6	186.5	6.2	33.2	16.7	1.2	2.9	94	74.6	99.1	56.3	232	27.9	124.9	32.1
RM13	119	568.5	4.9	29.6	22.8	2.6	5.2	76	21.7	87.8	54.9	228.3	11	58.7	30.4
RM14	138.3	197.4	6.7	33.6	32.2	0.4	4.8	104.9	32.4	124.4	66.8	221.5	14.1	269.7	34.3
RM15	134.7	335.8	4.7	33.4	14	0	1.7	73.3	22	111.4	228.6	218.6	18.2	95.2	31
RM16	135.2	182.2	5.9	31.5	19.2	0	4	89.1	137.5	102.5	49.3	214.2	16.7	195.4	31.7
RM17	136.3	280.2	6	30.6	66.5	1.9	4	59	63.7	120.3	68	242.5	24.6	317.6	34
RM18	129.7	258.1	5.2	34	45.4	1.2	5.8	103.1	31.7	110.8	57.2	231.3	22.5	335.7	30.3
RM19	151.5	209.2	7	36.5	44.2	0	5.3	195.8	70.3	88.2	40	235.1	23.1	491.1	29.7
RM20	129.6	158.4	5.2	30.8	36.5	1.4	3	95.3	17.9	111.3	56.2	221.4	26.6	403.5	31.3
RM21	166.5	372.9	6.9	36.1	23.9	1.3	4.1	80.6	3.1	109.7	85.8	220.7	35.4	227.8	25.7
RM22	170.3	304.4	7.4	42.5	23	1.5	4.7	138.1	168.4	104.8	69.3	225.3	33.3	165.5	27.7
RM23	143.5	316.5	6	33.2	43.6	1.6	5.9	115	101.5	106.3	58.8	227.1	30.9	348.2	31
RM24	160.4	391.7	7	35.3	43	0	2.1	90.8	0	105	69.6	208.3	29.4	340	25.1
RM25	126.4	164	6.2	32.8	51.9	1.6	5.6	97.2	17.2	115.1	67	231	15.9	314.6	33
RM26	135.2	201.2	6.1	33.1	31.8	1.8	3.6	97.1	36.5	85.9	44	214.2	18.1	221.1	30.2
RM27	135.3	204	5.8	34	17	0.1	2.1	65.4	27.4	105.3	239.1	213.2	23.4	135.5	31.4
RM28	140.1	208.2	6.1	35.2	45.3	0	1.5	92.5	26.3	108.8	259.1	223.8	16	339.8	32.5
RM29	140.9	185.6	7	37.2	29.7	0.9	1.9	89.4	48.3	108.1	259.5	226.4	25.8	165.7	33.2
RM30	129.5	313.6	5.3	31	24.6	1.2	5.6	87.3	68.5	99.6	71.5	229.9	14.2	326.2	31.9
RM31	130.4	342.2	4.7	32.2	21.8	1	1.5	86.2	70.3	96.3	63.8	229.1	27.9	175.9	31.1
RM32	159.9	356.7	6.2	32.4	9	2.5	5.7	39.3	28.7	100.2	63.6	195.6	26.8	214.4	25
MAG1	169.7	270.4	7	40.7	14.9	0.3	3.7	93.2	48.1	118.2	84.6	222.8	20.7	230.1	31.9
MAG2	150.4	572.9	5.9	34.6	20.4	1.2	4.6	98.4	68.1	133.7	108.3	207.3	26.7	503.1	25.4
K1	170.8	115.1	7.2	40.2	12.6	0	2.9	85.7	101.4	116	146.6	200.3	10	77.8	27.1
K2	167.7	154.9	6.9	38.9	23.2	0.7	3.1	97.3	72.4	123.4	147.7	203.1	8.2	154.5	27.1

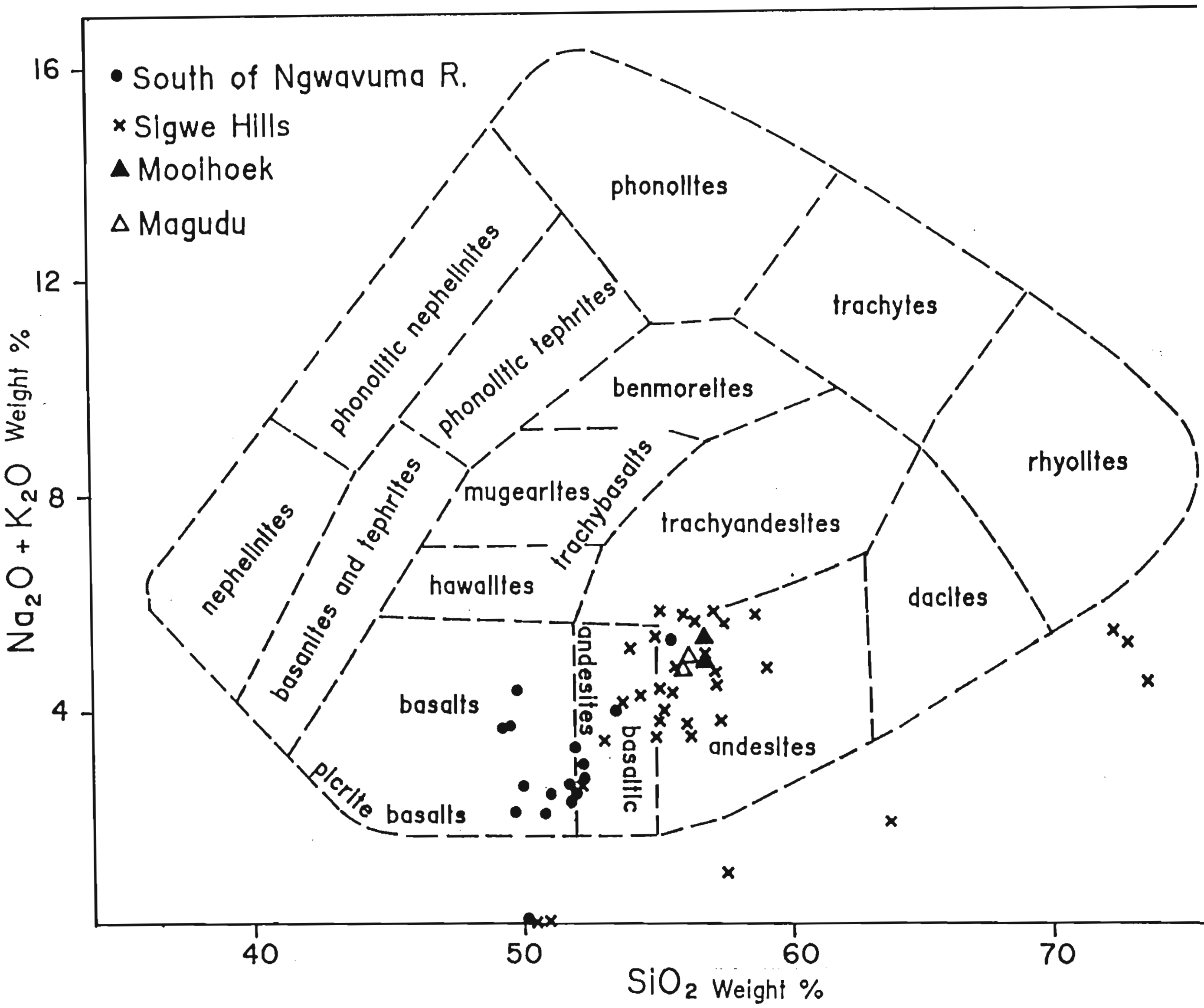

Figure 6.1 The nomenclature of normal (low-K) volcanic rocks showing the superimposed plots of the lavas. The boundary lines and fields of this diagram (Cox *et al.*, 1979) are arbitrary. The diagram serves to categorise the lavas, but is not a strict classification. Note the group of samples depleted in alkalis.

Table 6.2: Parameters and values used in plotting the frequency diagrams in Figure 6.2 determined for the forty seven samples.

ELEMENT	MEAN	STD. DEV	1ST QUARTILE	MEDIAN	3RD QUARTILE	I.Q. RANGE
SiO_2	55.49	5.37	52.07	55.19	56.74	4.67
Al_2O_3	14.12	1.52	13.14	14.39	14.95	1.81
Fe_2O_3	1.19	0.22	1.13	1.21	1.33	0.20
FeO	9.63	1.80	9.12	9.79	10.76	1.64
MnO	0.16	0.04	0.15	0.17	0.18	0.03
MgO	4.68	1.35	4.22	4.99	5.64	1.42
CaO	9.45	2.46	8.22	9.24	10.69	2.47
Na_2O	2.79	1.31	2.11	2.82	3.74	1.63
K_2O	0.95	1.01	0.31	0.69	1.16	0.85
TiO_2	1.07	0.34	0.85	0.99	1.38	0.53
P_2O_5	0.19	0.07	0.14	0.17	0.24	0.10
Zr	167.28	62.38	135.30	158.90	167.20	31.90
Sr	291.10	129.28	204.00	262.20	326.00	122.00
Nb	7.67	3.68	5.90	6.90	8.00	2.10
Y	36.92	10.34	33.00	35.20	37.30	4.30
Rb	25.83	21.31	7.76	22.80	43.00	35.40
U	0.90	1.08	0	0.50	1.60	1.60
Th	4.15	5.14	1.50	3.40	4.80	3.33
Zn	90.64	28.10	80.60	95.00	101.00	20.40
Cu	63.97	43.66	26.30	65.00	101.50	75.20
Ni	102.91	50.65	96.30	106.30	111.00	14.7
Cr	119.01	78.34	56.30	69.60	197.00	140.70
Va	224.24	55.95	214.20	229.90	253.00	38.80
La	26.92	20.65	18.00	23.00	27.00	9.00
Ba	234.96	213.84	79.00	175.90	326.20	247.20
Sc	29.88	6.49	29.70	31.40	34.00	4.30

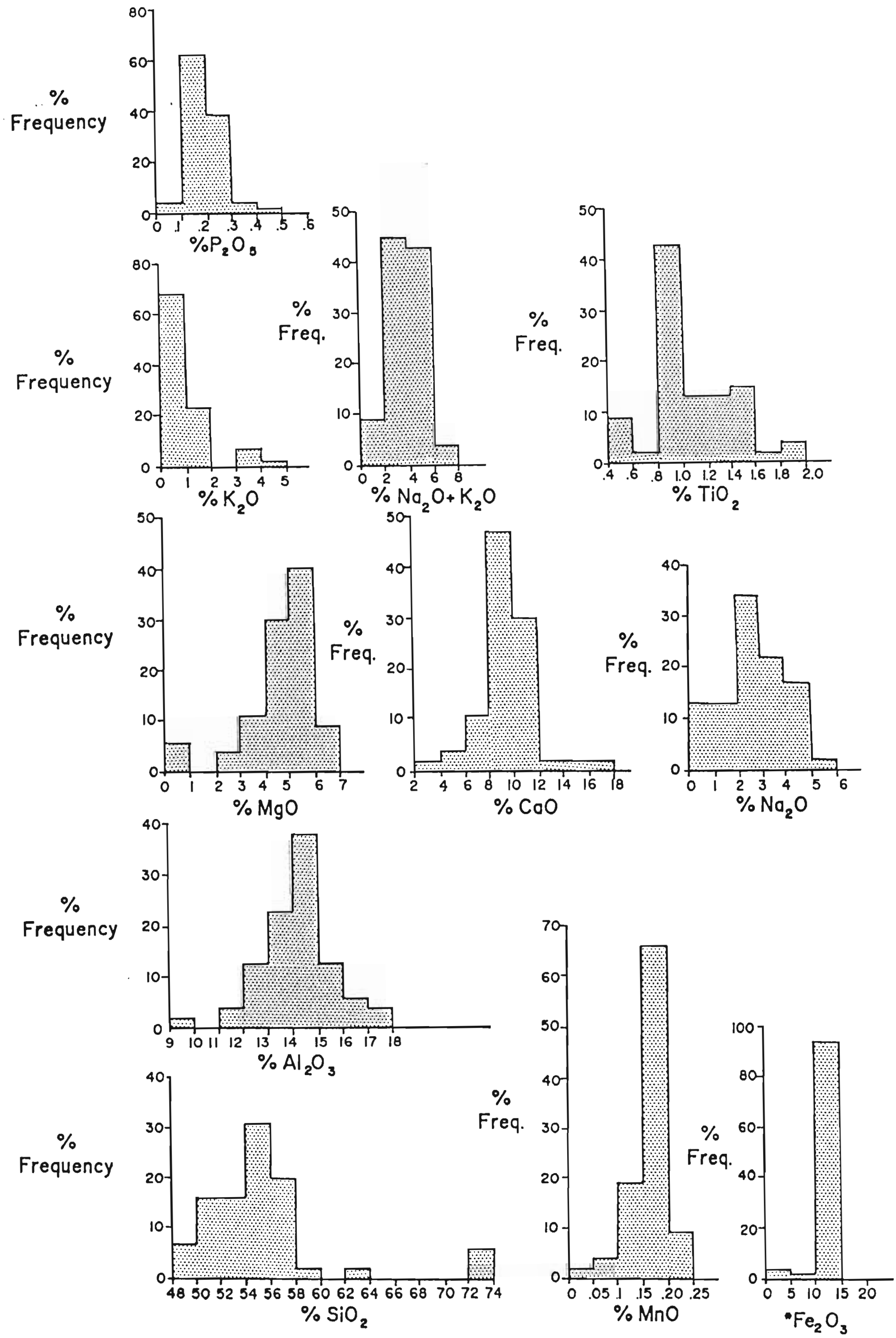

Figure 6.2a: Major element frequency distribution diagrams for the volcanic rocks.

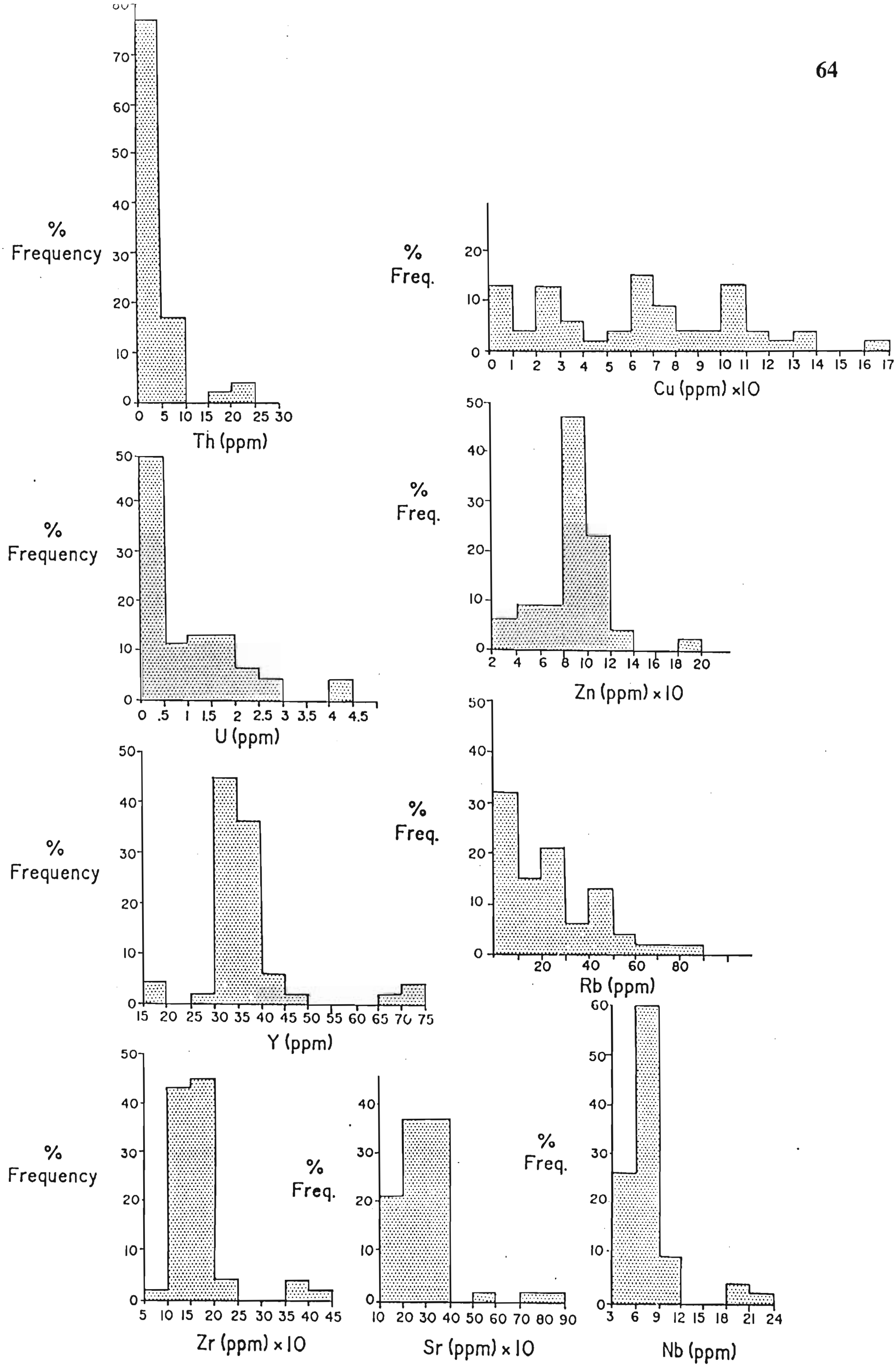

Figure 6.2b: Trace element frequency distribution diagrams for the volcanic rocks.

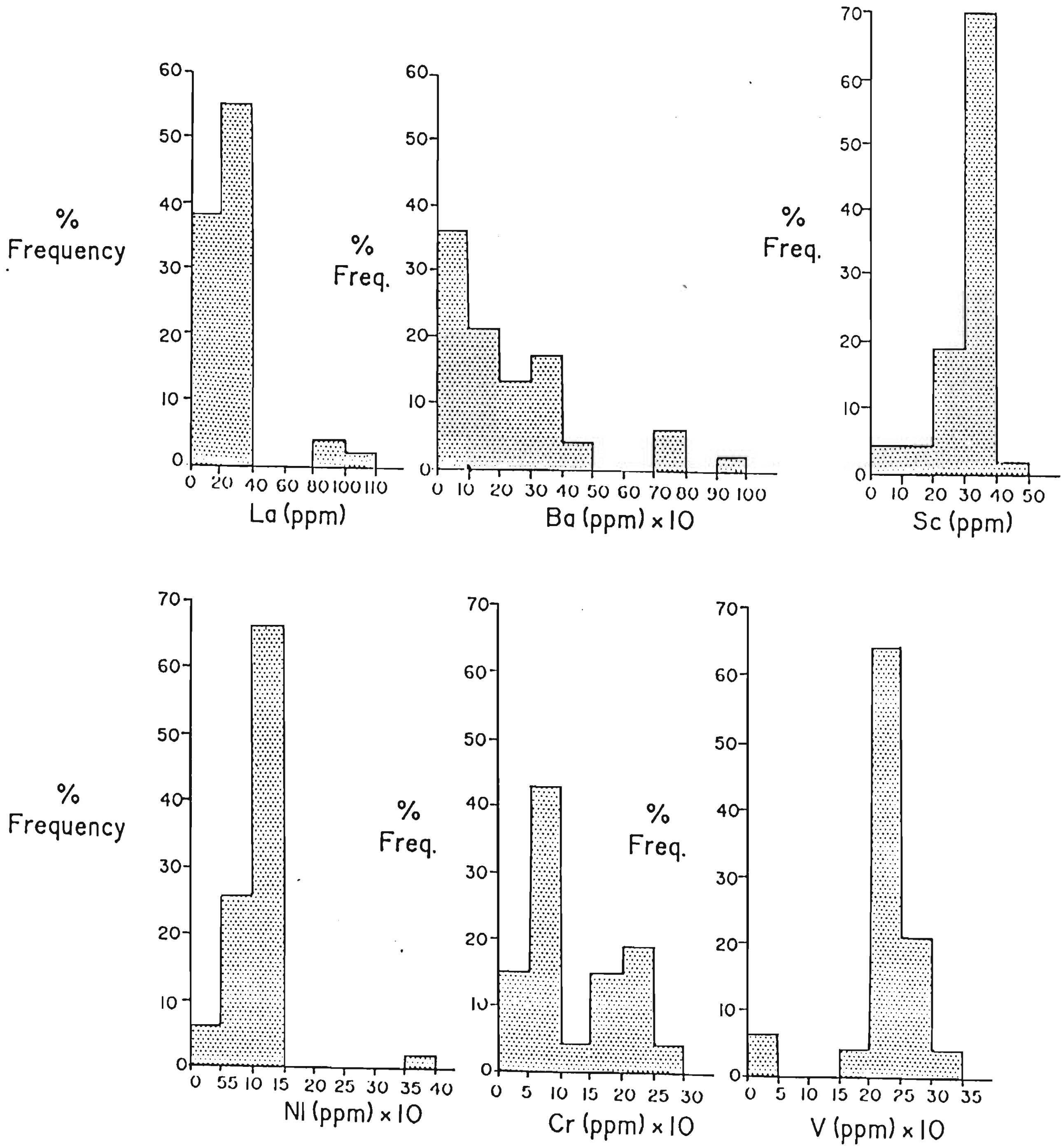

Figure 6.2b (continued).

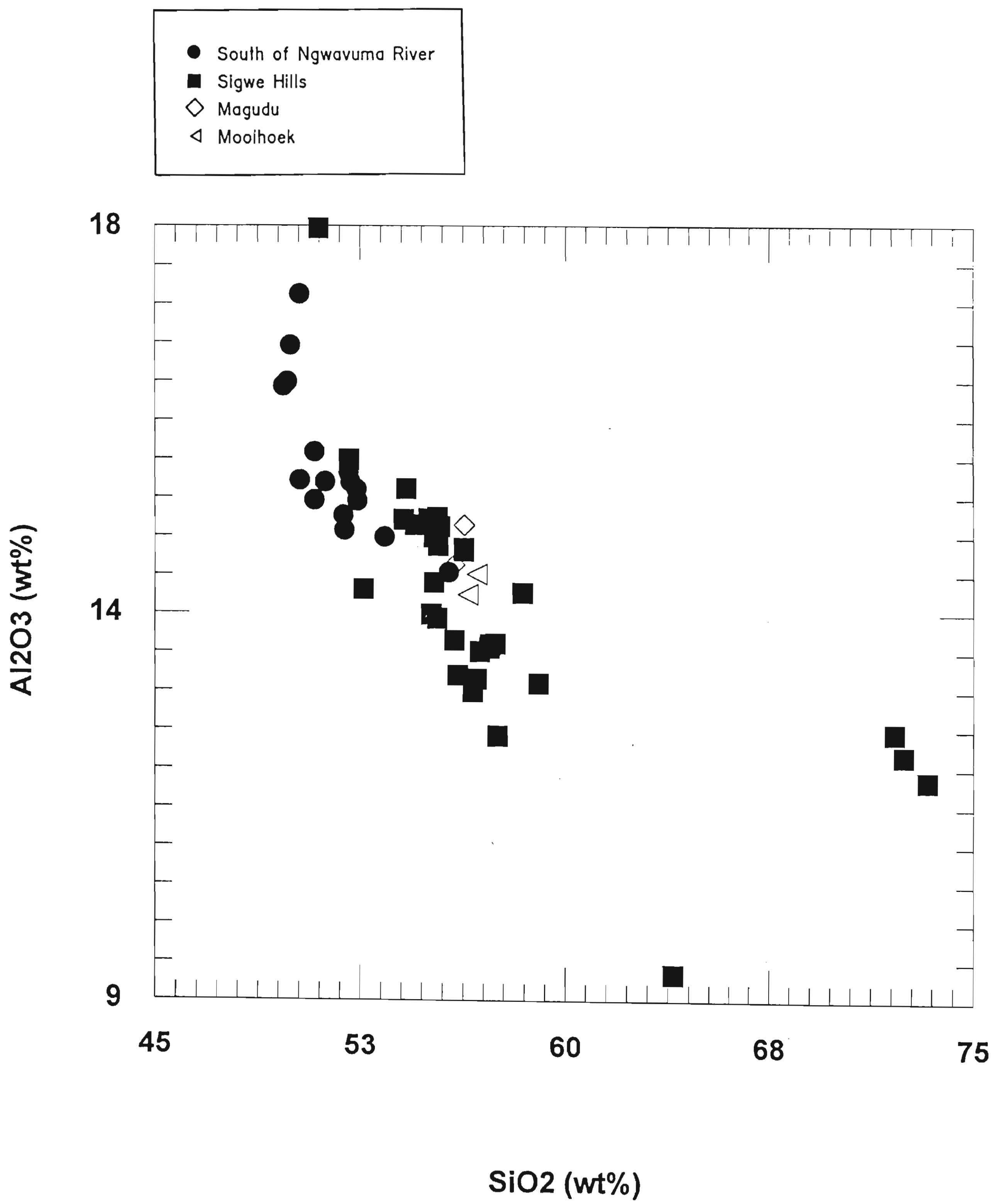

Figure 6.3: Variation diagram of Al_2O_3 vs SiO_2.

Calcium plot against SiO_2 (Figure 6.4c) overall displays a decrease with increasing SiO_2 concentrations. This is however not true for the three felsic samples for which there is clearly an increase in CaO with increase in SiO_2. The range in CaO content is large (from 3.8 to 18%) with a large number of the samples between 6 and 12%. Samples from south of the Ngwavuma River which are generally lower in SiO_2 have higher contents of CaO than the samples from Sigwe Hills in the north with only a few exceptions. The variation by this element may be the result of calcium mobility. During metamorphism, calcium would commonly be retained by actinolite or epidote which are present in the rocks in question. During albitization, sericitization and plagioclase recrystallization, calcium is released.

Titanium (TiO_2) shows also a general decrease with increase in SiO_2 (Figure 6.4d). Three distinct compositional fields were delineated. Samples from south of the Ngwavuma River typically have higher concentrations of this element (range between 1.2 - 1.9%) than those from Sigwe to the north (range between 0.8 - 1.15%). The third field comprises the three rhyolitic samples with the lowest TiO_2 levels of less than 0.5% weight. Sphene is present in samples which have high TiO_2 concentrations.

Total iron (as $*Fe_2O_3$) plotted against SiO_2 shows a general decrease in concentration with increase in silica (Figure 6.4e). The majority of samples have total iron concentrations between 10% and 15% weight. The three felsic samples have the lowest total iron between 4% and 6% weight.

Plots of K_2O, Na_2O and total alkalis ($K_2O + Na_2O$) versus silica all show an increase in concentration with an increase of silica (Figure 6.4 f,g,h). The range in K_2O content is small from 0 to 1.6%, with a majority of samples having about 0.5%. The lower silica samples from south of the Ngwavuma River have a lower K_2O content than the rest of the data set (Figure 6.4f).

Sodium (Na_2O) shows a wider range from 0% to 5.5%. A large number of samples lie in the range between 2% to 5%. The Na_2O concentration increases with increasing SiO_2 and (as seen in Figure 6.4g), this relationship seems to be represented by two distinct fields. The plot of total alkalis against silica (Figure 6.4h) shows an increase in the total alkalis with an increase in silica content and this relationship is also represented by two different fields. The suite of rocks with low alkali content seems more altered and are not necessarily from the same area. This suggests that the effects of alteration could be the same irrespective of the composition of the rocks being altered.

The phosphorus (P_2O_5) versus silica plot shows a well constrained trend of decreasing P_2O_5 with increasing SiO_2 (Figure 6.4i). The range in P_2O_5 is fairly large (from 0.1 to 0.34%) with samples from south of the Ngwavuma River having higher P_2O_5 contents than those from Sigwe Hills.

Major element oxides are shown plotted ag ainst MgO (Figure 6.5). These trends are less well defined than for plots against SiO_2. The observed scatter may reflect mobility of elements during metamorphism and/or alteration (Armstrong *et al.*, 1986). Some of these variation diagrams show two distinct groupings suggesting that the population of the samples south of the Ngwavuma River and those from Sigwe Hills are different.

Total alkalis plotted against MgO display a scatter (Figure 6.5a). Calcium (CaO) plotted against MgO shows that for samples south of the Ngwavuma River there is a decrease in the CaO content with increasing MgO content. The samples from Sigwe Hills show a scatter when plotted against MgO (Figure 6.5b). The plot of MnO versus MgO shows a positive correlation where there is an increase in the MnO content with an increase of the MgO (Figure 6.5c). Silica (SiO_2) plotted against MgO shows a scatter but there is an obvious grouping of two sets of populations with the samples from the Sigwe Hills having higher SiO_2 contents than those from south of the Ngwavuma River (Figure 6.5d).

Total iron ($^*Fe_2O_3$) against MgO is a scatter but also shows a group of iron enriched samples from south of Ngwavuma River as a distinct group as compared to those from the Sigwe Hills (Figure 6.5e). The plot of titanium (TiO_2) against MgO (Figure 6.5f) is a scatter but shows the two distinct groups of sample populations. The samples south of the Ngwavuma River valley are enriched in TiO_2 (all above 1.2%) compared with those from the north in the Sigwe Hills with TiO_2 contents below 1.2%. Phosphorus (P_2O_5) versus MgO displays a scatter (Figure 6.5g) with the samples grouped distinctly into two scatter fields. Plotting potassium (K_2O) against MgO shows a scatter (Figure 6.5h) with a large number of samples from south of the Ngwavuma River having lower K_2O contents ($<$ 0.5%) than those from the Sigwe Hills. Plots of Na_2O and Al_2O_3 against MgO both display wide scatter (Figure 6.5i and Figure 6.5j).

6.3.3 Trace element geochemistry

The diagrams for most of the trace elements plotted against SiO_2 are shown in Figure 6.6.

Copper shows considerable scatter when plotted against silica (Figure 6.6a). The observed Cu contents for the Pongola Sequence volcanic rocks (this study) are highly variable ranging from 0 ppm to 170 ppm. This variation in Cu is probably due to variable amounts of sulphide minerals present within the suite. Humphris and Thompson (1978) conclude that Cu is readily leached from metabasalts by hydrothermal fluids. However the Pongola Sequence volcanic rocks under investigation do not seem to show any positive evidence of leaching of Cu.

Nickel values are grouped together in the plot against SiO_2 showing no definite trend (Figure 6.6b). The range in Ni content is small, from 50 ppm to 148 ppm, with the majority of samples having about 110 ppm. A highly anomalous sample from Sigwe Hills has about 380 ppm Ni. The three highly siliceous and felsic samples have very low Ni contents.

In the plot of Cr versus SiO_2 (Figure 6.6c), there are two distinct groupings. The samples from south of the Ngwavuma River typically have high Cr contents ranging between 148 ppm and 250 ppm. Samples from the Sigwe Hills generally having lower Cr contents between 30 ppm and 90 ppm also forming their separate population. However, amongst the Sigwe Hills samples, there are four highly anomalous samples which have between 230 ppm and 260 ppm. The three felsic samples also from Sigwe Hills are depleted in Cr ($<$ 25 ppm).

Vanadium plotted against silica shows a general decrease in the V concentration with increasing silica content (Figure 6.6d). The rock samples from south of the Ngwavuma River valley, typically lower in SiO_2, have higher V concentration than those from Sigwe Hills which are slightly higher in SiO_2. The range in V is small from 190 ppm to 325 ppm. The high silica felsic samples from Sigwe Hills have very low V contents.

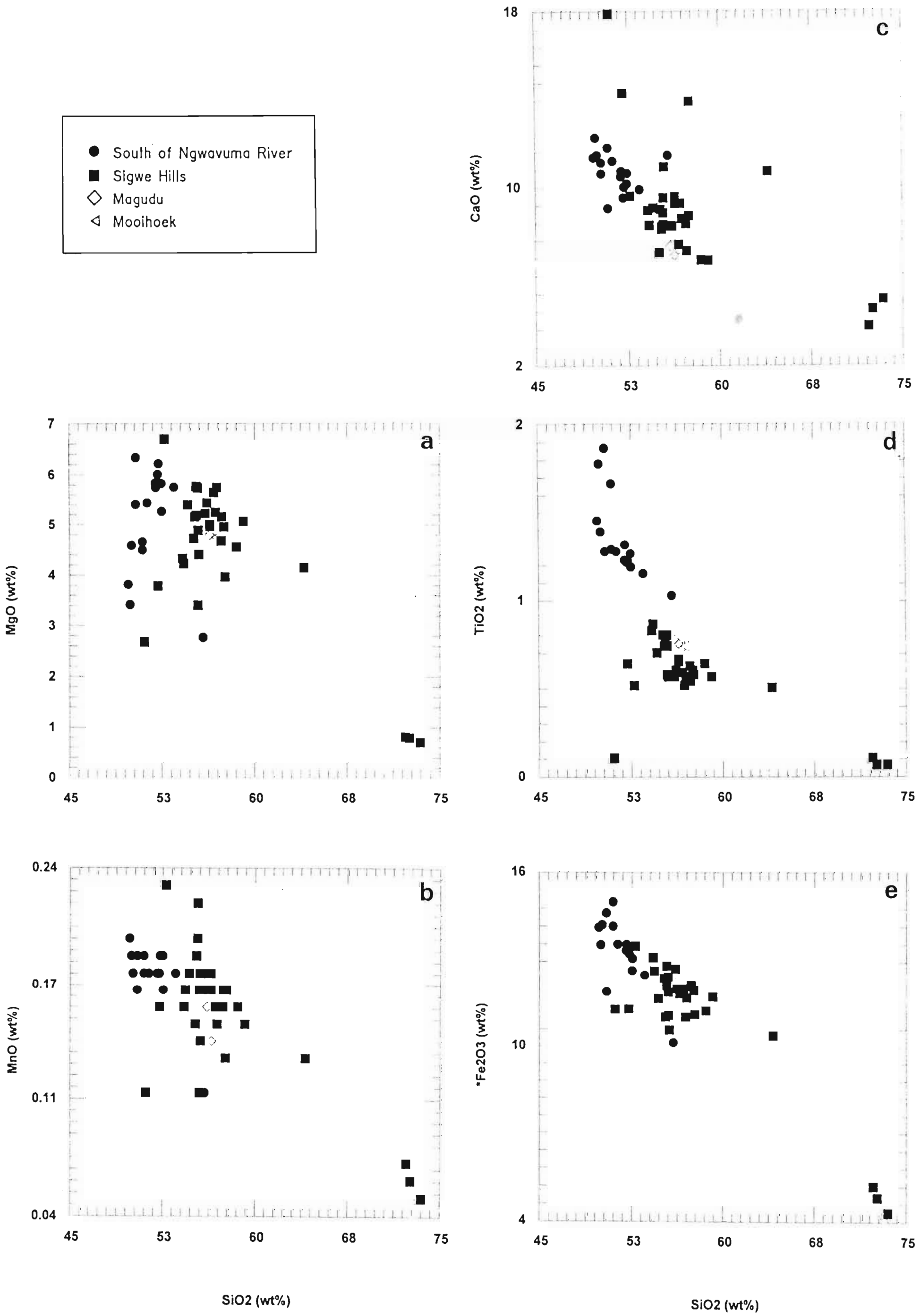

Figure 6.4: Major element oxides plotted against SiO_2.

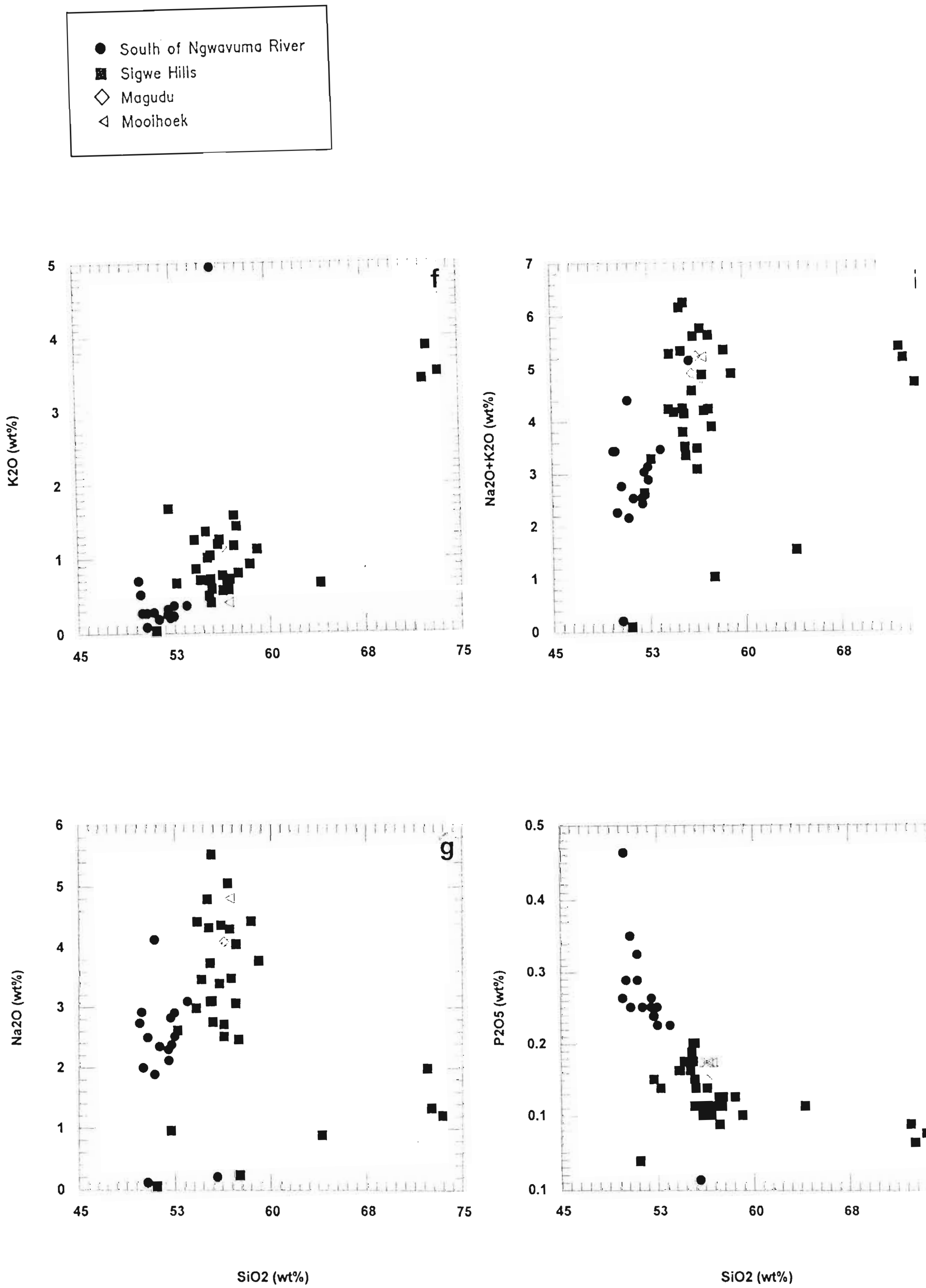

Figure 6.4: Major elements against silica (continued).

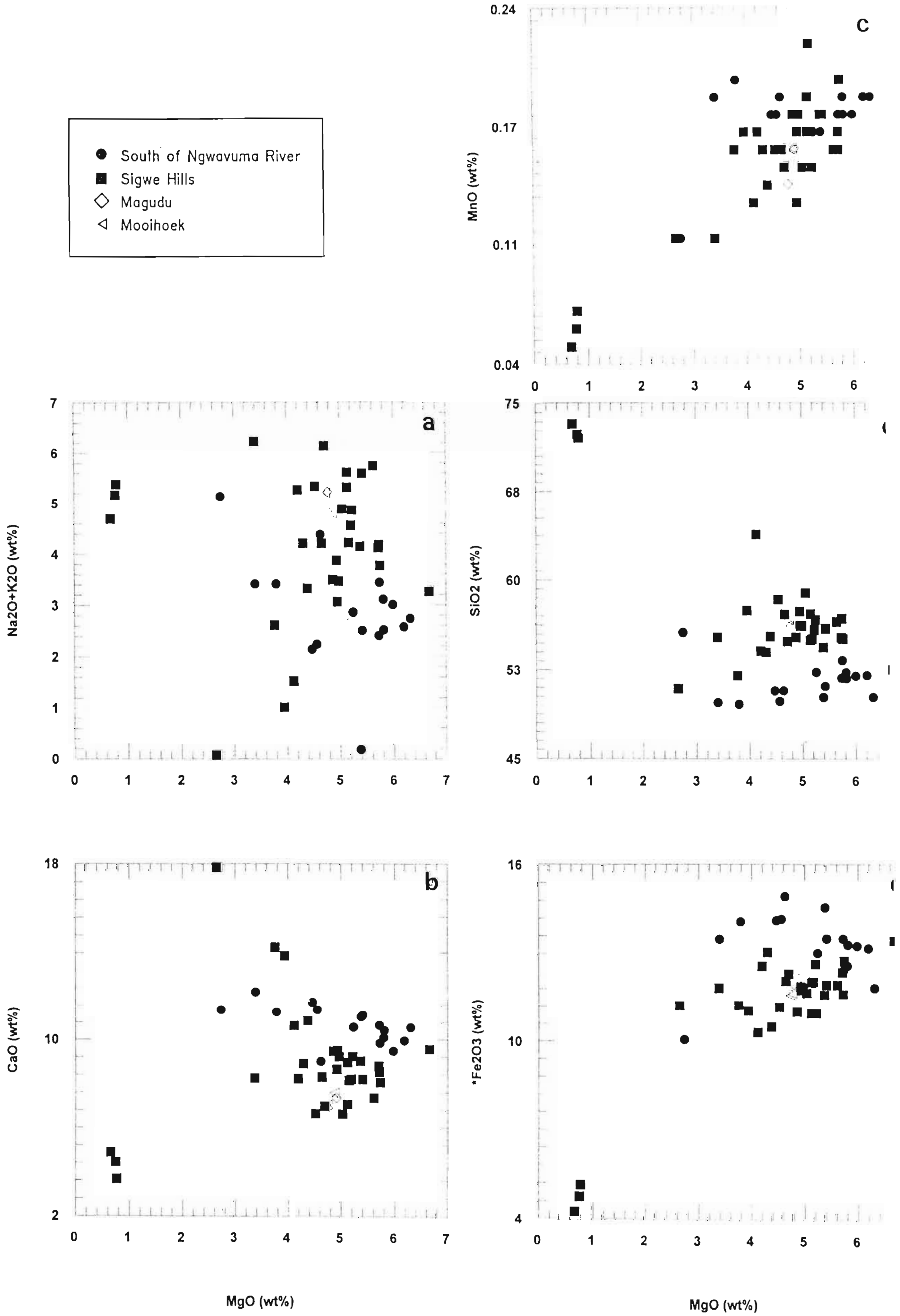

Figure 6.5: Variation diagrams of major element oxides plotted against MgO.

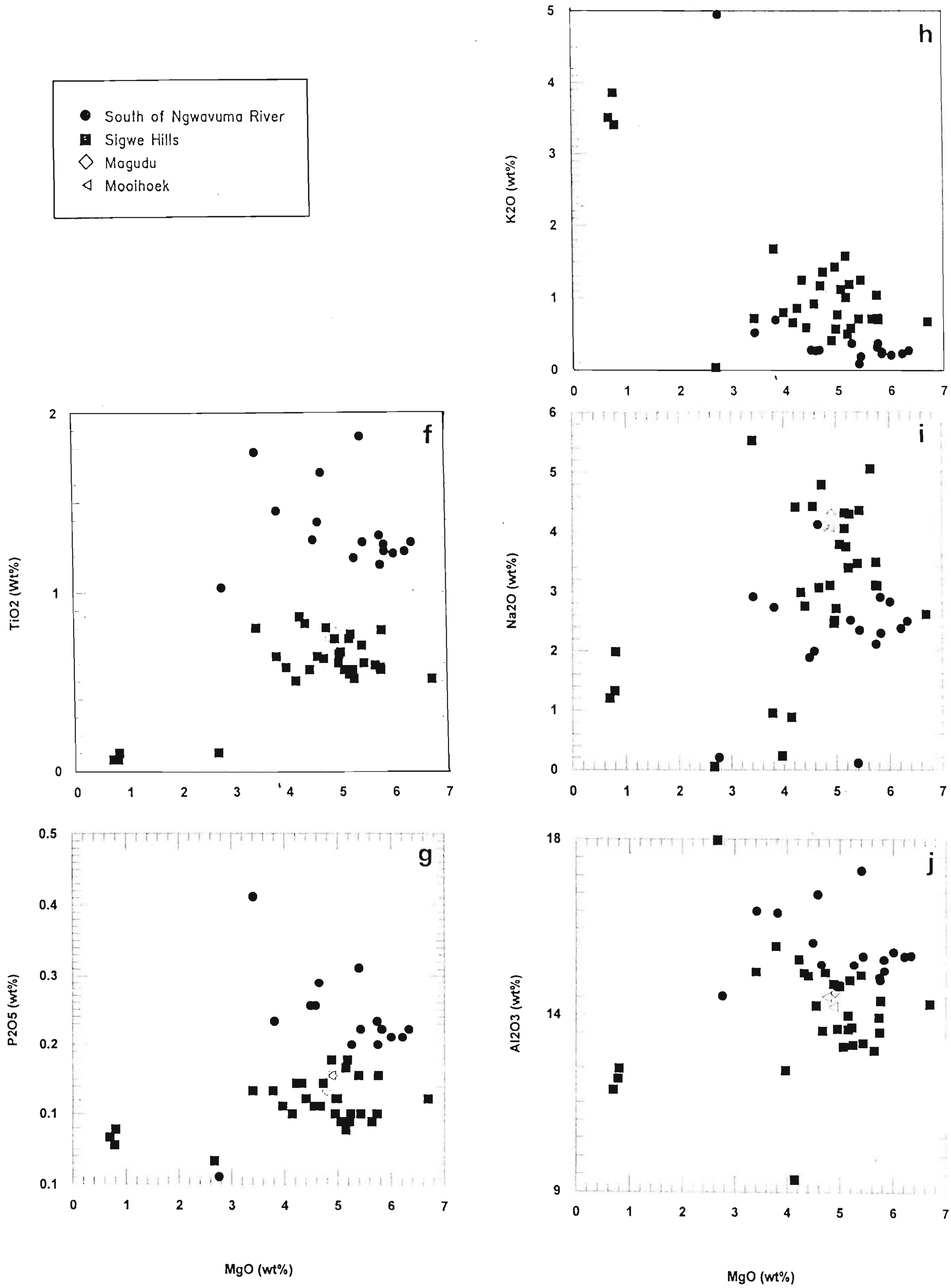

Figure 6.5: Major elements against MgO (continued).

Lanthanum plotted against silica (Figure 6.6e) shows a tight cluster for most samples with the three highly siliceous felsic samples having much higher values. These seem to suggest that La increases on a broad scale with increasing silica concentrations.

Niobium plotted against SiO_2 shows a curvilinear relationship whereby Nb concentrations decrease with increasing SiO_2 for the majority of the samples (Figure 6.6f). Generally the samples from south of the Ngwavuma River with less silica are more enriched in Nb than those with higher silica contents from Sigwe Hills. This apparent correlation is the inverse of what is observed for most magmatic systems and will be discussed in the section on the genesis of the lavas. At high silica levels (as shown by the three felsic/silica enriched samples from Sigwe Hills) it seems that Nb becomes highly enriched.

The plot of Zr versus SiO_2 for the low silica samples displays a rough curvilinear trend whereby Zr concentration decreases with increase in the SiO_2 content (Figure 6.6g). In contrast, the higher silica samples from the Sigwe Hills are strongly enriched in Zr (> 350 ppm). The range in Zr in the former group is fairly small (from 110 ppm to 230 ppm).

Rubidium plotted against silica (Figure 6.6h) shows a scatter with a general sympathetic trend. There are two distinct population groups, the low silica, low Rb samples from south of Ngwavuma and the more Rb enriched, higher silica samples from Sigwe Hills.

Strontium versus silica shows a scatter (Figure 6.6i). The range in Sr concentration is large from 110 ppm to 800 ppm. The majority of samples are grouped between 150 ppm and 400 ppm. The large variation in Sr may be related to substitution for Ca in plagioclase and for K in K-feldspar. According to Pierce and Cann (1973), features such as albitization and Ca-depletion in low-grade metamorphism, as well as fluctuating Sr values in otherwise chemically similar rocks, are good indicators of Sr mobility.

The Zn versus SiO_2 plot (Figure 6.6j) displays a scatter within which there is a field which suggests that Zn may decrease in concentration with increasing silica contents.

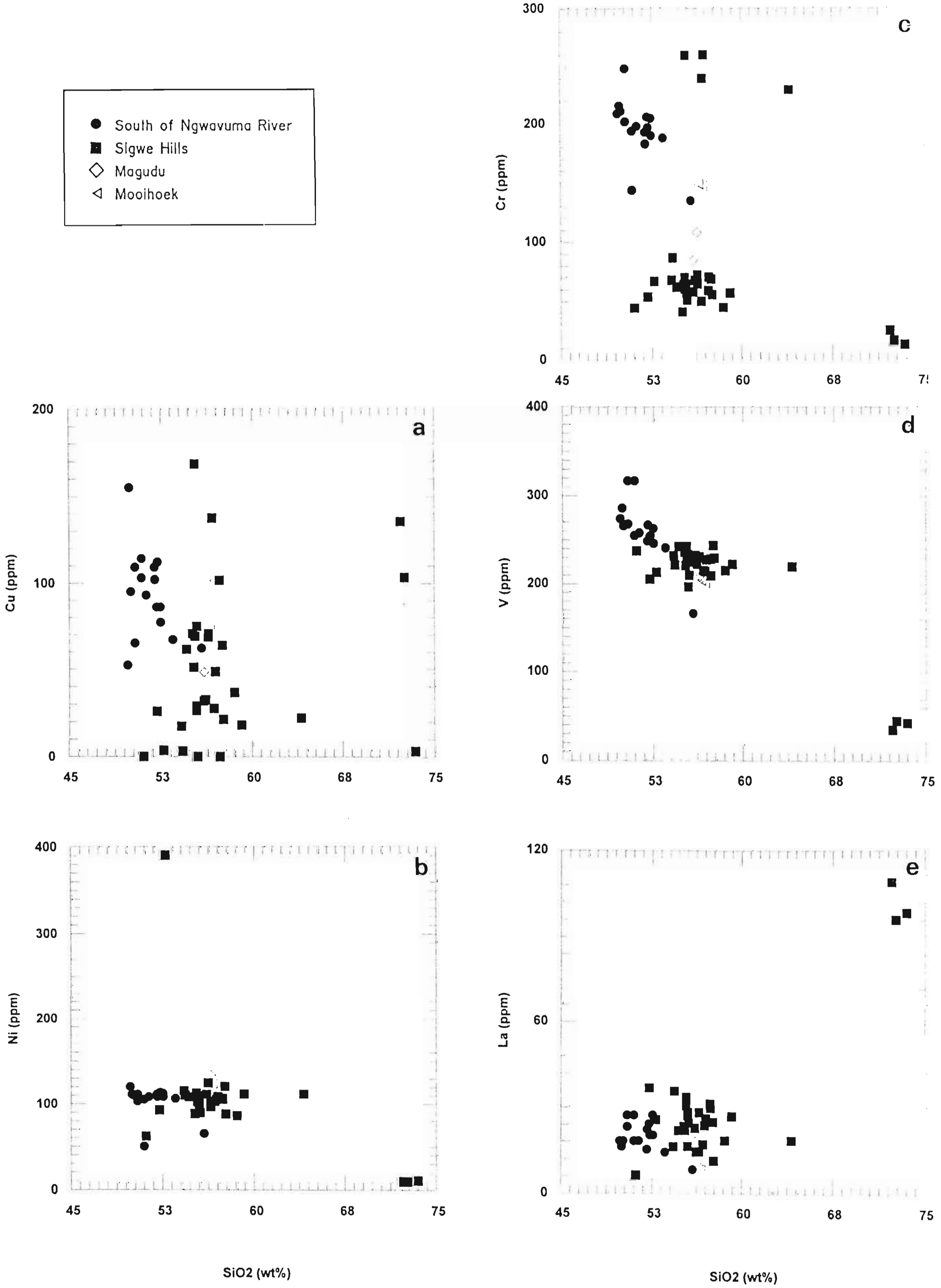

Figure 6.6: Variation plots of trace elements against SiO_2.

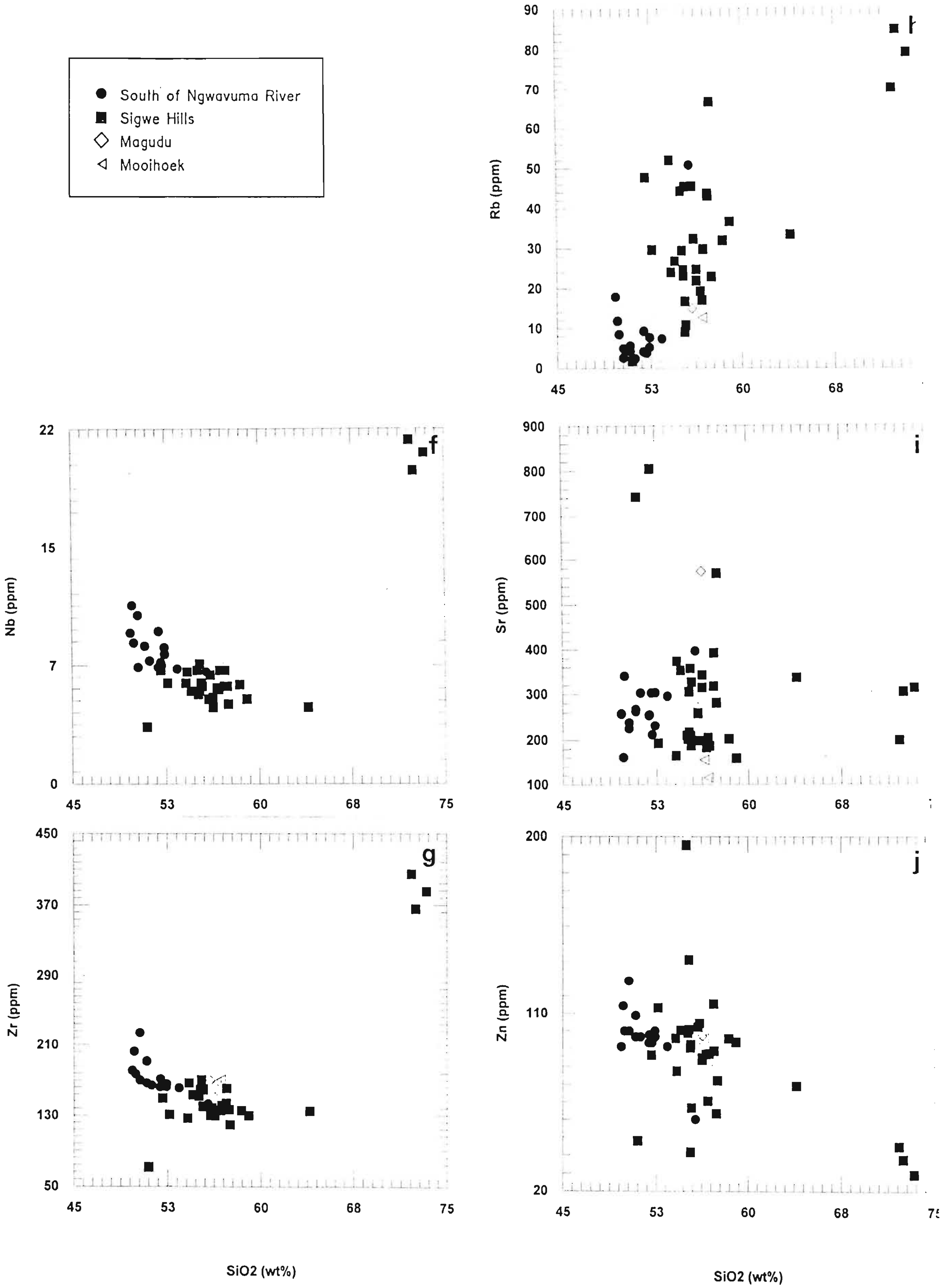

Figure 6.6: Trace elements against SiO_2 (continued).

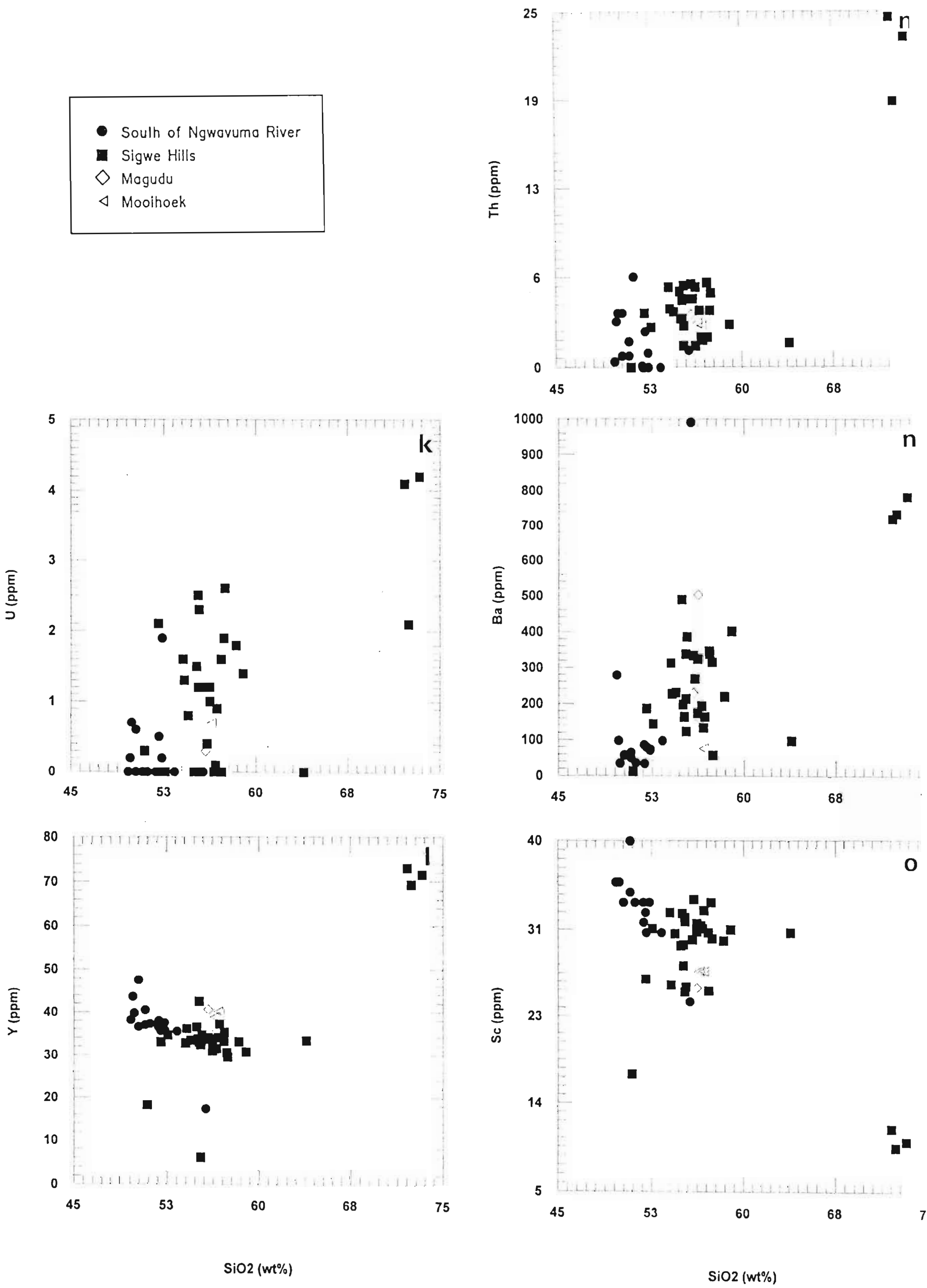

Figure 6.6: Trace elements against silica (continued).

Considerable scatter is observed when uranium is plotted against SiO_2 (Figure 6.6k). Most of the samples from south of the Ngwavuma River show absolute depletion in U. The samples from Sigwe Hills are generally slightly enriched in U. The two highly siliceous samples also have the highest U contents.

Yttrium plotted against SiO_2 shows that there are two distinct populations of indicating each rather dispersed but similar trends (Figure 6.6l). The two trends show that the concentration of Y increases with increasing SiO_2 contents. The samples from south of the Ngwavuma River are slightly enriched in Y compared with samples from Sigwe Hills in which there are a few highly anomalous cases with about 70 ppm Y. Generally the range in Y content is small (between 30 ppm and 48 ppm) with most samples having between 30 and 40 ppm.

The Th versus SiO_2 plot indicates that there is a general enrichment of Th with increasing SiO_2 (Figure 6.6m). The range in Th is small from 0 ppm to 7 ppm with the lower silica rocks from south of the Ngwavuma River having lower Th contents (< 5 ppm) compared to the bulk of rocks from the Sigwe Hills. A clear enrichment in Th with increasing SiO_2 is shown by the three felsic rocks from the Sigwe Hills.

Barium plotted against SiO_2 shows a consistent trend of increasing values with increasing silica (Figure 6.6n). The samples from south of the Ngwavuma River have low Ba contents, generally less than 100 ppm, except one highly anomalous sample with 1000 ppm Ba. Those samples from Sigwe Hills have Ba contents mostly above 100 ppm.

The Sc versus SiO_2 plot shows that with increasing silica concentrations, this element becomes depleted (Figure 6.6o). The rocks lower in SiO_2 from south of the Ngwavuma River are more enriched in Sc than the samples from Sigwe Hills which have more silica. The highest silica samples from Sigwe Hills (felsic), have the lowest Sc contents ($\sim$10 ppm) whereas the majority of the rocks have between 35 to 30 ppm Sc (Fig.6.6o).

The trace elements were also plotted against MgO and most of the variation diagrams obtained display considerable scatter (Figure 6.7).

Nickel plotted against MgO shows a trend of increasing values with increasing MgO (Figure 6.7a). This trend is especially true for the samples from Sigwe Hills. The range in Ni is small (from 50 to 125 ppm) with a majority of the samples at about 100 ppm. One MgO rich sample from Sigwe Hills is extremely enriched in Ni at about 380 ppm (not shown in figure). Three very low MgO samples from Sigwe (felsic) are depleted in Ni at about 10 ppm. However, considerable scatter in the data exists for this plot and a linear regression line is shown for all data for reference purposes.

Copper plotted against MgO shows considerable scatter (Figure 6.7b) with no distinct trend. The variation in the Cu content is very large ranging from 0 to 170 ppm.

Chromium plotted against MgO indicates that two clear fields of data exist (Figure 6.7c). The samples from the Sigwe Hills show a trend of increasing Cr content with increasing MgO. These samples have generally low Cr contents with a range between 10 to 80 ppm, but three anomalous samples average about 240 ppm Cr. On the other hand the rocks from south of Ngwavuma River seem to show a decrease in Cr with increase in MgO. These samples are generally high in their Cr content (averaging about 200 ppm), compared to those south of the Ngwavuma River.

Zinc plotted against MgO displays scatter but indicates an overall sympathetic trend (Figure 6.7d). The samples from Sigwe Hills are clearly depleted in Zn compared with those from south of the Ngwavuma River.

The plot of Zr versus MgO is a scatter (Figure 6.7e) with no distinct trend. The three felsic rocks from Sigwe Hills are highly enriched in Zr.

Vanadium plotted against MgO shows a scatter (Figure 6.7f) within which the samples from south of the Ngwavuma River, because of their higher V contents (> 250 ppm) are grouped together, whereas those from Sigwe Hills also form a group of their own with V contents below 250 ppm. The felsic samples, very low in MgO, are also very depleted in V (< 50 ppm).

Niobium plotted against MgO displays a scatter (Figure 6.7g) and the three low MgO felsic samples from Sigwe are highly enriched in Nb (averaging 20 ppm).

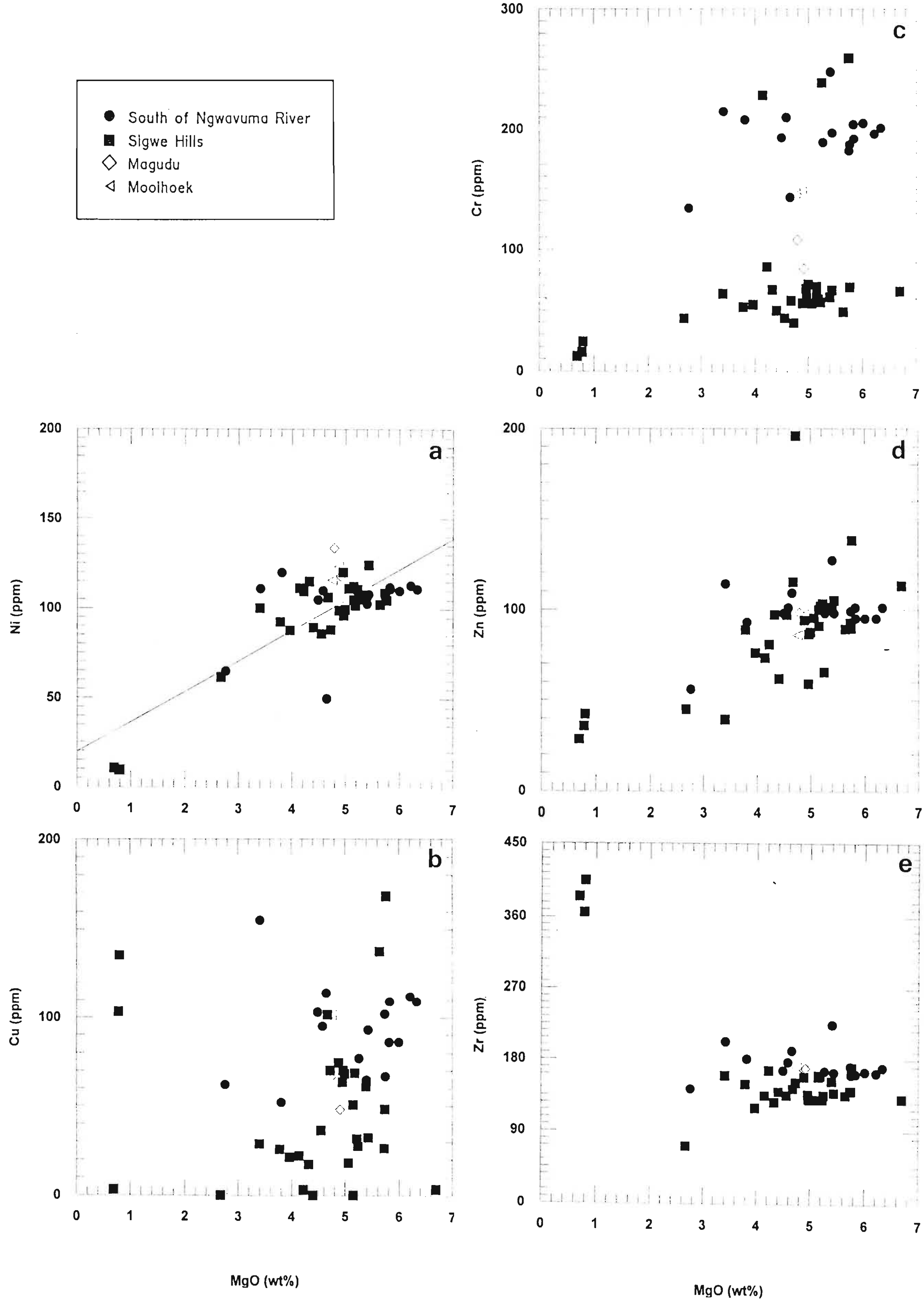

Figure 6.7: Variation diagrams of trace elements plotted against MgO for the volcanic rocks.

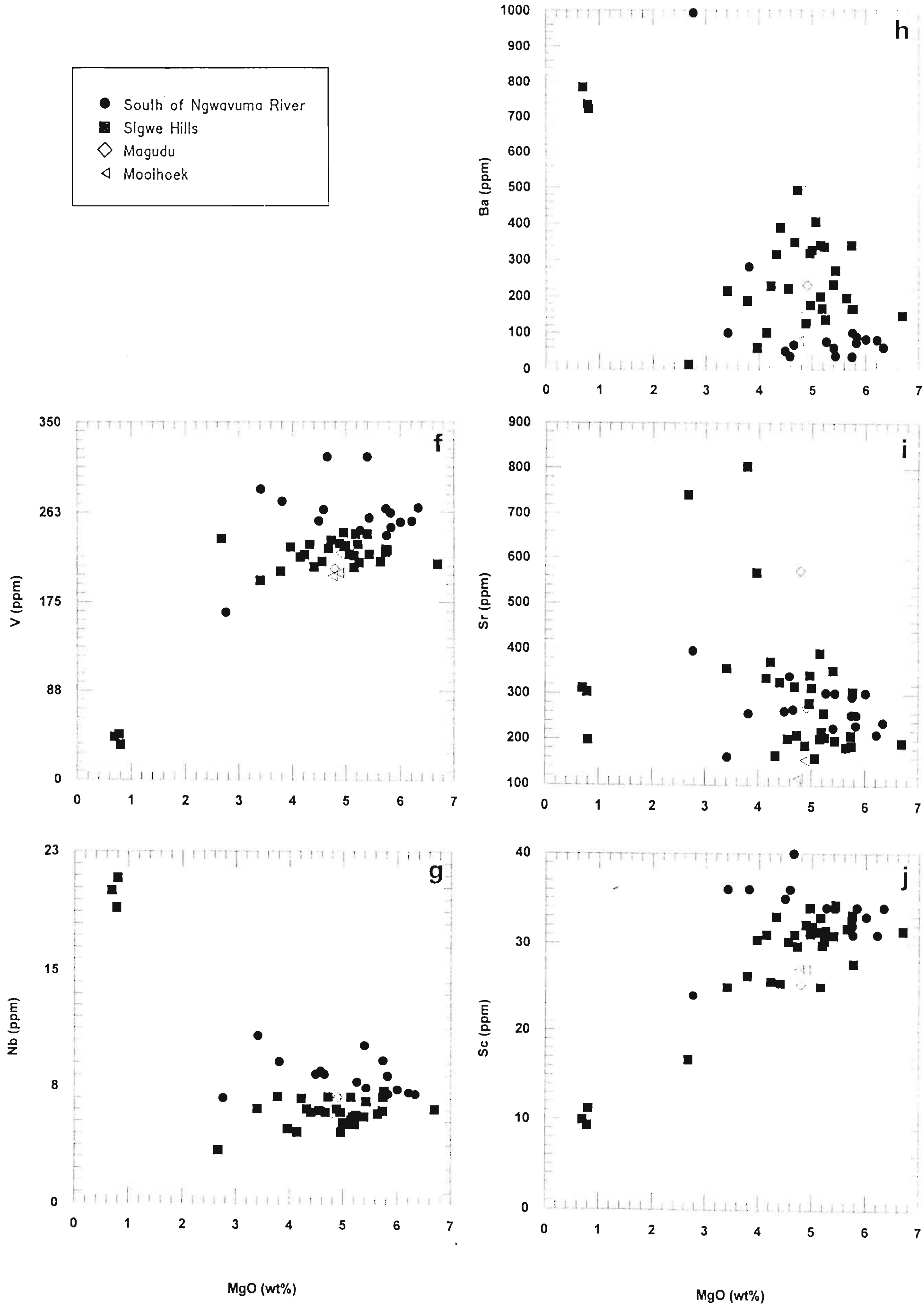

Figure 6.7: Trace elements plotted against MgO (continued.).

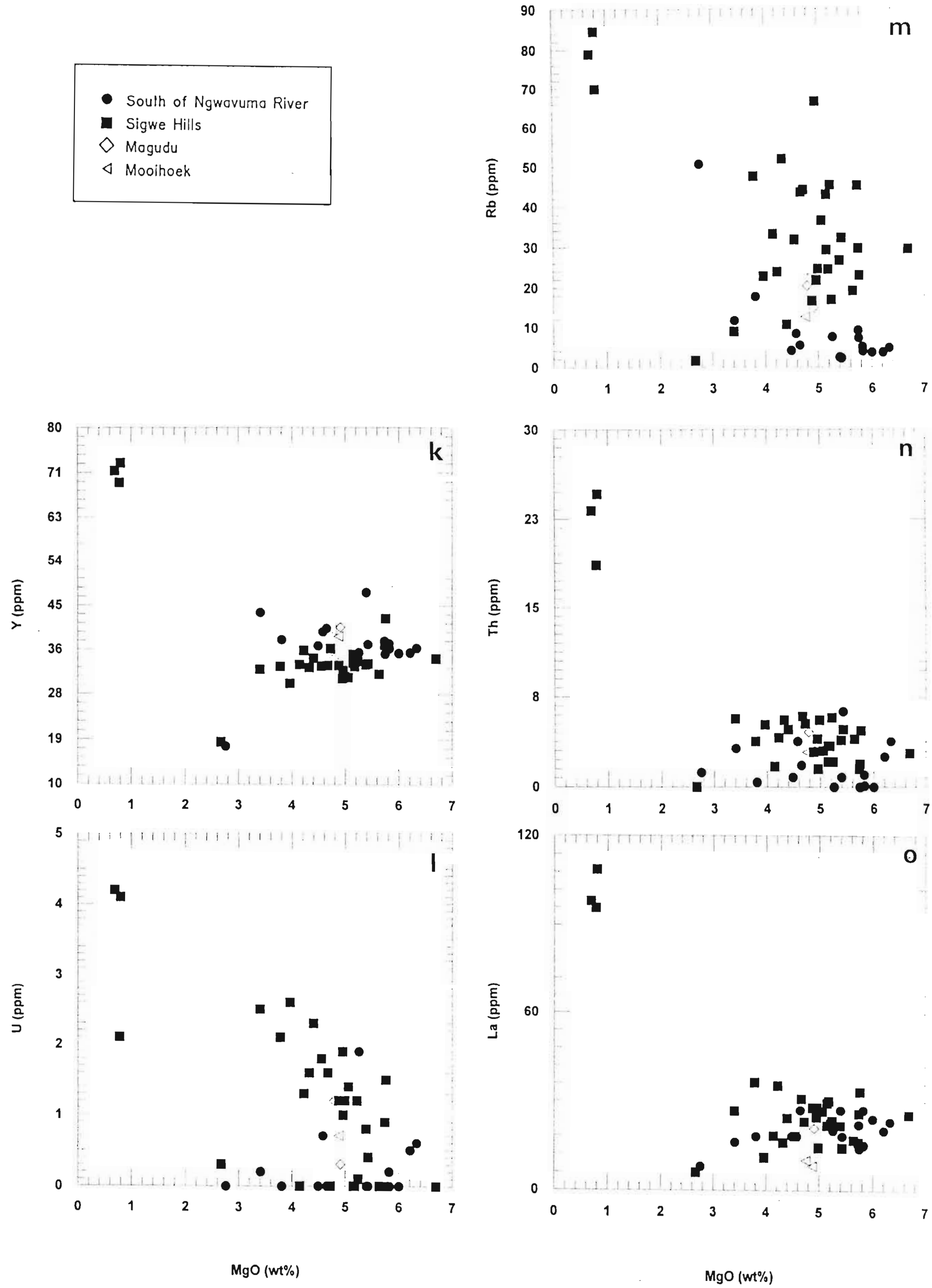

Figure 6.7: Trace elements plotted against MgO (continued.).

The plot of barium against MgO (Figure 6.7h) shows that the samples south of the Ngwavuma River are depleted in Ba (< 100 ppm) while the Sigwe Hills' samples are slightly enriched in Ba (> 100 ppm).

Strontium plotted against MgO displays considerable scatter with a very wide range of Sr contents (between 50 and 800 ppm) (Figure 6.7i). Such scatter is indicative of alteration of the samples.

A plot of Sc against MgO (Figure 6.7j) shows a scatter, but samples from Sigwe Hills display a trend of increasing Sc with increasing MgO.

Yttrium plotted against MgO (Figure 6.7k), does not show any particular trend because of the very small range in Y contents.

The plot of uranium against MgO (Figure 6.7l) show a very clear trend of decreasing U against increasing MgO, a trend especially true for the higher Mg samples from Sigwe Hills. The majority of samples from south of the Ngwavuma River are depleted in U.

Rubidium plotted against MgO (Figure 6.7m) shows considerable scatter. The samples from south of the Ngwavuma River in the range 4 to 7% MgO are depleted in Rb (< 10 ppm) compared to samples from Sigwe Hills with the same amount of MgO which have Rb contents of up to 55 ppm. The felsic samples are highly enriched in Rb (in excess of 70 ppm).

The plot of Th versus MgO (Figure 6.7n) is a scatter. The felsic samples from Sigwe are slightly enriched in Th with contents between 18 ppm and 25 ppm.

Lanthanum plotted against MgO (Figure 6.7o) shows a scatter with a small range in La for most of the samples (between 4 ppm and 40 ppm). The three felsic samples from Sigwe Hills which are also very low in Mg, are highly enriched in La with contents of between 98 ppm and 130 ppm.

Figure 6.8 shows the high field strength elements Nb, Zr, Sr and Y plotted against Mg number (Mg* calculated as Mg/(Mg+Fe tot)). These elements display vague increases with decreasing Mg* which is consistent with crystal fractionation (Armstrong, *et al.*, 1986). This overall trend is strongly controlled by the three felsic samples. Large ion lithophile (LIL) elements plotted against Mg* (eg. Rb) display scatter which probably reflects processes such as alteration and metamorphism imposed on a differentiation trend.

6.4 DISCUSSION

There are notable differences among the Pongola Sequence volcanic rocks with regards to enrichment and depletion of certain elements. The samples from south of the Ngwavuma River are significantly enriched in TiO_2, Zr and Y but depleted in Ba, U, and K_2O relative to samples from Sigwe Hills. In the same way, samples from south of the Ngwavuma River valley are high in Fe_2O_3 and are depleted in SiO_2 relative to the samples from Sigwe Hills.

The plot of Al_2O_3 against SiO_2 shows three population groups pertaining to each of the geographic locations of the samples. Two of the trends are controlled by two major populations of mafic samples and one minor population controlled by the relatively fewer felsic rocks. This plot shows a decrease in Al_2O_3 with increasing SiO_2. This decrease in Al_2O_3 is indicative of feldspar fractionation for the more mafic rock series. The samples with higher SiO_2 contents (>70%), are rhyolites and do not lie on the same trend as the more mafic rock samples.

Calcium decreases with increasing concentrations of SiO_2 to give a broad trend. In the plot, however, there are a number of samples which do not conform to this overall trend. This deviation may be the result of Ca mobility. Titanium plotted against SiO_2 shows three distinct fields, all showing a trend of decreasing TiO_2 with increasing SiO_2 levels. The three fields conform to the geographic locations of the samples from south of the Ngwavuma River, Sigwe Hills and the felsic rocks from Sigwe hills. The bulk of the samples, however, form a well constrained trend which is also consistent with feldspar fractionation. The samples from south of the Ngwavuma River contain sphene. Titanium would generally be considered an immobile element (Gelinas *et al.*, 1977), however, Pierce and Cann (1973) warn that in rocks containing sphene, care must be taken as this might indicate Ti mobility.

A well constrained trend is also observed for P plotted against SiO_2. Two distinct groupings are observed from this plot, those from south of the Ngwavuma River and those from Sigwe Hills. Total alkalis, Na_2O and K_2O plotted against SiO_2 all show a general increase with increasing SiO_2. The plot of Na_2O vs SiO_2 shows a stray group of samples which does not fall on the observed general trend and these show either depletion of Na_2O or enrichment of SiO_2 or both. These samples probably point to the easy mobility of Na.

The major element oxides plotted against MgO show trends that are not well defined but a more significant observation from these plots is the presence of two different population groups in the data set. The samples from south of the Ngwavuma River are different from those from Sigwe Hills, and within the suite of samples from Sigwe Hills are a minor population of felsic rhyolitic rock samples.

The variation diagrams for trace elements plotted against SiO_2 mostly display scattered trends. Chromium versus SiO_2 groups the data set into two major populations. In the one group of samples with higher Cr contents (south of Ngwavuma River), there is a crude trend of decreasing Cr with increasing SiO_2. This relationship is not true for the other major group of samples from Sigwe Hills which are also depleted in Cr and for which a scatter is observed. A minor population of four samples from Sigwe Hills are highly enriched in Cr, and their position cannot be explained using the present data. The three felsic samples from Sigwe Hills show that Cr decreases with increasing SiO_2 contents.

Vanadium plotted against SiO_2 decreases as the SiO_2 increases, and the samples south of the Ngwavuma River are enriched in V relative to those from Sigwe Hills.

Plots of Nb and Zr versus SiO_2 both show similar curvilinear variations of decreasing Nb and Zr with increasing SiO_2 for most of the samples. Only the felsic samples from Sigwe Hills do not lie on this trend. Zirconium and Nb are known to be immobile during alteration and low-grade metamorphic processes (Winchester and Floyd, 1977) but these plots show that these trace elements both decrease in concentration with increasing silica values (Figure 6.6f and g) except the three silica enriched/felsic samples which show an enrichment in Nb and Zr with increasing silica. The observed trends cannot be readily explained by fractionation processes. The general enrichment of the incompatible elements in the felsic rocks indicates clearly that these rocks are rhyolites and not highly silicified or altered basalts. However, it is also clear that these samples have undergone some degree of alteration and depletion of alkalis.

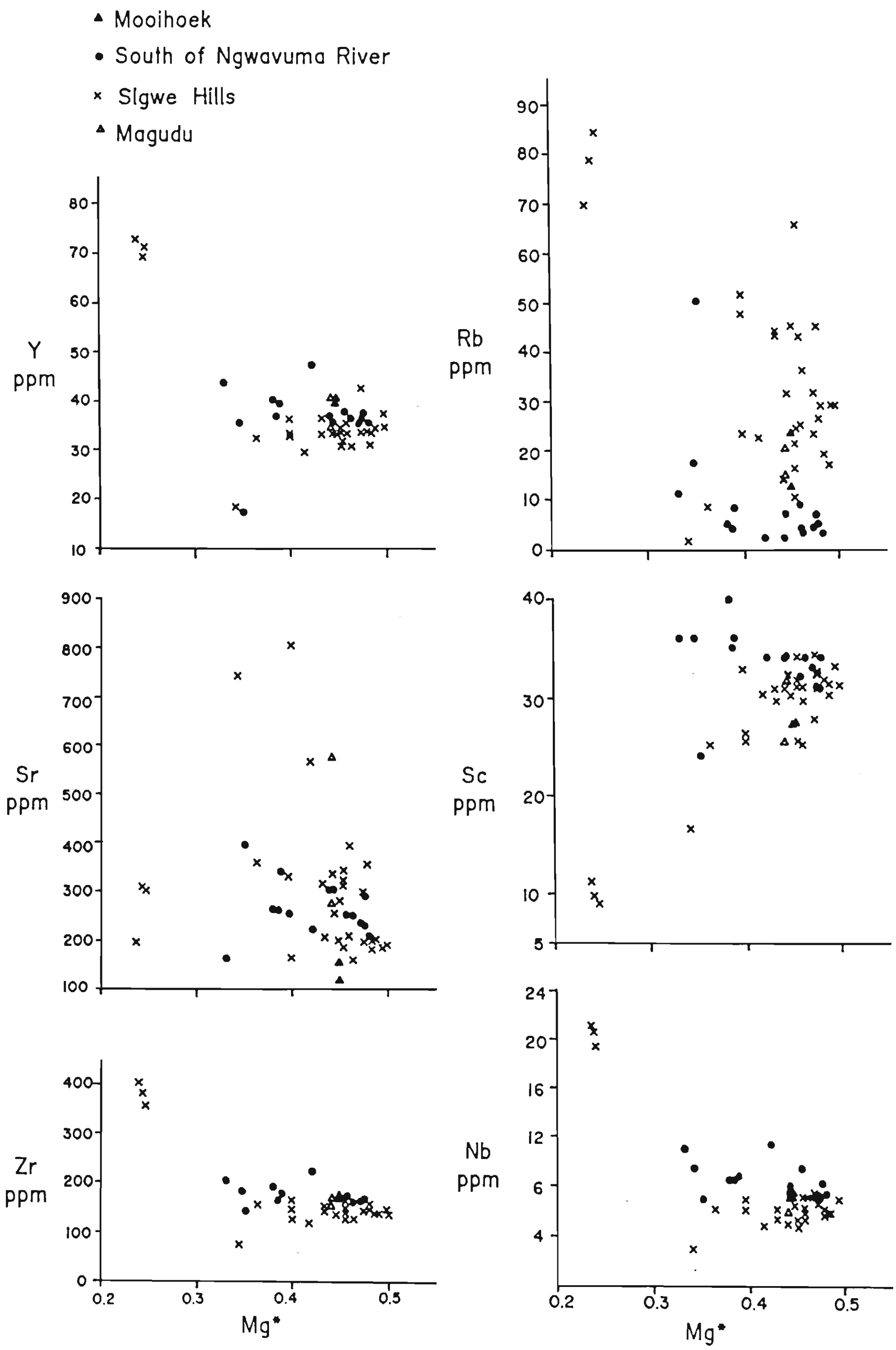

Figure 6.8: Some trace elements plotted against Mg number (Mg*).

The scatter shown by the Sr versus SiO_2 plot may be related to the substitution for Ca in plagioclase and for K in K-feldspar. According to Pierce and Cann (1973), processes such as albitization and Ca-depletion in low grade metamorphism, as well as fluctuating Sr values in otherwise chemically similar rocks, are good indicators of Sr mobility.

Barium in the plot against SiO_2 shows an overall increase with increasing SiO_2. Ba is an incompatible element in magmatic processes. Pierce and Cann (1973) conclude that this element is particularly mobile during weathering and metamorphism. Changes in Ba content can be the result of its substitution for K in K-feldspar or mica. Chloritization can have the effect of enriching the rock in Ba. This is consistent with the observations of the Sigwe Hills-Ngwavuma River Pongola Sequence rocks because they have been highly chloritized.

The plot of scandium against SiO_2 shows that with increasing silica contents, the Sc becomes depleted. Giles (1981) argues that at high silica levels, magnetite fractionation is largely responsible for the control of $^*Fe_2O_3$ and Sc, although mafic minerals such as clinopyroxene and amphibole influence the distribution of these elements during the first stages of differentiation.

In the plot of Y against SiO_2 the two different groups of samples stand out, with those from south of Ngwavuma River showing an enrichment in respect of Y relative to those from Sigwe Hills. Both groups display a trend of increasing Y with increasing SiO_2. However, three samples from Sigwe Hills lie off the well established trend. Giles (1981) notes that samples that show a relative depletion in Y would normally be enriched in Sr and visa-versa. This is true also for the volcanic rocks in this study.

Trace element plots against MgO mostly show scatter trends but the general characteristics of variation diagrams are similar to those observed in the silica variation diagrams. No further conclusions can be drawn from these plots.

6.5 SUMMARY OF CONCLUSIONS ARISING FROM THE VARIATION DIAGRAMS

The significant observations arising from the plots are as follows:-

1. Most elements show a clear population separation of the samples from Sigwe Hills, and south of the Ngwavuma River e.g TiO_2, P_2O_5 and Al_2O_3.

2. There is a high degree of scatter in most inter-element plots in the range 50-60% SiO_2 and this points to strong mobilization of elements by secondary processes.

3. In some cases reasonably well constrained trends are observed for the entire data set as is the case for e.g TiO_2 vs SiO_2, Fe_2O_3 vs SiO_2 and P_2O_5 vs SiO_2.

4. In some cases each population group forms a distinct trend e.g V vs MgO, MnO vs MgO, Cr vs MgO and CaO vs SiO_2.

5. The felsic rocks are confired as being rhyolites rather than silicified basalts.

6. The unexpected negative correlation of some of the incompatible elements versus SiO_2 for the mafic rocks (e.g Zr, Y, TiO_2, P_2O_5) strongly suggests major disturbance of the rock system, either by contamination or by late-stage alteration, or by a combination of both these effects.

7. The significant depletion in alkalis in some of the samples (including the three felsic rocks) is suggestive of element mobility during alteration.

8. The positive correlation of Cr and MgO for the suite of samples from Sigwe Hills indicates that a primary magmatic control may be observed, but it must also be emphasized that further modifications may have taken place during alteration.

6.6 MAGMATIC AFFINITY AND MAGMA GENESIS

An AFM diagram, as defined by Irvine and Baragar (1971), has been used to determine the magmatic affinity of the Ngwavuma-Sigwe rocks. Plotted in this diagram, the geochemical data from these rocks defines a trend which lies strongly in the tholeiitic field (Figure 6.9).

The observed chemical characteristics for the volcanic rocks raise the question as to whether they had the same origin and involvement of the same processes or otherwise. One way to examine consistency of the processes is to consider ratios of incompatible elements. Table 6.3 presents some elemental ratios for the two groups of samples from the lavas south of the Ngwavuma River and Sigwe Hills. These two groups of samples clearly do not have the same ratios for all trace elements and therefore they cannot be assumed to have had a common origin.

This is particularly evident for those ratios involving Zr vs TiO_2. The variation diagram for TiO_2 (Figure 6.10d) indicates that there are two linear trends according to the two groups of data sets. A major consideration is the extent to which later stage alteration may have affected the trace element abundances.

Figure 6.10a-e presents inter elemental plots for High Field Strength Elements on the assumption that these elements have not been significantly disturbed by later processes. The linearity displayed by the plots Y versus Zr, Nb vs Zr, Nb vs Y, Zr vs Ti_2O and Nb vs TiO_2 (Figures 6.10a-e respectively), supports the view that low silica volcanic rocks (with < 55% SiO_2 and > 4-6% MgO) from south of the Ngwavuma River had a common origin. If the volcanic rocks had been derived from various sources, the linearity observed from the plots would not be expected and indeed would be difficult to explain (Giles 1981). The second group of data from Sigwe Hills (with SiO_2 > 55% and MgO between 1-6%) conforms to the linear trends mentioned above, but these may be a result of a different part of the fractionation sequence.

In the plot of V against TiO_2 (Figure 6.10f), the data from south of the Ngwavuma River form a linear trend of increasing V with increasing TiO_2, whereas the data set from Sigwe Hills does not lie on this trend and instead forms a cluster of points. This may be further evidence that the suites of lavas had different histories. In another plot of P_2O_5 versus TiO_2 (Figure 6.10g), a common linear trend is observed for both data sets where the P_2O_5 increases with increasing TiO_2.

Additional plots of Cr vs Zr, Cr vs Ni and Ni vs Zr are shown in Figure 6.11a-c. The Cr vs Zr relationship shows some linearity for both data sets in which both Cr and Zr increase relative to each other (Figure 6.11a). The distinction between the two populations is not clear but the reason for the sympathetic variation of Cr with Zr, and the converse relationship shown by Nb and Zr with SiO_2, cannot be explained by high level fractionation or partial melting of the mantle source rocks.

The plot of Cr vs Ni (Figure 6.11b) for all data shows a curvilinear relationship whereby both Cr and Ni levels increase initially (linear relation) to a certain level of Ni, above which only the Cr increases, thus resulting in the observed curve. Giles (1981), suggests that such Ni behaviour with Cr might be due, in some cases, to alteration or preferential partitioning of Ni into sulphide phases.

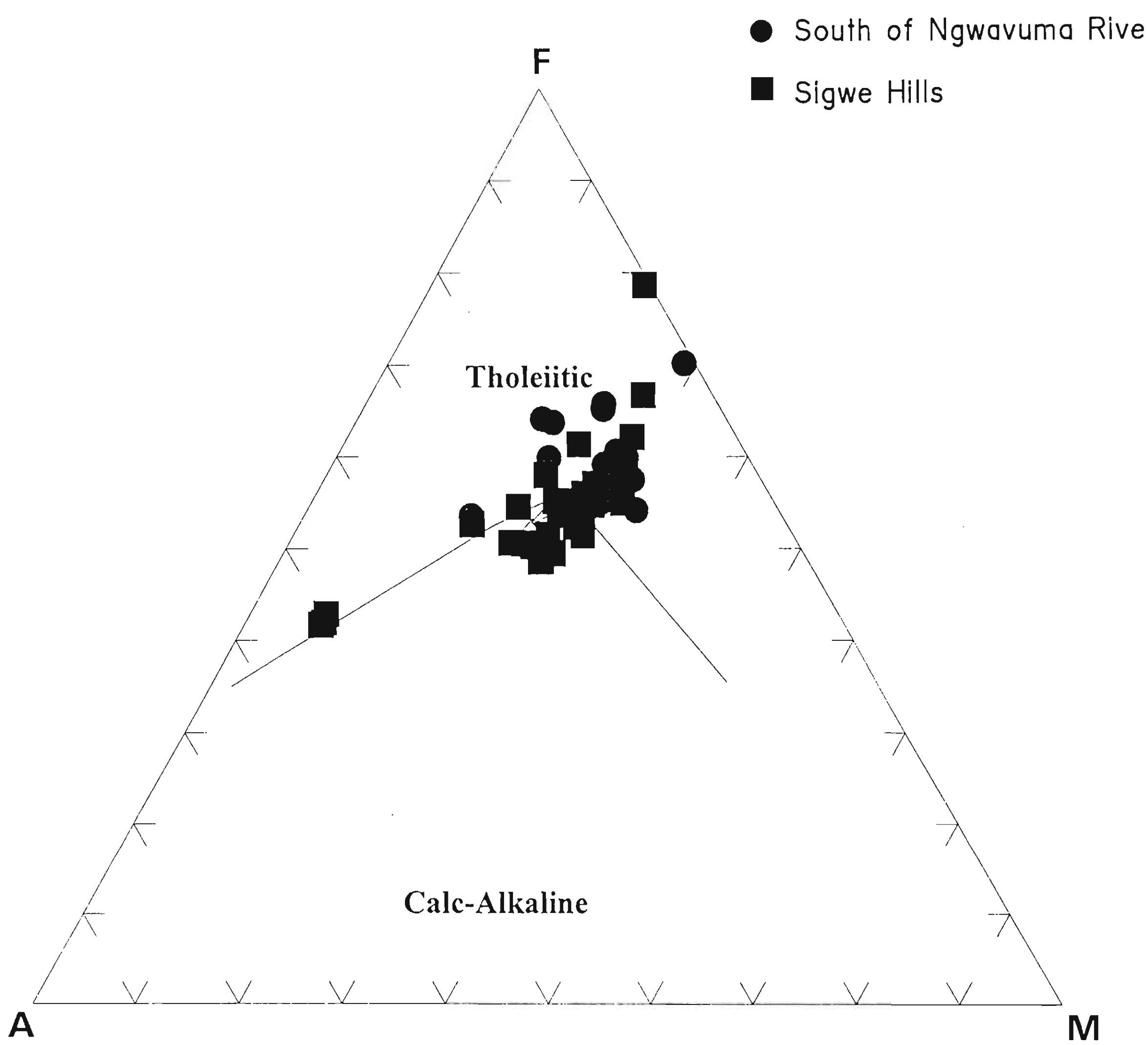

Figure 6.9: AFM diagram (Total alkalis-Total Fe-MgO) (Irvine and Baragar, 1971) showing compositional plots for the lavas. Solid line divides the tholeiitic and calc-alkaline fields.

Positive correlation between Ni and Cr, implies a primary factor such as differentiation, on the behaviour of both elements. Giles (1981) concludes that apparent sympathetic variability of MgO, Ni and Cr observed in low-silica andesites, can be satisfactorily explained in terms of differentiation from a range of primary magmas that have been produced as a result of partial melting of the uppermost mantle over a pressure interval of about 10-20 kb. The observed trend is consistent with early fractionation of clinopyroxene (rather than olivine) which would result from the strong partitioning of Cr into pyroxene. The very limited range in Ni values excludes olivine as a primary fractionating phase. Evidence for pyroxene fractionation also supports the magma type being a silica saturated tholeiite (Wilson. A.H., *pers. comm.*, 1993), and is consistent with theoretical modelling of Nsuze Group lavas by Armstrong (1980).

Nickel plotted against Zr (Figure 6.11c) shows a more constrained linear relationship for the mafic rocks but with some considerable dispersion. This relationship shows an increase in Zr with Ni. The positive relationship is best shown for the mafic samples for Sigwe Hills but in contrast to the general trend the felsic samples are highly depleted in Ni and enriched in Zr.

Table 6.3: Elemental ratios for the volcanic rocks under study.

	South of Ngwavuma River		**Sigwe Hills**	
RATIO	$\bar{x}$	sd	$\bar{x}$	sd
Y/Zr	0.21	± 0.026	0.231	± 0.023
Zr/Nb	20.91	± 1.60	23.29	± 2.88
Nb/Y	0.23	± 0.05	0.1874	± 0.037
TiO_2/Z	8.53	± 0.23	5.95	± 1.67
TiO_2/Y	40.90	± 7.87	21.2	± 6.77

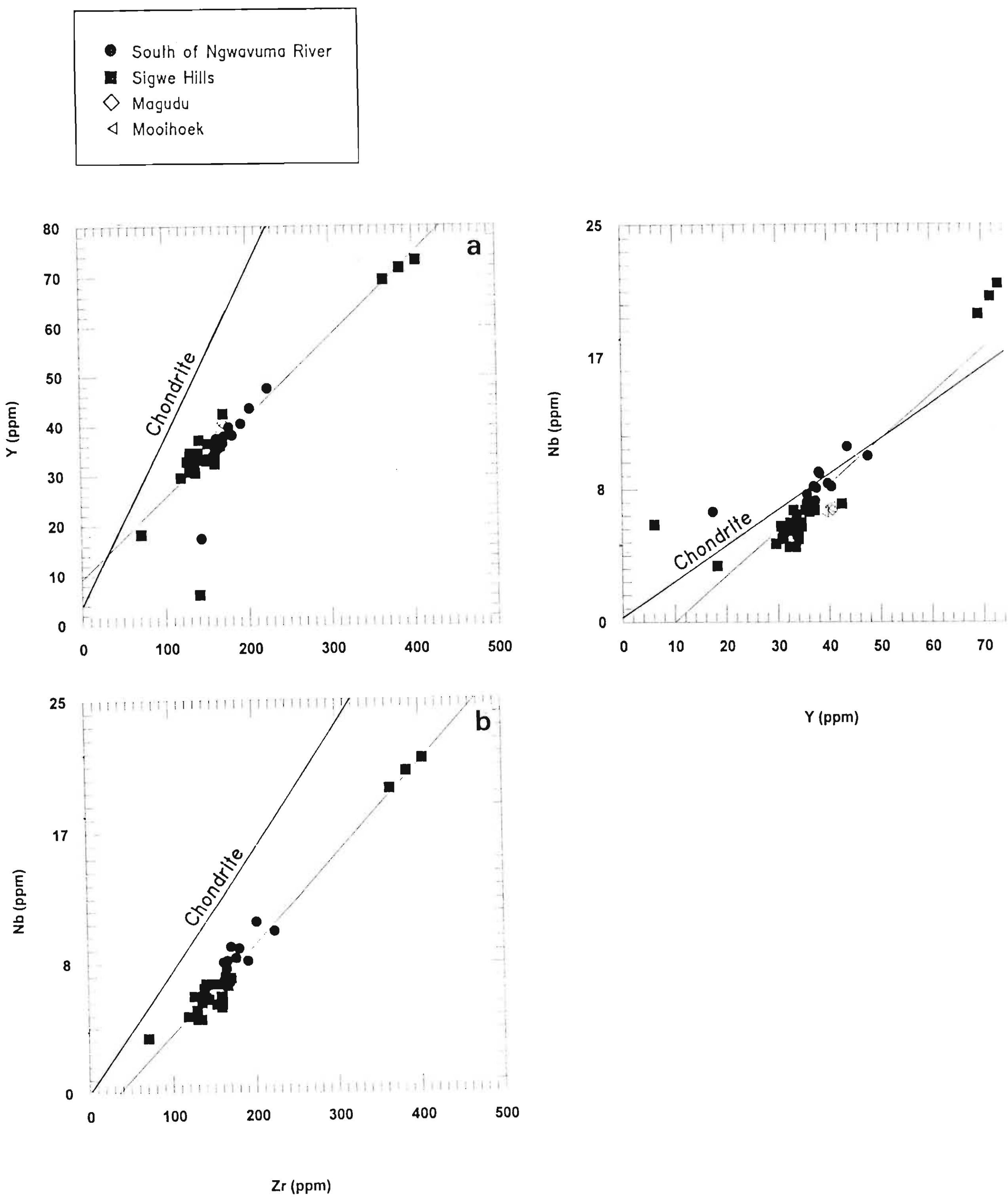

Figure 6.10: Variation diagrams of Y vs Zr, Nb vs Zr and Nb vs Y for the volcanic rocks. Chondritic lines are after Nesbitt and Sun (1976). The line for characteristic ratios is shown together with the linear regression line for the data set.

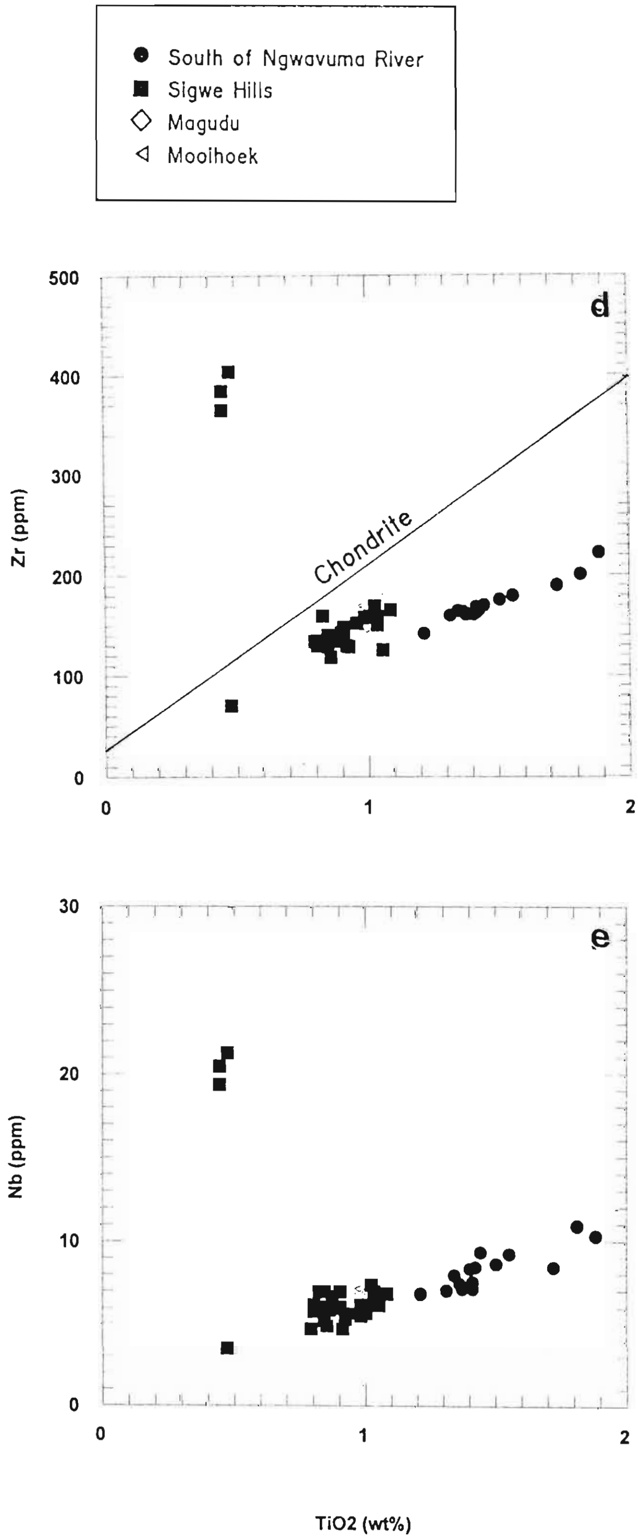

Figure 6.10 (continued): Plots of Zr vs Ti and Nb vs Ti.

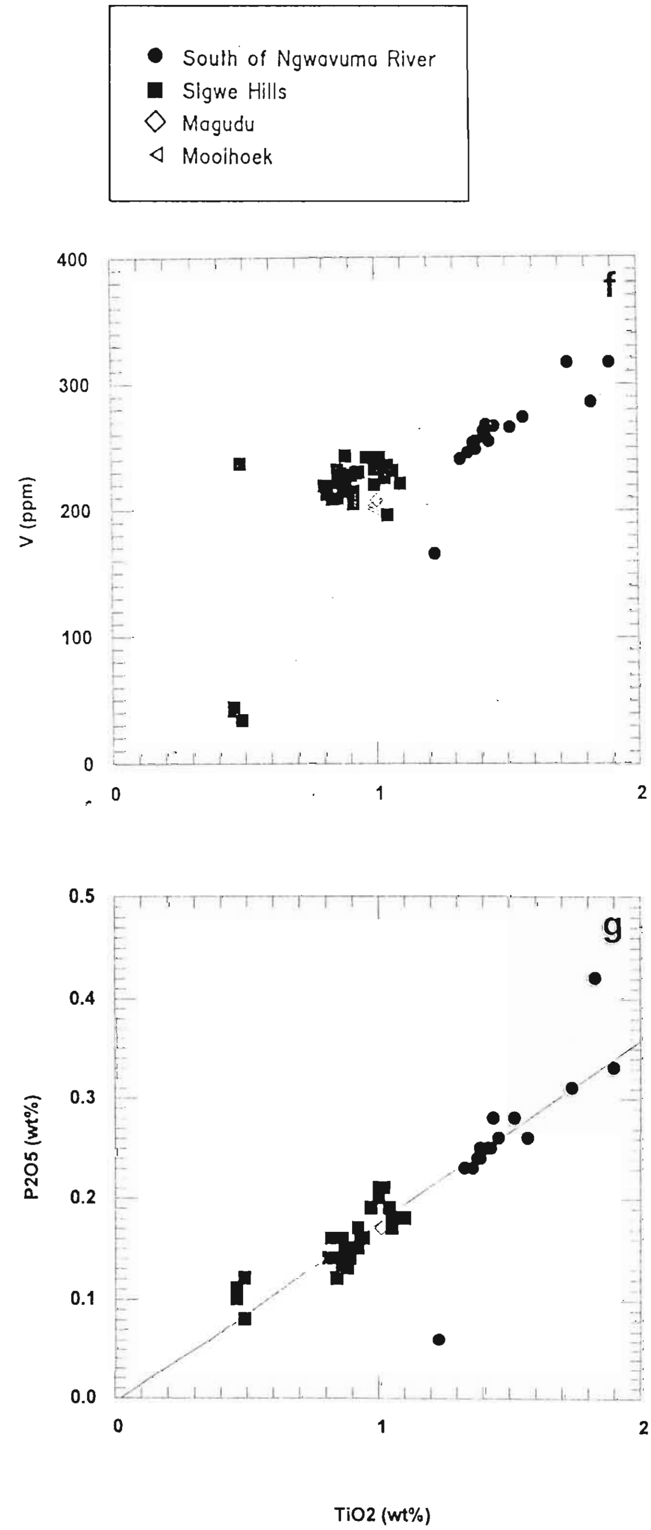

Figure 6.10 (continued) : Variation plots of V and P_2O_5 vs TiO_2.

Pierce and Norry (1979) conclude that within volcanic suites, increase in Zr is accompanied by decrease in Cr. This is the case for all cogenetic data sets from elsewhere which do not show any disturbance in the system. Since Cr is strongly partitioned into mafic phases (pyroxene (cpx) or amphiboles), Cr concentration in the melt should vary a little during partial melting but decrease rapidly during fractional crystallization. The unusual inverse correlations of Nb and Zr with SiO_2 (Figs. 6.6f and 6.6g), and the data distribution for Cr versus SiO_2 (Fig. 6.6c), does not represent the effect of normal fractionation which suggests that other processes were involved in the evolution of these magmas.

Hotter magmas (with higher Mg content) are more likely to assimilate country rock (or substrate) and therefore the higher magnesian, low silica magmas are more likely to have undergone contamination. This is proposed as the qualitative explanation of the observed trends with lower silica, higher magnesian compositions having high Nb and Zr contents (Wilson A.H., *pers. comm.*, 1994).

Immobile trace elements can be used to define magma series and tectonic setting. Pierce and Cann (1973),Pierce and Norry (1979) and Winchester and Floyd (1977) conclude that High Field Strength elements such as Ti, Zr, Y and Nb are immobile during alteration and metamorphism. In this light Pierce and Cann (1973) used Ti, Zr, Y, Nb and Sr to discriminate tectonic settings for recent, altered mafic volcanic rocks. The volcanic rocks under investigation were plotted in the Pierce and Cann (1973) discrimination diagram (Ti/100-Zr-Y. 3 - Figure 6.12) and all plot in calc-alkaline basalt field, except the three SiO_2 rich felsic samples; RM02, RM03 and RM04 which do not plot in any of the defined fields (and are also inappropriate for these plots).

However, the validity of the Pierce and Cann (1973) diagram must be questioned for Archaean volcanic rocks because the tectono-magmatic control may have been quite different for the Archaean compared to recent volcanics for which the diagram was constructed. This diagram also does not take into account the effects of contamination (notably Zr and Nb) which would have resulted from interaction with basement rocks.

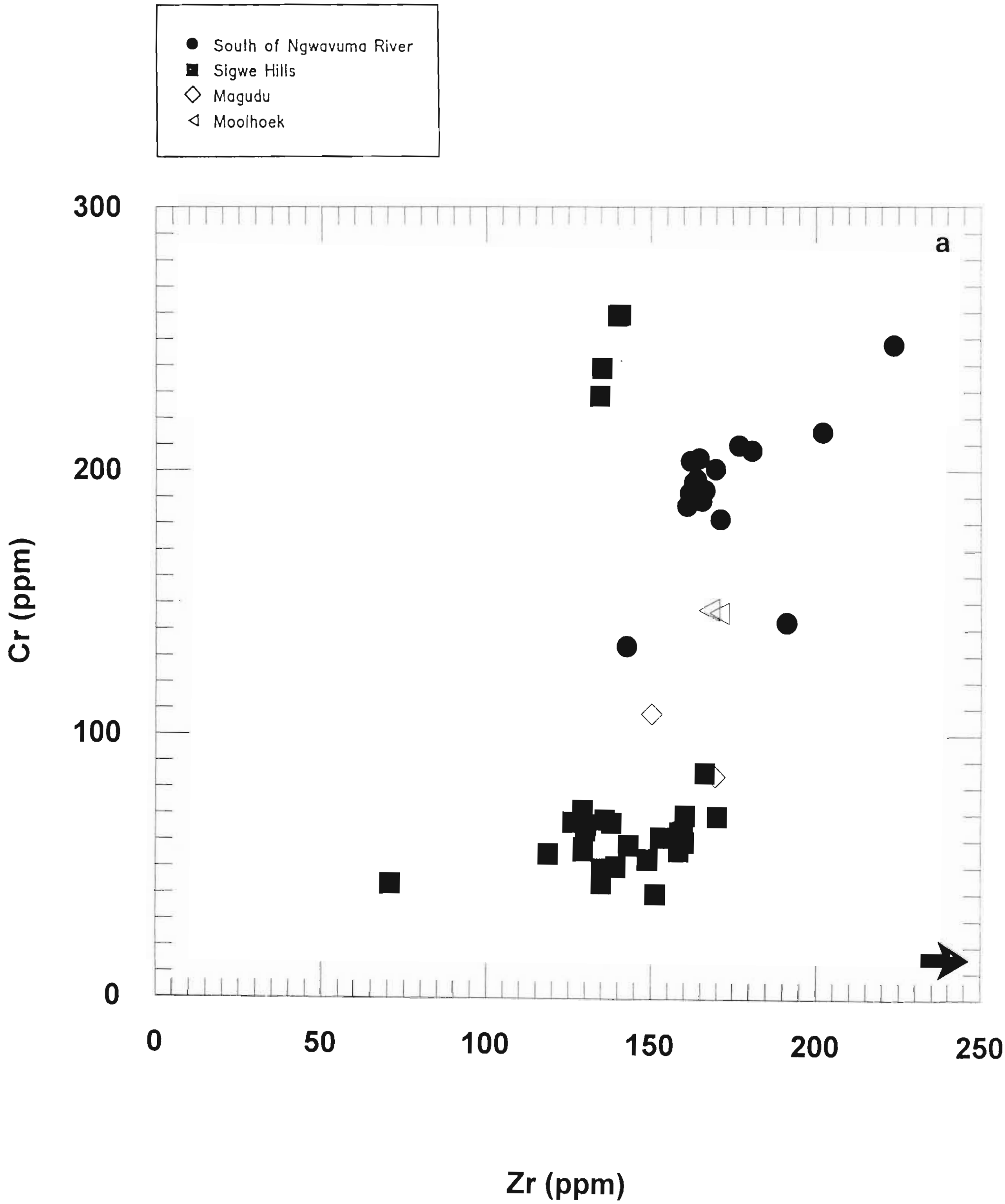

Figure 6.11: Variation diagram of Cr vs Zr. Arrow shows samples anomalously high in one of the variables plotted. These samples are not plotted because of the scale used.

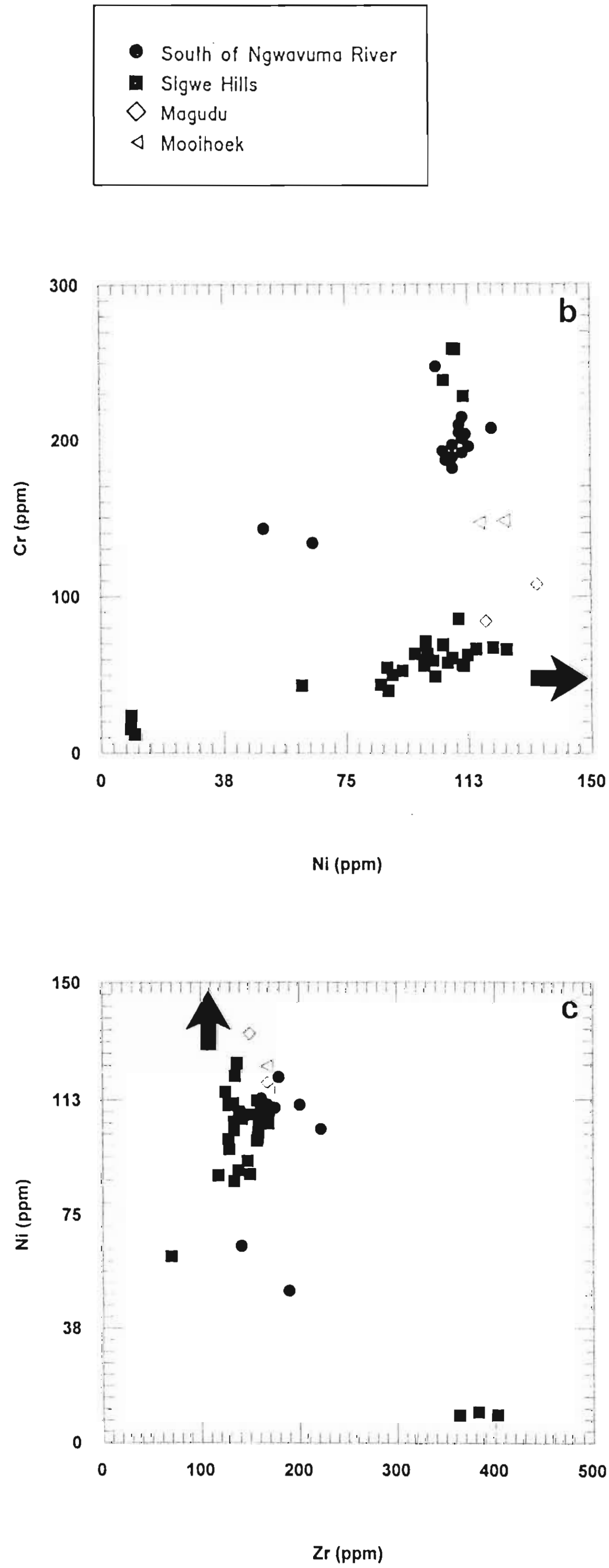

Figure 6.11 (continued): Plot of Cr vs Ni and Ni vs Zr. Arrows show samples with extreme values in one of the variables, not plotted for scale reasons.

In addition, Winchester and Floyd (1977) caution that under conditions of extreme alteration and metamorphism, the so called immobile elements may also show differential mobility.

In the Nb-Zr-Y diagram by Meschede (1986), Nb is relied upon as a sensitive indicator for the tectonomagmatic environment for mid-ocean basalts (MORB). Mantle related enrichment or depletion processes are reflected by the Nb content. The combination of Nb with Zr and Y in the ternary plot results in the subdivision of basalts into four fields (Figure 6.13). The volcanic lava rocks under study mainly plot between normal mid-ocean ridge basalt (N-type in field D) and tholeiitic basalts from within-plate environments (WPT) in field C (Figure 6.13)

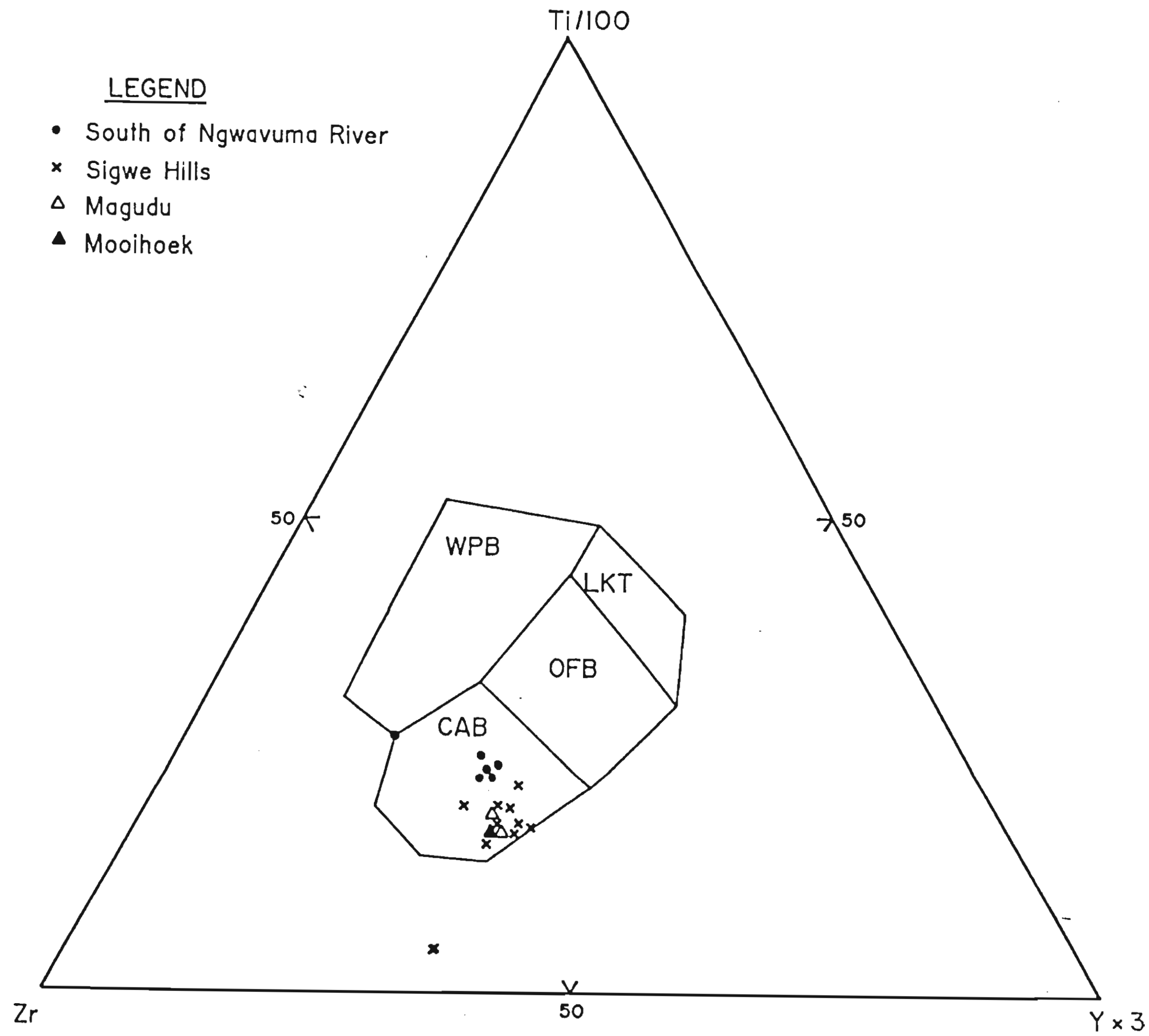

Figure 6.12: Ternary plot of Ti/100-Zr-Y x 3 for basaltic rocks of the Pongola Group from the shown localities. Field simplified after Pierce and Cann (1973). WBP, within plate basalt; LKT low K-tholeiites, OFB, ocean floor basalt; CAB, calc-alkaline basalt.

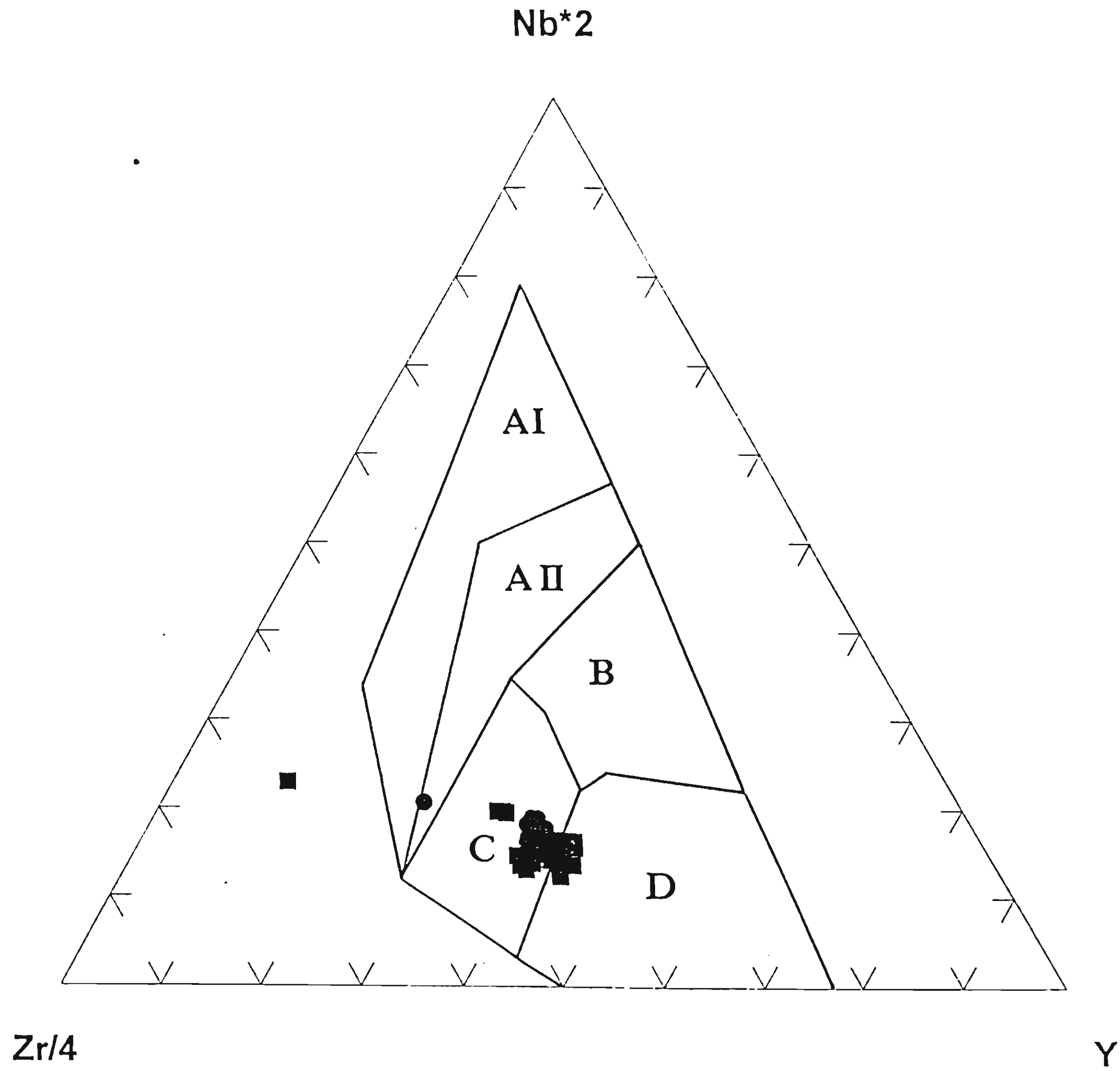

Figure 6.13: Ternary diagram of Nb-Zr-Y for mid-ocean ridge basalts (MORB) after Meschede (1986). Plotted samples are the lava rocks under study. The fields are; WPA, within plate alkaline basalts (A), P-type MORB, plume influenced basalts (B), WPT, within plate tholeiitic basalts (C) and N-type MORB, normal mid-ocean ridge basalt (D).

6.7 CRUSTAL CONTAMINATION

Crustal contamination is considered to be a major influence in the evolution the volcanic rocks of the Pongola Sequence but it is not easy to prove conclusively on the basis of major and trace elements. This is supported by the large Σ Nd value reported for the Nsuze Group lavas from Swaziland (Hegner *et al.*, 1984). The basement Ancient Gneiss Complex directly underlying the Pongola Sequence in Swaziland is a potential contaminant (Armstrong *et al.*, 1986). There is evidence from the present study that contamination has played an important role in the evolution of these lavas.

The contamination of rising basaltic magma could be accomplished initially with the emplacement of dykes under tensional conditions. The latent heat released by the crystallization from the dykes is presumed to raise temperatures in the crust (below level of free water circulation) to estimated levels by which melting of the more fusible components in the crust could take place (Patchett, 1980).

Contamination through mixing of cogenetic magmas on a local and limited scale may be responsible for or contribute to the deviation from normal standards of some of the lava rock chemical data. At Sigwe, field relations (absence of pyroclastics and tuffs, continuous lava flow units) indicate that the voluminous pile of lava was erupted rather quietly which favours this contamination process to be efficient and uniform.

The largely tholeiitic volcanics, Archaean (> 2.5 Ga) in age, are significant in that their chemistry bears no similarity to typical Archaean volcanic piles such as those found in greenstone belts. These lavas observed in the study overlie fluvial sediments and have intercalated fluvial sediments. They appear to have been extruded subaerially. Vesicles and amygdales are common but not uniform throughout the pile. Pillow lavas are absent. Tuffs and other pyroclastic rocks are also absent in these lava rocks.

Considerations of the tectonic setting of the volcanic rocks in question must be given mainly to continental environments. Modern convergent plate boundaries have explosive volcanism.

Divergent and within plate boundaries are characterized by proportions of fragmental volcanics which are missing in these lavas of the Pongola Sequence.

Continental flood basaltic volcanism in which acid rock types are very minor would seem an appropriate environment for these volcanic rocks. Contamination would have arisen by the interaction of mainly mafic magma with felsic basement crust. The acid rocks may be a result of partial melting of the felsic rocks.

6.8 COMPARISON OF COMPOSITIONS OF THE VOLCANIC ROCKS AND KNOWN NSUZE GROUP VOLCANIC LAVAS

The volcanic rocks studied have traditionally been regarded as being part of the Nsuze Group succession but this study presents the first geochemical analysis of the succession. Chemical studies have been carried out on volcanic rocks of the Nsuze Group from various parts of the Pongola basin by a number of workers (Armstrong, 1980; Preston, 1987). Armstrong (1980) investigated rocks of the Nsuze Group in northern Natal and southeastern Transvaal near Paulpietersburg (Witrivier), and Preston (1987) worked on the Mpongoza inlier also in northern Natal, east of Vryheid, which also constitute the Nsuze Group. It is appropriate to compare the geochemical characteristics obtained in this study with the data already existing for the Nsuze Group volcanics.

Figure 6.14 shows compositions of lavas from the Witrivier area (Armstrong, 1980) in Northern Natal and the Mpongoza inlier (Preston, 1987) plotted in the total alkalis versus silica diagram after Cox *et al.*, (1979). Data from the present study are shown as fields. The Nsuze rocks from the Witrivier area (Figure 6.14a) vary in composition from basalts and basaltic andesites, through andesites and dacites to rhyolites, with data showing a fairly coherent trend. The Mpongoza inlier rocks of the Nsuze Group (Figure 6.14b), largely plot outside the designated fields (therefore difficult to classify). Those samples that fall within the fields yield unrealistic classification names, apart from those within the andesitic field. The rocks from the Mpongoza inlier show extreme alteration and thus have caused serious dispersion of the data. The extreme depletion of alkalis is clearly one of the results of alteration. Samples in this study from southern Swaziland (shown as fields in Figures 6.14 and 6.1) also show significant depletion in alkalis, and therefore it must be inferred that alteration may have affected these samples. The general field of data for the Swaziland samples conforms closely to the range of basalts and basaltic andesites from the Witrivier area with the three felsic samples from Sigwe Hills being rhyolites. Most trace element data (e.g incompatible elements) suggest these as being rhyolites but it is also clear that alkali depletion has taken place. It is noticeable that there is no evidence of a suite of dacites in the Swaziland occurrence.

The same three sets of geochemical data were also plotted on an AFM diagram to confirm magmatic affinity (Figure 6.15, Irvine and Baragar, 1971). The data for rocks from the Paulpietersburg area plot in the tholeiitic field (Armstrong, 1980). In contrast, the data from the Mpongoza inlier are widely scattered with many points plotting in the calc-alkaline field (Preston, 1987). The rock samples from southern Swaziland fall dominantly in the tholeiitic field with the exception of three samples which plot in the calc-alkaline field (Figure 6.15 and Figure 6.9). A feature of the alteration process is to impose apparent calc-alkaline characteristics on basaltic rocks. There is clear indication that this has happened in the Mpongoza inlier and also indicated in this study.

A comparison of major and trace element data between the Nsuze section studied by Armstrong (1980) and that of the present study in southern Swaziland is shown in the form of histograms in Figure 6.16a and b. Compositions for the lavas are compared for appropriate magma types (basalts and basaltic andesites). There is consistency in the two data sets both in average values and ranges, indicating broadly similar magma compositions. The incompatible trace elements (Zr, Y, Nb and Zn) show almost identical patterns. The compatible elements Ni and Cr do not show good agreement because these are highly subject to fractionation processes. Other elements such as Sr and Ba are likely to have been modified by alteration, and Cu is influenced by the presence of small amounts of sulphide.

Another comparison of the present data set with that from Witrivier area on the Pierce and Cann (1973) diagram of Ti/100-Zr-Y.3 for magma type, as related to tectonic setting (Figure 6.17), indicate a close overlap. Both data sets fall in the calc-alkaline basalts of orogenic environments. A calc-alkaline magmatic affinity is not appropriate for the volcanic setting of the Pongola Sequence and probably reflects the shortcomings of using this approach for ancient volcanic rocks. The important observation illustrated in this diagram is that the ratios of the incompatible elements in the lavas from the Nsuze Group in south eastern Transvaal and the present data from Swaziland are effectively identical. The three felsic samples, RM02, RM03 and RM04 are not appropriate for this plot and all rhyolites have been omitted. Data from the Mpongoza inlier was not plotted onto this type of diagram because of inherent evidence of its alteration.

6.9 INCOMPATIBLE ELEMENT CONSIDERATIONS FOR THE LAVAS

When the basaltic lava rocks from the study area are normalized to primitive mantle composition (Figure 6.18) and plotted as a spidergram, it is evident that these rocks are relatively enriched in Ba, Rb, Th, U, Nb and Zr, but depleted in the Y, Cr, Ni and Zn. Normalized to continental crust (Figure 6.19) the Pongola Sequence volcanics are less depleted in respect to the crust in the Ba, Rb, Th and U trace element group. These lavas are significantly enriched in Nb, Sr and Zr. These plots give clear indication of a significant crustal component in the magmas. The trace element characteristics show an affinity to continental type settings (Norry and Fitton, 1983).

6.10 CONCLUSIONS BASED ON THE COMPARISON

There are essentially some similarities in respect of the major element compositions between the Nsuze Group lava rocks from the Witrivier area (Armstrong, 1980) and those from the present study. Significantly, the rocks from the present study are very different from the Nsuze Group volcanic rocks from the Mpongoza inlier area of Preston, 1987. This is probably due to the large extent to which the Mpongoza inlier rocks have been altered.

Considering incompatible element (Nb, Y, Zr and Ti) ratios, these are consistent and similar for the volcanic rocks from the present study and those from the Witrivier area. There are two very distinct data populations in the study area distinguished as Sigwe Hills and south of the Ngwavuma River. Element mobility is a definite feature in the Pongola Sequence volcanic rocks under study particularly considering the alkali elements. It is clear that these elements have undergone considerable depletion.

The rocks from the present study are restricted in compositional range to basalts and basaltic andesites, with a very minor population of rhyolites, than those from the Witrivier area which have a wider array. The apparent inverse relations between some incompatible elements and compatible elements may be a result of lava disturbance of data by alteration and possible crustal contamination.

The ratios of trace elements to continental crust, indicate a clear enrichment in elements more related to the crust and depletion in mantle type elements. The combination of these relationships are indicative of both significant crustal contamination and extensive fractionation processes.

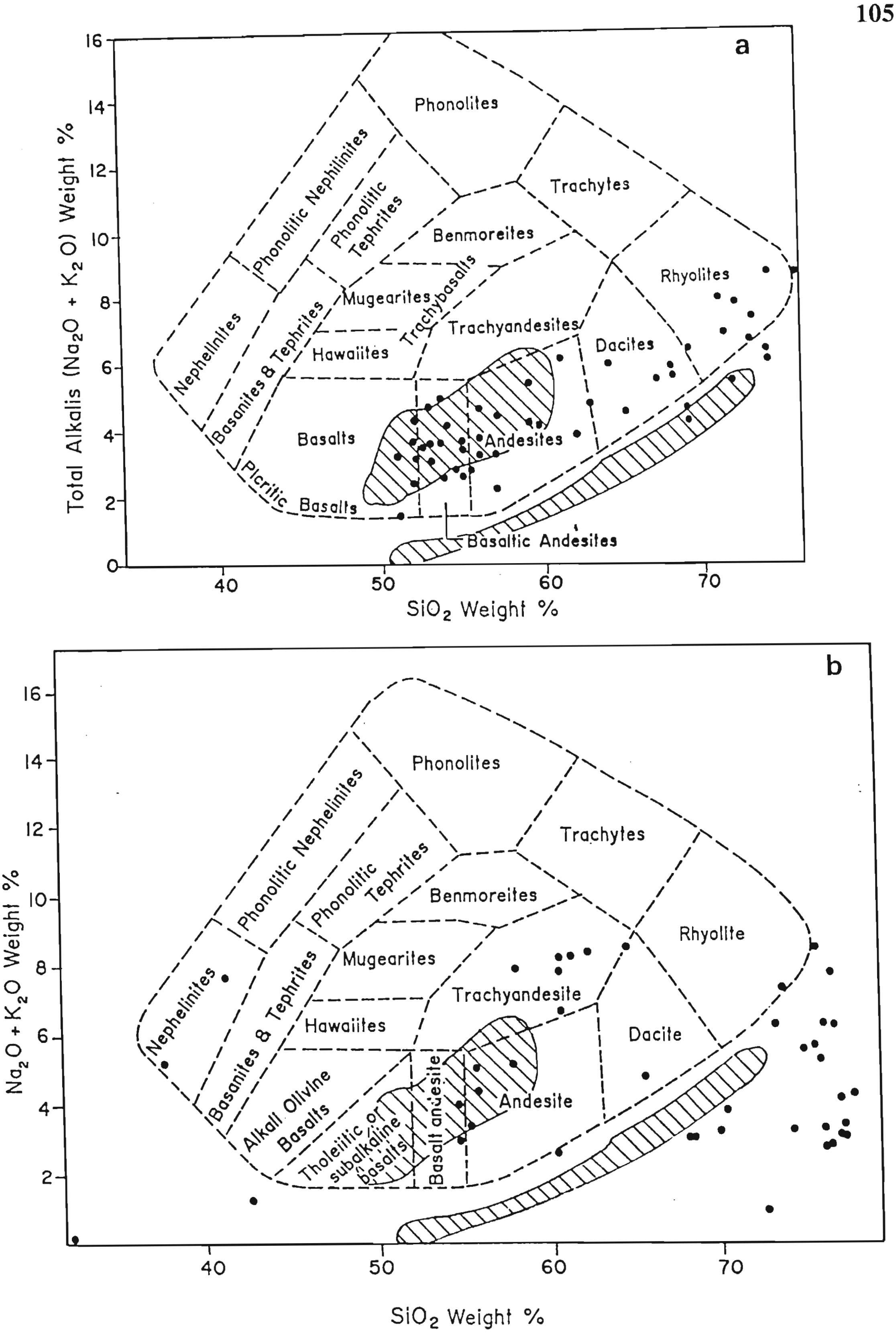

Figure 6.14: Compositional characteristics of the volcanic rocks in this study (dashed fields) compared with data from the Nsuze Group volcanic rocks. Designated fields are after Cox, *et al.*, 1979). a) Data points shown for the Nsuze Group volcanics from south eastern Transvaal (Armstrong, 1980). b) Data points shown for the Nsuze Group volcanics from the Mpongoza inlier (Preston, 1987).

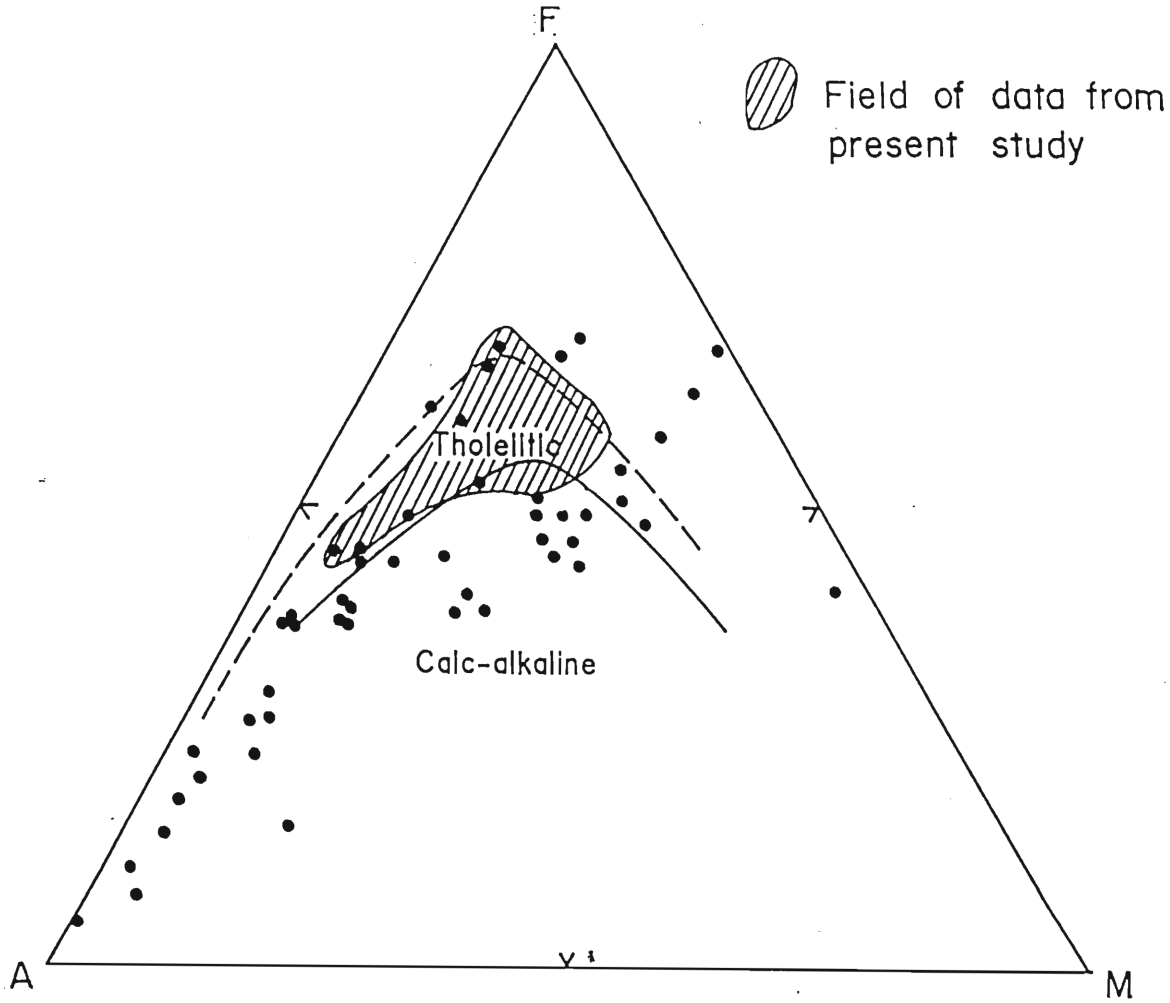

Figure 6.15: AFM diagram (Irvine and Baragar, 1971) for Nsuze Group volcanic rocks from the Mpongoza inlier and southeastern Transvaal. Solid line divides the tholeiitic and calc-alkaline fields. The hatched field is the trend for the data set obtained by Armstrong (1980) and the dots represent Mpongoza inlier rocks (Preston, 1987).

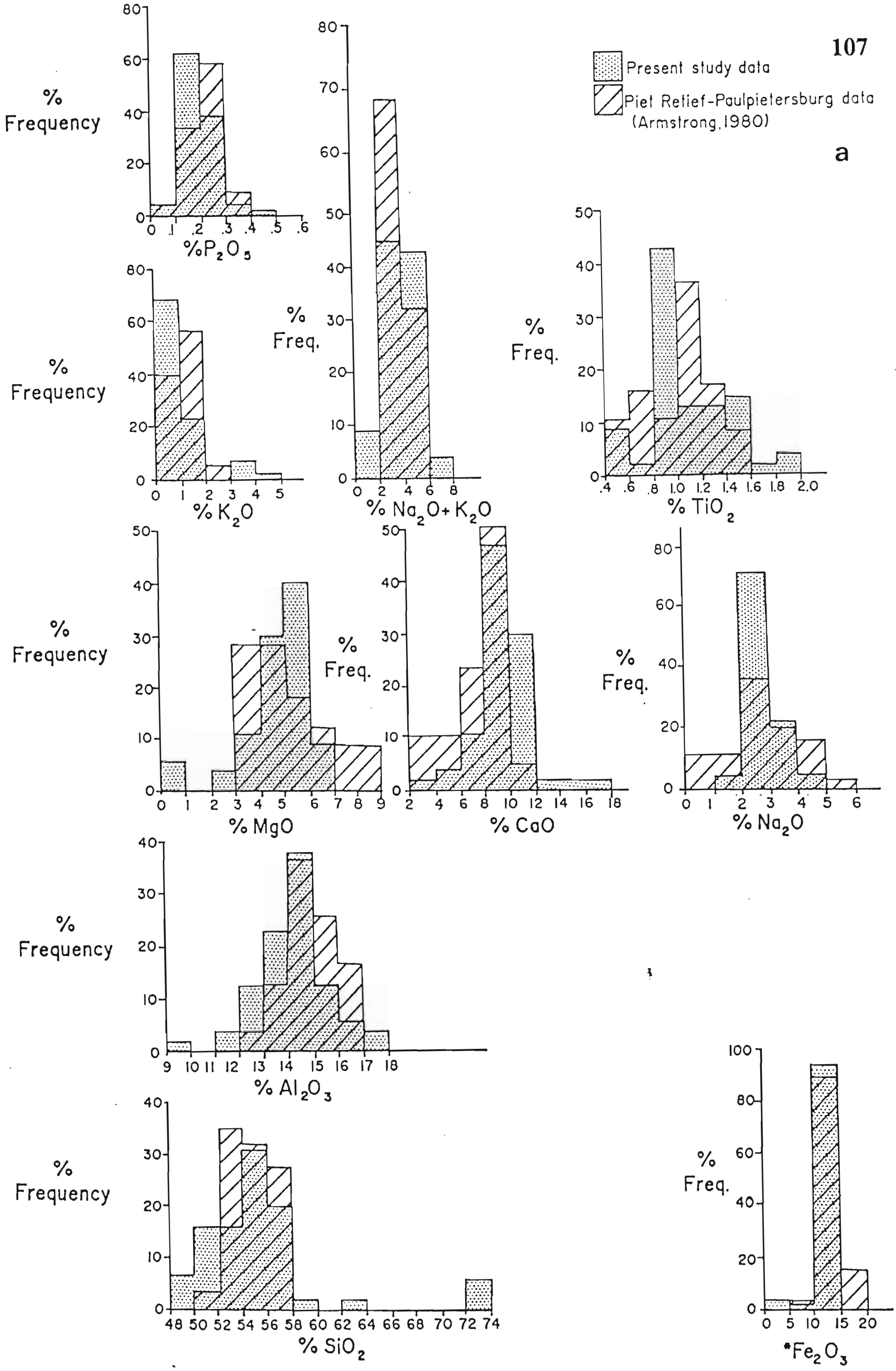

Figure 6.16: Element frequency distribution diagrams for data (basalt and basaltic andesite) from the Piet Retief-Paulpietersburg area (Armstrong 1980) and data from the present study; (a) Major elements (b) Trace elements.

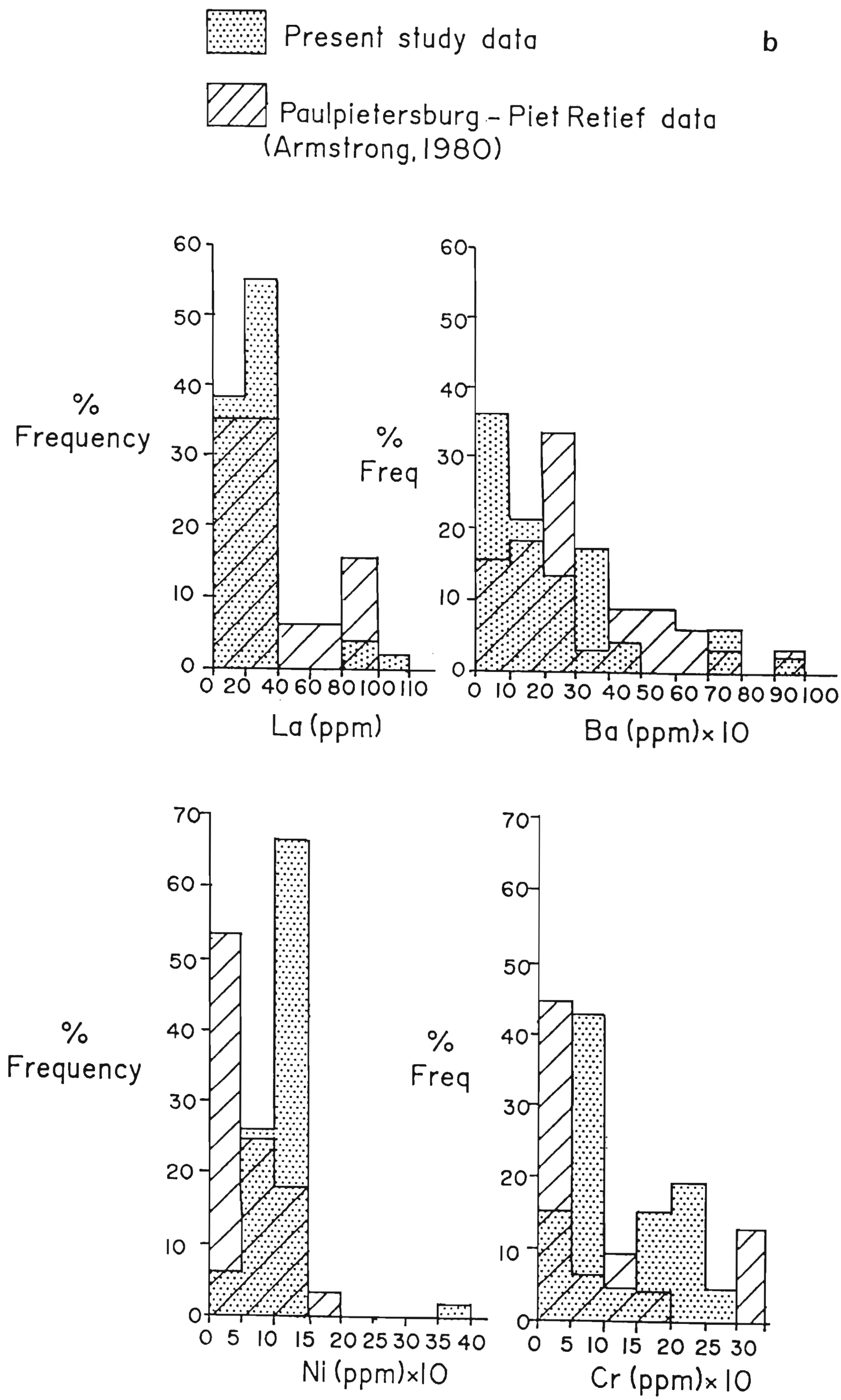

Figure 6.16 (continued).

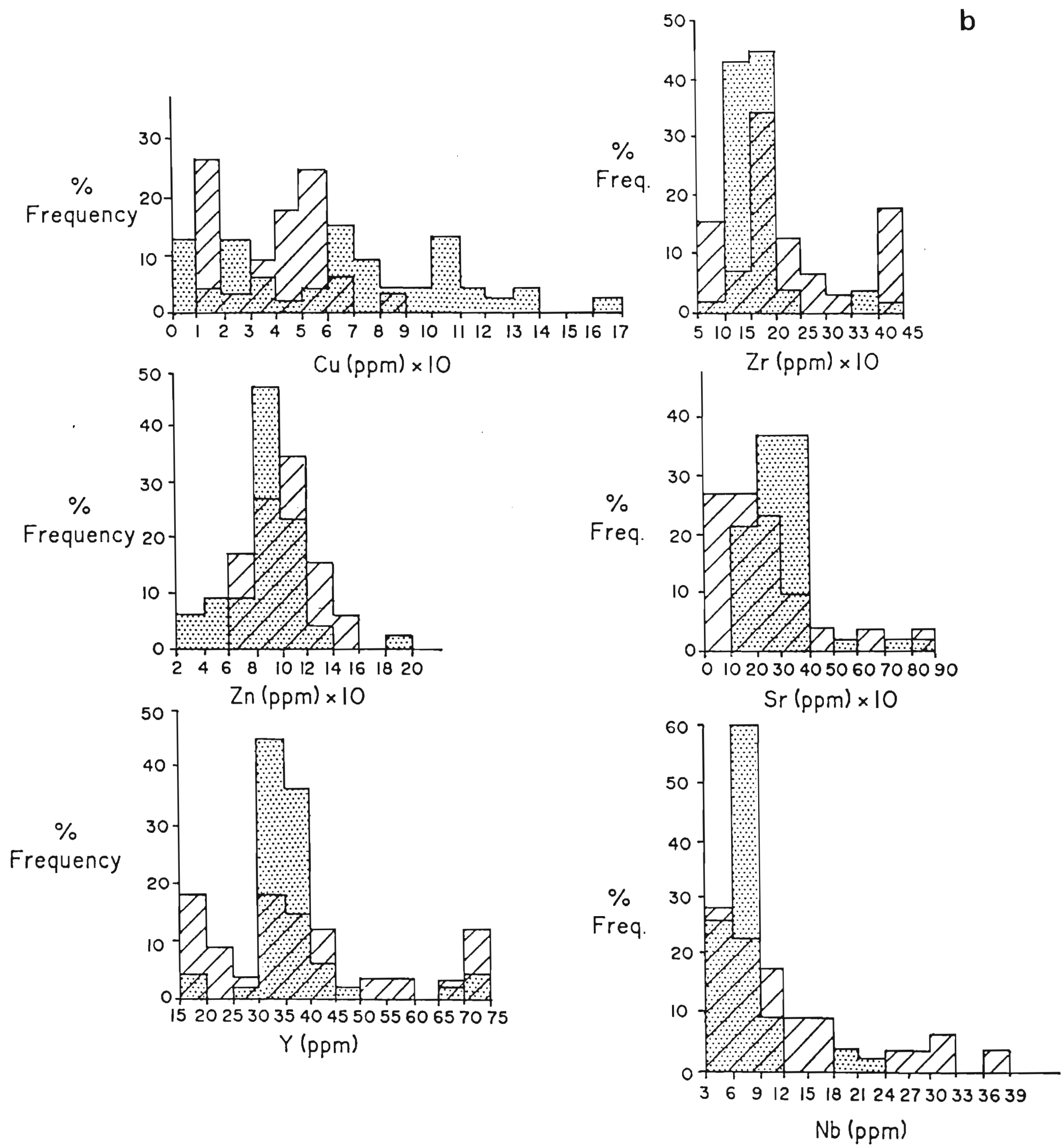

Figure 6.16 (continued).

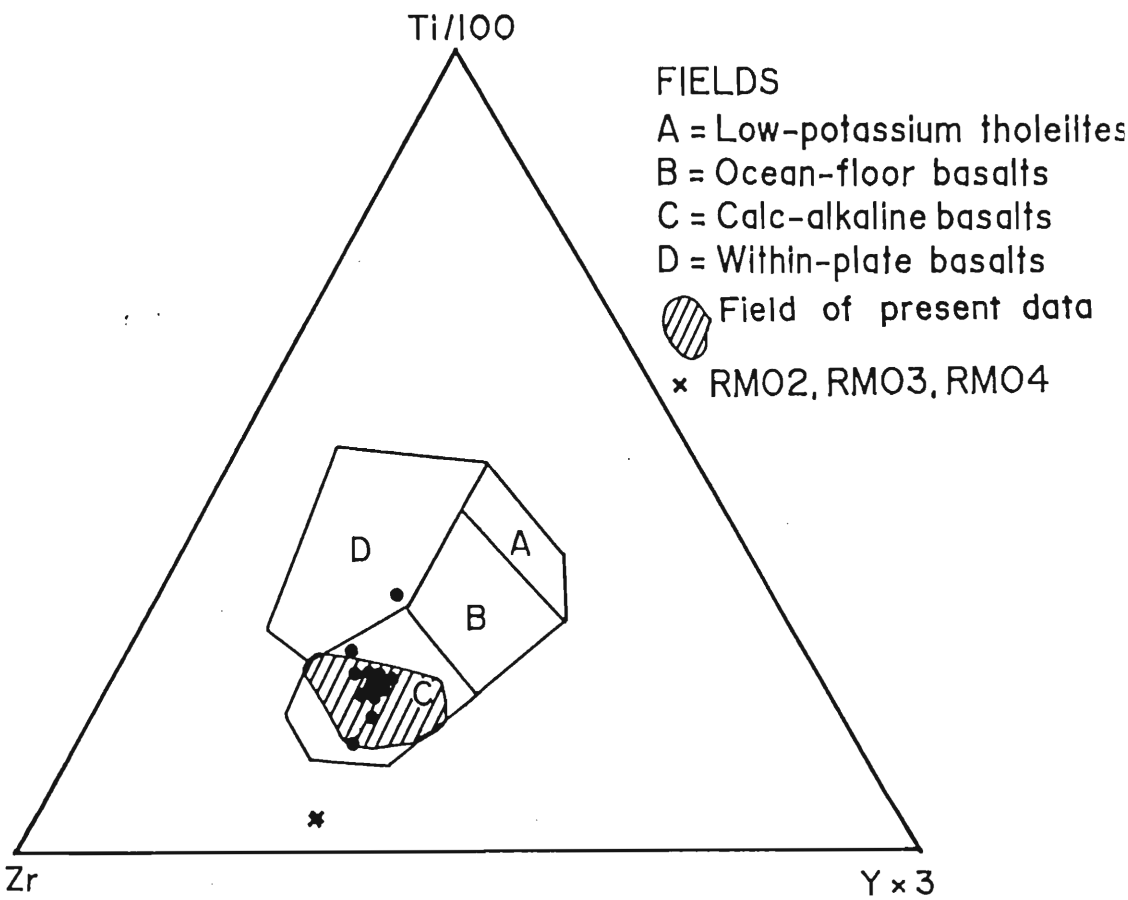

Figure 6.17: Pierce and Cann (1973) ternary plot for Nsuze Group volcanic rocks from the Witrivier area after Armstrong (1980) represented by dots. The outlined field is data for present study.

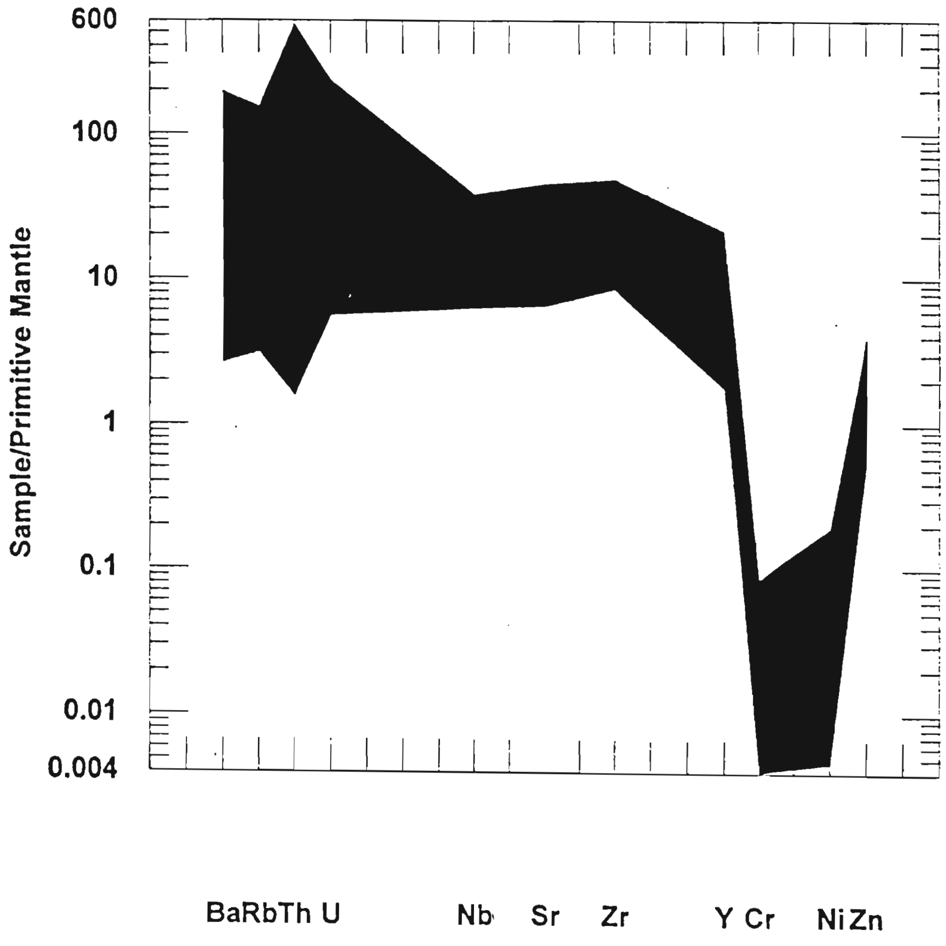

Figure 6.18: Block spider diagram showing the data of the present study normalized to primitive mantle composition.

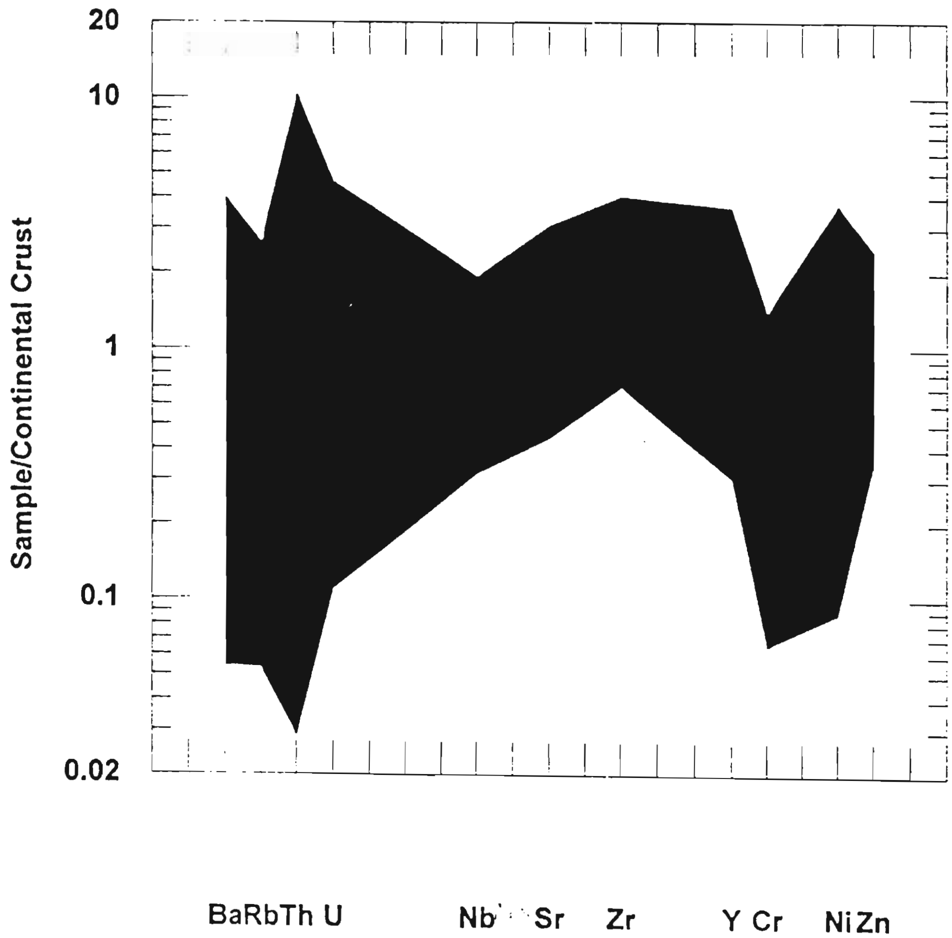

Figure 6.19: Block spider diagram showing the present study data normalized to the continental crust.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 CHARACTERISTICS AND CLASSIFICATION OF THE VOLCANIC ROCKS

The ~2.94 Ga Pongola Sequence volcanic rocks occupying the Sigwe Hills-Ngwavuma River valley consists of metavolcanic rocks interbedded with lenses of metaquartzite units and very minor phyllitic shales. The lack of marker horizons precludes the possibility of establishing the thicknesses of these lithologies. A number of granitoids and doleritic dykes intrude these Pongola Sequence rocks.

The lavas comprise mainly basalts, basaltic andesites and minor rhyolites. The intercalated sediments are mainly quartzites and arkosic sandstones which are regarded as fluvial deposits. The lava flows are amygdaloidal and vesicular in places owing to the effusive and quiet nature of their volcanism. Pillow lavas are absent and the pile is also devoid of tuffs and other pyroclastic material. The volcanism leading to these largely intermediate assemblages took place subaerially which is also supported by the vesicular nature of the flows in upper parts of the volcanic pile, the presence of intercalated fluvial sediments and lack of pillow lavas.

7.2 CORRELATIONS

The present study area is situated about 25 km southeast of Mooihoek, a locality where basaltic lava was identified and attributed to be part of the upper Mozaan stratigraphy (Hunter, 1963). This occurrence is in association with quartzite rocks of the Mozaan Group. The Mooihoek basalts occupy the core of a syncline whose axial trace trends northwest. The volcanic rocks and associated quartzites, strike north-south and are separated from the Mooihoek basalts by two granitic intrusions, the Mooihoek granite and the Kwetta granite. Xenolith metavolcanic rock bodies striking either north or northwest occur in the Kwetta batholith to the west of the study area. The Mooihoek basalts, the xenolithic bodies in the granite, and the metavolcanic rocks are considered to have originally been one large, elongate lava rock body which was fragmented by the granitic intrusions. This belt of volcanic rocks probably extended as far south as the Magudu area, some 60km from the study area where similar volcanic rocks are designated as part of the upper Mozaan Group (Hunter, *pers. comm.*, 1992). It is on these grounds that this correlation is considered feasible.

7.3 METAMORPHISM AND STRUCTURE

The volcanic rocks have undergone alteration and metamorphism. Petrological evidence reveals that they have been subjected to low-grade regional metamorphism imposed by low temperature and low pressure conditions. These rocks have been metamorphosed to low grade, amphibolite facies.

Poor outcrop in the Sigwe-Ngwavuma valley inhibits structural evaluations in this part of the Pongola basin. Regionally, there are two dominant structural trends: a northwesterly trend and a north-south trend. In southern Swaziland, the known Mozaan Group (Mooihoek-Kubuta) is located in the nose of a syncline whose axial trace trends northwest.

7.4 CLASSIFICATION AND GEOCHEMISTRY

The Pongola Sequence lavas in the area of study represent a suite of rocks constituting a continuum in chemical composition from basalts and basaltic andesites to rhyolites. These different varieties are classified according to their silica content and total alkalies (K_2O+Na_2O). Considerable scatter of the data in the variation diagrams indicate that these rocks have undergone alteration mainly as a result of metamorphism. It is also very evident from the various variation diagrams that within the suite of rocks under investigation there are two distinct groups, namely those from south of the Ngwavuma River (largely basaltic in nature), and those from the Sigwe Hills (andesitic to rhyolitic). The samples from south of the Ngwavuma River are generally enriched in TiO_2, Al_2O_3, CaO, Cr, Zr, Y and Nb but depleted in SiO_2, K_2O, Na_2O, Ba and U. This indicates that these rocks did not have a common origin even though they might have had a common source. The difference may have arisen through varying amounts of contamination and different fractionation processes. The majority of the samples from south of the Ngwavuma River have relatively low SiO_2 contents ($<55\%$) and high MgO (4-6%) and may be less evolved than the group from Sigwe Hills (with $SiO_2>55\%$ and MgO between 1-6%). The former group may have resulted from a different part of the fractionation sequence coupled with crustal contamination.

Variation diagrams involving the High Field Strength elements (Zr, Nb, Ti and Y), which are regarded being effectively immobile, all show well constrained trends. These plots indicate that the volcanic rocks are a suite with a chemical composition from basalts to basaltic andesites through to very minor rhyolites.

The magma type is tholeiitic even though some samples show affinity for the calc-alkaline field. The magma series and tectonic setting for these Pongola Sequence lavas is deduced as being tholeiitic basalts from a within plate environment.

7.5 GENESIS OF THE LAVAS

The variations observed within the volcanic rocks under study are attributed to fractional crystallization from a common parental magma source. Contamination of co-genetic magmas are considered responsible for the deviation from normality for some of the lava compositions within the suite. There is no evidence to suggest that these magmas were primary partial melts from the mantle. Considering the discrimination diagram plots, there is inconsistency between the various diagrams (e.g in the Ti-Zr/100-Y.3 diagram where the data plots as calc-alkaline basalts with a few samples plotting well outside the designated fields). Considering all the evidence, these volcanic lavas are seen as tholeiites which have undergone contamination and fractionation.

7.6 COMPARISON WITH NSUZE GROUP

Field descriptions of Armstrong (1980) indicated that in the southeastern Transvaal type area of the Nsuze Group there is presence of welded tuffs and air-fall tuffs which are absent in the area under investigation. In the Mpongoza inlier area, Preston (1987) described pyroclastics which are also absent in the present area of study. It seems, therefore, that the style of volcanism between these three areas is thus quite different.

Strong similarities exist between the volcanic rocks under investigation and those from the typical Nsuze Group Witrivier area. There are also similarities between the rocks under study and the four samples from known upper Mozaan Group localities (Hunter, 1963 and Hunter, *pers. comm.*, 1992) in southern Swaziland (Mooihoek), and northern KwaZulu-Natal (Magudu area). Notable differences between the present study and volcanic rocks from Mpongoza inlier

(Nsuze Group) are attributed to mainly alteration in the Mpongoza inlier rocks. Scatter of the data, as evidence of alteration (such as alkali depletion), increases from the Witrivier area (least altered) to the Mpongoza inlier (most altered) with the present study intermediate between these two. The degree of alteration of these rocks has not allowed detailed petrogenetic modelling to be carried out.

In the vicinity of Mooihoek in southern Swaziland, Hunter (1963) identified basaltic lavas located in a core of a syncline whose axial trace plunges northwest-southeast. He described these as "capping" a thick succession of Mozaan Group quartzites. These were unequivocally attributed to being the topmost exposed rocks in the Mozaan Group succession. Two samples from this area were analyzed together with the suite of rocks from the study area and it is very clear that their compositions are very similar. It is therefore logical in the present study, to correlate these volcanic lava bodies as being the stratigraphically highest parts of the Mozaan Group, as opposed to the Nsuze Group which in southern Swaziland is restricted to the far western border of the country.

The geochemical evidence indicates that the volcanic rocks in the study area are very similar to those in the Witrivier area, which is regarded as the type representative of the Nsuze Group lavas. There are also strong similarities to the four samples of volcanic rocks identified by Hunter (1963) as being part of the Mozaan Group. Field relations provide strong evidence that the volcanic rocks studied are part of the Mozaan Group and therefore it must be deduced that the magma which was emplaced in all periods of deposition of the Pongola basin was remarkably similar in composition.

In conclusion, it is clear that in the entire Pongola basin there are significant problems in terms of the structure and stratigraphy. In order for correlations to be made with more confidence, further studies need to be undertaken.

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APPENDIX 1

SAMPLE PREPARATION AND ANALYTICAL PROCEDURES

X-ray fluorescence spectrometry

Forty seven samples were analysed for major and trace elements by X-ray fluorescence spectrometry using a Philips PW 1404 X-ray spectrometer at the University of Natal, Pietermaritzburg. Major and minor elements were analysed using the lithium tetraborate fusion method of Norrish and Hutton (1969). Trace elements were analysed using pressed powder pellets.

A representative suite of rock samples for the above analyses were collected from fresh outcrops. Weathered material was removed from the sample and clean material was reduced to 5-10cm in size using a hydraulic splitter. These fragments were cleaned under running water, then in an ultrasonic cleaner and rinsed with distilled water. After being oven dried for one hour at 100°C they were then crushed in a jaw crusher with hardened steel jaws to fragments of less than 1cm in size and reduced to +/- 100g samples by cone and quartering. These were then milled in a steel mill to fine powders. The jaw crusher and mill were thoroughly cleaned using acetone after each sample had been processed.

Major elements were determined on Norrish fusion discs. The preparation of these disks involved the heating of approximately 0.5g of sample in silica crucibles (which had been previously cleaned in a dilute solution of HCl) to 100°C in order to dry the sample. The sample was then heated at 1000°C for a period of four hours, removed from the furnace and allowed to cool in a desiccator. The flux used for the fusion (Johnson Matthey Spectroflux 105) was preheated in Pt crucibles at 1000^{0}C and approximately 0.4g of the ashed sample was added so that the ratio of sample weight to flux was 1 : 5.4. The samples were then fused at 1000^{0}C for two hours in Pt crucibles and the product was cast in a brass disc maintained at 250^{0}C. The discs were annealed for approximately three hours on a heated asbestos plate and then allowed to cool gradually. Each new batch of flux was homogenised and a new set of standards made up.

Weight losses on ignition (L.O.I.) were calculated using a known amount of sample placed in silica crucible, ignited for two hours, cooled in a desiccator and then weighed. The difference in weight is the loss on ignition.

Pellets used to determine trace element concentrations were prepared in the following way. Approximately 8g of finely milled sample was mixed with 0.6ml of Mowiol binding agent using an agate pestle and mortar. The sample was then placed in a metal disc and compressed to a pellet ~ 5mm thick using ~ 8 tons of pressure. The pellets were hardened in an oven at 120^{0}C for four hours. Ragged edges on the pellets were then trimmed, care being taken to avoid contact with the surface to be radiated. The pellets separated by cardboard discs, were stored in airtight containers.

Instrument calibration was controlled with international standards and internal synthetic standards and blanks. International standards used were DTS-1, PCC-1, GSP-1, W-1, BCR-1, G- 2, AVG, NIM-G, NIM-N, NIM-P, NIM-D, NIM-S, NIM -L, BR, BHVO and DRN. Internationally accepted standard values are from Abbey (1980). Prof.A.H. Wilson of the Geology Department, University of Natal, Pietermaritzburg, compiled the computer programs for reduction of count data and calculation of mass absorption coefficients.

Analytical conditions, detection limits and accuracy are given in the Table below.

Conversions

Iron was determined as total iron ($*Fe_2O_3$) using the following formula:-

$$*Fe_2O_3 = [Fe_2O_3 + (FeO \times 1.1113)$$

+ allocation of Fe^{3+} is based on 10% of total Fe.

Element	Tube	KV	Ma	Analysing Line	Analysing Crystal	Collimator	Counter	Peak 2θ	Count Time Sec.	Background 2θ	Count Time Sec.	Standard	Blanks	Detection Limits	Analytical Accuracy
SiO_2	Cr	50	50	Ka	Pet	Coarse	Flow	109.165	60	106.000	30	SiO_2 100% NIMD 37.02%		0.004%	0.2%
Al_2O_3	Cr	50	50	Ka	"	"	"	145.040	60	139.160	30	NIML 13.90%	SiO_2	0.005%	0.5%
Fe_2O_3	Au	50	50	Ka	LiF200	Fine	"	57.525	40	Blank standards used to calibrate background.		NIML 10.28%	SiO_2 and 60CaO+40SiO_2	0.001%	0.5%
MnO	Au	50	50	Ka	LiF200	"	"	62.990	40			NIML 0.78%	SiO_2 and 60CaO+40SiO_2	0.001%	0.5%
MgO	Cr	50	50	Ka	PX-1	Coarse	"	23.300	60	25.300	30	W-1 6.55%	SiO_2	0.011%	0.3%
CaO	Cr	50	50	Ka	pet	Fine	"	45.240	40	Blank standards		NIML 3.32%	SiO_2 and 40Fe_2O_3.60SiO_2	0.0003%	0.2%
K_2O	Cr	50	50	Ka	Pet	"	"	50.720	40	used to calibrate		W-1 0.65%	SiO_2 and 60CaO+40SiO_2	0.0003%	0.2%
TiO_2	Cr	50	50	Ka	Pet	"	"	36.720	40	background		W-1 1.05%	SiO_2 and 60CaO+40SiO_2	0.0004%	0.2%
P_2O_5	Cr	50	50	Ka	Ge	Coarse	"	141.040	60	133.000 143.000	30 30	BR 1.10%	SiO_2	0.001%	0.2%
Na_2O	Cr	50	50	Ka	PX-1	Fine	"	28.170	60	30.000	30	BR 3.12%	SiO_2	0.018%	2%
Sc	Cr	50	50	Ka	LiF200	"	"	97.730	60	95.850 98.555	30 30	BCR 33 ppm	SiO_2 and $CaCO_3$	0.3 ppm	10%
Ba	Cr	50	50	La	LiF220	"	"	115.275	60	114.500 116.500	30 30	W-1 160 ppm	SiO_2 and MgO	1 ppm	± 20%
Zn	Au	50	50	Ka	LiF200	"	"	41.795	60	39.65 45.70	30 30	NIMP 100 ppm	SiO_2 and $CaCO_3$	0.3 ppm	± 10%
Cu	Au	50	50	Ka	LiF200	"	"	45.040	60	39.65 46.70	30 30	W-1 110 ppm	SiO_2 and $CaCO_3$	0.2 ppm	± 10%
Ni	Au	50	50	Ka	LiF200	"	"	48.690	60	46.70 50.00	30 30	BR 260 ppm	SiO_2 and $CaCO_3$	0.1 ppm	± 10%
Cr	Au	50	50	Ka	LiF200	"	"	69.375	60	68.10 70.80	30 30	JB1 400 ppm	SiO_2	0.6 ppm	10%
V	Au	50	50	Ka	LiF220	"	"	123.220	60	117.10 123.80	30 30	W-1 260 ppm	SiO_2	0.5 ppm	± 10%
La	Au	50	50	Ka	LiF220	"	"	138.920	60	132.60 141.80	30 30	BR 80 ppm	SiO_2	1.5 ppm	15%
Zr	Rh	50	50	Ka	LiF220	"	Scint	32.045	60	29.30 34.89	30 30	AGV 230 ppm	SiO_2	0.3 ppm	3%
Sr	Rh	50	50	Ka	LiF220	"	"	35.830	60	34.89 36.90	30 30	W-1 190 ppm	SiO_2	0.2 ppm	3%
Nb	Rh	50	50	Ka	LiF220	"	"	30.420	60	29.45 34.80	30 30	GSP 23 ppm	SiO_2	0.1 ppm	3%
Y	Rh	50	50	Ka	LiF220	"	"	33.855	60	29.45 34.80	30 30	NIMG 145 ppm	SiO_2	0.3 ppm	3%
Rb	Rh	50	50	Ka	LiF220	"	"	37.960	60	34.80 41.10	30 30	NIMG 320 ppm	SiO_2	0.4 ppm	2%
U	Rh	50	50	Ka	LiF220	"	"	37.300	100	36.50 41.10	30 30	NIMG 15 ppm	SiO_2	0.1 ppm	20%
Th	Rh	50	50	Ka	LiF220	"	"	39.250	100	36.90 41.10	30 30	GSP 105 ppm	SiO_2	0.5 ppm	20%

APPENDIX 2

THIN-SECTION DESCRIPTIONS

Brief thin section description of some of the geochemical samples used to characterise the chemistry of the Pongola Sequence volcanic rocks studied are given below :-

ROCK TYPE	SAMPLE NUMBER	MAJOR MINERALS	MINOR MINERALS	REMARKS
Basalt	RM 01	Actinolite, quartz, feldspar.	Epidote, zoisite, chlorite (penninite)opaques	Actinolite is altering to chlorite. Feldspar is saussuritized. Quartz is in amygdales and veins with groundmass.
Rhyolite	RM 02	Amphibole, quartz, feldspar.	Calcite, zoisite, ilmenite.	Amphiboles altering to chlorite. Quartz is phenocrystic but also in groundmass with chlorite, amphibole and feldspar. Ilmenite is altering to leucoxene.
Basalt	RM 09	Plagioclase, amphibole and quartz.	Chlorite and leucoxene.	Relict plagioclase crystals display albite twinning. Plagioclase is saussuritized. Amphibole is altering to chlorite.
Basalt	RM 10	Quartz, actinolite and feldspar.	Hornblende, penninite, zoisite and epidote.	Quartz, chlorite, epidote, amphiboles and zoisite found in groundmass and in fractures and veinlets.
Basalt	RM 11	Amphiboles (tremolite-actinolite and hornblende), quartz and feldspar.	chlorite and opaque grains.	Amphiboles have been altered to epidote and zoisite. Feldspar is saussuritized.
Basalt	MK 005	Amphiboles, plagioclase and quartz.	chlorite, zoisite, epidote and leucoxene.	Quartz is in the matrix and in veins. Plagioclase is relict due to saussuritization. Epidote, zoisite and chlorite also in veins with quartz.
Basalt	MK 013	Quartz and amphiboles.	Epidote, zoisite, sphene, haematite and leucoxene	Quartz is mainly in elliptically shaped amygdales. Chlorite, epidote and zoisite are the core of the amygdales and in groundmass.
Schist	HM 02	Andalusite and actinolite.	Chloritoid, chlorite and zoisite.	Actinolite has a brownish tinge (it is prograde)
Schist	M 17	Amphibole (grunerite, cummingtonite) and epidote.	Quartz and magnetite	Amphibole elongate grains wrap around quartz crystals forming a decussate texture. Epidote grows across the general foliation direction. Grunerite is breaking down.

APPENDIX 3

Some common parameters used in the description of structural data are shown below for the Sigwe Hills road cutting data :-

	JOINTS	S_0	S_1
N	30	21	31
Distribution type	Girdle	Girdle or cluster	Cluster
Woodcock fabric shape parameter	0.878	0.955	3.192
Strength of distribution	Weak preferential orientation	Weak preferential orientation	Weak preferential orientation
Woodcock fabric strength parameter	3.064	2.925	2.929
Lisle Hossack strength parameter	2.168	2.069	2.164
Fisher's constant (K)	-	-	10.245
Spherical variance	-	-	0.091
Raleigh uniformity parameter	0.658	-	0.909

APPENDIX 4

PETRONORMS

PETRONORMS PROGRAM

SAMPLE NUMBER MK001

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	52.36	52.517	0.874	0.874
Al2O3	14.94	14.985	0.147	0.294
Fe2O3	1.26	1.264	0.008	0.016
FeO	10.23	10.261	0.143	0.143
MnO	0.19	0.191	0.003	0.003
MgO	5.82	5.837	0.145	0.145
CaO	10.12	10.150	0.181	0.181
Na2O	2.90	2.909	0.047	0.094
K2O	0.22	0.221	0.002	0.005
TiO2	1.41	1.415	0.018	0.018
P2O5	0.25	0.251	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.70			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
2.463	0.000	1.304	24.611	27.179	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
11.749	9.725	0.000	0.000	21.474	0.000	0.000	1.832	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.688	0.594	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.870

CIPWNORM TOTAL = 100.015

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 54.713 FS 45.287

FELDSPAR COMPOSITION :KFS 2.456 AB 46.354 AN 51.190

PLAGIOCLASE PERCENT ANORTHITE 52.479

QUARTZ : FELDSPAR RATIOS:

QUARTZ 4.434 ORTHOCLASE 2.347 PLAGIOCLASE 93.219

QUARTZ 8.681 ORTHOCLASE 4.595 ALBITE 86.724

CHAPPELS A/CNK INDEX 0.638

MG No. IN CATIONS 47.72

AFM PARAMETERS: A = 0.15 F = 0.56 M = 0.29

JENSEN CATION PLOT A = 0.37 M = 0.17 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
2.310	0.000	1.320	26.440	27.520	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
11.545	9.556	0.000	0.000	21.101	0.000	0.000	1.338	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.996	0.531	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.446

CATANORM TOTAL =100.000

...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.42	0.00	0.00	26.44	27.52	0.00	0.00	0.00	25.23	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	13.42	0.00	0.00	0.00	0.00	0.00	1.34	0.00	25.225

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.60	0.00	2.99	0.00	0.00	0.00	0.00	0.00	2.112	

MESONORM TOTAL = 100.066

PETRONORMS PROGRAM
SAMPLE NUMBER MK002

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	49.93	50.090	0.834	0.834
Al2O3	16.61	16.663	0.163	0.327
Fe2O3	1.42	1.425	0.009	0.018
FeO	11.50	11.537	0.161	0.161
MnO	0.18	0.181	0.003	0.003
MgO	4.58	4.595	0.114	0.114
CaO	11.42	11.457	0.204	0.204
Na2O	1.99	1.996	0.032	0.064
K2O	0.26	0.261	0.003	0.006
TiO2	1.51	1.516	0.019	0.019
P2O5	0.28	0.281	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.68			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
2.914	0.000	1.541	16.892	35.735	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.672	11.474	0.000	0.000	21.146	0.000	0.000	2.065	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.879	0.665	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.180

CIPWNORM TOTAL = 100.017

PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 45.738 FS 54.262
FELDSPAR COMPOSITION :KFS 2.845 AB 31.184 AN 65.971
PLAGIOCLASE PERCENT ANORTHITE 67.903
QUARTZ : FELDSPAR RATIOS:
QUARTZ 5.104 ORTHOCLASE 2.700 PLAGIOCLASE 92.195
QUARTZ 13.649 ORTHOCLASE 7.220 ALBITE 79.130
CHAPPELS A/CNK INDEX 0.683
MG No. IN CATIONS 38.98

AFM PARAMETERS: A = 0.11 F = 0.65 M = 0.23
JENSEN CATION PLOT A = 0.39 M = 0.12 F = 0.48

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
2.767	0.000	1.580	18.377	36.644	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.393	11.143	0.000	0.000	20.536	0.000	0.000	1.527	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.165	0.602	0.000	0.000	0.000	0.000	0.000	0.000	0.00015.803	

CATANORM TOTAL =100.000

...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
1.20	0.00	0.00	18.38	36.64	0.00	0.00	0.00	21.51	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	14.36	0.00	0.00	0.00	0.00	0.00	1.53	0.00	21.513

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.68	0.00	3.25	0.00	0.00	0.00	0.00	0.00	2.528	

MESONORM TOTAL = 100.075

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PETRONORMS PROGRAM
SAMPLE NUMBER MK003

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	52.13	52.252	0.870	0.870
Al2O3	15.03	15.065	0.148	0.296
Fe2O3	1.32	1.323	0.008	0.017
FeO	10.70	10.725	0.149	0.149
MnO	0.19	0.190	0.003	0.003
MgO	6.21	6.225	0.154	0.154
CaO	9.98	10.003	0.178	0.178
Na2O	2.37	2.376	0.038	0.077
K2O	0.22	0.221	0.002	0.005
TiO2	1.38	1.380	0.017	0.017
P2O5	0.24	0.241	0.002	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.77			

....................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
3.909	0.000	1.303	20.100	29.792	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
13.558	11.098	0.000	0.000	24.656	0.000	0.000	1.918	0.000
il	**ap**	**cm**	**tn**	**pf**	**ns**	**ks**	**cs**	**ru**	**di**
2.621	0.570	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.146

CIPWNORM TOTAL = 100.015

PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 54.989 FS 45.011
FELDSPAR COMPOSITION :KFS 2.545 AB 39.262 AN 58.193
PLAGIOCLASE PERCENT ANORTHITE 59.713
QUARTZ : FELDSPAR RATIOS:
QUARTZ 7.095 ORTHOCLASE 2.365 PLAGIOCLASE 90.541
QUARTZ 15.445 ORTHOCLASE 5.148 ALBITE 79.407
CHAPPELS A/CNK INDEX 0.675
MG No. IN CATIONS 48.22

AFM PARAMETERS: A = 0.13 F = 0.57 M = 0.30
JENSEN CATION PLOT A = 0.37 M = 0.17 F = 0.46

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
3.679	0.000	1.324	21.672	30.276	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
13.381	10.953	0.000	0.000	24.333	0.000	0.000	1.405	0.000
il	**ap**	**cm**	**tn**	**pf**	**ns**	**ks**	**cs**	**ru**	**di**
1.954	0.511	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.846

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
2.13	0.00	0.00	21.67	30.28	0.00	0.00	0.00	20.51	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	18.45	0.00	0.00	0.00	0.00	0.00	1.41	0.00	20.511

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.57	0.00	2.93	0.00	0.00	0.00	0.00	0.00	2.118	

MESONORM TOTAL = 100.064

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PETRONORMS PROGRAM
SAMPLE NUMBER  MK004
 OXIDES GIVEN     RECALC 100%     MOL PROPS  CAT PROPS
   SiO2  50.28         50.542         0.841       0.841
  Al2O3  15.05         15.128         0.148       0.297
  Fe2O3   1.39          1.397         0.009       0.017
    FeO  11.24         11.298         0.157       0.157
    MnO   0.19          0.191         0.003       0.003
    MgO   6.33          6.363         0.158       0.158
    CaO  10.58         10.635         0.190       0.190
   Na2O   2.49          2.503         0.040       0.081
    K2O   0.26          0.261         0.003       0.006
   TiO2   1.42          1.430         0.018       0.018
   P2O5   0.25          0.251         0.002       0.004
  Cr2O3   0.00          0.000         0.000       0.000
 TOTAL   99.48
    ...................CIPW NORM.................
      q       c      or      ab      an      lc      ne      kp      wo
  0.131  0.000  1.544 21.178 29.271  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 13.237 11.179  0.000  0.000 24.416  0.000  0.000  2.026  0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  2.715 0.595 0.000 0.000 0.000 0.000 0.000 0.000 0.000 18.138
CIPWNORM TOTAL = 100.015
                    ****************************
        PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN   54.216  FS   45.784
FELDSPAR COMPOSITION   :KFS   2.970  AB  40.732  AN  56.298
PLAGIOCLASE PERCENT ANORTHITE  58.022
QUARTZ : FELDSPAR RATIOS:
QUARTZ  0.252  ORTHOCLASE  2.963  PLAGIOCLASE  96.785
QUARTZ  0.575 ORTHOCLASE 6.758 ALBITE 92.668
CHAPPELS A/CNK INDEX  0.637
MG No. IN CATIONS   47.46

AFM PARAMETERS: A = 0.13 F = 0.58 M = 0.29
JENSEN CATION PLOT   A = 0.36  M = 0.17 F = 0.47
       .............CATANORM.............
      q       c      or      ab      an      lc      ne      kp      wo
  0.123  0.000  1.567 22.807 29.711  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 13.021 10.996  0.000  0.000 24.017  0.000  0.000  1.482  0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  2.021 0.533 0.000 0.000 0.000 0.000 0.000 0.000 0.00017.738
 CATANORM TOTAL =100.000
  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q      C      Or     Ab      An      Lc      Ne      Wo      Ri    Act
 Ed
  0.00   0.00   0.00 20.73 29.71   0.00    0.00    0.00 19.46   0.00
6.64
  Di      Hy      Ol     (En      Fs      Fo      Fa)     Mt      Hm
HORNBLENDE
  0.00 15.91   0.00   0.00   0.00   0.00    0.00    1.48    0.00
26.095
   Ap     Cm     Tn     Pf     Ns     Ks     Cs     Ru   BIOTITE  Sp
  0.60   0.00   3.03   0.00   0.00   0.00   0.00   0.00    2.507
MESONORM TOTAL  =  100.067
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PETRONORMS PROGRAM
SAMPLE NUMBER MK005

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	51.91	52.209	0.869	0.869
Al2O3	14.47	14.553	0.143	0.285
Fe2O3	1.35	1.358	0.009	0.017
FeO	10.96	11.023	0.153	0.153
MnO	0.18	0.181	0.003	0.003
MgO	5.74	5.773	0.143	0.143
CaO	10.69	10.752	0.192	0.192
Na2O	2.11	2.122	0.034	0.068
K2O	0.31	0.312	0.003	0.007
TiO2	1.45	1.456	0.018	0.018
P2O5	0.26	0.261	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.43			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
4.835	0.000	1.842	17.956	29.263	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
11.646	10.510	0.000	0.000	22.156	0.000	0.000	1.969	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.765	0.619	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.611

CIPWNORM TOTAL = 100.016

PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 52.564 FS 47.436
FELDSPAR COMPOSITION :KFS 3.755 AB 36.599 AN 59.646
PLAGIOCLASE PERCENT ANORTHITE 61.973
QUARTZ : FELDSPAR RATIOS:
QUARTZ 8.970 ORTHOCLASE 3.418 PLAGIOCLASE 87.611
QUARTZ 19.627 ORTHOCLASE 7.479 ALBITE 72.894
CHAPPELS A/CNK INDEX 0.623
MG No. IN CATIONS 45.66

AFM PARAMETERS: A = 0.12 F = 0.60 M = 0.28
JENSEN CATION PLOT A = 0.36 M = 0.16 F = 0.48

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
4.574	0.000	1.881	19.461	29.893	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
11.477	10.357	0.000	0.000	21.834	0.000	0.000	1.450	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.072	0.558	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.277

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
2.90	0.00	0.00	19.46	29.89	0.00	0.00	0.00	26.50	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	13.12	0.00	0.00	0.00	0.00	0.00	1.45	0.00	26.501

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.63	0.00	3.11	0.00	0.00	0.00	0.00	0.00	3.010	

MESONORM TOTAL = 100.070

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PETRONORMS PROGRAM
SAMPLE NUMBER MK006

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	52.39	52.619	0.876	0.876
Al2O3	14.81	14.875	0.146	0.292
Fe2O3	1.31	1.316	0.008	0.016
FeO	10.57	10.616	0.148	0.148
MnO	0.17	0.171	0.002	0.002
MgO	5.26	5.283	0.131	0.131
CaO	10.60	10.646	0.190	0.190
Na2O	2.51	2.521	0.041	0.081
K2O	0.36	0.362	0.004	0.008
TiO2	1.35	1.361	0.017	0.017
P2O5	0.23	0.231	0.002	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.56			

..................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
4.025	0.000	2.137	21.330	28.203	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.251	9.769	0.000	0.000	20.020	0.000	0.000	1.908	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.584	0.547	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.261

CIPWNORM TOTAL = 100.014

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 51.205 FS 48.795
FELDSPAR COMPOSITION :KFS 4.135 AB 41.282 AN 54.583
PLAGIOCLASE PERCENT ANORTHITE 56.937
QUARTZ : FELDSPAR RATIOS:
QUARTZ 7.227 ORTHOCLASE 3.836 PLAGIOCLASE 88.936
QUARTZ 14.641 ORTHOCLASE 7.772 ALBITE 77.587
CHAPPELS A/CNK INDEX 0.623
MG No. IN CATIONS 44.38

AFM PARAMETERS: A = 0.14 F = 0.59 M = 0.26
JENSEN CATION PLOT A = 0.37 M = 0.15 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
3.797	0.000	2.175	23.052	28.727	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.036	9.564	0.000	0.000	19.599	0.000	0.000	1.401	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.930	0.492	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.826

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
2.27	0.00	0.00	23.05	28.73	0.00	0.00	0.00	28.06	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	9.63	0.00	0.00	0.00	0.00	0.00	1.40	0.00	28.059

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.55	0.00	2.90	0.00	0.00	0.00	0.00	0.00	3.481	

MESONORM TOTAL = 100.061

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PETRONORMS PROGRAM
SAMPLE NUMBER MK007

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	50.81	51.143	0.851	0.851
Al2O3	15.38	15.481	0.152	0.304
Fe2O3	1.41	1.419	0.009	0.018
FeO	11.46	11.535	0.161	0.161
MnO	0.18	0.181	0.003	0.003
MgO	4.49	4.519	0.112	0.112
CaO	11.76	11.837	0.211	0.211
Na2O	1.88	1.892	0.031	0.061
K2O	0.27	0.272	0.003	0.006
TiO2	1.43	1.437	0.018	0.018
P2O5	0.28	0.282	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL .	99.35			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
4.779	0.000	1.606	16.011	32.944	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
8.624	10.478	0.000	0.000	19.101	0.000	0.000	2.058	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.730	0.668	0.000	0.000	0.000	0.000	0.000	0.000	0.000	20.121

CIPWNORM TOTAL = 100.017

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 45.147 FS 54.853
FELDSPAR COMPOSITION :KFS 3.176 AB 31.667 AN 65.156
PLAGIOCLASE PERCENT ANORTHITE 67.294
QUARTZ : FELDSPAR RATIOS:
QUARTZ 8.636 ORTHOCLASE 2.902 PLAGIOCLASE 88.463
QUARTZ 21.338 ORTHOCLASE 7.171 ALBITE 71.491
CHAPPELS A/CNK INDEX 0.621
MG No. IN CATIONS 38.60

AFM PARAMETERS: A = 0.11 F = 0.66 M = 0.23
JENSEN CATION PLOT A = 0.38 M = 0.13 F = 0.50

..............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
4.551	0.000	1.651	17.469	33.876	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
8.385	10.187	0.000	0.000	18.572	0.000	0.000	1.526	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.059	0.606	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.691

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
2.57	0.00	0.00	17.47	33.88	0.00	0.00	0.00	29.20	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	9.03	0.00	0.00	0.00	0.00	0.00	1.53	0.00	29.202

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.68	0.00	3.09	0.00	0.00	0.00	0.00	0.00	2.641	

MESONORM TOTAL = 100.076

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PETRONORMS PROGRAM
SAMPLE NUMBER  MK008
 OXIDES GIVEN     RECALC 100%     MOL PROPS  CAT PROPS
   SiO2  51.20          51.451          0.856       0.856
  Al2O3  15.03          15.104          0.148       0.296
  Fe2O3   1.35           1.357          0.008       0.017
    FeO  10.97          11.024          0.153       0.153
    MnO   0.18           0.181          0.003       0.003
    MgO   5.43           5.457          0.135       0.135
    CaO  11.16          11.215          0.200       0.200
   Na2O   2.34           2.351          0.038       0.076
    K2O   0.18           0.181          0.002       0.004
   TiO2   1.42           1.428          0.018       0.018
   P2O5   0.25           0.251          0.002       0.004
  Cr2O3   0.00           0.000          0.000       0.000
 TOTAL   99.51

    ..................CIPW NORM.................
      q       c      or      ab      an      lc      ne      kp      wo
  2.998  0.000  1.069 19.896 30.122  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 10.601 10.150  0.000  0.000 20.751  0.000  0.000  1.967  0.000
     il     ap     cm     tn     pf     ns     ks     cs     ru     di
  2.713 0.595 0.000 0.000 0.000 0.000 0.000 0.000 0.000 19.905
CIPWNORM TOTAL = 100.015
                ****************************
       PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN    51.087  FS   48.913
FELDSPAR COMPOSITION   :KFS   2.092  AB  38.946  AN  58.962
PLAGIOCLASE PERCENT ANORTHITE  60.222
QUARTZ : FELDSPAR RATIOS:
QUARTZ  5.543  ORTHOCLASE  1.976  PLAGIOCLASE  92.481
QUARTZ  12.510 ORTHOCLASE 4.461 ALBITE 83.029
CHAPPELS A/CNK INDEX  0.618
MG No. IN CATIONS   44.27

AFM PARAMETERS: A = 0.13 F = 0.61 M = 0.27
JENSEN CATION PLOT   A = 0.37  M = 0.15 F = 0.48

      .............CATANORM.............
      q       c      or      ab      an      lc      ne      kp      wo
  2.832  0.000  1.090 21.531 30.723  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 10.389  9.947  0.000  0.000 20.336  0.000  0.000  1.446  0.000
     il     ap     cm     tn     pf     ns     ks     cs     ru     di
  2.029 0.536 0.000 0.000 0.000 0.000 0.000 0.000 0.00019.478
 CATANORM TOTAL =100.000
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  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q      C      Or     Ab      An      Lc      Ne     Wo     Ri    Act
 Ed
  0.54   0.00   0.00 21.53 30.72   0.00    0.00    0.00 28.91   0.00
0.00
  Di      Hy      Ol     (En      Fs      Fo      Fa)     Mt      Hm
HORNBLENDE
  0.00 11.52   0.00   0.00   0.00   0.00    0.00    1.45    0.00
28.912
   Ap     Cm     Tn     Pf     Ns     Ks     Cs     Ru   BIOTITE  Sp
  0.60   0.00   3.04   0.00   0.00   0.00   0.00   0.00    1.744
MESONORM TOTAL   =   100.067
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PETRONORMS PROGRAM
SAMPLE NUMBER MK009

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	49.81	49.921	0.831	0.831
Al2O3	16.19	16.226	0.159	0.318
Fe2O3	1.35	1.353	0.008	0.017
FeO	10.95	10.974	0.153	0.153
MnO	0.19	0.190	0.003	0.003
MgO	3.41	3.418	0.085	0.085
CaO	12.22	12.247	0.218	0.218
Na2O	2.91	2.916	0.047	0.094
K2O	0.51	0.511	0.005	0.011
TiO2	1.82	1.822	0.023	0.023
P2O5	0.42	0.421	0.003	0.006
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.78			

..................CIPW NORM................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	3.020	24.677	29.673	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
4.396	6.437	0.584	0.855	10.833	1.440	0.000	1.962	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
3.460	0.997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	23.963

CIPWNORM TOTAL = 100.024

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PARAMETERS FOR CIPW NORMATIVE MINERALS

OLIVINE COMPOSITION: FORSTERITE 40.578 FAYALITE 59.422
HYPERSTHENE COMPOSITION:EN 40.578 FS 59.422
FELDSPAR COMPOSITION :KFS 5.265 AB 43.013 AN 51.722
PLAGIOCLASE PERCENT ANORTHITE 54.596
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 5.265 PLAGIOCLASE 94.735
QUARTZ 0.000 ORTHOCLASE 10.905 ALBITE 89.095
CHAPPELS A/CNK INDEX 0.588
MG No. IN CATIONS 33.32

AFM PARAMETERS: A = 0.18 F = 0.64 M = 0.18
JENSEN CATION PLOT A = 0.40 M = 0.10 F = 0.50

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	3.086	26.760	30.328	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
4.197	6.146	0.559	0.819	10.343	1.378	0.000	1.446	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.593	0.899	0.000	0.000	0.000	0.000	0.000	0.000	0.000	23.167

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.00	0.00	0.00	24.07	30.33	0.00	0.00	0.00	25.64	0.00	8.61

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.18	0.00	0.00	0.00	0.00	0.00	1.45	0.00	34.252

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
1.01	0.00	3.89	0.00	0.00	0.00	0.00	0.00	4.937	

MESONORM TOTAL = 100.112

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PETRONORMS PROGRAM
SAMPLE NUMBER  MK010
 OXIDES GIVEN      RECALC 100%       MOL PROPS   CAT PROPS
   SiO2  52.07           52.273          0.870       0.870
  Al2O3  15.14           15.199          0.149       0.298
  Fe2O3   1.33            1.335          0.008       0.017
    FeO  10.76           10.802          0.150       0.150
    MnO   0.18            0.181          0.003       0.003
    MgO   6.00            6.023          0.149       0.149
    CaO   9.50            9.537          0.170       0.170
   Na2O   2.82            2.831          0.046       0.091
    K2O   0.20            0.201          0.002       0.004
   TiO2   1.37            1.378          0.017       0.017
   P2O5   0.24            0.241          0.002       0.003
  Cr2O3   0.00            0.000          0.000       0.000
 TOTAL   99.61

    ...................CIPW NORM.................
      q       c      or      ab      an      lc      ne      kp      wo
  2.453  0.000  1.186 23.953 28.171  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 13.251 11.287  0.000  0.000 24.539  0.000  0.000  1.936  0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  2.616 0.571 0.000 0.000 0.000 0.000 0.000 0.000 0.000 14.589
CIPWNORM TOTAL = 100.015
            ****************************
       PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN    54.001  FS   45.999
FELDSPAR COMPOSITION   :KFS    2.226  AB  44.932  AN  52.843
PLAGIOCLASE PERCENT ANORTHITE  54.046
QUARTZ : FELDSPAR RATIOS:
QUARTZ  4.400  ORTHOCLASE  2.128  PLAGIOCLASE  93.473
QUARTZ  8.892 ORTHOCLASE 4.300 ALBITE 86.809
CHAPPELS A/CNK INDEX  0.684
MG No. IN CATIONS   47.21

AFM PARAMETERS: A = 0.14 F = 0.57 M = 0.29
JENSEN CATION PLOT   A = 0.37  M = 0.17 F = 0.47
      .............CATANORM.............
      q       c      or      ab      an      lc      ne      kp      wo
  2.303  0.000  1.202 25.754 28.548  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 13.006 11.078  0.000  0.000 24.084  0.000  0.000  1.414  0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  1.944 0.510 0.000 0.000 0.000 0.000 0.000 0.000 0.00014.241
 CATANORM TOTAL =100.000
         **********************************
  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q      C      Or     Ab     An     Lc     Ne     Wo     Ri    Act
 Ed
  0.76   0.00   0.00 25.75 28.55   0.00   0.00   0.00 19.41   0.00
0.00
  Di     Hy     Ol    (En     Fs     Fo     Fa)    Mt     Hm
HORNBLENDE
  0.00 18.77   0.00   0.00   0.00   0.00   0.00   1.41   0.00
19.410
   Ap     Cm     Tn     Pf     Ns     Ks     Cs     Ru  BIOTITE  Sp
  0.57  0.00  2.92  0.00  0.00  0.00  0.00  0.00   1.923
MESONORM TOTAL  =  100.064
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PETRONORMS PROGRAM
SAMPLE NUMBER MK011

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	49.67	50.089	0.834	0.834
Al2O3	16.14	16.276	0.160	0.319
Fe2O3	1.41	1.422	0.009	0.018
FeO	11.38	11.476	0.160	0.160
MnO	0.20	0.202	0.003	0.003
MgO	3.81	3.842	0.095	0.095
CaO	11.31	11.405	0.203	0.203
Na2O	2.73	2.753	0.044	0.089
K2O	0.69	0.696	0.007	0.015
TiO2	1.56	1.577	0.020	0.020
P2O5	0.26	0.262	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.16			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	4.112	23.294	29.998	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
5.782	8.123	0.842	1.183	13.905	2.025	0.000	2.062	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.996	0.621	0.000	0.000	0.000	0.000	0.000	0.000	0.000	21.005

CIPWNORM TOTAL = 100.016

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PARAMETERS FOR CIPW NORMATIVE MINERALS

OLIVINE COMPOSITION: FORSTERITE 41.580 FAYALITE 58.420
HYPERSTHENE COMPOSITION:EN 41.580 FS 58.420
FELDSPAR COMPOSITION :KFS 7.163 AB 40.579 AN 52.258
PLAGIOCLASE PERCENT ANORTHITE 56.290
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 7.163 PLAGIOCLASE 92.837
QUARTZ 0.000 ORTHOCLASE 15.003 ALBITE 84.997
CHAPPELS A/CNK INDEX 0.626
MG No. IN CATIONS 34.93

AFM PARAMETERS: A = 0.17 F = 0.64 M = 0.19
JENSEN CATION PLOT A = 0.40 M = 0.11 F = 0.50

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	4.199	25.251	30.649	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
5.533	7.773	0.809	1.136	13.306	1.945	0.000	1.519	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.244	0.560	0.000	0.000	0.000	0.000	0.000	0.000	0.000	20.327

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.00	0.00	0.00	23.71	30.65	0.00	0.00	0.00	25.08	0.00	4.92

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	3.47	0.00	0.00	0.00	0.00	0.00	1.52	0.00	30.004

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.63	0.00	3.37	0.00	0.00	0.00	0.00	0.00	6.719	

MESONORM TOTAL = 100.070

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PETRONORMS PROGRAM
SAMPLE NUMBER MK012

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	51.88	52.259	0.870	0.870
Al2O3	14.64	14.747	0.145	0.289
Fe2O3	1.33	1.340	0.008	0.017
FeO	10.80	10.879	0.151	0.151
MnO	0.18	0.181	0.003	0.003
MgO	5.83	5.873	0.146	0.146
CaO	10.45	10.526	0.188	0.188
Na2O	2.29	2.307	0.037	0.074
K2O	0.24	0.242	0.003	0.005
TiO2	1.38	1.395	0.017	0.017
P2O5	0.25	0.252	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.27			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
4.246	0.000	1.429	19.517	29.169	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
12.062	10.607	0.000	0.000	22.669	0.000	0.000	1.942	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.649	0.596	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.796

CIPWNORM TOTAL = 100.015

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 53.208 FS 46.792
FELDSPAR COMPOSITION :KFS 2.851 AB 38.945 AN 58.205
PLAGIOCLASE PERCENT ANORTHITE 59.912
QUARTZ : FELDSPAR RATIOS:
QUARTZ 7.811 ORTHOCLASE 2.628 PLAGIOCLASE 89.561
QUARTZ 16.856 ORTHOCLASE 5.671 ALBITE 77.474
CHAPPELS A/CNK INDEX 0.636
MG No. IN CATIONS 46.42

AFM PARAMETERS: A = 0.12 F = 0.59 M = 0.29
JENSEN CATION PLOT A = 0.36 M = 0.16 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
4.007	0.000	1.455	21.101	29.723	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
11.878	10.445	0.000	0.000	22.323	0.000	0.000	1.427	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.980	0.536	0.000	0.000	0.000	0.000	0.000	0.000	0.00017.448	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
2.20	0.00	0.00	21.10	29.72	0.00	0.00	0.00	25.29	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	14.42	0.00	0.00	0.00	0.00	0.00	1.43	0.00	25.291

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.60	0.00	2.97	0.00	0.00	0.00	0.00	0.00	2.328	

MESONORM TOTAL = 100.067

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PETRONORMS PROGRAM

SAMPLE NUMBER MK013

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.73	55.962	0.931	0.931
Al2O3	13.98	14.038	0.138	0.275
Fe2O3	1.01	1.014	0.006	0.013
FeO	8.17	8.204	0.114	0.114
MnO	0.11	0.110	0.002	0.002
MgO	2.76	2.771	0.069	0.069
CaO	11.41	11.458	0.204	0.204
Na2O	0.20	0.201	0.003	0.006
K2O	4.94	4.961	0.053	0.105
TiO2	1.22	1.220	0.015	0.015
P2O5	0.06	0.060	0.000	0.001
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.59			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
8.923	0.000	29.313	1.699	22.752	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
2.091	2.862	0.000	0.000	4.954	0.000	0.000	1.471	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.318	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	28.433

CIPWNORM TOTAL = 100.005

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 42.214 FS 57.786

FELDSPAR COMPOSITION :KFS 54.521 AB 3.161 AN 42.318

PLAGIOCLASE PERCENT ANORTHITE 93.050

QUARTZ : FELDSPAR RATIOS:

QUARTZ 14.234 ORTHOCLASE 46.761 PLAGIOCLASE 39.006

QUARTZ 22.343 ORTHOCLASE 73.402 ALBITE 4.255

CHAPPELS A/CNK INDEX 0.529

MG No. IN CATIONS 35.14

AFM PARAMETERS: A = 0.30 F = 0.53 M = 0.16

JENSEN CATION PLOT A = 0.44 M = 0.10 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
8.554	0.000	30.330	1.866	23.552	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
2.031	2.780	0.000	0.000	4.810	0.000	0.000	1.097	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.759	0.130	0.000	0.000	0.000	0.000	0.000	0.000	0.000	27.901

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
17.93	0.00	13.23	1.87	23.55	0.00	0.00	12.19	0.00	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.00	0.000

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.15	0.00	2.64	0.00	0.00	0.00	0.00	0.00	27.364	

MESONORM TOTAL = 100.016

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PETRONORMS PROGRAM
SAMPLE NUMBER MK014

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	53.39	53.421	0.889	0.889
Al2O3	14.39	14.398	0.141	0.282
Fe2O3	1.25	1.251	0.008	0.016
FeO	10.11	10.116	0.141	0.141
MnO	0.18	0.180	0.003	0.003
MgO	5.75	5.753	0.143	0.143
CaO	9.87	9.876	0.176	0.176
Na2O	3.09	3.092	0.050	0.100
K2O	0.36	0.360	0.004	0.008
TiO2	1.32	1.323	0.017	0.017
P2O5	0.23	0.230	0.002	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.94			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
2.827	0.000	2.129	26.160	24.345	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
11.169	9.307	0.000	0.000	20.476	0.000	0.000	1.813	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.513	0.545	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.207

CIPWNORM TOTAL = 100.014

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 54.546 FS 45.454
FELDSPAR COMPOSITION :KFS 4.044 AB 49.702 AN 46.254
PLAGIOCLASE PERCENT ANORTHITE 48.203
QUARTZ : FELDSPAR RATIOS:
QUARTZ 5.097 ORTHOCLASE 3.838 PLAGIOCLASE 91.065
QUARTZ 9.085 ORTHOCLASE 6.841 ALBITE 84.074
CHAPPELS A/CNK INDEX 0.614
MG No. IN CATIONS 47.71

AFM PARAMETERS: A = 0.17 F = 0.55 M = 0.28
JENSEN CATION PLOT A = 0.37 M = 0.17 F = 0.46

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
2.648	0.000	2.152	28.078	24.627	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.959	9.132	0.000	0.000	20.091	0.000	0.000	1.323	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.864	0.487	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.729

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
1.13	0.00	0.00	28.08	24.63	0.00	0.00	0.00	28.13	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	9.99	0.00	0.00	0.00	0.00	0.00	1.32	0.00	28.126

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.55	0.00	2.80	0.00	0.00	0.00	0.00	0.00	3.444	

MESONORM TOTAL = 100.061

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PETRONORMS PROGRAM
SAMPLE NUMBER MK015

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	50.27	50.363	0.838	0.838
Al2O3	17.21	17.242	0.169	0.338
Fe2O3	1.46	1.463	0.009	0.018
FeO	11.82	11.842	0.165	0.165
MnO	0.17	0.170	0.002	0.002
MgO	5.40	5.410	0.134	0.134
CaO	11.08	11.100	0.198	0.198
Na2O	0.11	0.110	0.002	0.004
K2O	0.08	0.080	0.001	0.002
TiO2	1.89	1.890	0.024	0.024
P2O5	0.33	0.331	0.002	0.005
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.82			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
11.849	0.000	0.474	0.932	46.313	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
14.215	14.236	0.000	0.000	28.452	0.000	0.000	2.121	0.000
il	**ap**	**cm**	**tn**	**pf**	**ns**	**ks**	**cs**	**ru**	**di**
3.589	0.783	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.506

CIPWNORM TOTAL = 100.019

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 49.964 FS 50.036
FELDSPAR COMPOSITION :KFS 0.992 AB 1.954 AN 97.054
PLAGIOCLASE PERCENT ANORTHITE 98.026
QUARTZ : FELDSPAR RATIOS:
QUARTZ 19.892 ORTHOCLASE 0.795 PLAGIOCLASE 79.313
QUARTZ 89.393 ORTHOCLASE 3.573 ALBITE 7.034
CHAPPELS A/CNK INDEX 0.843
MG No. IN CATIONS 42.29

AFM PARAMETERS: A = 0.01 F = 0.70 M = 0.29
JENSEN CATION PLOT A = 0.38 M = 0.14 F = 0.48

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
11.415	0.000	0.492	1.029	48.178	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
14.165	14.186	0.000	0.000	28.351	0.000	0.000	1.590	0.000
il	**ap**	**cm**	**tn**	**pf**	**ns**	**ks**	**cs**	**ru**	**di**
2.738	0.719	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.487

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
10.34	0.00	0.00	1.03	48.18	0.00	0.00	0.00	0.02	0.00	0.00
Di	**Hy**	**Ol**	**(En**	**Fs**	**Fo**	**Fa)**	**Mt**	**Hm**	**HORNBLENDE**	
0.00	33.23	0.00	0.00	0.00	0.00	0.00	1.59	0.00	0.022	
Ap	**Cm**	**Tn**	**Pf**	**Ns**	**Ks**	**Cs**	**Ru**	**BIOTITE**	**Sp**	
0.81	0.00	4.11	0.00	0.00	0.00	0.00	0.00	0.788		

MESONORM TOTAL = 100.090

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PETRONORMS PROGRAM
SAMPLE NUMBER MK016

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	50.81	51.048	0.850	0.850
Al2O3	14.82	14.890	0.146	0.292
Fe2O3	1.50	1.507	0.009	0.019
FeO	12.11	12.167	0.169	0.169
MnO	0.19	0.191	0.003	0.003
MgO	4.65	4.672	0.116	0.116
CaO	9.02	9.062	0.162	0.162
Na2O	4.12	4.139	0.067	0.134
K2O	0.27	0.271	0.003	0.006
TiO2	1.73	1.741	0.022	0.022
P2O5	0.31	0.311	0.002	0.004
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.53			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	1.603	35.023	21.246	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
3.585	4.355	4.405	5.352	7.939	9.757	0.000	2.185	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
3.307	0.738	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.220

CIPWNORM TOTAL = 100.019

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PARAMETERS FOR CIPW NORMATIVE MINERALS
OLIVINE COMPOSITION: FORSTERITE 45.149 FAYALITE 54.851
HYPERSTHENE COMPOSITION:EN 45.149 FS 54.851
FELDSPAR COMPOSITION :KFS 2.770 AB 60.519 AN 36.712
PLAGIOCLASE PERCENT ANORTHITE 37.757
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 2.770 PLAGIOCLASE 97.230
QUARTZ 0.000 ORTHOCLASE 4.377 ALBITE 95.623
CHAPPELS A/CNK INDEX 0.631
MG No. IN CATIONS 38.11

AFM PARAMETERS: A = 0.20 F = 0.60 M = 0.21
JENSEN CATION PLOT A = 0.35 M = 0.13 F = 0.52

.............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	1.622	37.612	21.504	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
3.431	4.168	4.246	5.158	7.598	9.404	0.000	1.594	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.454	0.659	0.000	0.000	0.000	0.000	0.000	0.000	0.00017.552	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.00	0.00	0.00	31.40	21.50	0.00	0.00	0.00	5.07	0.00	19.88

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	13.62	0.00	0.00	0.00	0.00	0.00	1.59	0.00	24.948

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.74	0.00	3.68	0.00	0.00	0.00	0.00	0.00	2.595	

MESONORM TOTAL = 100.082

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PETRONORMS PROGRAM
SAMPLE NUMBER RM01

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	52.62	52.936	0.881	0.881
Al2O3	13.78	13.863	0.136	0.272
Fe2O3	1.35	1.358	0.009	0.017
FeO	10.91	10.975	0.153	0.153
MnO	0.23	0.231	0.003	0.003
MgO	6.69	6.730	0.167	0.167
CaO	9.58	9.637	0.172	0.172
Na2O	2.61	2.626	0.042	0.085
K2O	0.66	0.664	0.007	0.014
TiO2	0.81	0.818	0.010	0.010
P2O5	0.16	0.161	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.40			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
1.548	0.000	3.923	22.216	24.078	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
14.009	11.518	0.000	0.000	25.527	0.000	0.000	1.969	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.554	0.381	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.814

CIPWNORM TOTAL = 100.011

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 54.880 FS 45.120
FELDSPAR COMPOSITION :KFS 7.813 AB 44.239 AN 47.948
PLAGIOCLASE PERCENT ANORTHITE 52.011
QUARTZ : FELDSPAR RATIOS:
QUARTZ 2.990 ORTHOCLASE 7.579 PLAGIOCLASE 89.430
QUARTZ 5.591 ORTHOCLASE 14.170 ALBITE 80.238
CHAPPELS A/CNK INDEX 0.614
MG No. IN CATIONS 49.58

AFM PARAMETERS: A = 0.15 F = 0.55 M = 0.30
JENSEN CATION PLOT A = 0.34 M = 0.19 F = 0.47

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
1.451	0.000	3.968	23.851	24.364	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
13.762	11.315	0.000	0.000	25.077	0.000	0.000	1.436	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.153	0.341	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.359

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
1.25	0.00	0.00	23.85	24.36	0.00	0.00	0.00	30.10	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	10.58	0.00	0.00	0.00	0.00	0.00	1.44	0.00	30.098

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.38	0.00	1.73	0.00	0.00	0.00	0.00	0.00	6.349	

MESONORM TOTAL = 100.043

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PETRONORMS PROGRAM
SAMPLE NUMBER  RM02
 OXIDES GIVEN      RECALC 100%     MOL PROPS   CAT PROPS
   SiO2  72.12          72.517        1.207       1.207
  Al2O3  12.12          12.187        0.120       0.239
  Fe2O3   0.52           0.523        0.003       0.007
    FeO   4.17           4.193        0.058       0.058
    MnO   0.07           0.070        0.001       0.001
    MgO   0.80           0.804        0.020       0.020
    CaO   3.67           3.690        0.066       0.066
   Na2O   1.98           1.991        0.032       0.064
    K2O   3.40           3.419        0.036       0.073
   TiO2   0.48           0.485        0.006       0.006
   P2O5   0.12           0.121        0.001       0.002
  Cr2O3   0.00           0.000        0.000       0.000
 TOTAL   99.45

     .....................CIPW NORM.................
      q       c      or      ab      an      lc      ne      kp      wo
 36.798  0.000 20.202 16.845 14.219  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
  2.037  5.105  0.000  0.000  7.142  0.000  0.000  0.758  0.000
     il     ap     cm     tn     pf     ns     ks     cs     ru     di
  0.922 0.286 0.000 0.000 0.000 0.000 0.000 0.000 0.000  2.835
CIPWNORM TOTAL = 100.007
                  ****************************
       PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN   28.526  FS   71.474
FELDSPAR COMPOSITION   :KFS  39.406  AB  32.859  AN  27.736
PLAGIOCLASE PERCENT ANORTHITE  45.773
QUARTZ : FELDSPAR RATIOS:
QUARTZ  41.786  ORTHOCLASE  22.940  PLAGIOCLASE  35.275
QUARTZ  49.832 ORTHOCLASE 27.357 ALBITE 22.812
CHAPPELS A/CNK INDEX  0.891
MG No. IN CATIONS   23.52

AFM PARAMETERS: A = 0.50 F = 0.43 M = 0.07
JENSEN CATION PLOT   A = 0.59  M = 0.04 F = 0.36

      ..............CATANORM.............
      q       c      or      ab      an      lc      ne      kp      wo
 35.154  0.000 20.830 18.436 14.667  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
  1.902  4.767  0.000  0.000  6.669  0.000  0.000  0.564  0.000
     il     ap     cm     tn     pf     ns     ks     cs     ru     di
  0.697 0.260 0.000 0.000 0.000 0.000 0.000 0.000 0.000 2.722
 CATANORM TOTAL =100.000
               *********************************
  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q      C      Or     Ab     An     Lc      Ne     Wo     Ri     Act
 Ed
 39.17  0.00 13.56 18.44 14.67  0.00   0.00   0.66   0.00   0.00
0.00
  Di     Hy     Ol    (En     Fs      Fo      Fa)     Mt      Hm
HORNBLENDE
  0.00  0.00  0.00  0.00  0.00  0.00   0.00   0.56   0.00
0.000
   Ap     Cm     Tn     Pf     Ns     Ks     Cs     Ru   BIOTITE  Sp
  0.29  0.00  1.05  0.00  0.00  0.00  0.00  0.00  11.638
MESONORM TOTAL   =   100.033
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PETRONORMS PROGRAM
SAMPLE NUMBER RM03

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	72.45	72.702	1.210	1.210
Al2O3	11.86	11.901	0.117	0.233
Fe2O3	0.48	0.482	0.003	0.006
FeO	3.86	3.873	0.054	0.054
MnO	0.06	0.060	0.001	0.001
MgO	0.78	0.783	0.019	0.019
CaO	4.44	4.455	0.079	0.079
Na2O	1.32	1.325	0.021	0.043
K2O	3.85	3.863	0.041	0.082
TiO2	0.45	0.455	0.006	0.006
P2O5	0.10	0.100	0.001	0.001
Cr2O3.	0.00	0.000	0.000	0.000
TOTAL	99.65			

..................CIPW NORM................

q	c	or	ab	an	lc	ne	kp	wo
38.384	0.000	22.829	11.208	15.118	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
1.553	3.683	0.000	0.000	5.236	0.000	0.000	0.698	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
0.864	0.238	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.431

CIPWNORM TOTAL = 100.006

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 29.659 FS 70.341
FELDSPAR COMPOSITION :KFS 46.444 AB 22.801 AN 30.755
PLAGIOCLASE PERCENT ANORTHITE 57.427
QUARTZ : FELDSPAR RATIOS:
QUARTZ 43.848 ORTHOCLASE 26.079 PLAGIOCLASE 30.073
QUARTZ 53.001 ORTHOCLASE 31.523 ALBITE 15.476
CHAPPELS A/CNK INDEX 0.823
MG No. IN CATIONS 24.47

AFM PARAMETERS: A = 0.50 F = 0.42 M = 0.08
JENSEN CATION PLOT A = 0.61 M = 0.05 F = 0.35

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
36.822	0.000	23.638	12.317	15.660	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
1.460	3.464	0.000	0.000	4.924	0.000	0.000	0.522	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
0.656	0.217	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.245

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
40.60	0.00	16.80	12.32	15.66	0.00	0.00	1.97	0.00	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.000

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.24	0.00	0.98	0.00	0.00	0.00	0.00	0.00	10.938	

MESONORM TOTAL = 100.027

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PETRONORMS PROGRAM
SAMPLE NUMBER RM04

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	73.33	73.571	1.225	1.225
Al2O3	11.57	11.608	0.114	0.228
Fe2O3	0.43	0.431	0.003	0.005
FeO	3.46	3.471	0.048	0.048
MnO	0.05	0.050	0.001	0.001
MgO	0.69	0.692	0.017	0.017
CaO	4.88	4.896	0.087	0.087
Na2O	1.20	1.204	0.019	0.039
K2O	3.50	3.511	0.037	0.075
TiO2	0.45	0.454	0.006	0.006
P2O5	0.11	0.110	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.67			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
41.135	0.000	20.750	10.187	15.898	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
1.101	2.605	0.000	0.000	3.707	0.000	0.000	0.626	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
0.863	0.261	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.580

CIPWNORM TOTAL = 100.006

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 29.708 FS 70.292
FELDSPAR COMPOSITION :KFS 44.304 AB 21.750 AN 33.945
PLAGIOCLASE PERCENT ANORTHITE 60.948
QUARTZ : FELDSPAR RATIOS:
QUARTZ 46.760 ORTHOCLASE 23.588 PLAGIOCLASE 29.652
QUARTZ 57.075 ORTHOCLASE 28.791 ALBITE 14.134
CHAPPELS A/CNK INDEX 0.791
MG No. IN CATIONS 24.23

AFM PARAMETERS: A = 0.51 F = 0.42 M = 0.07
JENSEN CATION PLOT A = 0.62 M = 0.04 F = 0.33

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo	
39.535	0.000	21.525	11.217	16.499	0.000	0.000	0.000	0.000	
en	fs	fo	fa	hy	ol	ac	mt	hm	
1.038	2.455	0.000	0.000	3.493	0.000	0.000	0.468	0.000	
il	ap	cm	tn	pf	ns	ks	cs	ru	di
0.656	0.239	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.367

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
42.87	0.00	15.41	11.22	16.50	0.00	0.00	2.53	0.00	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.000

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.27	0.00	0.98	0.00	0.00	0.00	0.00	0.00	9.778	

MESONORM TOTAL = 100.030

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PETRONORMS PROGRAM

SAMPLE NUMBER RM05

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	52.08	52.319	0.871	0.871
Al2O3	15.29	15.360	0.151	0.301
Fe2O3	1.13	1.135	0.007	0.014
FeO	9.12	9.162	0.128	0.128
MnO	0.16	0.161	0.002	0.002
MgO	3.78	3.797	0.094	0.094
CaO	14.28	14.345	0.256	0.256
Na2O	0.95	0.954	0.015	0.031
K2O	1.67	1.678	0.018	0.036
TiO2	0.91	0.918	0.011	0.011
P2O5	0.17	0.171	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.54			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
5.825	0.000	9.913	8.075	32.672	0.000	0.000	0.000	0.000

en	fs	fo	fa	hy	ol	ac	mt	hm
3.827	4.516	0.000	0.000	8.343	0.000	0.000	1.646	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.744	0.405	0.000	0.000	0.000	0.000	0.000	0.000	0.000	31.388

CIPWNORM TOTAL = 100.011

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 45.868 FS 54.132

FELDSPAR COMPOSITION :KFS 19.568 AB 15.939 AN 64.492

PLAGIOCLASE PERCENT ANORTHITE 80.183

QUARTZ : FELDSPAR RATIOS:

QUARTZ 10.313 ORTHOCLASE 17.550 PLAGIOCLASE 72.137

QUARTZ 24.462 ORTHOCLASE 41.629 ALBITE 33.909

CHAPPELS A/CNK INDEX 0.521

MG No. IN CATIONS 39.93

AFM PARAMETERS: A = 0.16 F = 0.61 M = 0.23

JENSEN CATION PLOT A = 0.43 M = 0.12 F = 0.45

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
5.552	0.000	10.198	8.817	33.623	0.000	0.000	0.000	0.000

en	fs	fo	fa	hy	ol	ac	mt	hm
3.731	4.403	0.000	0.000	8.134	0.000	0.000	1.221	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.316	0.367	0.000	0.000	0.000	0.000	0.000	0.000	0.000	30.772

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
9.75	0.00	0.00	8.82	33.62	0.00	0.00	9.03	18.90	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22	0.00	18.898

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.41	0.00	1.97	0.00	0.00	0.00	0.00	0.00	16.316	

MESONORM TOTAL = 100.046

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PETRONORMS PROGRAM
SAMPLE NUMBER RM06

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	50.97	51.203	0.852	0.852
Al2O3	17.97	18.052	0.177	0.354
Fe2O3	1.03	1.035	0.006	0.013
FeO	8.30	8.338	0.116	0.116
MnO	0.11	0.111	0.002	0.002
MgO	2.67	2.682	0.067	0.067
CaO	17.85	17.932	0.320	0.320
Na2O	0.05	0.050	0.001	0.002
K2O	0.03	0.030	0.000	0.001
TiO2	0.48	0.486	0.006	0.006
P2O5	0.08	0.080	0.001	0.001
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.54			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
10.821	0.000	0.178	0.425	48.942	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
1.376	2.172	0.000	0.000	3.547	0.000	0.000	1.500	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
0.924	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	33.479

CIPWNORM TOTAL = 100.006
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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 38.781 FS 61.219
FELDSPAR COMPOSITION :KFS 0.359 AB 0.858 AN 98.783
PLAGIOCLASE PERCENT ANORTHITE 99.139
QUARTZ : FELDSPAR RATIOS:
QUARTZ 17.925 ORTHOCLASE 0.295 PLAGIOCLASE 81.780
QUARTZ 94.721 ORTHOCLASE 1.559 ALBITE 3.720
CHAPPELS A/CNK INDEX 0.552
MG No. IN CATIONS 34.03

AFM PARAMETERS: A = 0.01 F = 0.77 M = 0.22
JENSEN CATION PLOT A = 0.51 M = 0.09 F = 0.40

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
10.394	0.000	0.185	0.468	50.765	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
1.327	2.094	0.000	0.000	3.421	0.000	0.000	1.122	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
0.703	0.174	0.000	0.000	0.000	0.000	0.000	0.000	0.00032.768	

CATANORM TOTAL =100.000
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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
8.13	0.00	0.00	0.47	50.77	0.00	0.00	7.57	30.43	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	0.00	30.429

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.20	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.295	

MESONORM TOTAL = 100.022
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PETRONORMS PROGRAM
SAMPLE NUMBER RM07

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.40	55.814	0.929	0.929
Al2O3	14.51	14.618	0.143	0.287
Fe2O3	1.05	1.058	0.007	0.013
FeO	8.53	8.594	0.120	0.120
MnO	0.14	0.141	0.002	0.002
MgO	4.40	4.433	0.110	0.110
CaO	10.89	10.971	0.196	0.196
Na2O	2.75	2.771	0.045	0.089
K2O	0.58	0.584	0.006	0.012
TiO2	0.85	0.855	0.011	0.011
P2O5	0.16	0.161	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.26			

..................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
7.511	0.000	3.453	23.442	25.725	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
6.824	6.470	0.000	0.000	13.293	0.000	0.000	1.534	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.624	0.382	0.000	0.000	0.000	0.000	0.000	0.000	0.000	23.047

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 51.331 FS 48.669
FELDSPAR COMPOSITION :KFS 6.562 AB 44.549 AN 48.889
PLAGIOCLASE PERCENT ANORTHITE 52.322
QUARTZ : FELDSPAR RATIOS:
QUARTZ 12.491 ORTHOCLASE 5.742 PLAGIOCLASE 81.767
QUARTZ 21.830 ORTHOCLASE 10.036 ALBITE 68.134
CHAPPELS A/CNK INDEX 0.582
MG No. IN CATIONS 45.29

AFM PARAMETERS: A = 0.19 F = 0.55 M = 0.26
JENSEN CATION PLOT A = 0.42 M = 0.15 F = 0.43

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
7.059	0.000	3.503	25.241	26.107	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
6.658	6.313	0.000	0.000	12.971	0.000	0.000	1.122	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.209	0.342	0.000	0.000	0.000	0.000	0.000	0.000	0.00022.447	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
6.44	0.00	0.00	25.24	26.11	0.00	0.00	1.53	31.80	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	0.00	31.800

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.38	0.00	1.81	0.00	0.00	0.00	0.00	0.00	5.604	

MESONORM TOTAL = 100.043

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PETRONORMS PROGRAM
SAMPLE NUMBER  RM08
 OXIDES GIVEN     RECALC 100%     MOL PROPS  CAT PROPS
   SiO2  54.50        54.750         0.911      0.911
  Al2O3  14.53        14.597         0.143      0.286
  Fe2O3   1.16         1.165         0.007      0.015
    FeO   9.43         9.473         0.132      0.132
    MnO   0.18         0.181         0.003      0.003
    MgO   5.39         5.415         0.134      0.134
    CaO   9.04         9.082         0.162      0.162
   Na2O   3.46         3.476         0.056      0.112
    K2O   0.70         0.703         0.007      0.015
   TiO2   0.96         0.967         0.012      0.012
   P2O5   0.19         0.191         0.001      0.003
  Cr2O3   0.00         0.000         0.000      0.000
 TOTAL   99.54

    ..................CIPW NORM................
      q       c      or      ab      an      lc      ne      kp      wo
  2.621  0.000  4.155 29.410 22.149  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 10.619  9.090  0.000  0.000 19.709  0.000  0.000  1.690  0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  1.837 0.452 0.000 0.000 0.000 0.000 0.000 0.000 0.000 17.989
CIPWNORM TOTAL = 100.012
             ***************************
       PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN    53.878  FS    46.122
FELDSPAR COMPOSITION    :KFS   7.458  AB  52.787  AN  39.755
PLAGIOCLASE PERCENT ANORTHITE  42.959
QUARTZ : FELDSPAR RATIOS:
QUARTZ  4.493  ORTHOCLASE  7.123  PLAGIOCLASE  88.384
QUARTZ  7.243 ORTHOCLASE 11.483 ALBITE 81.274
CHAPPELS A/CNK INDEX  0.635
MG No. IN CATIONS   47.84

AFM PARAMETERS: A = 0.21 F = 0.52 M = 0.27
JENSEN CATION PLOT   A = 0.39  M = 0.17 F = 0.44

      .............CATANORM.............
      q       c      or      ab      an      lc      ne      kp      wo
  2.444  0.000  4.183 31.422 22.304  0.000  0.000  0.000  0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
 10.353  8.863  0.000  0.000 19.216  0.000  0.000  1.227  0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  1.357 0.402 0.000 0.000 0.000 0.000 0.000 0.000 0.00017.446
 CATANORM TOTAL =100.000
         *********************************
  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q      C      Or     Ab      An      Lc      Ne     Wo     Ri    Act
 Ed
  2.43  0.00  0.00 31.42 22.30  0.00   0.00   0.00 27.62  0.00
0.00
  Di     Hy     Ol    (En     Fs      Fo      Fa)     Mt     Hm
HORNBLENDE
  0.00  5.86  0.00  0.00  0.00  0.00   0.00   1.23   0.00
27.623
   Ap     Cm     Tn     Pf     Ns     Ks     Cs     Ru   BIOTITE  Sp
  0.45  0.00  2.04  0.00  0.00  0.00  0.00  0.00   6.692
MESONORM TOTAL  =  100.050
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PETRONORMS PROGRAM
SAMPLE NUMBER  RM09
 OXIDES GIVEN     RECALC 100%     MOL PROPS  CAT PROPS
   SiO2  55.09          55.430         0.923       0.923
  Al2O3  13.49          13.573         0.133       0.266
  Fe2O3   1.10           1.107         0.007       0.014
    FeO   8.89           8.945         0.124       0.124
    MnO   0.19           0.191         0.003       0.003
    MgO   5.15           5.182         0.129       0.129
    CaO   8.97           9.025         0.161       0.161
   Na2O   4.32           4.347         0.070       0.140
    K2O   1.00           1.006         0.011       0.021
   TiO2   0.99           0.992         0.012       0.012
   P2O5   0.20           0.201         0.001       0.003
  Cr2O3   0.00           0.000         0.000       0.000
 TOTAL   99.39

    ..................CIPW NORM................
      q       c      or      ab      an      lc      ne      kp      wo
  0.000   0.000   5.946  36.778  14.553   0.000   0.000   0.000   0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
  7.373   6.186   0.662   0.555  13.559   1.217   0.000   1.605   0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  1.884   0.477   0.000   0.000   0.000   0.000   0.000   0.000   0.000  23.995
CIPWNORM TOTAL = 100.013
                    ****************************
      PARAMETERS FOR CIPW NORMATIVE MINERALS
OLIVINE COMPOSITION: FORSTERITE  54.379  FAYALITE   45.621
HYPERSTHENE COMPOSITION:EN   54.379  FS   45.621
FELDSPAR COMPOSITION   :KFS  10.381  AB  64.211  AN  25.409
PLAGIOCLASE PERCENT ANORTHITE  28.352
QUARTZ : FELDSPAR RATIOS:
QUARTZ  0.000  ORTHOCLASE  10.381  PLAGIOCLASE  89.619
QUARTZ  0.000 ORTHOCLASE 13.917 ALBITE 86.083
CHAPPELS A/CNK INDEX  0.551
MG No. IN CATIONS   48.16

AFM PARAMETERS: A = 0.26 F = 0.49 M = 0.25
JENSEN CATION PLOT   A = 0.39  M = 0.17 F = 0.45

      .............CATANORM.............
      q       c      or      ab      an      lc      ne      kp      wo
  0.000   0.000   5.946  39.042  14.561   0.000   0.000   0.000   0.000
     en      fs      fo      fa      hy      ol      ac      mt      hm
  7.153   6.001   0.652   0.547  13.153   1.199   0.000   1.158   0.000
     il      ap      cm      tn      pf      ns      ks      cs      ru      di
  1.382   0.421   0.000   0.000   0.000   0.000   0.000   0.000   0.00023.137
 CATANORM TOTAL =100.000
                 *********************************
  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q      C      Or     Ab     An     Lc     Ne     Wo     Ri    Act
 Ed
  0.42   0.00   0.00  39.04  14.56   0.00   0.00   1.96  30.85   0.00
0.00
  Di     Hy     Ol    (En     Fs     Fo     Fa)    Mt     Hm
HORNBLENDE
  0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.16   0.00
30.851
   Ap     Cm     Tn     Pf     Ns     Ks     Cs     Ru   BIOTITE  Sp
  0.47   0.00   2.07   0.00   0.00   0.00   0.00   0.00   9.514
MESONORM TOTAL  =  100.053
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PETRONORMS PROGRAM
SAMPLE NUMBER RM10

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.19	55.409	0.922	0.922
Al2O3	14.39	14.447	0.142	0.283
Fe2O3	1.21	1.215	0.008	0.015
FeO	9.79	9.829	0.137	0.137
MnO	0.22	0.221	0.003	0.003
MgO	5.18	5.201	0.129	0.129
CaO	8.17	8.202	0.146	0.146
Na2O	3.74	3.755	0.061	0.121
K2O	0.49	0.492	0.005	0.010
TiO2	1.01	1.018	0.013	0.013
P2O5	0.21	0.211	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.60			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
3.704	0.000	2.907	31.770	21.113	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.985	10.180	0.000	0.000	21.165	0.000	0.000	1.761	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.934	0.499	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.160

CIPWNORM TOTAL = 100.014

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 51.902 FS 48.098
FELDSPAR COMPOSITION :KFS 5.211 AB 56.946 AN 37.843
PLAGIOCLASE PERCENT ANORTHITE 39.923
QUARTZ : FELDSPAR RATIOS:
QUARTZ 6.226 ORTHOCLASE 4.886 PLAGIOCLASE 88.887
QUARTZ 9.651 ORTHOCLASE 7.574 ALBITE 82.775
CHAPPELS A/CNK INDEX 0.668
MG No. IN CATIONS 45.91

AFM PARAMETERS: A = 0.21 F = 0.54 M = 0.26
JENSEN CATION PLOT A = 0.38 M = 0.16 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
3.457	0.000	2.928	33.970	21.277	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.661	9.879	0.000	0.000	20.540	0.000	0.000	1.280	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.429	0.444	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.674

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
3.02	0.00	0.00	33.97	21.28	0.00	0.00	0.00	22.15	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	11.02	0.00	0.00	0.00	0.00	0.00	1.28	0.00	22.153

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.50	0.00	2.14	0.00	0.00	0.00	0.00	0.00	4.685	

MESONORM TOTAL = 100.056

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PETRONORMS PROGRAM
SAMPLE NUMBER RM11

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.33	55.630	0.926	0.926
Al2O3	14.29	14.367	0.141	0.282
Fe2O3	1.16	1.166	0.007	0.015
FeO	9.43	9.481	0.132	0.132
MnO	0.18	0.181	0.003	0.003
MgO	4.88	4.906	0.122	0.122
CaO	9.49	9.541	0.170	0.170
Na2O	3.10	3.117	0.050	0.101
K2O	0.40	0.402	0.004	0.009
TiO2	0.99	0.996	0.012	0.012
P2O5	0.21	0.211	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.46			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
6.645	0.000	2.376	26.372	24.024	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
9.388	8.849	0.000	0.000	18.237	0.000	0.000	1.691	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.892	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.276

CIPWNORM TOTAL = 100.013

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 51.476 FS 48.524
FELDSPAR COMPOSITION :KFS 4.503 AB 49.972 AN 45.524
PLAGIOCLASE PERCENT ANORTHITE 47.671
QUARTZ : FELDSPAR RATIOS:
QUARTZ 11.183 ORTHOCLASE 4.000 PLAGIOCLASE 84.817
QUARTZ 18.774 ORTHOCLASE 6.715 ALBITE 74.511
CHAPPELS A/CNK INDEX 0.627
MG No. IN CATIONS 45.37

AFM PARAMETERS: A = 0.19 F = 0.56 M = 0.26
JENSEN CATION PLOT A = 0.39 M = 0.15 F = 0.45

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
6.237	0.000	2.408	28.358	24.349	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
9.152	8.627	0.000	0.000	17.778	0.000	0.000	1.236	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.406	0.447	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.781

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
5.11	0.00	0.00	28.36	24.35	0.00	0.00	0.00	28.07	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	6.48	0.00	0.00	0.00	0.00	0.00	1.24	0.00	28.066

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.50	0.00	2.11	0.00	0.00	0.00	0.00	0.00	3.852	

MESONORM TOTAL = 100.056

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PETRONORMS PROGRAM
SAMPLE NUMBER RM13

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	57.51	57.674	0.960	0.960
Al2O3	12.08	12.114	0.119	0.238
Fe2O3	1.11	1.113	0.007	0.014
FeO	8.97	8.996	0.125	0.125
MnO	0.17	0.170	0.002	0.002
MgO	3.96	3.971	0.099	0.099
CaO	13.89	13.930	0.248	0.248
Na2O	0.23	0.231	0.004	0.007
K2O	0.79	0.792	0.008	0.017
TiO2	0.86	0.858	0.011	0.011
P2O5	0.15	0.150	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.72			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
19.659	0.000	4.682	1.952	29.679	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
3.885	4.334	0.000	0.000	8.219	0.000	0.000	1.614	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.630	0.356	0.000	0.000	0.000	0.000	0.000	0.000	0.000	32.219

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 47.272 FS 52.728
FELDSPAR COMPOSITION :KFS 12.892 AB 5.374 AN 81.733
PLAGIOCLASE PERCENT ANORTHITE 93.830
QUARTZ : FELDSPAR RATIOS:
QUARTZ 35.123 ORTHOCLASE 8.364 PLAGIOCLASE 56.513
QUARTZ 74.771 ORTHOCLASE 17.806 ALBITE 7.423
CHAPPELS A/CNK INDEX 0.456
MG No. IN CATIONS 41.45

AFM PARAMETERS: A = 0.07 F = 0.67 M = 0.26
JENSEN CATION PLOT A = 0.38 M = 0.14 F = 0.48

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
18.989	0.000	4.881	2.160	30.956	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
3.854	4.299	0.000	0.000	8.152	0.000	0.000	1.214	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.247	0.328	0.000	0.000	0.000	0.000	0.000	0.000	0.000	32.074

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
19.34	0.00	0.00	2.16	30.96	0.00	0.00	6.96	29.37	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.21	0.00	29.368

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.37	0.00	1.87	0.00	0.00	0.00	0.00	0.00	7.809	

MESONORM TOTAL = 100.041

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PETRONORMS PROGRAM
SAMPLE NUMBER RM14

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.05	55.954	0.931	0.931
Al2O3	12.78	12.758	0.125	0.250
Fe2O3	1.20	1.198	0.008	0.015
FeO	9.70	9.683	0.135	0.135
MnO	0.18	0.180	0.003	0.003
MgO	5.43	5.421	0.134	0.134
CaO	8.21	8.196	0.146	0.146
Na2O	4.36	4.353	0.070	0.140
K2O	1.24	1.238	0.013	0.026
TiO2	0.88	0.881	0.011	0.011
P2O5	0.14	0.140	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.17			

...................CIPW NORM................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	7.315	36.827	11.618	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.479	7.490	0.611	0.540	15.969	1.150	0.000	1.737	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.672	0.331	0.000	0.000	0.000	0.000	0.000	0.000	0.000	23.389

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS

OLIVINE COMPOSITION: FORSTERITE 53.098 FAYALITE 46.902
HYPERSTHENE COMPOSITION:EN 53.098 FS 46.902
FELDSPAR COMPOSITION :KFS 13.118 AB 66.045 AN 20.836
PLAGIOCLASE PERCENT ANORTHITE 23.982
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 13.118 PLAGIOCLASE 86.882
QUARTZ 0.000 ORTHOCLASE 16.571 ALBITE 83.429
CHAPPELS A/CNK INDEX 0.545
MG No. IN CATIONS 47.31

AFM PARAMETERS: A = 0.26 F = 0.49 M = 0.25
JENSEN CATION PLOT A = 0.36 M = 0.17 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	7.324	39.139	11.638	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.206	7.248	0.600	0.530	15.455	1.129	0.000	1.254	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.229	0.293	0.000	0.000	0.000	0.000	0.000	0.000	0.000	22.539

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
1.34	0.00	0.00	39.14	11.64	0.00	0.00	1.77	31.00	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	31.005

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.33	0.00	1.84	0.00	0.00	0.00	0.00	0.00	11.718	

MESONORM TOTAL = 100.037

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PETRONORMS PROGRAM

SAMPLE NUMBER RM15

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	63.93	63.901	1.064	1.064
Al2O3	9.31	9.306	0.091	0.183
Fe2O3	1.03	1.030	0.006	0.013
FeO	8.37	8.366	0.116	0.116
MnO	0.13	0.130	0.002	0.002
MgO	4.14	4.138	0.103	0.103
CaO	10.67	10.665	0.190	0.190
Na2O	0.88	0.880	0.014	0.028
K2O	0.65	0.650	0.007	0.014
TiO2	0.80	0.795	0.010	0.010
P2O5	0.14	0.140	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.05			

....................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
28.566	0.000	3.839	7.442	19.524	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
5.118	5.079	0.000	0.000	10.196	0.000	0.000	1.493	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.509	0.331	0.000	0.000	0.000	0.000	0.000	0.000	0.000	27.107

CIPWNORM TOTAL = 100.009

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 50.191 FS 49.809

FELDSPAR COMPOSITION :KFS 12.463 AB 24.159 AN 63.378

PLAGIOCLASE PERCENT ANORTHITE 72.401

QUARTZ : FELDSPAR RATIOS:

QUARTZ 48.113 ORTHOCLASE 6.466 PLAGIOCLASE 45.420

QUARTZ 71.688 ORTHOCLASE 9.635 ALBITE 18.677

CHAPPELS A/CNK INDEX 0.432

MG No. IN CATIONS 44.25

AFM PARAMETERS: A = 0.10 F = 0.62 M = 0.28

JENSEN CATION PLOT A = 0.33 M = 0.17 F = 0.51

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
27.575	0.000	4.000	8.231	20.351	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
5.113	5.074	0.000	0.000	10.187	0.000	0.000	1.122	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.154	0.305	0.000	0.000	0.000	0.000	0.000	0.000	0.00027.076	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
27.39	0.00	0.00	8.23	20.35	0.00	0.00	4.35	30.12	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	0.00	30.118

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.34	0.00	1.73	0.00	0.00	0.00	0.00	0.00	6.400	

MESONORM TOTAL = 100.038

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PETRONORMS PROGRAM

SAMPLE NUMBER RM16

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.60	56.591	0.942	0.942
Al2O3	12.59	12.588	0.123	0.247
Fe2O3	1.20	1.200	0.008	0.015
FeO	9.70	9.698	0.135	0.135
MnO	0.16	0.160	0.002	0.002
MgO	5.64	5.639	0.140	0.140
CaO	7.38	7.379	0.132	0.132
Na2O	5.05	5.049	0.081	0.163
K2O	0.70	0.700	0.007	0.015
TiO2	0.87	0.866	0.011	0.011
P2O5	0.13	0.130	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.02			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	4.136	42.722	9.616	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.582	7.294	1.221	1.038	15.876	2.259	0.000	1.740	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.644	0.308	0.000	0.000	0.000	0.000	0.000	0.000	0.000	21.708

CIPWNORM TOTAL = 100.009

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PARAMETERS FOR CIPW NORMATIVE MINERALS

OLIVINE COMPOSITION: FORSTERITE 54.058 FAYALITE 45.942

HYPERSTHENE COMPOSITION:EN 54.058 FS 45.942

FELDSPAR COMPOSITION :KFS 7.323 AB 75.649 AN 17.028

PLAGIOCLASE PERCENT ANORTHITE 18.373

QUARTZ : FELDSPAR RATIOS:

QUARTZ 0.000 ORTHOCLASE 7.323 PLAGIOCLASE 92.677

QUARTZ 0.000 ORTHOCLASE 8.826 ALBITE 91.174

CHAPPELS A/CNK INDEX 0.560

MG No. IN CATIONS 48.26

AFM PARAMETERS: A = 0.26 F = 0.49 M = 0.25

JENSEN CATION PLOT A = 0.35 M = 0.18 F = 0.47

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	4.121	45.182	9.585	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.287	7.043	1.197	1.018	15.329	2.215	0.000	1.250	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.202	0.271	0.000	0.000	0.000	0.000	0.000	0.000	0.000	20.845

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.00	0.00	0.00	43.72	9.59	0.00	0.00	0.00	30.18	0.00	4.69

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	1.91	0.00	0.00	0.00	0.00	0.00	1.25	0.00	34.869

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.30	0.00	1.80	0.00	0.00	0.00	0.00	0.00	6.593	

MESONORM TOTAL = 100.034

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PETRONORMS PROGRAM
SAMPLE NUMBER RM17

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	57.43	57.383	0.955	0.955
Al2O3	13.15	13.139	0.129	0.258
Fe2O3	1.19	1.189	0.007	0.015
FeO	9.66	9.652	0.134	0.134
MnO	0.13	0.130	0.002	0.002
MgO	4.95	4.946	0.123	0.123
CaO	8.67	8.663	0.154	0.154
Na2O	2.46	2.458	0.040	0.079
K2O	1.42	1.419	0.015	0.030
TiO2	0.88	0.881	0.011	0.011
P2O5	0.14	0.140	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.08			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
9.677	0.000	8.384	20.797	20.628	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
9.657	9.264	0.000	0.000	18.921	0.000	0.000	1.724	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.673	0.331	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.873

CIPWNORM TOTAL = 100.009

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 51.041 FS 48.959
FELDSPAR COMPOSITION :KFS 16.832 AB 41.754 AN 41.413
PLAGIOCLASE PERCENT ANORTHITE 49.795
QUARTZ : FELDSPAR RATIOS:
QUARTZ 16.267 ORTHOCLASE 14.094 PLAGIOCLASE 69.638
QUARTZ 24.903 ORTHOCLASE 21.576 ALBITE 53.521
CHAPPELS A/CNK INDEX 0.616
MG No. IN CATIONS 45.12

AFM PARAMETERS: A = 0.20 F = 0.55 M = 0.25
JENSEN CATION PLOT A = 0.37 M = 0.16 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
9.133	0.000	8.541	22.488	21.023	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
9.456	9.070	0.000	0.000	18.526	0.000	0.000	1.267	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.251	0.298	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.475

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
11.81	0.00	0.00	22.49	21.02	0.00	0.00	0.18	27.40	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	27.397

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.34	0.00	1.88	0.00	0.00	0.00	0.00	0.00	13.665	

MESONORM TOTAL = 100.037

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PETRONORMS PROGRAM
SAMPLE NUMBER  RM18
 OXIDES GIVEN     RECALC 100%     MOL PROPS  CAT PROPS
   SiO2  55.92          56.023          0.932       0.932
  Al2O3  13.19          13.214          0.130       0.259
  Fe2O3   1.27           1.272          0.008       0.016
    FeO  10.28          10.299          0.143       0.143
    MnO   0.17           0.170          0.002       0.002
    MgO   5.22           5.230          0.130       0.130
    CaO   8.22           8.235          0.147       0.147
   Na2O   3.39           3.396          0.055       0.110
    K2O   1.18           1.182          0.013       0.025
   TiO2   0.85           0.848          0.011       0.011
   P2O5   0.13           0.130          0.001       0.002
  Cr2O3   0.00           0.000          0.000       0.000
 TOTAL   99.82

    ..................CIPW NORM................
       q       c      or      ab      an      lc      ne      kp      wo
   3.933   0.000   6.986  28.736  17.320   0.000   0.000   0.000   0.000
      en      fs      fo      fa      hy      ol      ac      mt      hm
  10.273  10.070   0.000   0.000  20.343   0.000   0.000   1.845   0.000
      il      ap      cm      tn      pf      ns      ks      cs      ru      di
   1.610 0.308 0.000 0.000 0.000 0.000 0.000 0.000 0.000 18.928
CIPWNORM TOTAL = 100.009
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      PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN   50.500  FS   49.500
FELDSPAR COMPOSITION    :KFS  13.170  AB  54.176  AN  32.654
PLAGIOCLASE PERCENT ANORTHITE  37.606
QUARTZ : FELDSPAR RATIOS:
QUARTZ  6.902  ORTHOCLASE  12.261  PLAGIOCLASE  80.837
QUARTZ  9.917 ORTHOCLASE 17.616 ALBITE 72.466
CHAPPELS A/CNK INDEX  0.605
MG No. IN CATIONS   44.89

AFM PARAMETERS: A = 0.22 F = 0.54 M = 0.25
JENSEN CATION PLOT   A = 0.36  M = 0.16 F = 0.48

      .............CATANORM.............
       q       c      or      ab      an      lc      ne      kp      wo
   3.683   0.000   7.062  30.835  17.517   0.000   0.000   0.000   0.000
      en      fs      fo      fa      hy      ol      ac      mt      hm
   9.967   9.770   0.000   0.000  19.737   0.000   0.000   1.345   0.000
      il      ap      cm      tn      pf      ns      ks      cs      ru      di
   1.194 0.275 0.000 0.000 0.000 0.000 0.000 0.000 0.00018.352
 CATANORM TOTAL =100.000
           *********************************
  ...MESONORM (HUCHISONS ALGORYTHM...)
   Q       C      Or      Ab      An      Lc      Ne      Wo      Ri     Act
 Ed
  5.33   0.00   0.00  30.83  17.52   0.00    0.00    0.00  29.93   0.00
0.00
  Di      Hy      Ol     (En      Fs       Fo       Fa)      Mt      Hm
HORNBLENDE
  0.00   1.68   0.00   0.00   0.00   0.00    0.00    1.35    0.00
29.932
   Ap     Cm     Tn      Pf      Ns      Ks      Cs      Ru    BIOTITE   Sp
  0.31   0.00   1.79   0.00   0.00   0.00   0.00   0.00   11.299
MESONORM TOTAL  =   100.034
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PETRONORMS PROGRAM
SAMPLE NUMBER RM19

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	54.99	54.945	0.915	0.915
Al2O3	14.60	14.588	0.143	0.286
Fe2O3	1.24	1.239	0.008	0.016
FeO	10.01	10.002	0.139	0.139
MnO	0.15	0.150	0.002	0.002
MgO	4.72	4.716	0.117	0.117
CaO	7.01	7.004	0.125	0.125
Na2O	4.79	4.786	0.077	0.154
K2O	1.35	1.349	0.014	0.029
TiO2	1.04	1.041	0.013	0.013
P2O5	0.18	0.180	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.08			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	7.971	40.496	14.338	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
4.558	4.696	3.781	3.895	9.254	7.676	0.000	1.796	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.976	0.426	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.078

CIPWNORM TOTAL = 100.011

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PARAMETERS FOR CIPW NORMATIVE MINERALS
OLIVINE COMPOSITION: FORSTERITE 49.255 FAYALITE 50.745
HYPERSTHENE COMPOSITION:EN 49.255 FS 50.745
FELDSPAR COMPOSITION :KFS 12.692 AB 64.479 AN 22.829
PLAGIOCLASE PERCENT ANORTHITE 26.148
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 12.692 PLAGIOCLASE 87.308
QUARTZ 0.000 ORTHOCLASE 16.446 ALBITE 83.554
CHAPPELS A/CNK INDEX 0.661
MG No. IN CATIONS 43.06

AFM PARAMETERS: A = 0.28 F = 0.51 M = 0.21
JENSEN CATION PLOT A = 0.39 M = 0.14 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	7.964	42.946	14.331	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
4.356	4.487	3.653	3.763	8.843	7.416	0.000	1.295	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.449	0.376	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.380

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.02	0.00	0.00	42.95	14.33	0.00	0.00	0.00	23.41	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	2.71	0.00	0.00	0.00	0.00	0.00	1.29	0.00	23.406

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.42	0.00	2.17	0.00	0.00	0.00	0.00	0.00	12.742	

MESONORM TOTAL = 100.047

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PETRONORMS PROGRAM
SAMPLE NUMBER RM20

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	59.00	58.958	0.981	0.981
Al2O3	12.69	12.681	0.124	0.249
Fe2O3	1.17	1.169	0.007	0.015
FeO	9.48	9.473	0.132	0.132
MnO	0.15	0.150	0.002	0.002
MgO	5.06	5.056	0.125	0.125
CaO	6.65	6.645	0.118	0.118
Na2O	3.78	3.777	0.061	0.122
K2O	1.11	1.109	0.012	0.024
TiO2	0.85	0.850	0.011	0.011
P2O5	0.13	0.130	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.07			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
8.200	0.000	6.554	31.960	14.370	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
10.664	9.861	0.000	0.000	20.525	0.000	0.000	1.695	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.615	0.308	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.781

CIPWNORM TOTAL = 100.009

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 51.955 FS 48.045
FELDSPAR COMPOSITION :KFS 12.394 AB 60.434 AN 27.172
PLAGIOCLASE PERCENT ANORTHITE 31.016
QUARTZ : FELDSPAR RATIOS:
QUARTZ 13.423 ORTHOCLASE 10.730 PLAGIOCLASE 75.846
QUARTZ 17.553 ORTHOCLASE 14.031 ALBITE 68.416
CHAPPELS A/CNK INDEX 0.650
MG No. IN CATIONS 46.13

AFM PARAMETERS: A = 0.24 F = 0.51 M = 0.25
JENSEN CATION PLOT A = 0.36 M = 0.17 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
7.665	0.000	6.613	34.228	14.505	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
10.367	9.587	0.000	0.000	19.954	0.000	0.000	1.234	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.195	0.274	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.331

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
9.54	0.00	0.00	34.23	14.51	0.00	0.00	0.00	22.39	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	5.45	0.00	0.00	0.00	0.00	0.00	1.23	0.00	22.388

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.31	0.00	1.79	0.00	0.00	0.00	0.00	0.00	10.581	

MESONORM TOTAL = 100.034

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PETRONORMS PROGRAM
SAMPLE NUMBER RM21

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	54.18	54.293	0.904	0.904
Al2O3	14.95	14.981	0.147	0.294
Fe2O3	1.26	1.263	0.008	0.016
FeO	10.22	10.241	0.143	0.143
MnO	0.17	0.170	0.002	0.002
MgO	4.22	4.229	0.105	0.105
CaO	8.25	8.267	0.147	0.147
Na2O	4.42	4.429	0.071	0.143
K2O	0.85	0.852	0.009	0.018
TiO2	1.09	1.094	0.014	0.014
P2O5	0.18	0.180	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.79			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	5.033	37.476	18.480	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
6.319	7.430	1.382	1.625	13.749	3.008	0.000	1.831	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.077	0.427	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.929

CIPWNORM TOTAL = 100.012

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PARAMETERS FOR CIPW NORMATIVE MINERALS

OLIVINE COMPOSITION: FORSTERITE 45.961 FAYALITE 54.039
HYPERSTHENE COMPOSITION:EN 45.961 FS 54.039
FELDSPAR COMPOSITION :KFS 8.253 AB 61.447 AN 30.301
PLAGIOCLASE PERCENT ANORTHITE 33.026
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 8.253 PLAGIOCLASE 91.747
QUARTZ 0.000 ORTHOCLASE 11.840 ALBITE 88.160
CHAPPELS A/CNK INDEX 0.645
MG No. IN CATIONS 39.85

AFM PARAMETERS: A = 0.25 F = 0.54 M = 0.20
JENSEN CATION PLOT A = 0.40 M = 0.13 F = 0.48

..............CATANORM..............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	5.058	39.971	18.577	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
6.020	7.078	1.327	1.560	13.097	2.887	0.000	1.327	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.531	0.379	0.000	0.000	0.000	0.000	0.000	0.000	0.00017.172	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.00	0.00	0.00	39.40	18.58	0.00	0.00	0.00	24.74	0.00	1.83

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	3.36	0.00	0.00	0.00	0.00	0.00	1.33	0.00	26.570

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.43	0.00	2.30	0.00	0.00	0.00	0.00	0.00	8.092	

MESONORM TOTAL = 100.047

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PETRONORMS PROGRAM

SAMPLE NUMBER RM22

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.19	55.338	0.921	0.921
Al2O3	13.86	13.897	0.136	0.273
Fe2O3	1.28	1.283	0.008	0.016
FeO	10.36	10.388	0.145	0.145
MnO	0.20	0.201	0.003	0.003
MgO	5.76	5.775	0.143	0.143
CaO	8.08	8.102	0.144	0.144
Na2O	3.09	3.098	0.050	0.100
K2O	0.69	0.692	0.007	0.015
TiO2	1.03	1.035	0.013	0.013
P2O5	0.19	0.191	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.73			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
5.312	0.000	4.088	26.215	21.969	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
12.768	11.266	0.000	0.000	24.033	0.000	0.000	1.861	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.965	0.451	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.117

CIPWNORM TOTAL = 100.012

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 53.125 FS 46.875

FELDSPAR COMPOSITION :KFS 7.821 AB 50.151 AN 42.028

PLAGIOCLASE PERCENT ANORTHITE 45.594

QUARTZ : FELDSPAR RATIOS:

QUARTZ 9.225 ORTHOCLASE 7.100 PLAGIOCLASE 83.675

QUARTZ 14.916 ORTHOCLASE 11.479 ALBITE 73.605

CHAPPELS A/CNK INDEX 0.675

MG No. IN CATIONS 47.14

AFM PARAMETERS: A = 0.18 F = 0.55 M = 0.27

JENSEN CATION PLOT A = 0.36 M = 0.17 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
4.981	0.000	4.137	28.160	22.242	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
12.489	11.020	0.000	0.000	23.509	0.000	0.000	1.358	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.459	0.403	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.751

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
5.38	0.00	0.00	28.16	22.24	0.00	0.00	0.00	20.31	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	13.34	0.00	0.00	0.00	0.00	0.00	1.36	0.00	20.312

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.45	0.00	2.19	0.00	0.00	0.00	0.00	0.00	6.620	

MESONORM TOTAL = 100.050

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PETRONORMS PROGRAM

SAMPLE NUMBER RM23

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	57.20	57.348	0.955	0.955
Al2O3	13.10	13.134	0.129	0.258
Fe2O3	1.21	1.213	0.008	0.015
FeO	9.81	9.835	0.137	0.137
MnO	0.16	0.160	0.002	0.002
MgO	4.67	4.682	0.116	0.116
CaO	8.32	8.342	0.149	0.149
Na2O	3.06	3.068	0.049	0.099
K2O	1.16	1.163	0.012	0.025
TiO2	0.90	0.904	0.011	0.011
P2O5	0.15	0.150	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.74			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
8.104	0.000	6.872	25.958	18.631	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
9.048	9.366	0.000	0.000	18.414	0.000	0.000	1.759	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.716	0.356	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.199

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 49.135 FS 50.865

FELDSPAR COMPOSITION :KFS 13.354 AB 50.442 AN 36.204

PLAGIOCLASE PERCENT ANORTHITE 41.784

QUARTZ : FELDSPAR RATIOS:

QUARTZ 13.605 ORTHOCLASE 11.538 PLAGIOCLASE 74.858

QUARTZ 19.797 ORTHOCLASE 16.789 ALBITE 63.414

CHAPPELS A/CNK INDEX 0.612

MG No. IN CATIONS 43.30

AFM PARAMETERS: A = 0.21 F = 0.55 M = 0.24

JENSEN CATION PLOT A = 0.37 M = 0.15 F = 0.48

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
7.627	0.000	6.981	27.989	18.934	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.788	9.097	0.000	0.000	17.885	0.000	0.000	1.289	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.279	0.320	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.697

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
9.28	0.00	0.00	27.99	18.93	0.00	0.00	0.00	28.39	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.71	0.00	0.00	0.00	0.00	0.00	1.29	0.00	28.385

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.36	0.00	1.92	0.00	0.00	0.00	0.00	0.00	11.170	

MESONORM TOTAL = 100.040

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PETRONORMS PROGRAM
SAMPLE NUMBER RM24

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	57.73	57.258	0.953	0.953
Al2O3	13.14	13.032	0.128	0.256
Fe2O3	1.21	1.200	0.008	0.015
FeO	9.77	9.690	0.135	0.135
MnO	0.17	0.169	0.002	0.002
MgO	5.15	5.108	0.127	0.127
CaO	7.09	7.032	0.125	0.125
Na2O	4.05	4.017	0.065	0.130
K2O	1.57	1.557	0.017	0.033
TiO2	0.83	0.818	0.010	0.010
P2O5	0.12	0.119	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.83			

..................CIPW NORM................

q	c	or	ab	an	lc	ne	kp	wo
2.987	0.000	9.201	33.987	12.931	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.128	9.550	0.000	0.000	19.678	0.000	0.000	1.740	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.554	0.282	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.648

CIPWNORM TOTAL = 100.008

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 51.469 FS 48.531
FELDSPAR COMPOSITION :KFS 16.396 AB 60.562 AN 23.042
PLAGIOCLASE PERCENT ANORTHITE 27.560
QUARTZ : FELDSPAR RATIOS:
QUARTZ 5.053 ORTHOCLASE 15.568 PLAGIOCLASE 79.379
QUARTZ 6.468 ORTHOCLASE 19.927 ALBITE 73.605
CHAPPELS A/CNK INDEX 0.618
MG No. IN CATIONS 45.81

AFM PARAMETERS: A = 0.26 F = 0.50 M = 0.24
JENSEN CATION PLOT A = 0.37 M = 0.16 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
2.781	0.000	9.247	36.254	13.000	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.794	9.235	0.000	0.000	19.029	0.000	0.000	1.261	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.146	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.00017.032	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
6.00	0.00	0.00	36.25	13.00	0.00	0.00	0.33	26.39	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.26	0.00	26.391

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.28	0.00	1.72	0.00	0.00	0.00	0.00	0.00	14.795	

MESONORM TOTAL = 100.031

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PETRONORMS PROGRAM
SAMPLE NUMBER RM25

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	54.08	54.388	0.905	0.905
Al2O3	14.59	14.673	0.144	0.288
Fe2O3	1.31	1.317	0.008	0.017
FeO	10.59	10.650	0.148	0.148
MnO	0.16	0.161	0.002	0.002
MgO	4.32	4.345	0.108	0.108
CaO	8.92	8.971	0.160	0.160
Na2O	2.98	2.997	0.048	0.097
K2O	1.24	1.247	0.013	0.026
TiO2	1.06	1.069	0.013	0.013
P2O5	0.18	0.181	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.43			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
3.667	0.000	7.369	25.358	22.901	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.741	10.451	0.000	0.000	19.193	0.000	0.000	1.910	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
2.031	0.429	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.154

CIPWNORM TOTAL = 100.011

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 45.545 FS 54.455
FELDSPAR COMPOSITION :KFS 13.247 AB 45.585 AN 41.168
PLAGIOCLASE PERCENT ANORTHITE 47.454
QUARTZ : FELDSPAR RATIOS:
QUARTZ 6.184 ORTHOCLASE 12.428 PLAGIOCLASE 81.388
QUARTZ 10.075 ORTHOCLASE 20.248 ALBITE 69.677
CHAPPELS A/CNK INDEX 0.650
MG No. IN CATIONS 39.55

AFM PARAMETERS: A = 0.21 F = 0.58 M = 0.21
JENSEN CATION PLOT A = 0.38 M = 0.13 F = 0.49

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
3.454	0.000	7.492	27.366	23.294	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
8.416	10.062	0.000	0.000	18.478	0.000	0.000	1.401	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.515	0.385	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.615

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
5.49	0.00	0.00	27.37	23.29	0.00	0.00	0.00	25.47	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	2.33	0.00	0.00	0.00	0.00	0.00	1.40	0.00	25.473

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.43	0.00	2.27	0.00	0.00	0.00	0.00	0.00	11.988	

MESONORM TOTAL = 100.048

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PETRONORMS PROGRAM
SAMPLE NUMBER RM26

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	58.43	58.348	0.971	0.971
Al2O3	13.74	13.721	0.135	0.269
Fe2O3	1.12	1.118	0.007	0.014
FeO	9.07	9.057	0.126	0.126
MnO	0.16	0.160	0.002	0.002
MgO	4.55	4.544	0.113	0.113
CaO	6.67	6.661	0.119	0.119
Na2O	4.43	4.424	0.071	0.143
K2O	0.91	0.909	0.010	0.019
TiO2	0.91	0.909	0.011	0.011
P2O5	0.15	0.150	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.14			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
5.624	0.000	5.370	37.430	14.897	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.448	9.214	0.000	0.000	18.663	0.000	0.000	1.622	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.727	0.355	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.323

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 50.627 FS 49.373
FELDSPAR COMPOSITION :KFS 9.307 AB 64.874 AN 25.820
PLAGIOCLASE PERCENT ANORTHITE 28.469
QUARTZ : FELDSPAR RATIOS:
QUARTZ 8.881 ORTHOCLASE 8.480 PLAGIOCLASE 82.639
QUARTZ 11.613 ORTHOCLASE 11.089 ALBITE 77.297
CHAPPELS A/CNK INDEX 0.674
MG No. IN CATIONS 44.59

AFM PARAMETERS: A = 0.27 F = 0.50 M = 0.23
JENSEN CATION PLOT A = 0.40 M = 0.15 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
5.230	0.000	5.390	39.882	14.961	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.105	8.880	0.000	0.000	17.985	0.000	0.000	1.174	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.272	0.314	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.791

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
6.42	0.00	0.00	39.88	14.96	0.00	0.00	0.00	21.09	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	5.63	0.00	0.00	0.00	0.00	0.00	1.17	0.00	21.089

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.35	0.00	1.91	0.00	0.00	0.00	0.00	0.00	8.624	

MESONORM TOTAL = 100.039

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PETRONORMS PROGRAM
SAMPLE NUMBER RM27

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.74	56.785	0.945	0.945
Al2O3	12.74	12.750	0.125	0.250
Fe2O3	1.10	1.101	0.007	0.014
FeO	8.89	8.897	0.124	0.124
MnO	0.15	0.150	0.002	0.002
MgO	5.24	5.244	0.130	0.130
CaO	9.24	9.247	0.165	0.165
Na2O	4.30	4.303	0.069	0.139
K2O	0.57	0.570	0.006	0.012
TiO2	0.81	0.812	0.010	0.010
P2O5	0.14	0.140	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.92			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
2.528	0.000	3.371	36.411	13.788	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
7.930	6.638	0.000	0.000	14.568	0.000	0.000	1.596	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.542	0.332	0.000	0.000	0.000	0.000	0.000	0.000	0.000	25.873

CIPWNORM TOTAL = 100.009

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 54.437 FS 45.563
FELDSPAR COMPOSITION :KFS 6.292 AB 67.969 AN 25.738
PLAGIOCLASE PERCENT ANORTHITE 27.467
QUARTZ : FELDSPAR RATIOS:
QUARTZ 4.506 ORTHOCLASE 6.009 PLAGIOCLASE 89.485
QUARTZ 5.975 ORTHOCLASE 7.967 ALBITE 86.058
CHAPPELS A/CNK INDEX 0.520
MG No. IN CATIONS 48.60

AFM PARAMETERS: A = 0.24 F = 0.49 M = 0.26
JENSEN CATION PLOT A = 0.37 M = 0.17 F = 0.45

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
2.347	0.000	3.377	38.722	13.820	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
7.708	6.451	0.000	0.000	14.159	0.000	0.000	1.153	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.133	0.294	0.000	0.000	0.000	0.000	0.000	0.000	0.000	24.994

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
1.43	0.00	0.00	38.72	13.82	0.00	0.00	1.87	35.61	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	35.605

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.33	0.00	1.70	0.00	0.00	0.00	0.00	0.00	5.404	

MESONORM TOTAL = 100.037

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PETRONORMS PROGRAM
SAMPLE NUMBER RM28

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.31	55.379	0.922	0.922
Al2O3	13.44	13.457	0.132	0.264
Fe2O3	1.24	1.242	0.008	0.016
FeO	10.05	10.063	0.140	0.140
MnO	0.17	0.170	0.002	0.002
MgO	5.73	5.737	0.142	0.142
CaO	8.81	8.821	0.157	0.157
Na2O	3.10	3.104	0.050	0.100
K2O	1.03	1.031	0.011	0.022
TiO2	0.85	0.856	0.011	0.011
P2O5	0.14	0.140	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.87			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
3.866	0.000	6.094	26.262	19.740	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
11.270	9.816	0.000	0.000	21.086	0.000	0.000	1.800	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.626	0.332	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.203

CIPWNORM TOTAL = 100.009

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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 53.449 FS 46.551
FELDSPAR COMPOSITION :KFS 11.698 AB 50.411 AN 37.891
PLAGIOCLASE PERCENT ANORTHITE 42.910
QUARTZ : FELDSPAR RATIOS:
QUARTZ 6.909 ORTHOCLASE 10.889 PLAGIOCLASE 82.201
QUARTZ 10.674 ORTHOCLASE 16.824 ALBITE 72.502
CHAPPELS A/CNK INDEX 0.605
MG No. IN CATIONS 47.77

AFM PARAMETERS: A = 0.20 F = 0.53 M = 0.27
JENSEN CATION PLOT A = 0.36 M = 0.17 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
3.619	0.000	6.157	28.164	19.953	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
11.016	9.595	0.000	0.000	20.611	0.000	0.000	1.312	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.205	0.296	0.000	0.000	0.000	0.000	0.000	0.000	0.00018.682	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
4.68	0.00	0.00	28.16	19.95	0.00	0.00	0.00	30.51	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	3.43	0.00	0.00	0.00	0.00	0.00	1.31	0.00	30.510

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.33	0.00	1.81	0.00	0.00	0.00	0.00	0.00	9.851	

MESONORM TOTAL = 100.037

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PETRONORMS PROGRAM
SAMPLE NUMBER RM29

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.85	56.770	0.945	0.945
Al2O3	13.06	13.042	0.128	0.256
Fe2O3	1.17	1.168	0.007	0.015
FeO	9.44	9.427	0.131	0.131
MnO	0.16	0.160	0.002	0.002
MgO	5.74	5.732	0.142	0.142
CaO	8.54	8.528	0.152	0.152
Na2O	3.48	3.475	0.056	0.112
K2O	0.71	0.709	0.008	0.015
TiO2	0.85	0.849	0.011	0.011
P2O5	0.14	0.140	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.14			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
5.560	0.000	4.190	29.403	17.892	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.947	8.892	0.000	0.000	19.840	0.000	0.000	1.694	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.613	0.331	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.486

CIPWNORM TOTAL = 100.009
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PARAMETERS FOR CIPW NORMATIVE MINERALS
HYPERSTHENE COMPOSITION:EN 55.179 FS 44.821
FELDSPAR COMPOSITION :KFS 8.137 AB 57.110 AN 34.752
PLAGIOCLASE PERCENT ANORTHITE 37.831
QUARTZ : FELDSPAR RATIOS:
QUARTZ 9.746 ORTHOCLASE 7.344 PLAGIOCLASE 82.909
QUARTZ 14.200 ORTHOCLASE 10.701 ALBITE 75.099
CHAPPELS A/CNK INDEX 0.593
MG No. IN CATIONS 49.37

AFM PARAMETERS: A = 0.21 F = 0.51 M = 0.28
JENSEN CATION PLOT A = 0.36 M = 0.18 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
5.190	0.000	4.222	31.448	18.037	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
10.723	8.710	0.000	0.000	19.433	0.000	0.000	1.231	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.193	0.295	0.000	0.000	0.000	0.000	0.000	0.000	0.00018.952	

CATANORM TOTAL =100.000
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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
5.06	0.00	0.00	31.45	18.04	0.00	0.00	0.00	31.06	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	4.33	0.00	0.00	0.00	0.00	0.00	1.23	0.00	31.062

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.33	0.00	1.79	0.00	0.00	0.00	0.00	0.00	6.755	

MESONORM TOTAL = 100.037
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PETRONORMS PROGRAM
SAMPLE NUMBER RM30

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.27	56.114	0.934	0.934
Al2O3	14.23	14.190	0.139	0.278
Fe2O3	1.19	1.187	0.007	0.015
FeO	9.63	9.603	0.134	0.134
MnO	0.18	0.179	0.003	0.003
MgO	4.99	4.976	0.123	0.123
CaO	9.23	9.204	0.164	0.164
Na2O	2.71	2.702	0.044	0.087
K2O	0.76	0.758	0.008	0.016
TiO2	0.93	0.926	0.012	0.012
P2O5	0.16	0.160	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.28			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
8.145	0.000	4.478	22.866	24.351	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.962	9.455	0.000	0.000	19.418	0.000	0.000	1.721	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.759	0.378	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.895

CIPWNORM TOTAL = 100.011

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 51.305 FS 48.695
FELDSPAR COMPOSITION :KFS 8.663 AB 44.232 AN 47.104
PLAGIOCLASE PERCENT ANORTHITE 51.572
QUARTZ : FELDSPAR RATIOS:
QUARTZ 13.612 ORTHOCLASE 7.484 PLAGIOCLASE 78.904
QUARTZ 22.951 ORTHOCLASE 12.619 ALBITE 64.430
CHAPPELS A/CNK INDEX 0.645
MG No. IN CATIONS 45.39

AFM PARAMETERS: A = 0.18 F = 0.56 M = 0.26
JENSEN CATION PLOT A = 0.39 M = 0.16 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
7.668	0.000	4.550	24.661	24.752	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.736	9.240	0.000	0.000	18.976	0.000	0.000	1.261	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.311	0.339	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.482

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
8.01	0.00	0.00	24.66	24.75	0.00	0.00	0.00	25.99	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	5.74	0.00	0.00	0.00	0.00	0.00	1.26	0.00	25.986

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.38	0.00	1.97	0.00	0.00	0.00	0.00	0.00	7.281	

MESONORM TOTAL = 100.042

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PETRONORMS PROGRAM
SAMPLE NUMBER RM31

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.27	56.218	0.936	0.936
Al2O3	14.26	14.247	0.140	0.279
Fe2O3	1.18	1.179	0.007	0.015
FeO	9.57	9.561	0.133	0.133
MnO	0.17	0.170	0.002	0.002
MgO	4.96	4.955	0.123	0.123
CaO	9.53	9.521	0.170	0.170
Na2O	2.51	2.508	0.040	0.081
K2O	0.56	0.559	0.006	0.012
TiO2	0.92	0.921	0.012	0.012
P2O5	0.16	0.160	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	100.09			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
9.522	0.000	3.306	21.218	25.965	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.909	9.395	0.000	0.000	19.304	0.000	0.000	1.709	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.750	0.379	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.858

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 51.333 FS 48.667
FELDSPAR COMPOSITION :KFS 6.548 AB 42.025 AN 51.427
PLAGIOCLASE PERCENT ANORTHITE 55.030
QUARTZ : FELDSPAR RATIOS:
QUARTZ 15.867 ORTHOCLASE 5.509 PLAGIOCLASE 78.624
QUARTZ 27.968 ORTHOCLASE 9.711 ALBITE 62.321
CHAPPELS A/CNK INDEX 0.646
MG No. IN CATIONS 45.40

AFM PARAMETERS: A = 0.16 F = 0.57 M = 0.27
JENSEN CATION PLOT A = 0.39 M = 0.15 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
8.981	0.000	3.366	22.927	26.444	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
9.703	9.199	0.000	0.000	18.903	0.000	0.000	1.255	0.000
il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.307	0.340	0.000	0.000	0.000	0.000	0.000	0.000	0.00016.477	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
8.61	0.00	0.00	22.93	26.44	0.00	0.00	0.00	25.99	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	7.08	0.00	0.00	0.00	0.00	0.00	1.26	0.00	25.994

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.38	0.00	1.96	0.00	0.00	0.00	0.00	0.00	5.385	

MESONORM TOTAL = 100.043

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PETRONORMS PROGRAM
SAMPLE NUMBER RM32

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.32	55.342	0.921	0.921
Al2O3	14.62	14.626	0.143	0.287
Fe2O3	1.19	1.190	0.007	0.015
FeO	9.61	9.614	0.134	0.134
MnO	0.11	0.110	0.002	0.002
MgO	3.40	3.401	0.084	0.084
CaO	8.27	8.273	0.148	0.148
Na2O	5.52	5.522	0.089	0.178
K2O	0.71	0.710	0.008	0.015
TiO2	1.04	1.041	0.013	0.013
P2O5	0.17	0.170	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.96			

...................CIPW NORM................

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	4.197	46.724	13.023	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
0.300	0.409	3.620	4.928	0.709	8.548	0.000	1.726	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.977	0.403	0.000	0.000	0.000	0.000	0.000	0.000	0.000	22.704

CIPWNORM TOTAL = 100.010

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PARAMETERS FOR CIPW NORMATIVE MINERALS
OLIVINE COMPOSITION: FORSTERITE 42.348 FAYALITE 57.652
HYPERSTHENE COMPOSITION:EN 42.348 FS 57.652
FELDSPAR COMPOSITION :KFS 6.564 AB 73.071 AN 20.366
PLAGIOCLASE PERCENT ANORTHITE 21.796
QUARTZ : FELDSPAR RATIOS:
QUARTZ 0.000 ORTHOCLASE 6.564 PLAGIOCLASE 93.436
QUARTZ 0.000 ORTHOCLASE 8.242 ALBITE 91.758
CHAPPELS A/CNK INDEX 0.588
MG No. IN CATIONS 36.20

AFM PARAMETERS: A = 0.31 F = 0.53 M = 0.17
JENSEN CATION PLOT A = 0.41 M = 0.11 F = 0.48

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
0.000	0.000	4.192	49.528	13.011	0.000	0.000	0.000	0.000
en	fs	fo	fa	hy	ol	ac	mt	hm
0.282	0.383	3.409	4.641	0.665	8.051	0.000	1.243	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.449	0.355	0.000	0.000	0.000	0.000	0.000	0.000	0.00021.507	

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
0.00	0.00	0.00	46.09	13.01	0.00	0.00	1.88	17.54	0.00	11.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.00	28.544

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.40	0.00	2.17	0.00	0.00	0.00	0.00	0.00	6.706	

MESONORM TOTAL = 100.044

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PETRONORMS PROGRAM

SAMPLE NUMBER MAG1

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	55.94	56.118	0.934	0.934
Al2O3	14.07	14.115	0.138	0.277
Fe2O3	1.22	1.224	0.008	0.015
FeO	9.91	9.942	0.138	0.138
MnO	0.16	0.161	0.002	0.002
MgO	4.91	4.926	0.122	0.122
CaO	7.36	7.383	0.132	0.132
Na2O	4.31	4.324	0.070	0.140
K2O	0.59	0.592	0.006	0.013
TiO2	1.02	1.026	0.013	0.013
P2O5	0.19	0.191	0.001	0.003
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.68			

..................CIPW NORM................

q	c	or	ab	an	lc	ne	kp	wo
2.758	0.000	3.497	36.584	17.357	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
10.387	10.211	0.000	0.000	20.598	0.000	0.000	1.775	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.948	0.451	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.044

CIPWNORM TOTAL = 100.012

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 50.427 FS 49.573

FELDSPAR COMPOSITION :KFS 6.089 AB 63.692 AN 30.219

PLAGIOCLASE PERCENT ANORTHITE 32.178

QUARTZ : FELDSPAR RATIOS:

QUARTZ 4.582 ORTHOCLASE 5.810 PLAGIOCLASE 89.608

QUARTZ 6.438 ORTHOCLASE 8.164 ALBITE 85.398

CHAPPELS A/CNK INDEX 0.667

MG No. IN CATIONS 44.29

AFM PARAMETERS: A = 0.24 F = 0.53 M = 0.24

JENSEN CATION PLOT A = 0.38 M = 0.15 F = 0.47

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
2.567	0.000	3.513	39.008	17.444	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
10.012	9.842	0.000	0.000	19.854	0.000	0.000	1.286	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.436	0.400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.492

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
2.50	0.00	0.00	39.01	17.44	0.00	0.00	0.00	21.79	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	9.79	0.00	0.00	0.00	0.00	0.00	1.29	0.00	21.788

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.45	0.00	2.15	0.00	0.00	0.00	0.00	0.00	5.621	

MESONORM TOTAL = 100.050

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PETRONORMS PROGRAM
SAMPLE NUMBER MAG2

OXIDES	GIVEN	RECALC 100%	MOL PROPS	CAT PROPS
SiO2	56.30	56.312	0.937	0.937
Al2O3	14.53	14.533	0.143	0.285
Fe2O3	1.20	1.200	0.008	0.015
FeO	9.69	9.692	0.135	0.135
MnO	0.14	0.140	0.002	0.002
MgO	4.79	4.791	0.119	0.119
CaO	6.93	6.931	0.124	0.124
Na2O	4.09	4.091	0.066	0.132
K2O	1.14	1.140	0.012	0.024
TiO2	1.00	1.000	0.013	0.013
P2O5	0.17	0.170	0.001	0.002
Cr2O3	0.00	0.000	0.000	0.000
TOTAL	99.98			

...................CIPW NORM.................

q	c	or	ab	an	lc	ne	kp	wo
2.938	0.000	6.738	34.613	17.924	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
10.562	10.383	0.000	0.000	20.945	0.000	0.000	1.740	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.898	0.403	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.811

CIPWNORM TOTAL = 100.011

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PARAMETERS FOR CIPW NORMATIVE MINERALS

HYPERSTHENE COMPOSITION:EN 50.427 FS 49.573
FELDSPAR COMPOSITION :KFS 11.367 AB 58.394 AN 30.239
PLAGIOCLASE PERCENT ANORTHITE 34.117
QUARTZ : FELDSPAR RATIOS:
QUARTZ 4.723 ORTHOCLASE 10.830 PLAGIOCLASE 84.447
QUARTZ 6.634 ORTHOCLASE 15.213 ALBITE 78.153
CHAPPELS A/CNK INDEX 0.707
MG No. IN CATIONS 44.22

AFM PARAMETERS: A = 0.25 F = 0.52 M = 0.23
JENSEN CATION PLOT A = 0.39 M = 0.15 F = 0.46

.............CATANORM.............

q	c	or	ab	an	lc	ne	kp	wo
2.735	0.000	6.770	36.918	18.019	0.000	0.000	0.000	0.000
en	**fs**	**fo**	**fa**	**hy**	**ol**	**ac**	**mt**	**hm**
10.183	10.011	0.000	0.000	20.194	0.000	0.000	1.261	0.000

il	ap	cm	tn	pf	ns	ks	cs	ru	di
1.399	0.357	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.345

CATANORM TOTAL =100.000

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...MESONORM (HUCHISONS ALGORYTHM...)

Q	C	Or	Ab	An	Lc	Ne	Wo	Ri	Act	Ed
4.90	0.00	0.00	36.92	18.02	0.00	0.00	0.00	17.90	0.00	0.00

Di	Hy	Ol	(En	Fs	Fo	Fa)	Mt	Hm	HORNBLENDE
0.00	7.71	0.00	0.00	0.00	0.00	0.00	1.26	0.00	17.899

Ap	Cm	Tn	Pf	Ns	Ks	Cs	Ru	BIOTITE	Sp
0.40	0.00	2.10	0.00	0.00	0.00	0.00	0.00	10.833	

MESONORM TOTAL = 100.045

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