THE USUSHWANA COMPLEX IN THE SOUTHEASTERN TRANSVAAL, WITH SPECIAL REFERENCE TO ITS ECONOMIC MINERAL POTENTIAL

by

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ABSTRACT

The Usushwana Complex consists of a suite of hypabyssal, volcanic and plutonic rocks emplaced after deposition of the Pongola Group and in turn intruded by Pongola granite.

The geological history against which the petrology of the complex is discussed starts with the deposition of the Pongola Group sediments including widespread extrusion of basaltic lavas of the Ngwempisi Formation. Deposition of these rocks was followed by deformation, viz. the formation of the Amsterdam syncline and similar synforms east and southeast of Piet Retief and the subsequent disruption of these structures by normal and strike-faulting. During this period of structural deformation ultramafic sills of the Thole Formation, the magma of which bears resemblance to the Geluk type of basaltic komatiite of the Barberton area, were emplaced into the pile of rocks of the Pongola Group.

After an erosional hiatus the volcanic phase of the Usushwana Complex ensued with the extrusion of rocks of the Amsterdam and Vaalkop Formations. Except for the rhyolitic Athole Member in the north-central part of the Amsterdam syncline, the Amsterdam Formation consists of pyroclastic rocks of predominantly dacitic composition. They exhibit characteristic macroscopic and microscopic features of ash flow tuffs, e.g. lack bedding and sorting, variation in the abundance of clasts of foreign material to such an extent that the rock may grade into bodies of pyroclastic breccia in places, broken and corroded crystal fragments, microlites of tridymite which are typical in the vapour phase of ash flows as well as crystallites and lithophysae. Many of the diagnostic microscopic textures usually exhibited by ash flow tuffs have, however, subsequently been destroyed by devitrification and recrystallisation.

The Vaalkop Formation, which is developed in the Piet Retief

area and farther south, consists of rhyolite ranging from a porphyritic, granophyric rock containing euhedral, totally altered plagioclase laths, to a felsitic type.

The volcanic rocks in places constitute the roof of the plutonic phase of the Usushwana Complex. The intrusive rocks are subdivided in the gabbroic Piet Retief Suite and the acidic Hlelo Suite. Three types of gabbroic rocks are recognised, i.e. normal gabbro, ferrogabbro and quartz gabbro. Whereas the ferrogabbro is considered to be an iron-enriched differentiate of the quartz gabbro, no genetic link between these two varieties and the gabbro could be established. Except for sporadic segregations of magnetitite in the ferrogabbro these rocks do not display direct evidence of differentiation. Although the petrological relationships of a fourth type, hyperite, are not quite conclusive it is included in the Piet Retief Suite because it is usually associated with these rocks, both in the area mapped and in Swaziland. The Hlelo Suite comprises granodiorite and microgranite. The granodiorite is considered to be partly a product of differentiation of the gabbroic suite and partly of assimilation of roof rocks, viz. Vaalkop rhyolite and quartzite of the Pongola Group. In places it grades into microgranite, which in turn cannot always be readily distinguished from the Vaalkop rhyolite, neither in the field nor petrochemically. The microgranite is considered to be essentially a product of remelting of the Vaalkop rhyolite.

The geological setting of the Usushwana Complex appears not to have afforded favourable conditions for the formation of ore deposits. The magnetite layers are invariably very restricted and, moreover, the V_2O_5 content is only in the order of 0,25 per cent. Sulphides occur sparingly in the gabbroic rocks and in the basaltic lava of the Ngwempisi Formation. Even where they are somewhat more conspicuous the concentrations of Cu, Ni and Zn remain in the 0,00X to 0,0X per cent range

and only one exposure of hyperite containing over 0,1 per cent Cu was observed. A geochemical stream sediment survey covering about 750 km^2 was conducted over the northern part of the area mapped.

The apparent absence of mineralisation is discussed in the light of petrological evidence.

SAMEVATTENDE OORSIG

Die Usushwanakompleks bestaan uit 'n suite van hipabissale, vulkaniese en plutoniese gesteentes wat na afsetting van die Groep Pongola ingeplaas is en wat op hulle beurt weer deur Pongolagraniet ingedring word.

Die geologiese geskiedenis waarteen die petrologie van die kompleks bespreek word, begin met die afsetting van die sedimente van die Groep Pongola, insluitende die wydverspreide uitvloeiing van basaltiese lawa van die Formasie Ngwempisi. Die afsetting van hierdie gesteentes is gevolg deur vervorming, te wete die vorming van die Amsterdamsinklien en soortgelyke sinvorme ten ooste en suidooste van Piet Retief en daaropvolgende ontwrigting van hierdie strukture deur af- en strekkingsverskuiwings. Gedurende hierdie periode van strukturele vervorming is ultramafiese plate van die Formasie Thole, die magma waarvan ooreenkoms toon met die Geluk-tipe basaltiese komatiïet van die Barbertongebied, ingeplaas in die opeenvolging van die Groep Pongola.

Na 'n erosiehiaat het die vulkaniese fase van die Usushwanakompleks gevolg met die ekstrusie van gesteentes van die Formasies Amsterdam en Vaalkop. Met uitsondering van die riolitiese Lid Athole in die noordelik-sentrale Amsterdamsinklien, bestaan die Formasie Amsterdam uit piroklastiese gesteentes van hoofsaaklik dasitiese samestelling. Hulle vertoon kenmerkende makroskopiese en mikroskopiese eienskappe van asvloeituwwe, soos byvoorbeeld gebrek aan gelaagdheid en sortering, variasie in die menigte brokstukke vreemde materiaal tot so 'n mate dat die gesteente in plekke oorgaan in liggame van piroklastiese breksie, gebreekte en gekorrodeerde kristalfragmente, mikroliete van tridimiet wat tipies is in die gasfase van asvloeiinge sowel as kristalliete en litofises. Baie van die diagnostiese mikroskopiese teksture wat gewoonlik deur asvloeituwwe vertoon word is egter vernietig deur ontglasing en herkristallisasie.

Die Formasie Vaalkop, wat in die gebied Piet Retief en verder suid ontwikkel is, bestaan uit rioliet wat varieer van 'n porfiritiese, granofiriese gesteente, wat eievormige en heeltemal veranderde plagioklaaskristalle bevat, na 'n felsitiese tipe.

Die vulkaniese gesteentes maak plek-plek die dak uit van die plutoniese fase van die Usushwanakompleks. Die intrusiewe gesteentes word onderverdeel in die gabbroïese Suite Piet Retief en die suur Suite Hlelo. Drie tipes gabbroïese gesteentes word onderskei, naamlik 'n normale gabbro, ferrogabbro en kwartsgabbro. Waar die ferrogabbro beskou word 'n ysterverrykde differensiaat van die kwartsgabbro te wees, kon geen genetiese verband tussen hierdie twee gesteentes en die gabbro bepaal word nie. Afgesien van sporadiese segregasies van magnetitiet in die ferrogabbro vertoon hierdie gesteentes geen direkte getuienis van differensiasie nie. Alhoewel die petrologiese verhoudinge van 'n vierde tipe, hiperiet, nie oortuigend is nie, word dit by die Suite Piet Retief ingesluit vanweë sy meer algemene verband met hierdie gesteentes, beide in die gekarteerde gebied en in Swaziland. Die Suite Hlelo sluit granodioriet en mikrograniet in. Die granodioriet word beskou gedeeltelik 'n produk van differensiasie van die gabbroiese gesteentes te wees en gedeeltelik van assimmilasie van dakgesteentes, dit wil sê Vaalkoprioliet en kwartsiet van die Groep Pongola. Plek-plek gaan dit oor in mikrograniet, wat op sy beurt nie altyd maklik in die veld of petrochemies van Vaalkoprioliet onderskei kan word nie. Die mikrograniet word beskou hoofsaaklik 'n produk van opsmelting van Vaalkoprioliet te wees.

Die geologiese raamwerk van die Usushwanakompleks het blykbaar geen gunstige toestande vir die vorming van ertsafsettings opgelewer nie. Die magnetietlae is sonder uitsondering baie beperk en bowendien is die V_2O_5-inhoud slegs min of meer 0,25 persent. Sulfiede is skaars in die gabbroïese gesteentes en in die basaltiese lawa van die Formasie Ngwempisi. Selfs waar hulle effens meer ooglopend is, bly die konsentrasies van Cu, Ni en Zn in die orde van 0,00X tot 0,0X persent en slegs een dagsoom wat meer as 0,1 persent Cu bevat, is opgemerk. 'n Geochemiese riviersedimentopname is van sowat 750 km^2 in die noordelike gedeelte van die gekarteerde gebied uitgevoer.

Die skynbare afwesigheid van mineralisasie word in die lig van petrologiese gegewens bespreek.

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I. INTRODUCTION

A. Locality and physiography of the study area

The area reported on in this dissertation is situated in the southeastern Transvaal and includes the towns of Piet Retief and Amsterdam; it is delimited by 26°30'S and 27°S latitude and skirts the Swaziland border in a belt 10 to 27 km wide. The total area mapped is some 1250 km^2 in extent (Folders IA and IB). The locality of the area in question is shown in Figures 1 and 2. Figure 1 outlines the main features of the Usushwana Complex in its entirety and Figure 2 is a generalised geological map of the area investigated during this study.

Climatologically the area is considered to fall into the Highveld region, bordering on the escarpment. Piet Retief and Amsterdam have altitudes of 1260m and 1200m respectively, compared with 1700m for Ermelo, for instance. The area has a relatively high average annual rainfall, e.g. 920mm for Piet Retief, resulting in innumerable perrennial streams which contribute to some large rivers, such as the Usutu River north of Amsterdam, the Ngwempisi and Hlelo Rivers between Amsterdam and Piet Retief and the Assegaai River south of Piet Retief, all of which are tributaries of the Great Usutu River in Swaziland. Both the Ngwempisi and the Hlelo Rivers cut back in pronounced and deeply incised meanders, indicating youthful age and giving rise to a very beautiful scenery in places. Geographically the area is considered to be part of the southeastern and eastern Midlands, occupying that part of the country between the Great Escarpment and the Lebombo belt (Van Eeden, 1972, Fig. 1).

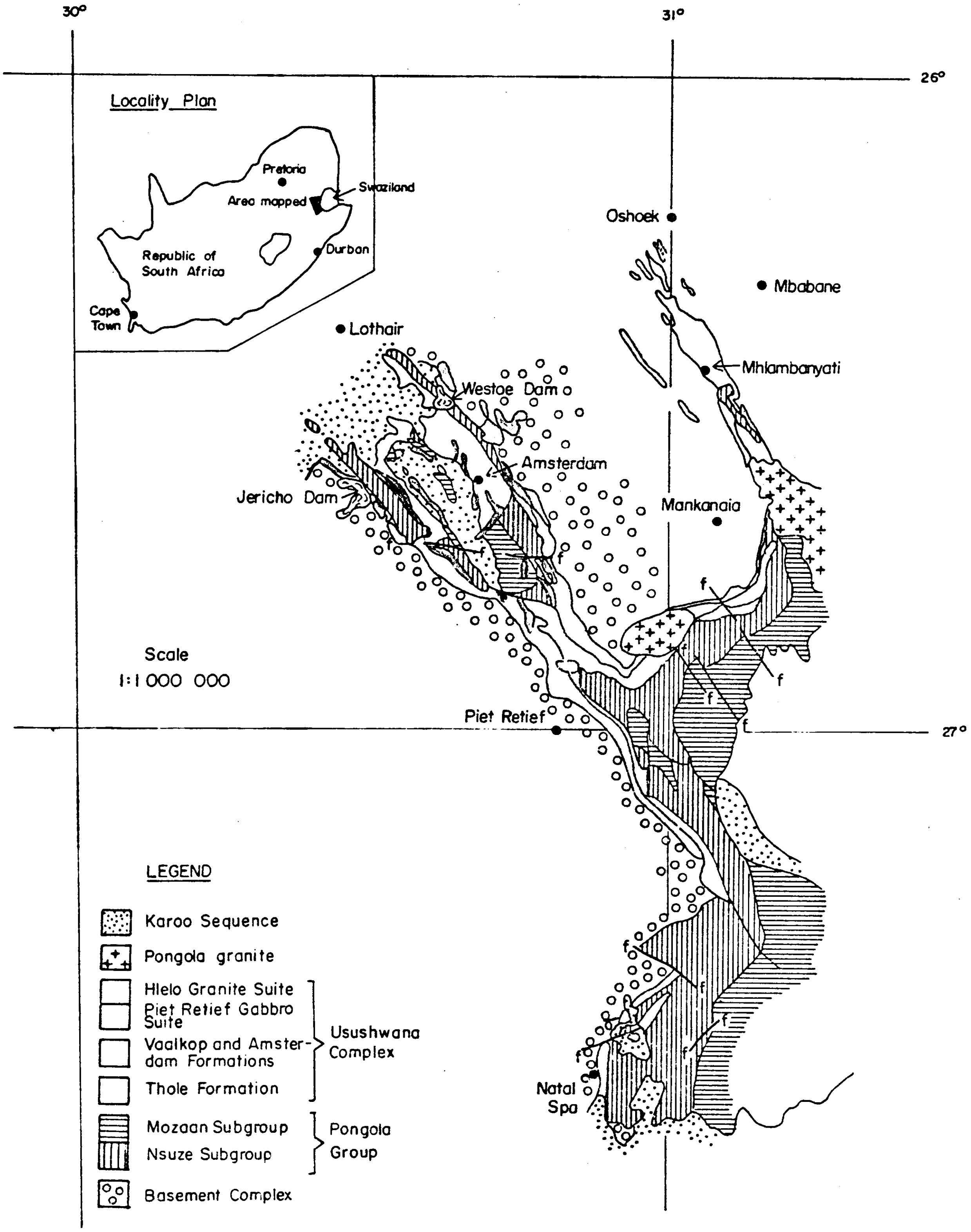


FIG. I MAIN FEATURES OF THE USUSHWANA COMPLEX

(After Humphrey and Krige, 1931; Hunter, 1970a; Geological map of S. Afr., 1970; Visser et al, 1949 and this investigation)

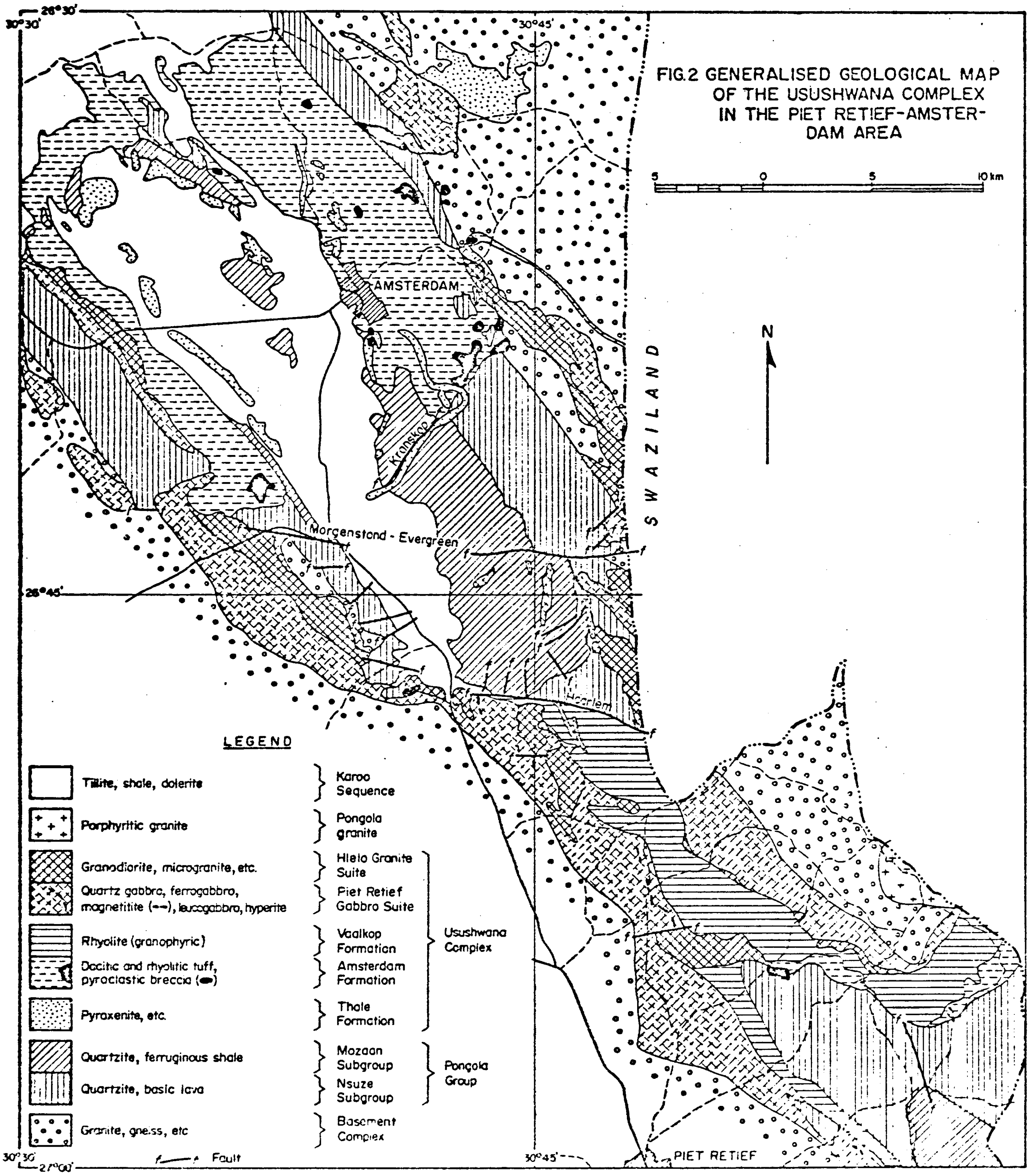


FIG.2 GENERALISED GEOLOGICAL MAP OF THE USUSHWANA COMPLEX IN THE PIET RETIEF-AMSTERDAM AREA

B. Historical review and scope of this investigation

The first reference to the area in question was by M.E. Frames in 1904 who reported on a visit to the Amsterdam valley. During the 1910's and the early twenties L.J. Krige mapped the entire area underlain by rocks of the Usushwana Complex on the Transvaal side of the border (Fig. 1). The work on the area south of 27^{o} latitude was published by Humphrey and Krige (1931), but the field maps of the area north of this line were never completed and unfortunately the work was not reported on. No further work was done until 1963 when C.J. van Vuuren mapped an area of 230 km^2 to the south and southeast of Amsterdam, during the course of an investigation for a dam-site in the Ngwempisi River on Merriekloof 420 IT. This investigation was rounded off in a M.Sc. thesis, which proved to be a very useful introduction for the present study (Van Vuuren, 1965).

More or less simultaneously P.E. Winter (1965), then of the Geological Survey of Swaziland, reported on the sub-parallel belt of basic rocks occurring 40 to 50 km east of Amsterdam. On the basis of this occurrence D.R. Hunter coined the name Usushwana Complex after the Usushwana or Little Usutu River (Winter, 1965, p. 2). A comprehensive description of the complex in Swaziland was subsequently published by Hunter (1970 a). An interpretation of the available data from Swaziland is incorporated in Figure 1.

The purpose of the present investigation was to investigate that portion of the Usushwana Complex present in the Transvaal which was hitherto largely undescribed and more specifically to assess its economic potential.

C. Methods of investigation

Mapping was carried out in the field on aerial photographs on an approximate scale of 1:30 000. The field investigations

10 000.

were corroborated by stereoscopic interpretation of the aerial photos and the geology was subsequently compiled on published topographical maps on a scale of 1:50 000.^{10000} The topographical maps contain much useful information all of which could unfortunately not be transferred onto the geological maps (Folders IA and B). Reference to the relevant topographical maps may therefore be helpful in understanding some aspects of this text.

In the laboratory a large number of thin sections were studied petrographically. Some optical determinations were made with the universal stage, and modal analyses as well as some X-ray diffraction identifications were carried out. A comparatively large number of mineral analyses were performed with the aid of a JEOL JXA-50A microanalyser. The accelerating voltage during the analyses was KeV 15, the specimen current 0,02 microamps and the beam diameter was maintained at approximately 3 micron. The counting time for each element was 3 x 10 seconds on the peak and 2 x 10 seconds for background. The following standards were employed: SiO_2-quartz; TiO_2-rutile; Al_2O_3-corundum; Cr_2O_3-chromite; FeO-hematite; MnO-pyrolusite; MgO-periclase; NiO-trevorite; CaO-wollastonite; Na_2O-albite and K_2O-sanidine. The analyses are calculated according to methods outlined by Bence and Albee (1968).

In view of the fact that comparatively little was known about the geology of the area, and because correlation of rock formations was complicated by poor outcrop conditions in some parts, a relatively large number of whole rock chemical analyses of the major elements and selected trace elements were called for. The majority of these analyses were carried out by the National Institute for Metallurgy and by the General Superindence, Co. A few additional analyses were done in the Geological Survey laboratory. A geochemical stream sediment survey was conducted over the northern portion of the area mapped. Methods employed for this investigation are discussed in detail in the text. The stream sediment samples were analysed by the National Institute for Metallurgy and by the

General Superindence, Co.

The following methods of analysis were employed:

(i) X-ray fluorescence spectrometry for SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 and S

(ii) Volumetric analysis for FeO

(iii) Gravimetry for H_2O^+, H_2O^- and CO_2

(iv) Atomic absorption for Cr, V, Zn, Cu and Ni

(v) Fire assay for the platinum group metals and gold

At the laboratory of the Geological Survey samples were analysed by energy dispersive XRF spectrometry.

D. Acknowledgements

Sincere appreciation is expressed to the Director of the Geological Survey for granting permission to utilize official information for the purpose of this thesis, as well as to Dr. C.B. Coetzee for suggesting this investigation and for his subsequent support in the execution thereof.

Help from the following colleagues at the Geological Survey is gratefully acknowledged:

Dr. J.E.J. Martini collected a traverse of samples in the field, investigated these samples petrographically and performed certain X-ray diffraction analyses.

Dr. R.J. Kleywegt arranged the gravity survey of the area and assisted in the interpretation of the results.

Dr. C. Frick instructed me in the use of the microprobe and Messrs. R.C. Wallace, B.P. Twigg and L.W. Esterhuysen assisted with the mineral analyses.

Dr. R. Beeson and other members of the Geochemical Section assisted with the interpretation of the geochemical data.

The Drawing Office staff produced the maps and text figures.

Many thanks are due to the farming community of the area, especially to Mr. and Mrs. David Forbes on whose farm I have camped on several occasions, for their hospitality.

Finally I wish to thank professors C.P. Snyman and G. von Gruenewaldt, under whose guidance this work was completed, for their helpful criticism and suggestions during the course of the investigations.

II. GENERAL GEOLOGY

A. Distribution of the rock types

The stratigraphical column and distribution of rock types occurring in the Piet Retief-Amsterdam area are shown in Figure 2. The main features of the various rock units are briefly as follows.

1. The Basement Complex

Two main types of granitic rocks, i.e. tonalitic gneiss and granodiorite of the Ancient Gneiss Complex (Hunter, 1970 b) and Homogeneous Hood granite (Hunter, 1973), constitute the floor of the ensuing sedimentary and magmatic events. The former type is restricted to the southern portion of the area and underlies the terrain southeast of Piet Retief, from where it extends into Swaziland. Homogeneous Hood granite is found to the north of Piet Retief towards Amsterdam, where it builds the basement rocks on both sides of the Usushwana Complex.

2. The Pongola Group

The Pongola Group consists essentially of a succession of quartzite, basic lava and ferruginous shale which are grouped into the Nsuze and Mozaan Subgroups. The Nsuze Subgroup consists of a succession of quartzite (Glen Eland Formation) overlain by basic lava (Ngwempisi Formation). The Mozaan Subgroup also has a quartzite at its base (Skurwerant Formation) followed by mainly ferruginous shale (Voorslag Formation).
Bivane

These rocks were deposited on a floor of Basement granite and in the present area, they are preserved in two synclinal structures, i.e. firstly in the Amsterdam area and secondly to the east and southeast of Piet Retief.

3. The Usushwana Complex

The Usushwana Complex comprises three magmatic events which were emplaced over an extended period of time, viz. a sill phase, a volcanic phase and a plutonic phase.

a) The Sill Phase

The magmatic cycle commenced with the emplacement of ultrabasic to basic sheets and sills of the Thole Formation mainly at various levels in the Mozaan Subgroup. They usually consist of harzburgite at the base, grading upwards into pyroxenite and even to gabbro or norite in places.

The sheets and sills attain their best development in the synclinal structure of rocks of the Pongola Group west of Amsterdam but rocks of the Thole Formation are also observed outside this basin.

b) The Volcanic Phase

Two formations are distinguished in the rocks of the volcanic phase, i.e. the Amsterdam Formation and the Vaalkop Formation.

The type-area of the Amsterdam Formation is in the vicinity of the settlement of Amsterdam. It is predominantly pyroclastic and consists of a basal rhyolitic rock (the Athole Member), developed in low-lying areas some 15 km northwest of the village, followed by the main body of a massive fine-grained, dark coloured rock which is mainly of dacitic composition. This formation is characterised by the presence of accidental pyroclasts, which may in places become so plentiful as to constitute pyroclastic breccia. These breccia bodies may range in size from small outcrops, some tens of metres across to huge bodies up to 1 km^2 in extent. Twenty-five such occurrences have been observed in the area, but there are probably more. The best development of this breccia is to the southeast of Amsterdam.

The Vaalkop Formation, which is of rhyolitic composition, is found in the area northeast of Piet Retief. It extends beyond the present area into Swaziland and to the southeast of Piet Retief, at least as far as Pipe Klip Berg 21 HU. In both these areas this rock has previously been described as granophyre (Humphrey and Krige, 1931, p. 42; Winter, 1965, p. 10; Hunter 1970 a, p. 650).

c) The Plutonic Phase

The plutonic phase is subdivided into a mafic and an acidic suite. The mafic suite, i.e. the Piet Retief Gabbro Suite consists predominantly of quartz gabbro with minor amounts of ferrogabbro, an apparently older gabbro and a hypersthene gabbro or hyperite. In the area mapped the mafic rocks occupy the two outer limbs of the complex, separated from one another by rocks of the Pongola Group, the Thole, Amsterdam and Vaalkop Formations and the Karoo Sequence. The two limbs are closest to each other about 15 km due north of Piet Retief. The western limb is more continuous than the eastern one and it can be followed intermittently from Bankplaats 279 IT in the northwest (Geological map, Sheet 64) past the Jericho Dam and Piet Retief to Cometje 13 HU in the southeast (Geological map, Sheet 68), a total strike length of 90 km.

Granodiorite and microgranite, which constitute the acidic suite or Hlelo Granite Suite, are in places associated with the Piet Retief Suite and have a intermittent mode of occurrence. These rocks are not considered to be part of a layered sequence.

4. Pongola granite

A pluton of Pongola granite occurs northeast of Piet Retief, on the Swaziland border. A number of associated dykes are found intrusive into quartz gabbro as well as the Vaalkop and Amsterdam Formations. This particular pluton of the Pongola granite has been termed the Sicunusa pluton (Hunter, 1973, p. 139).

5. The Karoo Sequence

After a very long depositional hiatus the area was subjected to glaciation, which is much in evidence in the Amsterdam area, followed by the deposition of the Dwyka Tillite Formation and shale of the Ecca Group. Subsequently sills and dykes of dolerite were emplaced. Rocks of the Karoo Sequence blanket the Usushwana Complex in the northwest and occupy most of the ground in the Amsterdam valley.

B. Extent and shape of the Usushwana Complex

The Usushwana Complex is a large dyke-like intrusive which has the form of an inverted lower case letter "h". The longer leg of the "h" is over 100 km long and stretches in a more or less straight line from Pipe Klip Berg 21 HU in the southeast, past Piet Retief and Amsterdam towards Lothair in the northwest, where it apparently terminates rather abruptly (Figure 3). The bearing of this line is about N 140^{o}E. In the area north of 27^{o} latitude the basic rocks of the intrusive outcrops in the two parallel zones separated from one another by either the Vaalkop and the Amsterdam Formations or rocks of the Pongola Group. East of Piet Retief on Strydkraal 477 IT the eastern zone swings east-northeast, extending for about 30 km into Swaziland before it swings back north-northwest to extend for almost 60 km to south of Oshoek (Figure 1).

1. Aeromagnetic survey

The above dimensions are partly derived from surface geology and partly from the aeromagnetic survey carried out on behalf of the Geological Survey in 1969 (Figure 3). No detailed interpretation of these results has yet been undertaken, but on cursory examination they seem to supplement the surface geology in some important aspects, namely:

(i) The northernmost part of the complex is overlain by rocks of the Karoo Sequence from immediately south of the Westoe Dam to Lothair, i.e. for about 20 km, where its presence under this cover is clearly revealed magnetically.

(ii) In Swaziland the main massif of the intrusive terminates about 8 km from the border and only isolated gabbroic bodies occur from this point northwards to about 5-8 km SW of Oshoek. However, the aeromagnetic survey indicates that its sub-outcrop extends at least 20 km farther to the northwest, into the Transvaal.

(iii) A narrow magnetic zone parallel to the general outline of the complex is observed on its north-eastern side. Only scattered outcrops of gabbro and other basic rocks occur in places but these thus seem to be part of a larger dyke-like basic intrusive. The outcrops of the Thole Formation on Lions Glen 398 IT and Stafford 399 IT, (Folder IA, G. 1/2) on the other hand, do not show up magnetically.

In the Amsterdam area aeromagnetic anomalies higher than 7000 nanotesla (gamma) and as high as 15 000 nanotesla seem to be related to near-surface occurrences of iron-formation of the Voorslag Formation. The magnetite-rich rocks of the Usushwana Complex produce a fairly well defined zone of magnetic anomalies in the order of 7000 nanotesla.

The aeromagnetic data do not indicate any break in continuity in the central part of the complex, which in those parts is covered by either rocks of the Pongola Group or the Vaalkop Formation and it is thus possible that the two parallel zones of gabbro referred to above are linked in depth, but this may also be ascribed to underlying basic lava of the Ngwempisi

Formation and ferruginous shale and iron-formation of the Voorslag Formation.

2. Gravity survey

a) Regional gravity survey

The gravity map of the Republic (1970) shows two gravity highs over the Usushwana Complex. The higher anomaly of -110 mgal is situated due south of Lothair and thus verifies the abovementioned observation of a continuation of the complex in that direction underneath the cover of rocks of the Karoo Sequence. The second anomaly of -100 mgal is located south of Amsterdam and serves to indicate that rocks of higher density underlie the Pongola Group in this area. Rocks of higher magnetic intensity were also shown to be present in this zone.

b) Detailed reconnaissance survey

At the request of the author a more detailed gravity survey was carried out by the Geophysical Section of the Geological Survey in order to obtain more information on the structure of the complex.

Two traverses were surveyed in the Amsterdam area, where they not only covered the Usushwana Complex, but also parts of the Pongola Group. Another two traverses were studied in the Piet Retief area where, apart from the Vaalkop Formation, the complex has been stripped of its roof and is thus better suited for such an investigation. The result of these two groups of gravity surveys are presented in Figures 4 and 5 respectively.

The following deductions can be made from the above gravity anomalies, but these must be regarded as being of a tentative nature only since this investigation has not yet been finally concluded:

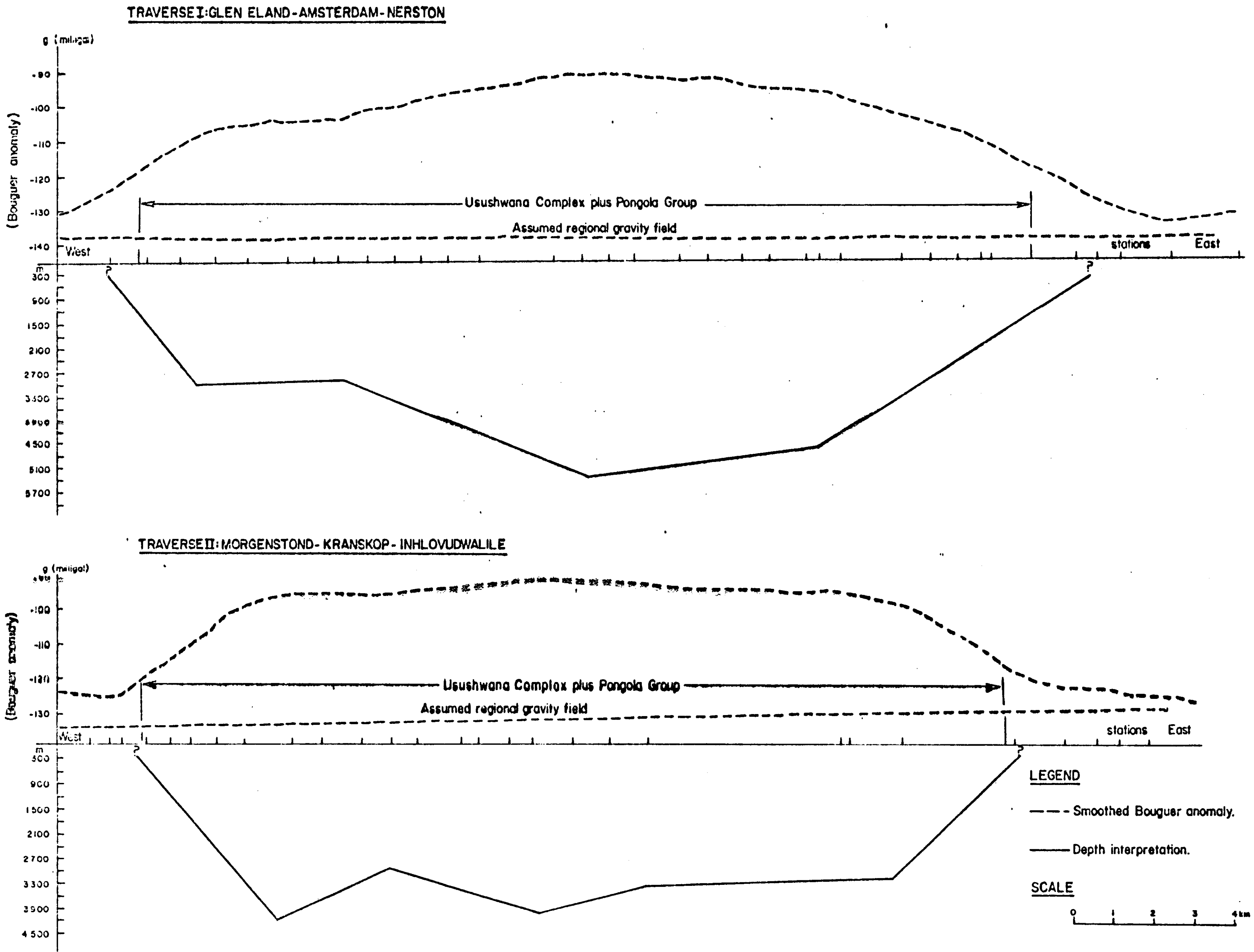


FIG. 4 : GENERALISED DEPTH INTERPRETATION OF THE USUSHWANA COMPLEX AND THE PONGOLA GROUP FROM GRAVITY DATA IN THE AMSTERDAM AREA. (AFTER BASSON (1972) AND R.J. KLEYWEGT (PERSONAL COMMUNICATION))

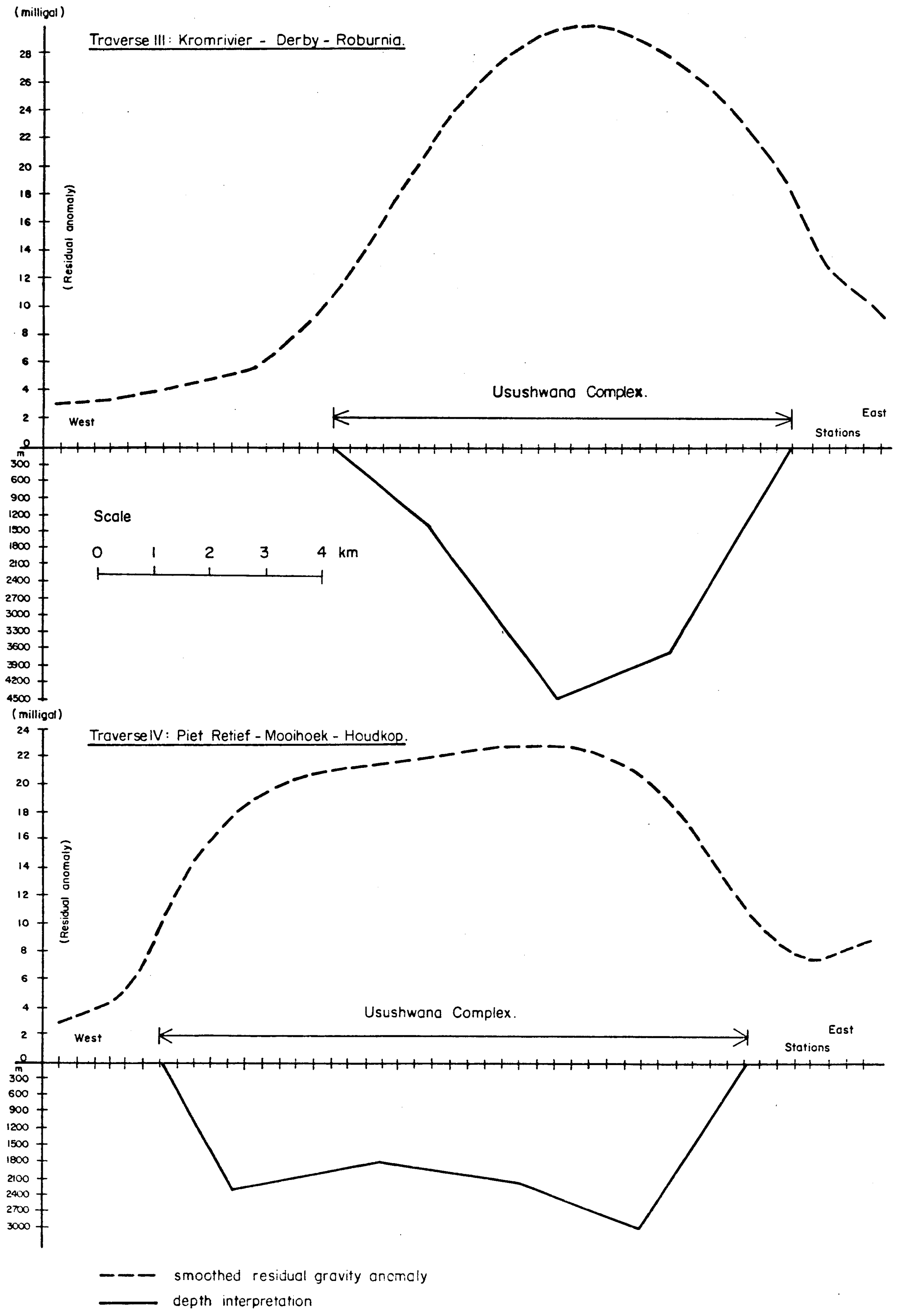


Fig. 5 : Generalised depth interpretation of the Usushwana Complex from gravity data in the Piet Retief area. (After Basson (1972) and R.J. Kleywegt (personal communication))

(i) The maximum inferred depths of the Usushwana Complex in the Amsterdam and Piet Retief areas are in the order of 4200-5500m and 3000-4500m respectively.

(ii) The contacts of the complex appear to be fairly steep. The indicated inclination varies from about 45° in the Amsterdam area to approximately 65° northeast of Piet Retief.

(iii) In the Amsterdam sector the structure appears to be basin shaped and to have a fairly flat bottom. Here, much of the central part of this basin is built by basic lava of the Nsuze Subgroup, which cannot be distinguished from the gabbro of the Usushwana Complex, in view of their almost identical densities (2860-2910 and 2900 kg/m^3, respectively).

(iv) The shape disclosed by traverse III (Fig. 5) is the best defined one and approaches that of a longitudinal funnel-section. At this locality the structure of the Usushwana Complex is comparable with that of the Great Dyke, Rhodesia, especially the southern part of the Hartley Complex (traverses 10 and 12; Podmore, 1970, p. 618-620). The form revealed by the southernmost traverse (IV, Fig. 5) is in agreement with the surface geology in that the two belts of gabbro, which are observed in the area, also seem to be separated by other rocks in depth.

(v) The shape observed in the Amsterdam area presumably reflects that of the synclinal structure of the Pongola Group and here the true relationships of the intrusive gabbro cannot be ascertained.

(vi) No feeder of the intrusive could be defined although such a feature may be surmised along traverse III (Fig. 5), where the geophysical field data indicates a greater depth extension. It is, however, considered unlikely that a feeder, if it is a narrow structure, can be delimited by a survey of this nature (R.J. Kleywegt, personal communication).

It is of interest that a detailed gravity survey of the northwest trending Mhlambanyati limb of the intrusive in Swaziland revealed that the walls of the intrusive are nearly vertical for at least 5 km (Burley, et al, 1970, Fig. 11). These conditions apply especially in the northwest, whereas in the southeast reduced maximum anomalies were observed and consequently less steep gradients were interpreted.

C. Structural setting

The Usushwana Complex was emplaced along a northwest trending structure which van Eeden (1972, Fig. 3) termed the Pongola-Usushwana fold-axis and to which an age of 3000 m.y. is assigned.

The structural setting of the Usushwana Complex in the Amsterdam-Piet Retief area is shown in Figure 6. This map was compiled from Landsat images and from Figure 1. Most of the lineaments shown in Figure 6 are developed in pre-Karoo formations, especially in the Basement granite where several large joints can also be mapped on aerial photographs.

An attempt was made to analyse the structural pattern in the Amsterdam-Piet Retief area and for this purpose local, intermediate and large structures, approximately 1-5 km, 5-20 km and over 20 km long, respectively, were distinguished and their orientations plotted in rose diagrams (Fig. 7). A much larger amount of small features than shown in Figure 6 were taken into

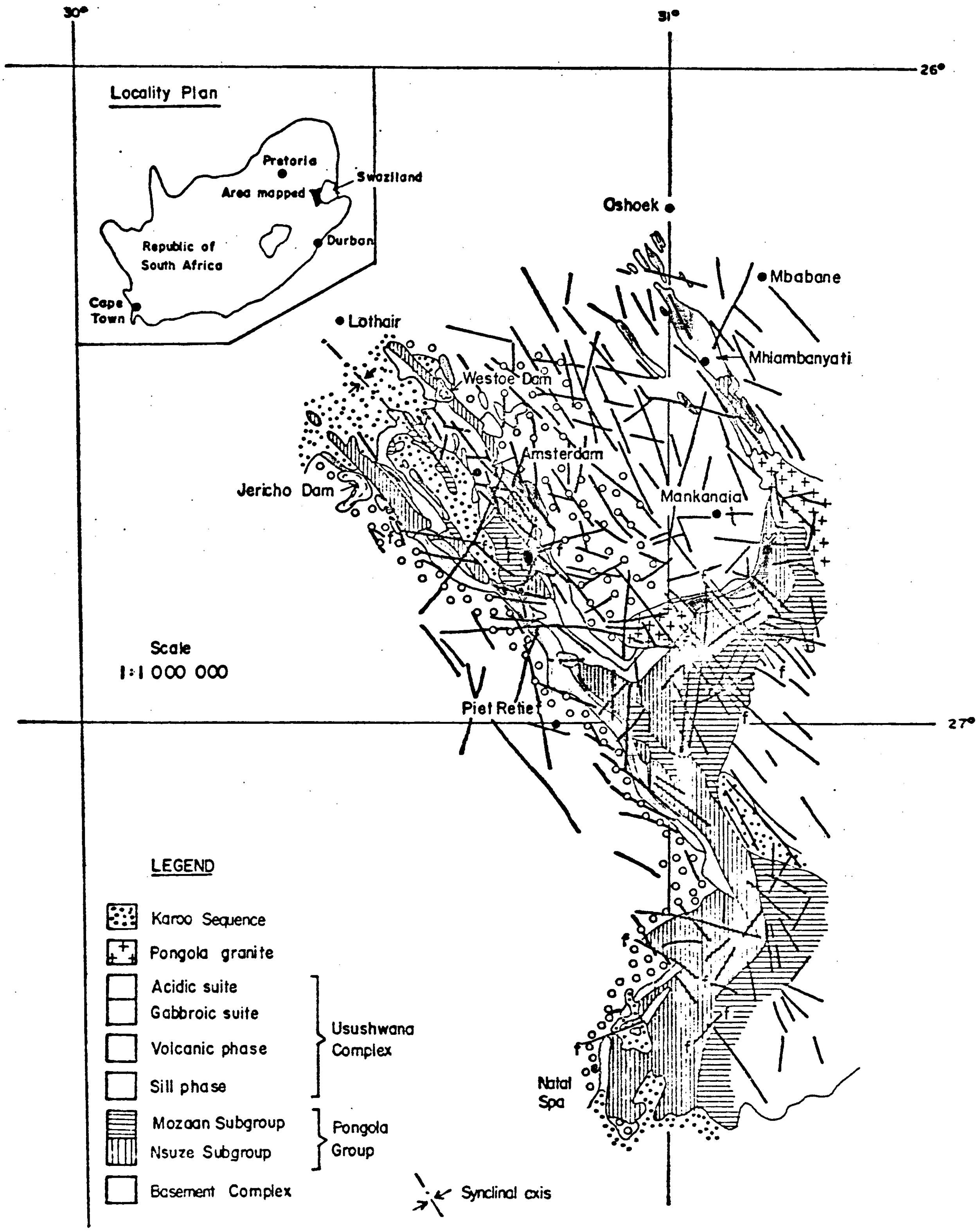
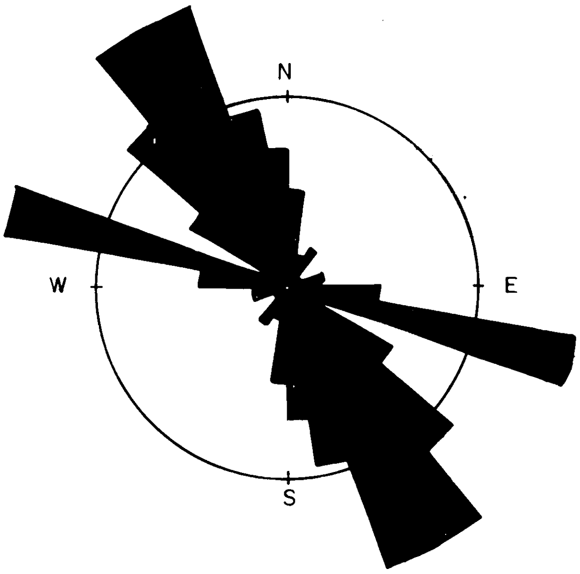


FIG. 6: MAIN STRUCTURAL FEATURES AND OTHER LINEAMENTS (LANDSAT IMAGE INTERPRETATION) IN RELATION TO THE DISTRIBUTION OF THE PONGOLA GROUP AND THE USUSHWANA COMPLEX.

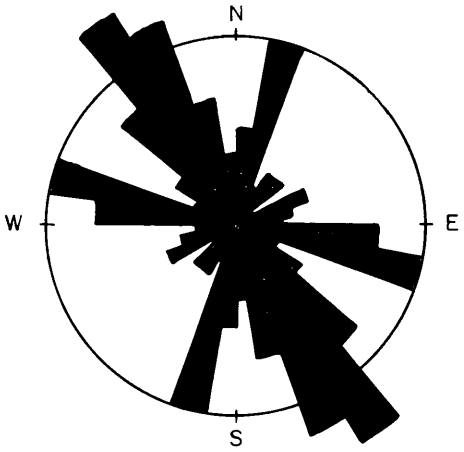
a) LOCAL LINEAMENTS : 1-5 Km

(180 POINTS)



b) INTERMEDIATE LINEAMENTS : 5-20 Km

(132 POINTS)



c) LARGE LINEAMENTS : > 20 Km

(16 POINTS)

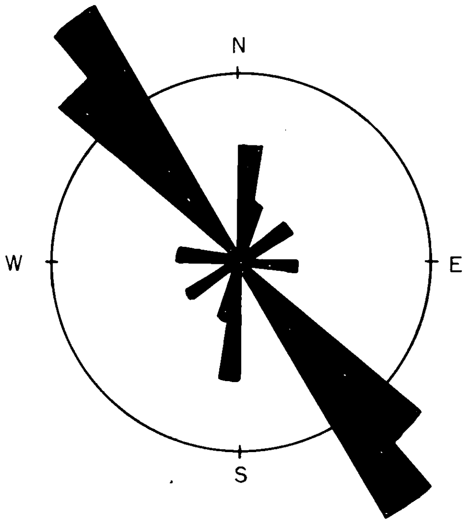


FIG 7 : ORIENTATION OF VARIOUS STRUCTURAL FEATURES AND LINEAMENTS IN THE PIET RETIEF-AMSTERDAM AREA account for this analysis. The predominating overall structural orientation is in the range of N 130° - 170°E; the direction N 140° - 160°E preponderates in the small and intermediate structures and most of the large lineaments fall into the range of N 130° - 150° E. A considerable proportion of the small and intermediate structures have an orientation of N 90° - 110° E, whereas the direction N 0° - 20° E is an additional important structural element in features longer than 5 km.

The most important structural feature in the area mapped is the Amsterdam syncline. This structure is about 20 km wide and extends from Haarlem 443 IT in the south, northwestwards for at least 40 km before it disappears under a cover of Karoo sediments on Westoe 394 IT and the northern parts of Athole 392 IT and Forbes Athole 393 IT. In the south the syncline is terminated by the Haarlem fault. The village of Amsterdam is situated on the eastern side of a 8 km wide valley in the central part of the syncline.

The syncline has been deformed by a considerable number of normal transverse and longitudinal faults, presumably as a result of the emplacement of the Usushwana Complex. More important examples of such faults are described below. Lava of the Ngwempisi Formation has been brought into juxtaposition with Vaalkop rhyolite along the Haarlem fault, which is a transverse fault with its downthrow on the southern side (Fig. 2 and Folder IB). The actual displacement along this fault cannot be determined. The largest transverse fault in the area under discussion is not a single structure but rather a zone of parallel faults, i.e. the Morgenstond and Evergreen faults (Fig. 2 and Folder IA). It cuts in an east-west direction right across the syncline from Morgenstond 418 IT (C.7) in the west to the Swaziland border east of Evergreen 425 IT (H/I.8), over a distance of 25 km. The fault zone is of pre-Karoo age and is therefore obscured on Wolvenkop 427 IT in the central part of the syncline (F.8). The total lateral displacement of the Glen Eland Formation along the Morgenstond fault is 7,5 km and that of the Skurwerant Formation along the Evergreen fault is 3 km.

Whereas the Morgenstond fault can best be described as a horizontal transverse fault the Evergreen fault is a wrench fault as a result of which the dips of the Skurwerant Formation increase from 25°W on Redcliff 426 IT (G.7) north of the fault-zone to 50°W on Evergreen 425 IT (H.8). The observed disparity in displacement along the Morgenstond and Evergreen faults can only be explained by postulating a concealed additional disruption somewhere towards the centre of the synclinal structure. Furthermore, the whole syncline seems to have sagged along the Morgenstond-Evergreen fault-zone, as evidenced from the partial closure of the structure by outcrops of the Skurwerant Formation both in the south on The Cascade 442 IT (H. 9), where the dip is 20°NW and on Athole 392 IT (A/B.3), where the quartzite dips about 15°SE. Gabbro of the Usushwana Complex cuts across the fault zone on Morgenstond and is thus clearly of younger age; the relationship is less clear in respect of the microgranite due to poor outcrop conditions.

Another transverse fault, strikes N 45°E, and occurs south of Amsterdam on Kranskop 422 IT and Merriekloof 420 IT (F/G.6). The downthrow is on the southern side but the vertical displacement of the Skurwerant quartzite on Kranskop is only in the order of 500m. The fault seems to pre-date the emplacement of the Thole Formation. An inclined ultramafic sheet dipping about 35°N has exploited this weak zone and transgresses from a position underneath the Skurwerant Formation in the north to a position above it in the south where it has been eroded away, giving rise to the dyke-like exposure of the Thole Formation on Kranskop 422 IT (Folder IA, F.7-G.6).

The Amsterdam syncline has also been affected by small-scale faulting of the Glen Eland Formation, mainly on Wolvenkop 427 IT (F.8/9) and Inhlovudwalile 421 IT (I.7). The downthrow of most of these faults is to the south, but in some it is to the north resulting in a few small horsts and grabens. In one such horst, on Wolvenkop 427 IT along the old Amsterdam-Piet Retief road, a block of Skurwerant quartzite has been uplifted and protrudes through the overlying shale of the Ecca Group.

In addition to the above transverse faults the synclinal structure has been disrupted by at least four large zones of strike faulting. These cannot be mapped in the field and they are thus not shown on the accompanying maps, but their existence can be deduced from the following observations.

(i) The presence of such a concealed zone somewhere in the centre of the Amsterdam syncline has already been inferred above from divergencies in dip and displacement along the Morgenstond-Evergreen fault-zone.

(ii) East of Amsterdam the Glen Eland Formation is highly disturbed in an area bounded by a possible extension of the Kranskop fault on Merriekloof 420 IT, in the south, and a zone of disruption on the border between Sandbach 407 IT and Glen Aggy 408 IT in the north (Folder IA, G.5-F.2). The rocks of the Nsuze Subgroup terminate abruptly against the Amsterdam Formation on Merriekloof, but to the north of this contact bits and pieces of disorientated quartzite protrude through the overlying Amsterdam Formation. The quartzite only resumes its normal continuous north-northwest strike on the northern part of Tweepoort, north of the Amsterdam-Nerston road, but here it dips almost vertically, compared with the normal south-westerly dip of 25° of the Skurwerant Formation, at Amsterdam. This discrepancy in dip indicates a major longitudinal structural disturbance between the Nsuze and Mozaan Subgroups which is concealed by the pyroclastic rocks of the Amsterdam Formation (Folder IA).

(iii) North of Amsterdam the exposure of Ngwempisi lava on Athole 382 IT (B/C 2) and an outcrop of quartzite on Westoe 394 IT (D 1/2) indicate duplication of the succession. This can be explained either by a hidden northwest trending longitudinal fault zone or by gentle anticlinal folding along a northwest trending fold axis.

(iv) The contact of the Glen Eland Formation with the Basement granite in the area north of the Amsterdam-Nerston road appears to be a faulted one. Much shearing is in evidence in the granite, especially on Broadholms 254 IT and Deepdene 395 IT (E.1) and the quartzite becomes progressively thinner towards the Usutu River.

In the southern part of the mapped area the rocks of the Pongola Group also show considerable deformation by way of shearing and some faulting, e.g. on Blesbokspruit 515 IT and Athalie 520 IT (Folder IB, L/M. 14/15). However, since these outcrops represent only the northernmost position of the main development of the Pongola Group farther to the south no conclusive observations are possible. The sharp flexure in the vicinity of Strydkraal 477 IT as a result of which the strike becomes northeasterly may perhaps be ascribed to interference folding along a north-south fold axis. However, no clear evidence for this could be found except for the subordinate preferred orientation of the mega-lineaments in the direction N 0°-20° (Fig. 7). South of 27°S latitude structual features, identical to those in the Amsterdam syncline, are observed namely synclinal structures which are disturbed by a number of comparatively large-scale normal transverse and strike faults (Geol. map of Piet Retief, 1931).

III. FORMATIONS PRE-DATING THE USUSHWANA COMPLEX

A. The Basement Complex

1. Field relationships

Granitic rocks build the peneplained floor on which the sedimentary and volcanic rocks of the Pongola Group have been deposited. The following rock types of the Basement Complex are recognised in the area under discussion.

a) Ancient Gneiss Complex

A medium to dark coloured gneiss, as a rule exhibiting strong foliation, occurs east of Piet Retief. In places the gneiss contains very striking parallel to sub-parallel light and dark layers indicating an advanced stage of granitisation. This rock occupies the entire granitic terrain between the Usushwana Complex and the Swaziland border south of latitude 26°45'S and extends into Swaziland where it has been described as tonalite, granulite, gneiss, granodiorite, migmatite, etc. of the Ancient Gneiss Complex (Hunter, 1970 b, p. 108-126; 1973, p. 133-134; and 1974, p. 264-265).

To the west of the Usushwana Complex the northern boundary of the Ancient Gneiss Complex, can tentatively be drawn along a northeast trending line passing through Piet Retief (Folder IB).

b) Homogeneous Hood granite

Light coloured granite occurs north of Piet Retief along the western side of the Usushwana Complex and in the area east of Amsterdam, between the complex and the Swaziland border (Folder IA). In Swaziland this granite is known as the Homogeneous Hood granite (Hunter, 1973, p. 137).

The granite contains many xenolithic inclusions and schlieren of amphibolite, presumably altered rocks of the Ancient Gneiss Complex, in many places criss-crossed by pegmatites. Fine examples of such relationships can be observed in the old quarry near the Jericho Dam, immediately west of the area mapped, as well as on the northernmost portion of Imbama 414 IT (A.6) near the contact of the granite and the Pongola Group, and east of Amsterdam on De Hoop 402 IT (G.3), where the association between gneissic and amphibolitic xenoliths and the granite or pegmatitic matrix can be very intricate (Fig. 8a). Pegmatitic phases in the granite have been described by Van Vuuren (1965) from Inhlovudwalile 421 IT (H.6) and Tweepoort 404 IT (G.4) and are also well developed east of the Jericho Dam in the valley of the Mpama River, outside the area mapped.

Xenoliths of rocks of the Ancient tonalite gneiss (?) in leucocratic granite can also be seen near the Malmani homestead on Welgekozen 514 IT (Folder IB, J.14) and on a larger scale, on the western part of Wolvenkop 427 IT (Folder IB, F.9), where a porphyroblastic rock is found in contact with andesitic lava and ferruginous metaquartzite and mylonite. These rocks can presumably be correlated with metasediments of the Ancient Gneiss Complex of Swaziland (Hunter, 1970b). Metaquartzite is also present on Inhlovudwalile 421 IT, close to the Swaziland border, immediately north of the Ngwempisi River and north of Dwalile Kop (Folder IA, I.7).

c) Migmatite

Granitic rocks assigned to the Nelspruit migmatite and gneiss are not generally present in the area, but Visser et al (1949, p. 20-21) described a porphyritic granite on Glen Eland 413 IT and Kliprug 281 IT immediately west of the area mapped. In fact, two types may be distinguished, viz. a non-foliated, markedly porphyritic variety, northeast of the Jericho Dam in which small xenoliths of fine-grained granitic material can be observed and another porphyritic type reminiscent of the Pongola granite on Glen Eland 413 IT, along the road from Amsterdam to

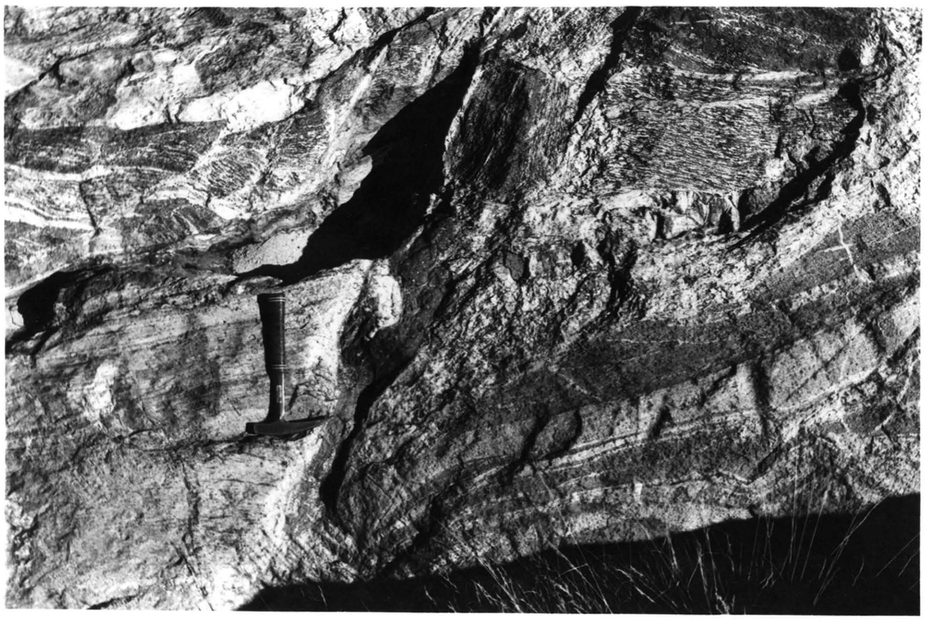


Fig. 8a: Disrupted fragments of gneiss and amphibolite (Ancient Gneiss Complex) in Homogeneous Hood granite, Basement Complex. De Hoop 402 IT

Fig. 8b: Banded gneiss of the Ancient Gneiss Complex. Holstein 468 IT

Sheepmoor via the Jericho Dam, just outside the area mapped. According to Professor Allsop (personal communication) the former variety is of Nelspruit migmatite age.

2. Petrography

a) Fabric

The rocks of the Ancient Gneiss Complex are generally coarse, foliated and in places exhibit a marked banding of quartz-feldspathic and gneissic layers rich in ferromagnesian minerals (Fig. 8b). The rock has a characteristic dark-grey colour.

The Homogeneous Hood granite around Amsterdam and along the western side of the Usushwana Complex, southwards towards Piet Retief, is generally medium to coarse grained. It is leucocratic and greyish in colour, containing varying amounts of pink K-feldspar which may impart a reddish tinge to the rock. Foliation is usually discernible but may be indistinct in places. However, strongly foliated varieties are also developed as for instance on Imbama 414 IT. This gneissic variety is leucocratic to mesocratic and dull grey in colour.

b) Mineralogy

The mineralogical composition of the more important granitic rocks of the Basement Complex is briefly as follows:

Quartz occurs in amounts of approximately 30 per cent. It usually exhibits marked undulating extinction.

K-feldspar Orthoclase, perthite and microcline are present in varying amounts in the different rock types of the Basement Complex. In the Nelspruit migmatite and the Homogeneous Hood granite K-feldspar preponderates over plagioclase. The feldspar is usually considerably altered.

Plagioclase The tonalite and granodiorite of the Ancient Gneiss Complex are characterised by porphyroblastic oligoclase crystals, 2 to 3 mm in diameter. Plagioclase observed in the Homogeneous Hood granite is also oligoclase but in most thin sections studied no exact identification was possible because of extensive saussuritisation.

Ferromagnesian minerals Hornblende, pleochroic in green and brown, and biotite are conspicuous in places, especially in the dark granodiorite of the Ancient Gneiss Complex which may contain about 20 per cent ferromagnesian minerals.

Accessory minerals Apatite and magnetite are the most common accessory minerals, but varying amounts of zircon and sphene have also been observed.

Secondary minerals Chlorite, sericite, stilpnomelane, epidote and tremolite are common secondary minerals and are found in all the granites.

c) Petrochemistry

The chemical composition of a number of Basement granites from the Amsterdam-Piet Retief area is presented in Table 1 and characteristic chemical features of some of the rock types are summarised in Table 2. Excluded from this comparison are two widely diverging analyses of Nelspruit migmatite as well as one analysis of tonalite (Table 1, No. 4), which is of doubtful origin.

Table 1 : Chemical composition of Basement granites from the Amsterdam and Piet Retief areas, Southeastern Transvaal

Sample Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	56,02	56,52	58,77	67,18	65,17	63,14	70,98	77,99	72,88	74,29	74,06	73,87	76,56	74,2
TiO_2	1,31	0,48	1,25	0,47	0,58	0,74	0,36	0,18	0,25	0,01	0,21	0,01	0,11	0,1
Al_2O_3	16,57	14,73	12,53	17,29	14,91	17,00	14,14	11,01	14,05	14,87	12,89	15,06	14,19	13,9
Fe_2O_3*	9,12	8,96	11,11	3,74	5,15	6,30	3,52	3,01	2,11	1,11	2,96	1,08	1,24	2,0
MnO	0,16	0,17	0,16	0,05	0,08	0,07	0,07	0,06	0,02	0,10	0,06	0,05	0,04	0,0
MgO	2,59	6,52	3,68	0,28	1,99	2,28	1,35	0,01	0,05	0,01	0,14	0,01	0,01	0,0
CaO	5,73	7,88	6,85	1,76	4,07	4,36	2,16	0,23	1,26	1,00	0,86	0,70	0,54	1,0
Na_2O	4,74	3,55	4,38	4,10	3,74	3,03	3,00	4,44	3,31	2,37	3,51	2,65	2,15	2,4
K_2O	1,92	0,65	0,91	1,16	1,42	1,27	3,37	3,06	5,16	4,38	5,00	4,33	4,29	4,7
P_2O_5	0,68	0,31	0,30	0,20	0,24	0,32	0,03	0,01	0,01	0,01	0,01	0,01	0,01	0,0
Total	98,84	99,77	99,94	96,23	97,35	98,51	95,64	100,00	99,10	98,15	99,70	97,77	99,14	96,8
Na_2O/K_2O	2,5	5,5	4,8	3,5	2,6	2,4	0,9	1,5	0,6	0,5	0,7	0,6	0,5	0,5

Analyst: Geological Survey Laboratory

* Total iron reported as Fe_2O_3

1. Granodiorite, Ancient Gneiss Complex (Fragment in Homogenous Hood granite, cf. 10) Jericho 304 IT (ECH 536a)
2. Tonalite, Ancient Gneiss Complex, Blesbokspruit 515 IT (ECH 753)
3. Tonalite, Ancient Gneiss Complex, Wolvenkop 427 IT (ECH 470)
4. Tonalite, Ancient Gneiss Complex (Fragment in Amsterdam Formation), Mooihoek 491 IT (ECH 761)
5. Tonalite, Ancient Gneiss Complex, Holstein 468 IT (ECH 793)
6. Granodiorite, Ancient Gneiss Complex, Morgenstond 418 IT (ECH 479)
7. Migmatite (?), Gneiss, Jericho 304 IT (ECH 733)
8. Migmatite, Gneiss, Wolvenkop 427 IT (ECH 464)
9. Granite, Homogenous Hood granite, Imbama 414 IT (ECH 522)
10. Granite, Homogenous Hood granite, Jericho 304 IT (ECH 536b)
11. Adamellite, Homogenous Hood granite, Deepdene 395 IT (ECH 735)
12. Granite, Homogenous Hood granite, Welgekozen 514 IT (ECH 737)
13. Granite, Homogenous Hood granite, Springvalley 429 IT (ECH 506)
14. Granite, Homogenous Hood granite, Stafford 399 IT (ECH 736)

Table 2: Average values and standard deviations of selected elements in the Ancient Gneiss Complex and the Homogeneous Hood granite of the Amsterdam-Piet Retief area

	Ancient Gneiss Complex	Homogeneous Hood granite
Fe_2O_3	8,13 ± 2,13	1,76 ± 0,68
MgO	3,41 ± 1,66	0,04 ± 0,05
CaO	5,78 ± 1,46	0,91 ± 0,24
P_2O_5	0,37 ± 0,16	0,01
Na_2O/K_2O	3,56 ± 1,74	0,57 ± 0,01

The chemical composition of the granitic rocks of the present area compares well with average compositions of the respective rock types from Swaziland and the Barberton area (Hunter, 1973, p. 138). The Na_2O/K_2O ratio is a particularly useful index to distinguish the different granitic rocks, as depicted in Figure 9. The three main types of granitic rocks, i.e. tonalite and granodiorite from the Ancient Gneiss Complex, Nelspruit migmatite and gneiss and the Homogeneous Hood granite fall into distinct fields defined by the Na_2O/K_2O ratios of 1,67; 1,0 and 0,67 respectively.

3. Discussion

As a result of the paucity of exposures in the granitic terrain and of present afforestation, the area under consideration does not lend itself to a detailed study of the Basement Complex, and the conclusions reached here are inevitably of a rather general and tentative nature. Two main granitic varieties are recognised in the area, viz. granodiorite and tonalitic gneiss of the Ancient Gneiss Complex east of Piet Retief and Homogeneous Hood granite in the Amsterdam area. A third type, resembling Nelspruit migmatite, was observed only in an isolated outcrop just outside the area mapped.

The tonalite gneiss and granodiorite of the Ancient Gneiss

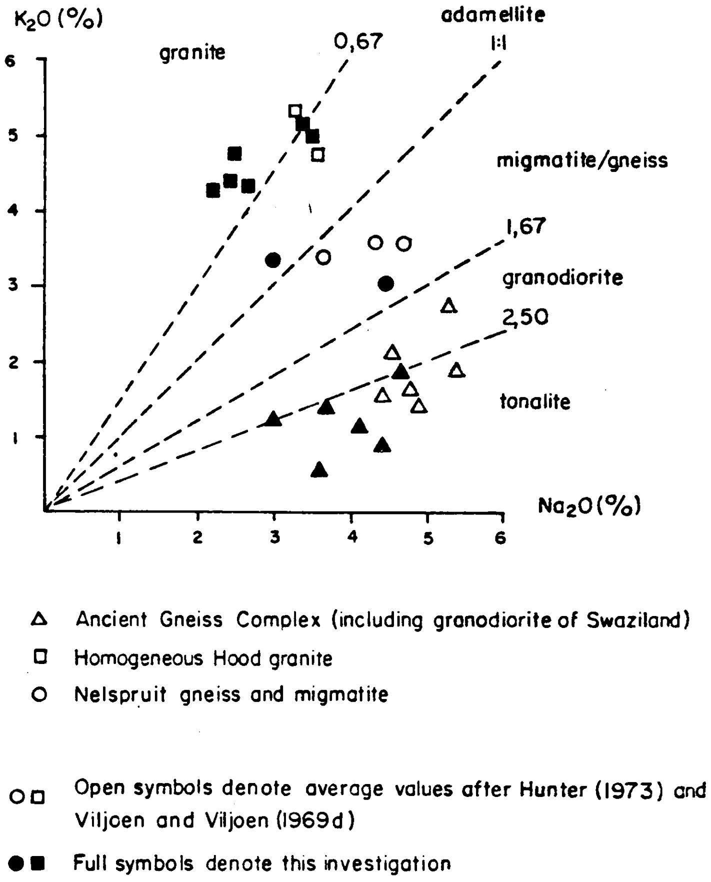


FIG. 9 : Na_2O/K_2O RELATIONSHIP OF VARIOUS GRANITES OF THE BASEMENT COMPLEX

Complex represent the earliest granitic crustal rocks, as demonstrated in Swaziland by Hunter (1970b and 1973) and in the Barberton area by Viljoen and Viljoen (1969c and d). Hunter (1973, p. 146-147) considers the Ancient Gneiss Complex as being possibly older than the Swaziland Sequence and that the Homogeneous Hood granite represents a later intrusive event. Viljoen and Viljoen (1969c, p. 179-180), however, expressed the opinion that the Ancient Gneiss Complex, almost invariably underlies the Homogeneous Hood granite and (1969d, p. 189) that the tonalitic granite-gneiss.... "was reconstituted by a thermal potash metasomatic and granitic event, which at higher levels gave rise to the formation of a homogeneous leucocratic "hood" granite with associated volatile pegmatitic phases".

B. The Pongola Group

1. Subdivision and general geology

The regional development and the correlation of the Pongola Group has been described by various authors in the past and the latest status of the Pongola System was summarised by Haughton (1969, p. 62-67).

During the present investigation the distribution and development of the sequence north of 27° latitude were briefly examined and it is compared with that in adjoining areas. Suitable type-areas are described in view of the revision of the nomenclature and some formal names, which would apply to the northernmost part of the Pongola basin, are proposed (Table 3). The stated

Table 3 : Provisional subdivisions of the Pongola Group in the Amsterdam-Piet Retief area

Group	Subgroup	Formation	Lithology	Maximum thickness (m)
Pongola	Mozaan	Bergplaats	Quartzite and shale with 150 m thick basaltic lava band (Tobolsk Member) near the top	± 2250
		Voorslag	Ferruginous shale and quartzite. Bands of iron-formation: near the bottom the Altona Member (6-15 m) in the south; Cascade Member (13 m) in the north and higher up in the succession the Redcliff Member (c.f. Fig. 10)	± 1580
		Skurwerant	Quartzite with a 30 m thick ferruginous shale (Madola Member) in the middle	± 660
		Assegaai	Andalusite-mica shist and phyllite	± 730
	Nsuze	Ngwempisi	Basaltic and andesitic lava	± 4880
		Glen Eland	Quartzite with a 30 m thick layer of basaltic lava (Mpama Member) in the middle and sporadic iron-formation (Wolvenkop bed) near the base	± 880

maximum thicknesses are mainly cited from the work of Humphrey and Krige (1931) who provided the first detailed account of the beds of the Pongola Group in the area south of Piet Retief. They subdivided the Nsuze Subgroup (previously Insuzi Series) into the First or Warmbad quartzite (± 840m) followed by a 4880m thick pile of basaltic and andesitic lava, containing up to five impersistent layers of quartzite or phyllite. In this area the Nsuze Subgroup is apparently conformably overlain by the Mozaan Subgroup, although local unconformable relationships are reported. The Mozaan Subgroup appears to attain its fullest development south of Piet Retief and consists of a 5000m succession of alternating beds of quartzite and shale including a 150m thick unit of lava near the top of the sequence (Fig. 10).

The area south of Piet Retief has not been studied during the present investigation but for the purpose of lithostratigraphic correlation the work of Humphrey and Krige (1931, p. 24) affords sufficient detail to subdivide the Mozaan into four main assemblages of rocks. Quartzite and andalusite-mica schist and phyllite, which overlie the basic lava of the Nsuze Subgroup, are reportedly best developed along the Assegaai River particularly in the gorge where this river cuts through the Mahamba Mountains in Swaziland. The formal name Assegaai Formation is suggested for this sequence. It is followed by massive quartzite with thin interbedded shale and iron-formation and is correlated with the Skurwerant Formation described below from near Amsterdam. A thick succession of ferruginous shale with interbedded iron-formation, which is best developed on Altona 47 HU, and quartzite, follows. Much of this sequence can reportedly be seen on Voorslag 24 HU (Humphrey and Krige, 1931, p. 24) and consequently it is proposed to term it the Voorslag Shale Formation and the iron-formation the Altona Member. The fourth sequence consists of alternating shale and quartzite and is developed from Bergplaats 25 HU to Mozaan 37 HU. Since the latter name has always been in use for the whole sub-

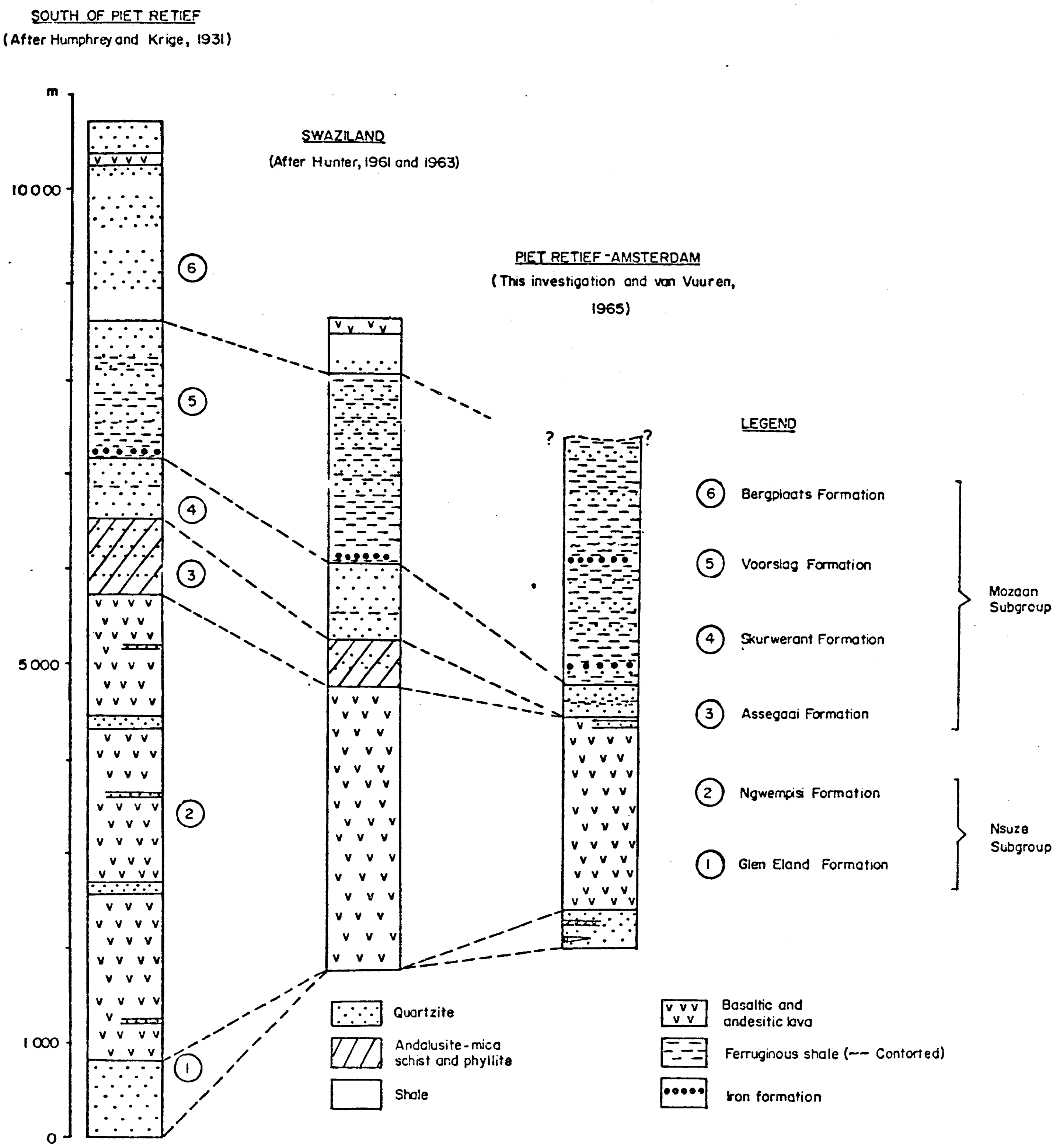


FIGURE 10 : SCHEMATIC PRESENTATION OF THE DEVELOPMENT OF THE PONGOLA GROUP IN SOUTHEAST TRANSVAAL AND SWAZILAND.

group Bergplaats Formation is proposed. An interbedded andesitic lava band occurs near the top of the succession, inter alia on Tobolsk 28 HU, and the name Tobolsk Member is suggested.

Matthews and Scharrer (1968, p. 264-266) demonstrated that the Pongola Group rests with a graded unconformity on Basement granite along the western rim of the basin in northern Natal and southeastern Transvaal, whereas it is intruded by Pongola granite in the east. Humphrey and Krige (1931) concluded that the contact between the Nsuze and Mozaan Subgroups is conformable but they drew attention to the fact that certain of the lower beds of the Mozaan Subgroup are not developed throughout, due to local disconformities. On a regional scale a marked unconformity is evident from a comparison of the succession in the area south of Piet Retief with that in Swaziland and in the present area (Fig. 10).

In Swaziland the sedimentary sequence of the Nsuze Subgroup is poorly developed and in those areas bordering on the Transvaal it is absent; only andesitic and felsitic lavas are found (Hunter, 1961, p. 44). The Mozaan Subgroup on the other hand is fully developed and has been described in detail by Hunter (1963, p. 10). It consists essentially of a succession of quartzite and shale and a lava flow near the top. No reference is made as to the nature of the contact between the Nsuze and the Mozaan Subgroups.

2. Distribution in the Amsterdam-Piet Retief area

(a) The Nsuze Subgroup

The distribution of the Pongola Group south of Amsterdam has been described by Van Vuuren (1965) and in the area immediately north of the Jericho Dam, 20 km due west of Amsterdam, by Visser et al. (1949). The basal quartzite of the Nsuze Subgroup rests with a sedimentary contact on Basement granite. This is best observed on Glen Eland 413 IT (A.5), directly south of the point where this formation is cut by the Mpama River. A section across this succession was measured immediately north of the river, more or less along the road from Amsterdam to Sheepmoor (Fig. 11). Because of the good exposure of the succession at this locality, the formal name Glen Eland Quartzite Formation is proposed for this sequence. East of Amsterdam the nature of the contact between the floor of Basement granite and sediments of the Pongola Group is obscured by subsequent tectonism and magmatism. On Tweepoort 404 IT (G.3) the quartzite stands almost vertical and further north intrusions of gabbro and exposures of volcanic breccia occur along the contact on De Hoop 402 IT, Lions Glen 398 IT and on Broadholms 254 IT (E.1-F.2). At the latter locality the Basement granite adjacent to the quartzite displays much shearing.

The true thickness of the quartzite in the present area is in the order of 200-250m. An interposed layer of basaltic lava, not more than 30m thick, can be observed intermittently from Imbama 414 IT (B.6) northwestwards past the Jericho Dam and it is also present on Morgenstod 418 IT (E.718) immediately south of the Evergreen-Morgenstond fault. Where developed this lava band constitutes a definite mappable unit and its position within the succession at the Mpama River, from which its name Mpama Member was derived, is shown in Figure 11. A zone of ferruginous quartzite occurs in places near the base of the Glen Eland Formation (Fig. 11), but although this bed is widely developed it could not be mapped on a regional scale; it is most prominent on Wolvenkop 427 IT where a small, low-grade iron deposit is found (F.9).

The Glen Eland Formation is overlain by a thick pile of basic lava with interlayered amygdaloidal zones. On Glen Eland 413 IT it is about 1700m thick, but the maximum thickness, observed on Imbama 414 IT and Kolwani 412 IT (B.6) as well as on Merriekloof 420 IT and Inhlovudwalile 421 IT (GIH.6), south of

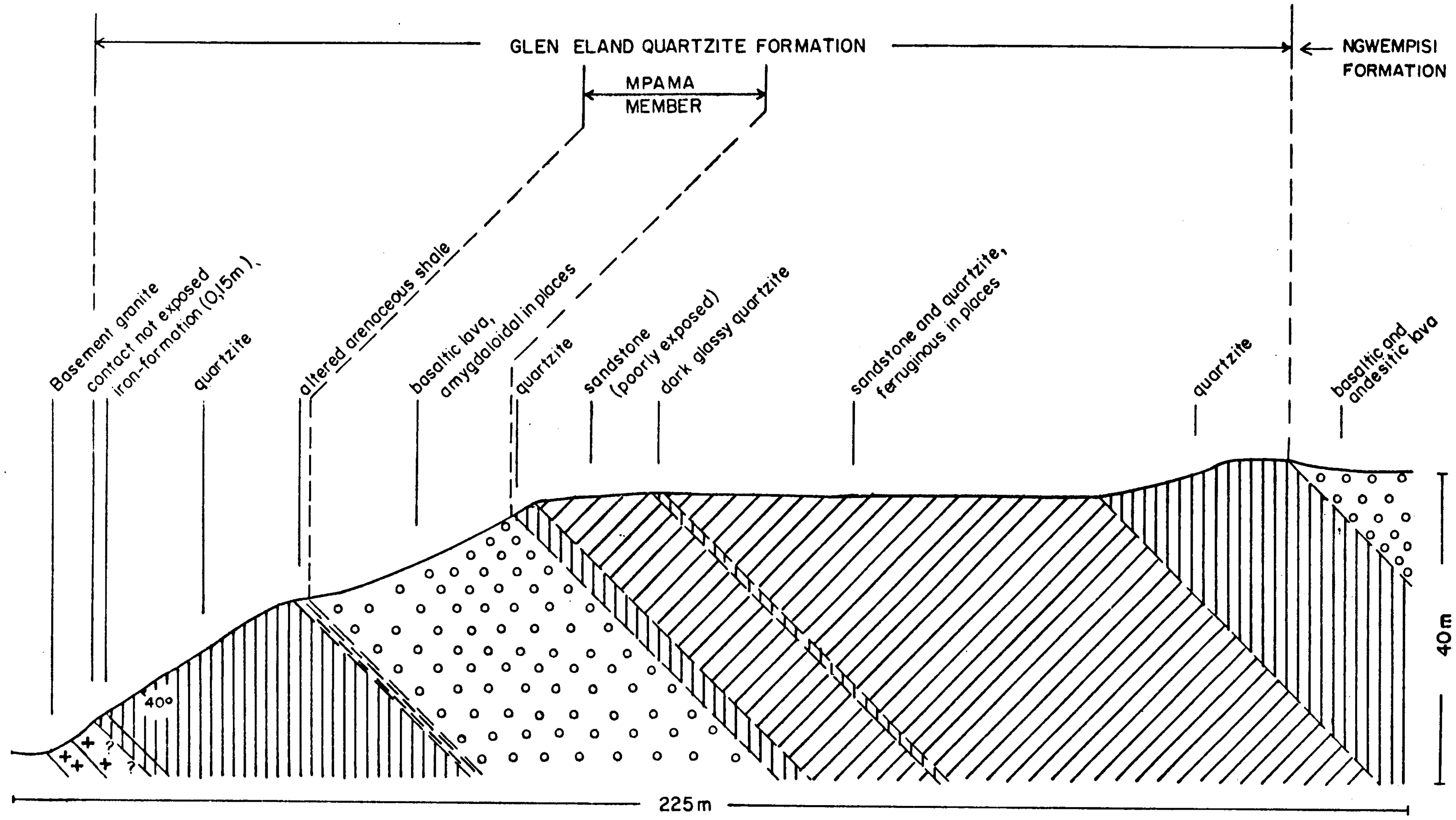


FIGURE 11 SECTION ACROSS THE GLEN ELAND QUARTZITE FORMATION, NSUZE SUBGROUP, SHOWING THE POSITION OF THE MPAMA BASALTIC MEMBER, GLEN ELAND 413 IT.

Amsterdam, is in the order of 2000m. This pile of lava is intersected by the Ngwempisi River along both legs of the Amsterdam syncline, giving rise to deeply incised gorges, and the name Ngwempisi Formation is therefore suggested.

These areas are rather remote and are partly under afforestation. Outcrop conditions are poor. A reasonably well exposed succession can however be seen on Glen Eland 413 IT along the road from Amsterdam to Ermelo (A/B.5). East of Piet Retief the Ngwempisi lava is as a rule strongly sheared and altered and contains several beds of metaquartzite and phyllite. A persistent zone of altered tuff (?) is found on Bothashoop 521 IT. This is a soft, decomposed rock of off-white to light brown colour, depending on the degree of iron-staining. X-ray diffraction analyses indicate that it consists of varying amounts of quartz and sericite, with a little montmorillonite in places. The Masala Quarry on Bothashoop (Folder IB) is situated at a locality where this zone is thickened and duplicated by structural deformation and where the rock is enriched in sericite.

(b) The Mozaan Subgroup

In the Amsterdam area the Mozaan Subgroup consists of two prominent quartzite members, separated by a very persistent ferruginous shale horizon, which here is only 10-15m thick, followed by a succession of quartzite, ferruginous shale and iron-formation. The name Skurwerant Quartzite Formation is proposed for the two thick quartzite beds and the intercalated shale. This name is derived from the Skurwerant, a scenic vantage point south of Amsterdam. The succession can be seen along the new provincial road from Amsterdam to Piet Retief, just south of the Skurwerant. In two boreholes drilled on Kranskop 422 IT (F.6/7) during the fifties by the Central Mining and Investment Corporation, the true thickness of the lower quartzite member was found to be 150m and 180m and that of the upper quartzite 165m and 177m respectively.

The shale horizon referred to above is an extremely persistent unit which is also recognisable on aerial photographs. It can adequately be seen along the Amsterdam-Piet Retief road and also further south along the Hlelo River on Haarlem 443 IT (I.9). Krige and Humphrey (1931, p. 24) described it from Madola 154 HT and hence the name Madola Shale Member is proposed. The Skurwerant quartzite is poorly preserved in the Piet Retief sector of the mapped area. Prominent fault-bounded outcrops of quartzite which are presumably the equivalent of the lower quartzite of this formation in the Amsterdam area, occur on Athalie 520 IT (N.15), but their exact correlation is uncertain because much of the area is obscured by afforestation.

The maximum development of the argillaceous sequence of the Mozaan Subgroup in the present area is in the southeastern portion of the Amsterdam syncline on the farms Evergreen 425 IT and Redcliff 426 IT (G/H.8/9), south of the Evergreen-Morgenstond fault. Here the terrain is rugged and inaccessible and, moreover, the normal succession has been affected by structural deformation. Only the lower part of the succession is preserved in the area north of Piet Retief and therefore the name Voorslag Shale Formation, as described from the area south of Piet Retief, is retained.

Van Vuuren (1965, Folder) mapped altogether 16 individual quartzite beds in the Voorslag Formation on Evergreen 425 IT and Redcliff 426 IT (H.8), but on the present map some were grouped together and only seven are shown. Two beds of iron-formation are developed in the area mapped. The lower iron-formation can be followed over at least 20 km from Sterkfontein 418 IT (I.6) southwards to The Cascade 442 IT and westwards to Wolvenkop 427 IT (G.9). The upper bed is exposed for some 5 to 6 km on Wolvenkop 427 IT and Redcliff 426 IT (G/H.8) before it disappears under Karoo cover in the west and is truncated by the Evergreen-Morgenstond fault in the east. These two zones, are referred to as the Cascade Member, which can be correlated with the Altona Member described from the area south of Piet Retief, and the Redcliff Member, respectively. The Cascade Member was determined to be about 13m thick on The Cascade 442 IT where Krige (1924) has studied it in detail.

Beukes (1973, p. 974-976) described the iron-formation of the Pongola Group in some detail. The rock is in places a typical banded iron-formation, consisting of alternating layers of iron oxides and chert. However, it may have a massive appearance, containing little chert, and may grade into ferruginous shale. In places the rock is oolitic. The massive variety predominates in the Amsterdam area and for this reason Beukes (ibid) referred to these rocks as ironstones in contrast to the banded iron-formation, which is better developed in the Piet Retief-Vryheid area. However, in view of the presence of chert-rich and oolitic iron-formation in the Voorslag Formation, both in the Amsterdam area and farther south, this distinction appears not to be justified, and these iron deposits could therefore be considered as being of the Lake Superior-type (Gross, 1965, p. 83; Hammerbeck et al, 1977, p. 148). Moreover, the rock has a high silica content of approximately 40 per cent and a relatively low alumina content of 3 to 5 per cent (Van Vuuren, 1965, p. 93) and the silica/alumina ratio is therefore more typical of iron-formation than of ironstone (Stanton, 1972, p. 424-425 and 435).

The Cascade and Redcliff Members can be followed over a total distance of approximately 22 km. Assuming an average width of 10m and a density of 3400 kg/m^3 (Krige, 1924), the near-surface resources to a depth of 100m down dip, which is also subparallel to the topography as a result of which the bed actually in places forms a dipslope, is in the order of 75 million tons. However, in addition to this comparatively small resource the metallic iron content of this rock is only in the order of 30-35 per cent (Krige, 1924 and van Vuuren, 1965, p. 93). Chemical analyses reveal a MnO content of 3-7 per cent and on

Kranskop 422 IT enrichment in manganese has taken place to such an extent that limited exploitation was warranted. In order of abundance the most important minerals present are cryptomelane, nsutite and pyrolusite. The genesis of the mineralisation is clearly supergene (Van Vuuren 1965, p. 87).

3. Petrochemistry of the Bivane Ngwempisi lava

A detailed petrochemical study of the Ngwempisi lava is beyond the scope of the present investigation and only a broad characterisation of these extrusive rocks is attempted here. In Table 4 the average composition of 14 analyses of Ngwempisi lava taken from various sources (Matthews, unpublished data; Visser, 1964, p. 133) and one new analysis is compared with Nockold's average composition of andesite, quartz basalt and tholeiite (Barth, 1962, p. 59). Although the standard deviation computed for the average composition of the lava can be comparatively large in some instances, a feature most probably due to differences in composition of successive lava flows, the overall composition of the Ngwempisi Formation seems to correspond more closely to that of tholeiite than andesite (Table 4). The chemical composition of the sample obtained from Haarlem 443 IT is remarkably similar to the average composition of the Ngwempisi lava.

Table 4 : Chemical composition of Ngwempisi lava compared with average andesite, quartz basalt and tholeiite

1.						
Chemical composition	SiO_2	52,98	CIPW norm		Q	8,86
	TiO_2	1,38			or	5,02
	Al_2O_3	15,29			ab	25,21
	Fe_2O_3	2,56			an	25,83
	FeO	9,39		di	wo	2,22
	MnO	0,05			en	1,07
	MgO	3,60			fs	1,15
	CaO	6,82		hy	en	9,40
	Na_2O	2,98			fs	10,19
	K_2O	0,85			mt	3,71
	P_2O_5	0,19			cm	0,04
	Cr_2O_3	0,03			ilm	2,62
	CO_2	0,23			ap	0,44
	H_2O^+	2,91			cc	0,52
	H_2O^-	0,01			H_2O	2,92
	Total	99,27			Total	99,20

Analyst: National Institute for Metallurgy, Johannesburg

	2.	3.	4.	5.
SiO_2	52,89 ± 2,07	54,20	55,46	50,83
Al_2O_3	14,28 ± 0,81	17,17	16,85	14,07
Fe_2O_3	2,18 ± 0,56	3,48	2,13	2,88
FeO	8,77 ± 1,44	5,49	4,86	9,06
MgO	5,21 ± 1,23	4,36	6,31	6,34
CaO	7,99 ± 1,20	7,92	7,86	10,42
Na_2O	2,34 ± 0,53	3,67	3,30	2,33
K_2O	0,64 ± 0,49	1,11	1,40	0,82

1. Basaltic lava, Ngwempisi Formation, Haarlem 443 IT (ECH 498 c)
2. Average of 14 samples of Ngwempisi lava with standard deviations
3. Andesite (Barth, 1962, p. 59)
4. Quartz basalt (Barth, 1962, p. 59)
5. Tholeiite (Barth, 1962, p. 59)

IV. THE GEOLOGY OF THE USUSHWANA COMPLEX

A. Introduction

The magmatic evolution of the Usushwana Complex can be subdivided into three stages, namely a sill phase, a volcanic phase and a plutonic phase. The sill phase comprises differentiated sheets of ultrabasic to basic rocks which are intrusive into the Mozaan Subgroup, and which have been folded concomitantly with the latter during the formation of the Amsterdam syncline. The volcanic phase comprises a succession of intermediate to acidic volcanics which transgressively overly the sedimentary rocks of the Pongola Group, including the abovementioned intrusive sills. These volcanics partly constitute the roof of the plutonic phase of the complex, which consists of a gabbroic and a granitic suite.

B. The Sill Phase

Say possibly sill formation by group of [illegible]

1. Field relationships

The basic and ultrabasic sheets comprising the sill phase of the Usushwana Complex are best developed within the Amsterdam syncline, where large, though dissected exposures can be observed at many places (Folder IA). A number of prominent outcrops skirt the Thole River on Athole 392 IT and Forbes Athole 393 IT (B.3-D.3) and therefore the designation Thole Formation is suggested.

Although no occurrences of the Thole Formation were noted in the Piet Retief sector of the area mapped (Folder IB), its distribution is not confined to the Amsterdam syncline. A comparatively large sheet-like exposure of these rocks is found on Lions Glen 398 IT and Stafford 399 IT (G.1/2), some 10 km northeast of Amsterdam. Here the Thole Formation rests directly on Basement granite and appears to be preserved in low-lying areas of this floor. Similar conditions reportedly also obtain in western Swaziland (Hunter, personal communication).

In the Amsterdam syncline sheets of the Thole Formation are more or less concordantly emplaced into the Mozaan Subgroup, particularly into the upper parts of the Skurwerant quartzite. Two very extensive sills are indicated in the Amsterdam area (Folder IA). The lower sheet is well exposed on Merriekloof 420 IT and Kranskop 422 IT (Folder IA, G.5/6) where it outcrops in the form of a dyke on Kranskop and a "ring-dyke" on Merriekloof; the latter is believed to be a topographical feature. The dip of the sill is 35°N on the southern side of the ring and the north-trending exposure has a general low-angle westerly dip, but no reliable dip measurements could be made here. The ring is not closed on its southwestern side where it is overlain by the Amsterdam Formation. The emplacement of the sill post-dated the Kranskop fault and the intrusive transgressed from below the Skurwerant quartzite to the north of the fault to a position above the quartzite in the south. Subsequent erosion of the Thole Formation in the area south of the fault resulted in the observed dyke-like expression of the exposure.

North-northwestwards the lower sill can be traced continuously to just south of Amsterdam and from there onwards it protrudes intermittently through the overlying Amsterdam Formation as far as Westoe 394 IT and farther northwest at a solitary outcrop exposed in a deeply incised valley on the northeastern part of Athole 392 IT (Folder IA).

Several fairly large blocks of quartzite have been uplifted by the sill where it was emplaced near the top of the Skurwerant quartzite, e.g. on the eastern and northeastern parts of Forbes Athole 393 IT (C.4, D.4), as well as on Kolwani 412 IT (C.5). These xenoliths are in places somewhat deformed. Isolated outcrops of pyroxenite can be traced from the southern part of the

Amsterdam Townlands northwestwards over a distance of 16 to 17 km, where it swings westwards and subsequently southeastwards over a comparable distance to the western part of Sterkfontein 419 IT. The configuration of these exposures along both limbs of the Amsterdam syncline is strongly suggestive of a continuous sheet and the intermittancy of the outcrops in this case is caused by the deposition of the younger Karoo rocks onto a paleo-relief, marked by hillocks of ultramafics and Skurwerant quartzite, in similar fashion to the lower sill discussed above, which is overlain by the Amsterdam Formation. In fact, due south of Amsterdam the sheet is partly overlain by both.

Higher up in the succession two small sub-parallel sills of ultramafic rocks are found in ferruginous shale of the Voorslag Formation on Redcliff 426 IT and somewhat larger outcrops are found on the eastern part of Sterkfontein 419 IT. However, these latter occurrences are presumably part of the upper sheet, which, like the lower sheet on Kranskop, is emplaced here in a slightly transgressive mode.

2. Petrography

a) Fabric

Three types of ultrabasic and basic rocks can be distinguished, viz. harzburgite at the base, pyroxenite constituting the central and upper part of the sills and in places gabbro or norite at the top. This is borne out by the modal compositions of these rocks which were determined by Van Vuuren (1965, p. 54) and which are reinterpreted here in Figure 12. Thicknesses have been calculated for an inclination of the sills of 10°. A gradual transition from ultrabasic to basic rocks is evident in most cases and these profiles can be considered as being typical of all the sheets.

The harzburgite contains numerous ortho- and clinopyroxene

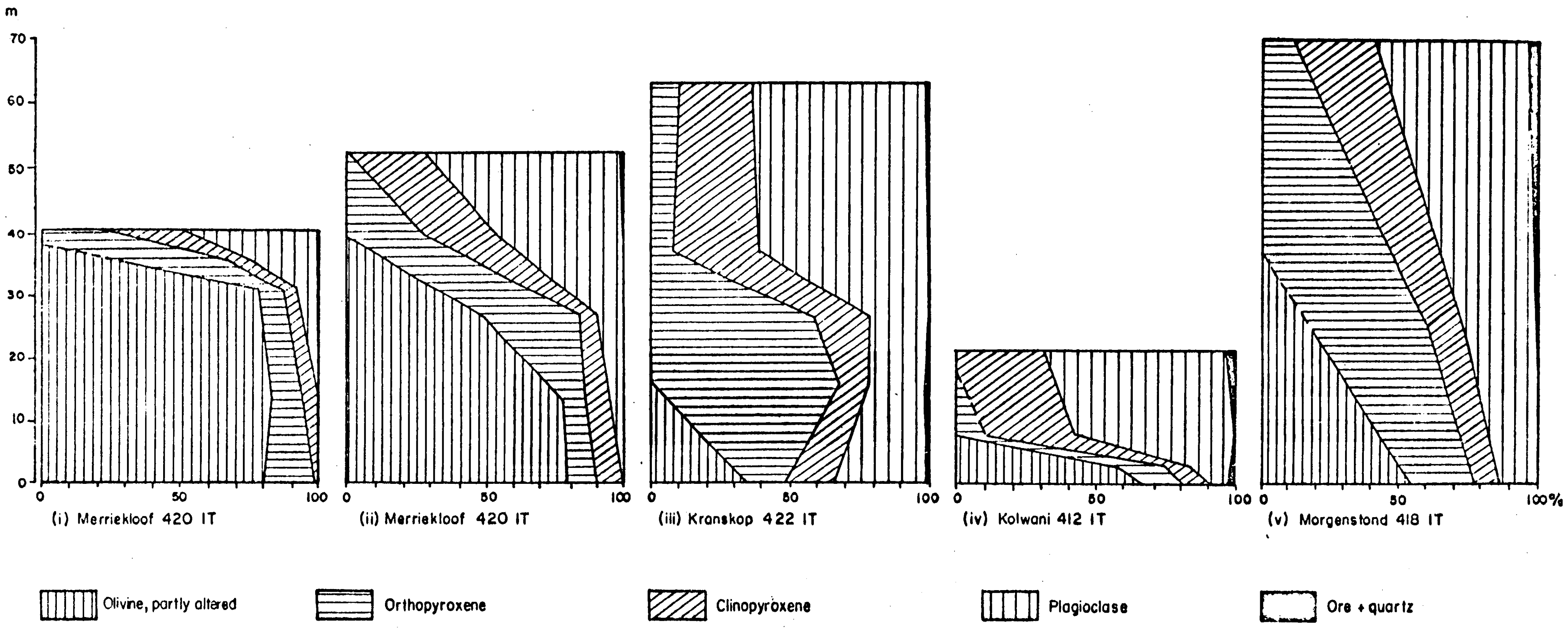


FIG. 12: MODAL COMPOSITION OF THOLE PYROXENITE SILLS FROM VARIOUS LOCALITIES IN THE AMSTERDAM AREA (AFTER VAN VUUREN, 1965)

crystals, up to 10 mm in diameter, which poikilitically include rounded grains of olivine.

Olivine and pyroxene represent the original cumulus minerals in the harzburgite and the pyroxenite. The pyroxenes were subsequently enlarged by reaction of the olivine with the interstitial liquid and kernels of olivine are thus poikilitically surrounded by large unzoned pyroxene crystals.

Plagioclase is present in small amounts as an intercumulus mineral in the ultramafic rocks but constitutes a cumulus component in the uppermost gabbroic zone, together with clinopyroxene and, in places, orthopyroxene.

The large pyroxene crystals stand out on weathering and impart a characteristic rugged and knobbly surface to the rock. Differentiation is pronounced in that olivine disappears upwards and eventually the large pyroxene crystals diminish and the rock attains an equigranular texture.

b) Mineralogy

In addition to the work of Van Vuuren (1965, p. 54-58) a number of thin sections from different sills were studied, and in particular a series of seven samples obtained from one sill on Forbes Athole 393 IT (Figure 13).

Olivine is the main cumulus mineral in the harzburgite zone of the ultramafic sheets. It is invariably chrysolite with a composition of Mg_{81-84} (Table 5) and $2V_z$ = 88^o-92^o, values which correspond to the optical determinations by Van Vuuren (1965, p. 54) on olivine from Merriekloof 420 IT and Kranskop 422 IT. The samples analysed by electron microprobe originated from the sill on Forbes Athole and display surprisingly little variation in composition over the width of the sill (Fig. 13).

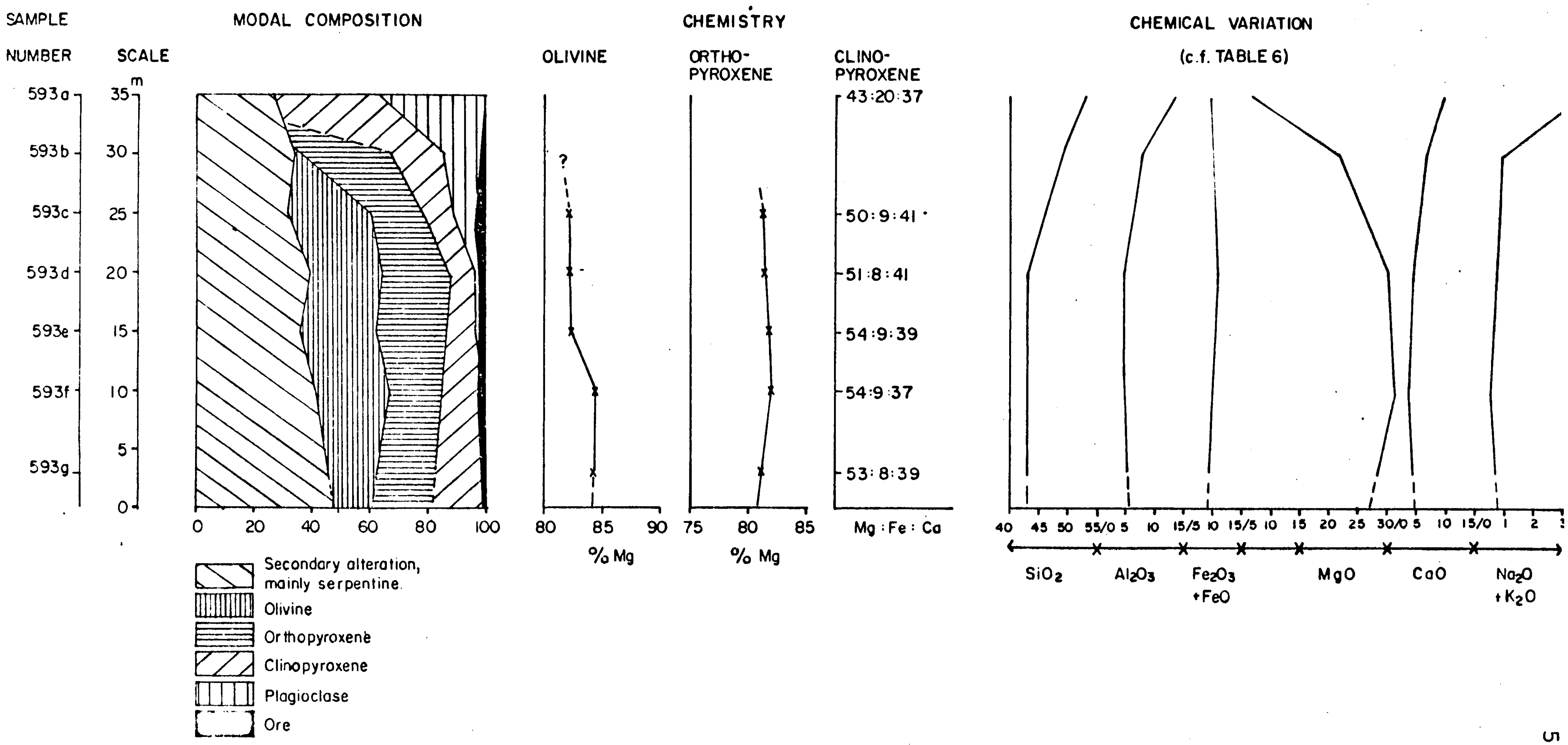


FIG 13 MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF THE ROCKS OF THE THOLE FORMATION ON FORBES ATHOLE 393 IT.

Table 5 : **Electron microprobe analyses of olivine, orthopyroxene, clinopyroxene and plagioclase of the Thole Formation, Forbes Athole 393 IT**

		Olivine						Orthopyroxene					Clinopyroxene						Plagioclase	
Sample No.		593 c	593 d	593 e	593 f	593 g		593 c	593 d	593 e	593 f	593 g	593 a	593 c	593 d	593 e	593 f	593 g		593 a
No. of analyses		3	3	2	2	2		1	1	2	2	1	2	1	1	1	1	1		1
Chemical composition	SiO_2	38,20	38,17	38,12	37,34	36,70		54,20	54,87	54,97	54,40	53,83	53,12	51,89	53,24	53,36	53,83	52,57		49,82
	Al_2O_3	-	-	-	-	-		1,38	1,44	1,32	1,39	1,82	2,03	2,39	2,50	1,81	1,47	3,28		31,20
	Cr_2O_3	-	-	-	-	-		0,46	0,57	0,49	0,62	0,52	0,26	0,98	1,03	0,91	0,75	1,20		-
	FeO*	16,53	16,38	16,99	15,97	15,49		9,68	9,56	9,39	8,63	9,02	11,23	5,00	4,78	5,54	5,68	4,65		1,03
	MgO	44,30	44,64	43,84	45,49	46,55		30,08	30,33	30,57	30,37	30,46	14,21	17,46	17,68	18,22	18,69	18,81		-
	CaO	-	-	-	-	-		2,24	2,15	2,36	2,34	2,74	17,40	19,87	19,62	19,25	18,05	19,47		13,31
	NiO	0,33	0,35	0,37	0,35	0,42		0,05	0,13	0,13	0,00	0,05	0,28	-	-	-	-	-		-
	Na_2O	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-		4,41
	K_2O	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-		0,23
	Total	99,23	99,54	99,32	99,15	99,16		98,09	99,05	99,23	97,75	98,49	98,53	97,59	98,85	99,09	98,47	99,98		100,00
Structural formula - Number of oxygens : 4	Si	0,97	0,97	0,97	0,95	0,94	Number of oxygens : 6	1,95	1,95	1,95	1,94	1,93	1,98	1,93	1,95	1,95	1,97	1,90	Number of oxygens : 32	9,09
	Al	-	-	-	-	-		0,06	0,06	0,06	0,06	0,08	0,09	0,10	0,11	0,08	0,06	0,14		6,71
	Cr	-	-	-	-	-		0,01	0,02	0,01	0,02	0,01	0,01	0,03	0,03	0,03	0,02	0,03		-
	Fe	0,35	0,35	0,36	0,32	0,33		0,29	0,28	0,27	0,26	0,27	0,35	0,16	0,15	0,17	0,17	0,14		0,16
	Mg	1,68	1,69	1,67	1,68	1,77		1,61	1,61	1,62	1,62	1,62	0,79	0,97	0,96	0,99	1,02	1,01		-
	Ca	-	-	-	-	-		0,09	0,08	0,09	0,09	1,11	0,70	0,79	0,77	0,75	0,71	0,75		2,60
	Ni	0,01	0,01	0,01	0,01	0,01		0,00	0,00	0,00	0,00	0,00	0,01	-	-	-	-	-		-
	Na	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-		1,56
	k	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-		0,05
	Z**	0,97	0,97	0,97	0,95	0,94		2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00		15,80
	W	-	-	-	-	-		0,09	0,08	0,08	0,09	1,11	0,72	0,08	0,78	0,75	0,73	0,78		-
	X	-	-	-	-	-		1,91	1,90	1,90	1,89	1,89	1,16	1,14	1,11	1,16	1,19	1,15		4,21
	Y	2,05	2,06	2,05	2,07	2,12		0,02	0,03	0,02	0,03	0,02	0,09	0,06	0,10	0,07	0,05	0,07		-
							Mg	81	81	81	82	81	43	50	51	52	54	53	An	62
	Mg	82	82	82	84	84	Fe	15	15	15	13	14	20	9	8	9	9	8	Ab	37
	Fe	18	18	18	16	16	Ca	4	4	4	5	5	37	41	41	39	37	39	Or	1

593a: Gabbro, Thole Formation (top of sill), Forbes Athole 393 IT
593c: Harzburgite, Thole Formation, Forbes Athole 393 IT
593d: Harzburgite, Thole Formation, Forbes Athole 393 IT
593e: Harzburgite, Thole Formation, Forbes Athole 393 IT
593f: Harzburgite, Thole Formation, Forbes Athole 393 IT
593g: Harzburgite, Thole Formation (base of sill), Forbes Athole 393 IT

Analyst: E. Hammerbeck, Geological Survey

(* Total Fe as FeO; ** Z group filled after Deer, Howie and Zussman, Vol. 2, p. 6)

Orthopyroxene has a general composition of Mg_{81-82} Fe_{13-15} Ca_{4-5} (Table 5) and $2V_z = 88^\circ-92^\circ$, thus being bronzite. Again no change in the composition of the orthopyroxene is discernible from the bottom to the top of the harzburgite zone. No orthopyroxene was observed in the upper portion of the sill on Forbes Athole 393 IT (Fig. 13).

Clinopyroxene of the ultramafic rocks of the Thole Formation has a composition of Mg_{50-54} Fe_{8-9} Ca_{37-41} and that of the upper gabbroic differentiate Mg_{42-44} Fe_{18-22} Ca_{35-40} (Table 5) (Fig. 13). The lower ultramafic portion contains chromian augite which is markedly enriched in magnesium and chromium and depleted in iron as compared with the augite of the upper gabbroic part.

Plagioclase is a subordinate intercumulus constituent in the harzburgite and in the pyroxenite. It is usually saussuritised and its composition could not be determined. Higher up in the gabbroic zone this mineral becomes more important and constitutes a cumulus mineral. Van Vuuren (1965, p. 54) reported compositions in the range of An_{64-75}, i.e. labradorite-bytownite for the plagioclase of these rocks. A single microprobe analysis of plagioclase from the sill on Forbes Athole showed it to be labradorite (An_{62}) (Table 5).

Accessory minerals. Magnetite, in the form of euhedral to subhedral crystals and in disseminated grains or blebs, is the most common accessory mineral, followed by pyrite. No chromite was observed in any of the polished sections studied.

Secondary minerals. The ultramafic rocks of the Thole Formation are extensively serpentinised. Stringers of chrysotile, which is the most common serpentine mineral present, can be seen replacing the olivine crystals along cracks. Finely disseminated blebs and stringers of magnetite in these zones are products of the serpentinisation process. Veinlets of cross-fibre chrysotile can be seen in a few places in the harzburgite.

c) Petrochemistry

The petrochemistry of the Thole Formation was studied in samples obtained from traverses taken over three separate sills.

The chemical composition, the CIPW norms, Niggli values and katanorms of these rocks are presented in Table 6.

The chemical composition of the ultrabasic rocks i.e. harzburgite and pyroxene compare well with the average compositions of peridotite and pyroxenite respectively (Table 7). The standard deviation of the reported average values especially in the case of the pyroxenite, is comparatively large, which is due to considerable fluctuations in the compositions of these rocks as a result of the differentiated nature of the sills.

It has been shown that the Thole Formation consists mainly of harzburgite and pyroxenite with very subordinate gabbro or norite. The actual proportions of these rock types are difficult to assess but the general impression gained is that harzburgite preponderates slightly over pyroxenite. In order to obtain an average composition for the magma of the Thole Formation, a bulk composition was calculated assuming a ratio of harzburgite: pyroxenite: gabbro of 50:45:5. In Table 7 this composition of the magma of the Thole Formation is compared with that of komatiites from the Onverwacht Group in the Barberton Mountain Land. It is evident that the Thole Formation can best be compared with the Geluk type of basaltic komatiite even though the latter is slightly less basic.

The chemical variation within the sheet of Thole Formation on

Table 6 : Chemical composition and some norms of rocks of the Thole Formation

			1	2	3	4	5	6	7	8	9	10	11
Chemical composition		SiO_2	53,71	49,28	42,72	43,06	43,19	41,40	45,60	50,60	52,64	46,64	42,97
		TiO_2	0,59	0,28	0,22	0,23	0,22	0,48	0,46	0,65	0,29	0,20	0,21
		Al_2O_3	13,51	7,72	4,90	4,45	5,30	2,10	1,92	3,60	7,02	4,89	5,81
		Fe_2O_3	0,88	1,77	2,19	1,86	2,23	4,49	3,79	3,23	1,12	3,00	2,48
		FeO	8,59	8,30	8,76	8,09	7,02	10,65	9,89	10,29	8,02	7,50	7,56
		MnO	0,21	0,19	0,05	0,05	0,05	0,08	0,08	0,08	0,06	0,06	0,05
		MgO	7,08	21,46	30,27	31,63	28,48	28,24	23,55	15,57	20,65	26,54	29,38
		CaO	9,41	6,58	4,12	3,74	4,32	3,10	7,96	12,13	5,42	4,24	4,14
		Na_2O	2,83	0,84	0,35	0,27	0,31	0,33	0,33	0,84	0,44	0,17	0,15
		K_2O	0,80	0,10	0,38	0,22	0,35	0,80	0,77	0,00	0,49	0,42	0,52
		P_2O_5	0,13	0,06	0,03	0,04	0,02	0,03	0,01	0,02	0,03	0,00	0,01
		Cr_2O_3	-	-	0,77	0,59	0,68	0,42	0,42	0,28	0,39	0,63	0,78
		CO_2	0,05	0,21	-	-	-	-	-	-	-	-	-
		H_2O^+	1,78	2,91	5,07	5,52	6,35	7,41	5,44	3,23	3,66	5,42	5,49
		H_2O^-	0,10	0,10	0,08	0,03	0,10	0,00	0,00	0,01	0,01	0,00	0,00
		Total	99,66	99,79	99,90	99,77	98,61	99,52	100,27	100,62	100,23	99,70	99,54
CIPW Norm		Q	2,50	0,00	0,00	0,00	0,00	0,00	0,00	1,28	2,29	0,00	0,00
		c	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		or	4,72	0,59	2,24	1,30	2,06	4,72	4,55	0,00	2,89	2,48	3,07
		ab	23,94	7,10	2,96	2,28	2,62	2,79	2,79	7,10	3,72	1,43	1,26
		an	21,80	17,00	10,67	10,28	12,03	1,88	1,48	6,05	15,73	11,34	13,64
	di	wo	9,75	5,55	3,78	3,17	3,66	5,29	15,10	21,72	4,37	3,83	2,70
		en	6,04	4,65	3,37	2,85	3,32	4,60	12,83	16,72	3,66	3,45	2,42
		fs	3,70	0,89	0,42	0,31	0,33	6,69	2,26	5,00	0,70	0,38	0,27
	hy	en	13,95	38,51	18,26	22,36	26,03	20,84	21,00	25,50	50,70	42,99	23,65
		fs	8,55	7,33	2,26	2,48	2,57	3,11	3,70	7,62	9,66	4,78	2,63
	ol	fo	0,00	9,60	40,91	40,56	31,69	34,87	20,41	0,00	0,00	16,13	35,30
		fa	0,00	1,83	5,06	4,51	3,13	5,21	3,61	0,00	0,00	1,79	3,92
		mt	1,27	2,56	3,17	2,69	3,23	6,50	5,49	4,68	1,62	4,34	3,59
		cm	0,00	0,00	1,13	0,86	1,00	0,61	0,61	0,41	0,57	0,92	1,14
		ilm	1,12	0,53	0,41	0,43	0,41	0,91	0,89	1,23	0,55	0,37	0,39
		ap	0,30	0,14	0,07	0,09	0,04	0,07	0,02	0,04	0,07	0,00	0,02
		H_2O	1,87	3,00	5,14	5,54	6,44	7,40	5,48	3,23	3,66	5,41	5,46
		Total	99,55	99,32	99,90	99,77	98,61	99,52	100,27	100,62	100,23	99,70	99,54
Niggli values		al	19,97	8,60	4,61	4,17	5,31	2,05	1,98	4,20	8,38	5,10	5,62
		alk	8,16	1,66	0,93	0,64	0,89	1,38	1,42	1,61	1,49	0,77	0,78
		fm	48,58	76,41	87,41	88,81	85,94	91,04	81,66	68,43	78,36	86,09	86,33
		c	25,29	13,33	7,05	6,37	7,87	5,52	14,94	25,76	11,76	8,04	7,28
		si	134,69	93,16	68,22	68,51	73,39	68,81	79,87	100,27	100,62	82,56	70,48
		k	0,16	0,07	0,42	0,35	0,43	0,61	0,60	0,00	0,42	0,62	0,69
		mg	0,57	0,80	0,82	0,85	0,84	0,77	0,75	0,67	0,80	0,81	0,83
Katanorm		Q	1,88	0,00	0,00	0,00	0,00	0,00	0,00	0,84	1,94	0,00	0,00
		Or	4,84	0,59	2,22	1,29	2,11	4,91	4,68	0,00	2,92	2,51	3,07
		Ab	26,04	7,55	3,11	2,40	2,84	3,08	3,05	7,79	3,98	1,55	1,35
		An	22,35	17,02	10,58	10,18	12,84	1,96	1,53	6,26	15,86	11,49	13,65
		Wo	9,89	6,12	3,80	3,18	3,78	5,53	15,61	22,32	4,43	3,93	2,76
		En	20,03	40,56	13,76	18,42	25,75	17,55	28,96	44,41	57,45	46,26	21,14
		Hy	13,35	11,93	11,45	10,77	9,08	13,69	12,85	14,06	11,54	9,28	9,49
		Mt	0,94	1,85	2,27	1,92	2,38	4,87	4,08	3,49	1,18	3,18	2,59
		Cp	0,26	0,12	0,06	0,08	0,04	0,06	0,02	0,04	1,06	0,00	0,00
		Ru	0,42	0,20	0,15	0,16	0,16	0,35	0,34	0,47	0,20	0,14	0,15
		Hm	0,00	0,00	1,39	1,39	1,39	1,39	1,39	1,39	1,39	1,39	1,39
		Cm	0,00	0,00	0,84	0,64	0,76	0,48	0,47	0,32	0,43	0,70	0,86
		Fo	0,00	14,06	51,76	50,97	40,82	47,53	28,42	0,00	0,00	20,96	44,96

1. Gabbro (top of sill), Forbes Athole 393 IT (ECH 593a)
2. Pyroxenite, Forbes Athole 393 IT (ECH 593b)
3. Harzburgite, Forbes Athole 393 IT (ECH 593d)
4. Harzburgite, Forbes Athole 393 IT (ECH 593f)
5. Harzburgite (base of sill), Forbes Athole 393 IT (ECH 593g)
6. Harzburgite (base of sill), Westoe 394 IT (ECH 578a)
7. Pyroxenite, Westoe 394 IT (ECH 578b)
8. Pyroxenite (top of sill), Westoe 394 IT (ECH 578c)
9. Pyroxenite (top of sill), Evergreen 425 IT (ECH 720b)
10. Pyroxenite, Evergreen 435 IT (ECH 720c)
11. Harzburgite (base of sill), Evergreen 425 IT (ECH 720d)

Analysts: National Institute for Metallurgy and General Superintendence Co.,
Johannesburg

Table 7 : Comparison between the chemical composition of the Thole Formation, average ultramafic rocks and komatiites

	1	2	3	4	5	6	7	8	9
SiO_2	43,33 ± 1,60	49,53 ± 2,57	43,54	50,50	46,07	52,73	52,22	47,37	45,94
TiO_2	-	-	-	-	0,34	-	-	-	-
Al_2O_3	4,58 ± 1,18	5,07 ± 2,27	3,99	4,10	5,19	9,83	5,42	6,79	2,98
Fe_2O_3	2,71 ± 0,86	2,48 ± 1,08	2,51	2,44	2,53	-	-	-	-
FeO	8,26 ± 1,20	9,13 ± 0,98	9,84	7,37	8,60	-	-	-	-
MnO	-	-	-	-	0,08	-	-	-	-
MgO	29,09 ± 1,61	20,31 ± 2,93	34,02	21,71	24,85	10,10	15,25	20,39	33,79
CaO	3,94 ± 0,42	8,02 ± 2,54	3,46	10,99	5,68	9,99	12,83	8,31	4,73
Na_2O	0,26 ± 0,08	0,61 ± 0,23	0,56	0,45	0,52	3,11	1,30	0,45	0,18
K_2O	0,45 ± 0,18	0,34 ± 0,31	0,25	0,21	0,43				
P_2O_5	-	-	-	-	0,03	-	-	-	-
Cr_2O_3	-	-	-	-	0,52	-	-	-	-
H_2O^+	-	-	-	-	4,93	-	-	-	-
H_2O^-	-	-	-	-	0,03	-	-	-	-
Total	-	-	-	-	99,80	-	-	-	-

1. Average composition of harzburgite, Thole Formation (6 samples)
2. Average composition of pyroxenite, Thole Formation (4 samples)
3. Average peridotite, Nockolds (1954, p. 1023)
4. Average pyroxenite, Nockolds (1954, p. 1022)
5. Bulk composition of Thole Formation based on a ratio of harzburgite: pyroxenite: gabbro of 50:45:5
6. Barberton type of basaltic komatiite (Viljoen and Viljoen, 1969a)
7. Badplaas type of basaltic komatiite (Viljoen and Viljoen, 1969a)
8. Geluk type of basaltic komatiite (Viljoen and Viljoen, 1969a)
9. Peridotitic komatiite (Viljoen and Viljoen, 1969b)

Forbes Athole 393 IT is depicted in Figure 13. The harzburgite is chemically remarkably homogeneous but a marked differentiation trend emerges in the upper portion of the sill; only iron remains more or less constant from the bottom to the top. Similar relationships are observed in sills on Westoe 394 IT and Evergreen 425 IT (Table 6).

In Chapter V the petrochemistry of the Thole Formation is further discussed in relation to some of the other rock types of the Usushwana Complex.

3. Discussion

a) Age relationships

On unpublished maps of the area around Amsterdam L.J. Krige (1920-1922) grouped the ultramafic rocks with the Karoo dolerite. Van Vuuren (1965, p. 51) who made a detailed study of some of the sheets considered them to be post-Pongola, but pre-Karoo in age.

Apart from the fact that the Thole Formation consists of different rocks, which are in no way comparable to Karoo dolerite dykes and sills found in the area, its greater age is demonstrated conclusively by a number of observations:

(i) The upper ultramafic sheet in the Amsterdam valley referred to above is concurrently folded with the Skurwerant quartzite in the formation of the Amsterdam syncline, as can be seen in the northern part of the area (Folder IA).

(ii) On Forbes Athole near the boundary with Sandbach 407 IT (D.3/4), Dwyka tillite can be seen to rest with a sedimentary contact on ultramafic rocks, with no sign of metamorphic alteration being evident in the former.

(iii) On the northwestern portion of Forbes Athole a sill c rocks of the Thole Formation is transgressed by a dyk containing numerous euhedral feldspar phenocrysts, which are very typical of Karoo dolerite dykes in thi area.

(iv) A small, isolated occurrence of harzburgite on the central portion of Forbes Athole (C.4), consisting of a couple of loose boulders appears to be out of place and probably represents erratics in Dwyka tillite. Large erratics of other rocks, mainly quartzite, abound in the tillite nearby. Boulders of basic or ultrabasic rocks have also been observed in tillite elsewhere in the area but these are invariably highly weathered and decomposed and could not be identified with certainty.

Likewise, the Thole Formation is considered to predate the Amsterdam Formation owing to the lack of metamorphic effects in the latter. Moreover, on Amsterdam Townlands 408 IT (E. 314) a Thole pyroxenite sill is blanketed by the Amsterdam Formation and no chilled contacts were observed (cf. Fig. 23).

b) Parental magma of the Thole Formation

McIver (1975) demonstrated that magnesium-rich peridotitic and basaltic intrusives and extrusives recur in the geological column of Southern Africa, having been described from the Onverwacht, Ventersdorp, Great Dyke and Karoo sequences. The Thole Formation represents a further manifestation of magnesium-rich magmatic material in the geological history of the subcontinent and it has been shown that chemically it resembles the more basic varieties of komatiite from the Barberton Mountain Land. Viljoen and Viljoen (1969a, p. 97 and b, p. 112) are of the opinion that the komatiites of the Barberton area are mainly extrusive rocks, but it is stated that some of them are contemporaneous near-surface intrusives. Examples are the Kaapmuiden, Ship Hill and Stolzburg intrusions. All these rocks are of peridotitic komatiite affiliation (Viljoen and Viljoen)

1970), which is considerably more basic than the Thole Formation (Table 7).

The mode of occurrence of the Thole Formation, especially where it occurs within the sedimentary pile of the Mozaan Subgroup, suggests that it is intrusive rather than extrusive. Xenoliths of Skurwerant quartzite in the ultramafic sheets and the observed differentiated nature support such a supposition. Elsewhere in the area, where the Thole Formation is observed lying on, and filling depressions in, Basement granite it could be of extrusive origin. However, pillow lavas and other characteristic features of ultramafic extrusives, such as spinnifex textures and chilled and fractured tops of flow units (Pyke et al, 1973, p. 961-967), were not recorded and the observed relationships can possibly be ascribed to irregularities in the floor of the intrusive.

Owing to the fact that the Usushwana Complex was emplaced along a regional lineament it is quite likely that the magnesium-rich magma was generated in the mantle as a result of pressure release (Carmichael _et al_, 1974, p. 354).

C. _The Volcanic Phase_

1. Subdivision and Nomenclature

A suite of predominently fine-grained and dark coloured pyroclastic rocks build two conspicuous ranges of hills along the northern parts of both limbs of the Amsterdam syncline. Similar rocks are also developed in the area east and northeast of Piet Retief, but here they are overlain by a felsic rock type. In both areas the hills are typically bare of bush and tree vegetation, except in some sheltered kloofs.

The first mentioned rocks have their best development in the direct vicinity of Amsterdam and therefore the name _Amsterdam Formation_ is proposed for the entire succession of pyroclastic rocks in this area. On both parts of the farm Athole 392 IT and on Forbes Athole 393 IT the pyroclastic rocks are more felsic and are therefore termed the _Athole Rhyolite Member_ of the Amsterdam Formation. Other varieties within the Amsterdam

Formation are indicated in Table 8, but these could not be mapped systematically.

The Amsterdam Formation is in places characterised by an abundance of accidental ejecta of foreign material, which are much more common than bombs. These accidental pyroclasts may range from large angular, sub-rounded and rounded blocks, up to 250 mm in diameter, to small lapilli and ash. In places the fragments become very plentiful, grading into a pyroclastic breccia. The terminology adopted here for the classification of grain-sizes of the pyroclastic rocks is that of Fisher (1966) and Füchtbauer (1974, p. 160-161). As will be shown in section 4d the rocks of the Amsterdam Formation are considered to be ash flow deposits and the term "tuff", used in the sequel, implies "ash flow tuff" as defined by Ross and Smith (1960). No "ash fall tuff" has been observed in the present area.

The second group of rocks referred to above, i.e. a felsic volcanic rock in the Piet Retief area (Folder IB), overly the Amsterdam Formation transgressively. This formation builds a conspicuous series of hills (Fig. 14a), some of which rise up to 250m above the surrounding plains. The most prominent of these is the Vaalkop, on Vaalkop 482 IT (M.13) and hence the name <u>Vaalkop Rhyolite Formation</u> is suggested.

Humphrey and Krige (1932, p. 42-44), Winter (1965, p. 10-11) and Hunter (1970a, p. 650) described the acidic rocks associated with the gabbroic rocks of the Usushwana Complex in the Piet Retief area and in Swaziland as granophyre. Humphrey and Krige (<u>ibid</u>) distinguished several varieties of granophyre south of Piet Retief, e.g. granophyre, microgranite, quartz prophyry and acid dykes. Although granophyric texture is a common feature, some varieties are devoid of it and the rock then resembles the microcrystalline variety of the Amsterdam Formation (Table 8). The acidic rocks of the Vaalkop Formation appear to

Fig. 14a: The Vaalkop Rhyolite Formation in its type-area on Rooksdrift 484 IT, Rooipoort 480 IT and Vaalkop 482 IT, seen from the north. Vaalkop hill is on the extreme right

Fig. 14b: Shearzone demonstrating the faulted nature of the contact between the Amsterdam Formation and the Skurwerant Formation along the western limb of the Amsterdam syncline. Glen Eland 413 IT

be of volcanic origin and, according to their chemical composition (Table 12), should be termed rhyolite.

Van Vuuren (1965, p. 19) described the rocks east of Amsterdam as "dark granophyre" which he envisaged to be metasomatically altered Nsuze lava, mainly because of the spatial relationship between the two formations in the area southeast of Amsterdam. He first drew attention to the extensive occurrences of brecciated material which were termed "hybrid rocks" because of their mixed nature.

The salient features of the different rock types and varieties discussed in this chapter are summarised in Table 8.

2. The Amsterdam Formation

a) Field relationships

(i) In the Amsterdam syncline

Around Amsterdam dark dacitic tuff of the Amsterdam Formation covers an area of at least 95 km^2 extending in an approximately 5 km wide continuous belt from Merriekloof 420 IT to the Westoe Dam, where it disappears under Karoo cover. In the west the zone is in the order of 1 to 4 km wide and can be followed more or less continuously over a distance of 18 km from Morgenstond 418 IT to Athole 392 IT, covering an area of approximately 30 km^2 (Folder IA). In both limbs of the synclinal structure the southerly termination of the Amsterdam Formation is very abrupt. Such relationships may be expected in ash flows. However, southeast of Amsterdam the Kranskop fault may have influenced the distribution of the Amsterdam Formation.

The Athole Member, which consists of a distinctly red rhyolitic tuff occupies the entire north-central part of the Amsterdam syncline, where it overlies Skurwerant quartzite and Ngwempisi lava and underlies Dwyka tillite, as can be observed on Athole 392 IT and Glen Aggy 413 IT (Folder IA, C/D.3). A peculiar variety of this rock is observed on the northeastern part of

Table 8 : Salient features of the Amsterdam and Vaalkop Formations

	Rock-type	Type - area	Field relationships	Colour		Mineralogy	Chemistry
				Fresh	Weathered		
Vaalkop Formation	Rhyolite	Rooksdrift 484 IT, Rooipoort 480 IT, and Vaalkop 482 IT; builds Vaalkop hill (Fig. 15.a)	Builds conspicuous mountains and hills, barren of trees and bush. Occupies the central and high-lying parts of the ridges	Mainly dull grey, attaining reddish tinge in places	Predominantly red	Crypto- to microcrystalline rock with varying interstitial granophyric component, spherulitic growths in places. Feldspar totally altered	SiO_2: 71,6-73,3 (2 analyses) Q+Or+Ab = 85,1-89,1
		Strydkraal 477 IT	Occupies lateral and low-lying parts of the ridges. Changes gradually into the above variety	Distinctly red	Distinctly red, weathered surface pitted	Crypto- to micro crystalline; strongly granophyric but felsitic elsewhere	SiO_2: 70,8-73,0 Q+Or+Ab = 83,6-88,2
Amsterdam Formation	Dacitic ash flow tuff and subordinate pyroclastic breccia	Amsterdam area, along northern part of both limbs of the syncline	Most common variety, builds hilly country barren of trees and bush. Transgressively overlies Pongola Group. Occurs also in dyke form in Archaean Complex. Pyroclastic breccia in places	Medium to dark grey; in places greenish-grey. White and pink feldspar and dark amphibole frequently vissible	Dull grey to brown or red-brown	Mainly microcrystalline, incipient granophyric texture in places, especially in upper regions. Anhedral to subhedral plagioclase, frequently corroded. Greenish-grey variety diabasic in texture	SiO_2: 60,8-65,7 Q+Or+Ab = 60,4-71,2
		SE of Amsterdam and along western limb of the syncline	No definite relationship with above variety, but probably gradational	Very dark grey to almost black	Grey-brown to yellow-brown	Micro - to cryptocrystalline. Minute needles of plagioclase and actinolite in places discernible in hand specimen. Tiny dark crystallites characteristic	SiO_2: 61,5-65,2 (2 analyses) Q+Or+Ab = 62,3-72,0
	Rhyolitic tuff (Athole Member)	Athole 392 IT, middle of northern part of Amsterdam syncline	Basal member occurring in low-lying parts of the Amsterdam syncline. Flow structures and abundant accidental pyroclasts	Varying shades of grey to distinctly reddish	Distinctly red but in places greyish	Crystallites, spherulitic aggregates and recrystallized blebs (pumice?) in felsitic matrix In places corroded plagioclase crystals. Granophyric texture scarce	SiO_2: 71,6 (1 analysis) Q+Or+Ab= 82,6

Athole 392 IT (B/C.2), where the rock is in places distinctly amygdaloidal and contains lithophysae of calcite, up to 10 cm in diameter, which on weathering cause a strongly pitted surface. Occasional accidental pyroclasts, mainly blocks and lapilli of quartzite, indicate that this rock is part of the pyroclastic sequence.

As a result of the unbedded massive nature of the rocks of the Amsterdam Formation the true, present attitude cannot be determined with certainty. If the formation is taken to lie flat, as it appears to do, its thickness is in the order of 250 m, e.g. the difference between its upper elevation in the hills around Amsterdam and that of the exposed floor on say Athole 392 IT. If it is inclined its true thickness will be proportionately more.

Most of the 25 bodies of pyroclastic breccia, and certainly all the larger ones, are situated within the Amsterdam synclinal structure, particularly around Amsterdam (Folder IA).

The Amsterdam Formation unconformably overlies the older rocks, including the Ngwempisi Formation on a regional scale. East of Amsterdam the pyroclastic rocks overly parts of the highly disturbed Glen Eland Formation on Merriekloof 420 IT and Tweepoort 404 IT where they extend eastward onto Basement granite and south of the village they transgress partly over the Skurwerant Formation, thereby undoubtedly demonstrating that the Amsterdam Formation is younger than the Pongola Group and that it post-dates the zone of faulting east of Amsterdam, described in Chapter II C.

The unconformable nature of the contact between the Skurwerant and Amsterdam Formations is also evident from the relationship between these rocks on the western side of the Amsterdam syncline. On the border between Sterkfontein 419 IT and Kolwani

412 IT (D.6) the pyroclastic rocks transgress gradually over the quartzite from the west, as one proceeds northwards towards the Ngwempisi River, where the phenomenon can best be studied. Parts of the quartzite are in places completely overlain by dacitic tuff and pyroclastic breccia (D.6). Immediately north of the river the quartzite disappears and only occasional inliers can be traced further northwards; the two most prominent ones being near the Moolman homestead on Kolwani 412 IT and immediately north of the Amsterdam-Ermelo road, near the Kritalspruit. This latter occurrence has undoubtedly a faulted contact with the pyroclastic rocks (Fig. 14b).

(ii) Outside the Amsterdam syncline

East of the Amsterdam syncline between the Glen Eland quartzite and the Swaziland border, a long, narrow dyke consisting of dark tuff can be followed northwestwards from the southern border of Avoca 403 IT, where it enters the Transvaal, to Tweepoort 404 IT (Folder IA, I.5-G.3). At two localities on Tweepoort 404 IT and De Hoop 402 IT pyroclastic breccia is found to rest on such dykes. Several other occurrences of breccia are found on the latter farm, one of which is interesting in that it builds a prominent little ridge which abuts against Glen Eland quartzite and is situated directly on the extension of the long dyke described above. No trace of either dyke material or breccia could be found in Basement granite along the little streambed separating the two exposures.

In the northern part of the Piet Retief sector of the mapped area (Folder IB) the dark dacitic tuff is only sporadically developed and is unconformably overlain by the Vaalkop Formation. On the eastern portion of Ishlelo 441 IT and on Haarlem 443 IT (H/I.10), the dacitic tuff was observed in places, but could not be mapped with certainty because of poor exposure. Further south, on Mooihoek 491 IT and Rooksdrift 484 IT (K/L.13) this formation is better developed and is also associated with pyroclastic breccia, which is so characteristic in the Amsterdam area. Exposures are generally very poor. Another area underlain by dark dacitic tuff is found in the southeastern corner of the area mapped (N.13), where it covers an area of approximately 4 km^2 on Potgieters Hoek 519 IT.

On Mooihoek 491 IT, Rooksdrift 484 IT and Blesbokspruit 515 IT (K-M.13) the dark tuff can be seen in juxtaposition with quartzite of the Glen Eland Formation. It is not clear whether this is the result of faulting or of deposition on a paleo-relief. This latter explanation seems more likely since the pyroclastic rock partly skirts and possibly even overlies the quartzite along the northern trace of the south-plunging synclinal structure (Folder IB).

(iii) Outside the mapped area

Since the dark tuff of the Amsterdam area was originally considered by Krige to be granophyre, careful remapping of the formation shown as such on Geological Survey Map 68 (Piet Retief) may reveal that dark dacitic tuff is present in places.

Hunter (1961, p. 61) refers to two types of microgranodiorite which are associated with the Usushwana Complex in Swaziland. The description given of the second type, which is best developed near the Makwanakop border beacon, 8 km south-southeast of Oshoek is so characteristic of the Amsterdam Formation that there can be little doubt that reference is made to the very same rock type. Hunter states (ibid): "The rock itself is grey and medium to fine-grained and is distinguished by the presence of xenoliths and pegmatitic material. These vary in size from less than ¼ inch in diameter to larger blebs reaching up to 3 to 4 inches in diameter. The blebs represent incompletely digested granitic and pegmatitic material. The microgranodiorite of Makwanakop includes a phase where digestion of the incorporated granite is complete and no xenoliths are present.

This phase occurs in the core of the dyke. It contains small plagioclase phenocrysts." He continues (ibid) "The porphyritic variety is exactly similar to the more normal type, with the exception that the quartz-felspar blebs are absent and that small euhedral grains of plagioclase are set in the granophyric base." The field relationships of these occurrences appear to be similar to the dyke-like bodies in the area outside the Amsterdam syncline referred to above. The Makwanakop occurrence forms reportedly a 1,6 km long ridge and Hunter (ibid) also described similar dykes near the Bomvu Ridge iron ore deposit.

b) Petrography

(i) Macroscopical features and fabric

The tuff of the Amsterdam Formation is essentially dark grey to almost black in colour when fresh, but it is mainly dull grey on weathered surfaces. It is very fine-grained, but short, fine needles of plagioclase and amphibole can frequently be seen. Owing to its dark colour this rock can very easily be mistaken for a mafic rock. East of Piet Retief the macroscopical and textural features are somewhat different in that the rock is even darker in colour and finer grained. In places phenocrysts are common but ejecta are only occasionally found.

The formation is generally massive and uniform in appearance and does not exhibit bedding, flow textures, banding or layering. One of the most striking features of this rock is the presence of ejecta of foreign material and of pegmatitic blebs of quartz and K-feldspar, presumably representing altered lythophysae (Fig. 15a). Although isolated pyroclasts may be observed in many places, mainly in the eastern limb around Amsterdam, they become more plentifull in some areas and may even constitute the major part of the rock. Solitary fragments are usually not more than 10 cm in diameter, but these become increasingly larger towards those areas in which the pyroclastic breccia pre-

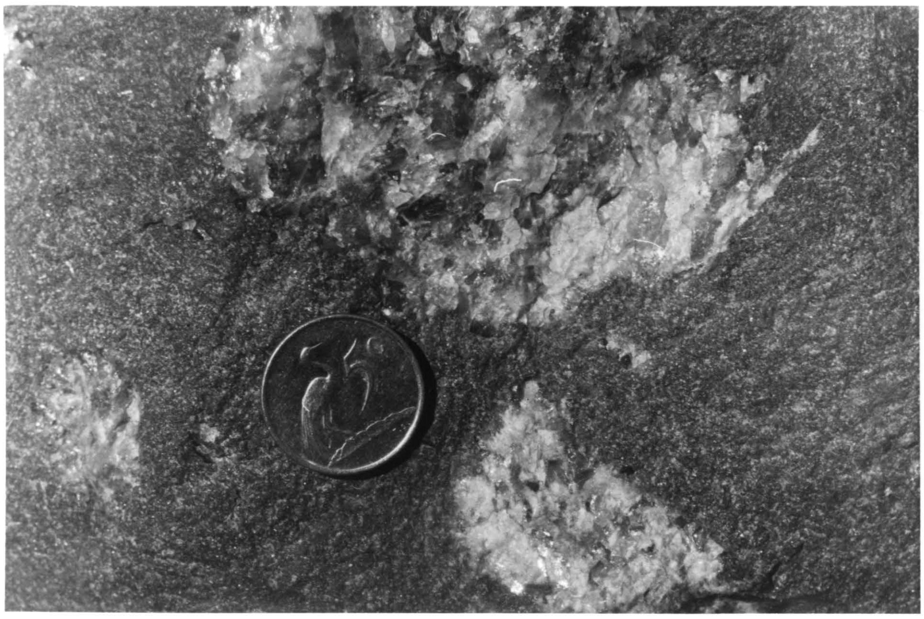


Fig. 15a: Blebs of coarsly crystalline quartz and K-feldspar (recrystallised lythophysae ?) are a common feature of the Amsterdam ash flow tuff. Tweepoort 404 IT

Fig. 15b: Pyroclastic breccia containing accidental ejecta of quartzite and altered Basement granite (?). Merriekloof 420 IT

dominates, where they can be of any size and form but subangular and rounded fragments preponderate (Fig's. 15b, 16a and 16b). Fragments of Basement granite usually predominate, but quartzite may also be present. On Merriekloof 420 IT these ejecta are surrounded by a chilled margin in the matrix, thus clearly indicating that they fell into hot unconsolidated tuff (Fig. 16b). On Morgenstond 418 IT the breccia contains cognate (?) fragments of crystalline dacitic material.

The rhyolitic tuff of the Athole Member of the Amsterdam Formation is a distinctly red, fine-grained pyroclastic rock. However, laterally, it grades into the grey dacitic variety of the Amsterdam Formation. In places crystal tuff is found consisting of broken and corroded crystals set in a matrix rich in dark crystallites and microlites of quartz (Fig. 17a).

Diagnostic features of ash flows, such as accidental blocks and lapilli, mainly of quartzite, are plentiful in places and devitrification textures, such as spherulites can be observed even in hand-specimen. Furthermore, the rhyolitic tuff frequently contains small, dark, fine-grained inclusions which could be fragments of collapsed pumice. In places, e.g. on Glen Aggy 406 IT (D.3) as well as on both parts of Athole 392 IT (A-C.2) small, extremely fine-grained fragments which are usually completely altered to secondary minerals such as chlorite can be observed. They may contain peculiar incipient growths of quartz (?) in a quartz-rich matrix which is extremly fine-grained (Fig. 17b). These fragments are reminiscent of collapsed pumice (Rose and Smith, 1960, p. 27) and they are found also in other varieties of the Amsterdam Formation. Near, but not necessarily at the base of the pile, flow structures are developed in many places indicating that a certain amount of movement has taken place in the volcanic pile (Fig. 18a). In most cases this phenomenon is only visible on weathered surfaces and no trace thereof can be found in the fresh rock. On Athole 392 IT (A.2) this structure can be seen in outcrops in a riverbed,

Fig. 16a: Accidental pyroclasts of quartzite in the Amsterdam Formation. Note the congealed apparent movement of one such fragment. Mooihoek 491 IT

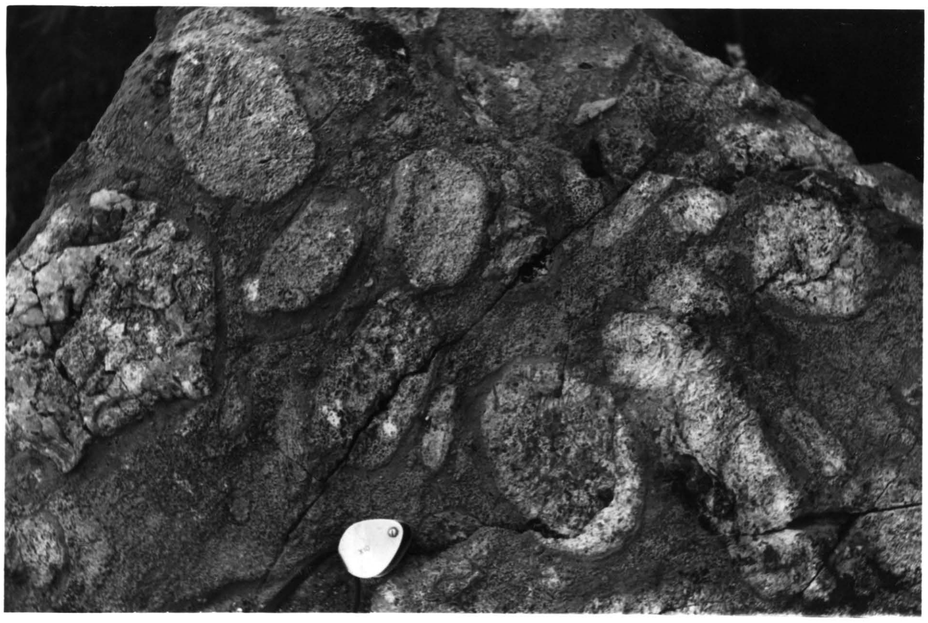


Fig. 16b: Rounded to sub-rounded pyroclasts of Basement granite in pyroclastic breccia of the Amsterdam Formation. Note chilled margins in the matrix surrounding the fragments. Merriekloof 420 IT

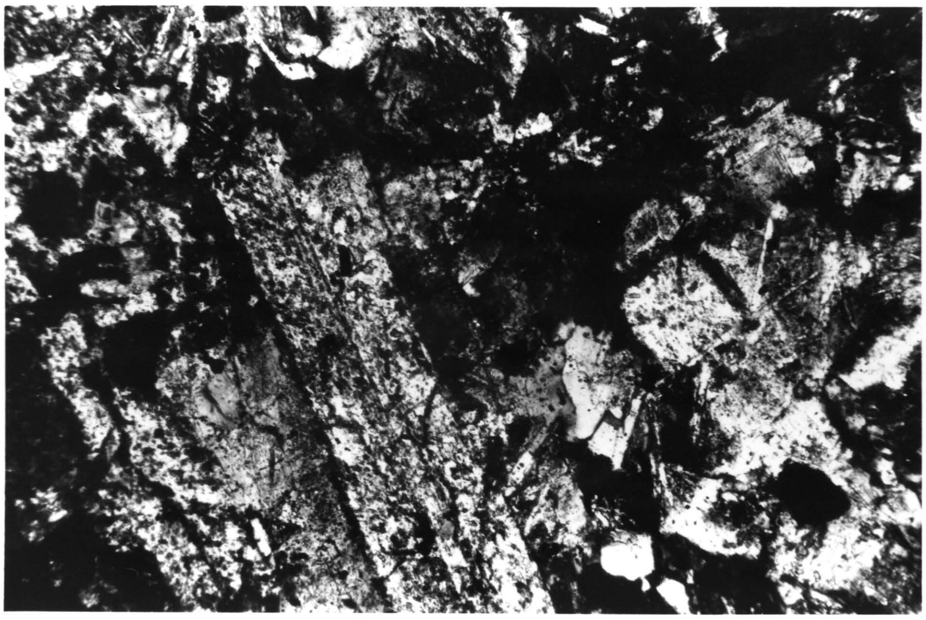


Fig. 17a: Crystal tuff of the Athole Member of the Amsterdam Formation. Note the subhedral but stumped and corroded plagioclase crystals (light to dark grey) set in a fine-grained quartz-rich matrix (dark grey to black). Crossed nicols, X 100, Athole 392 IT (ECH 516)

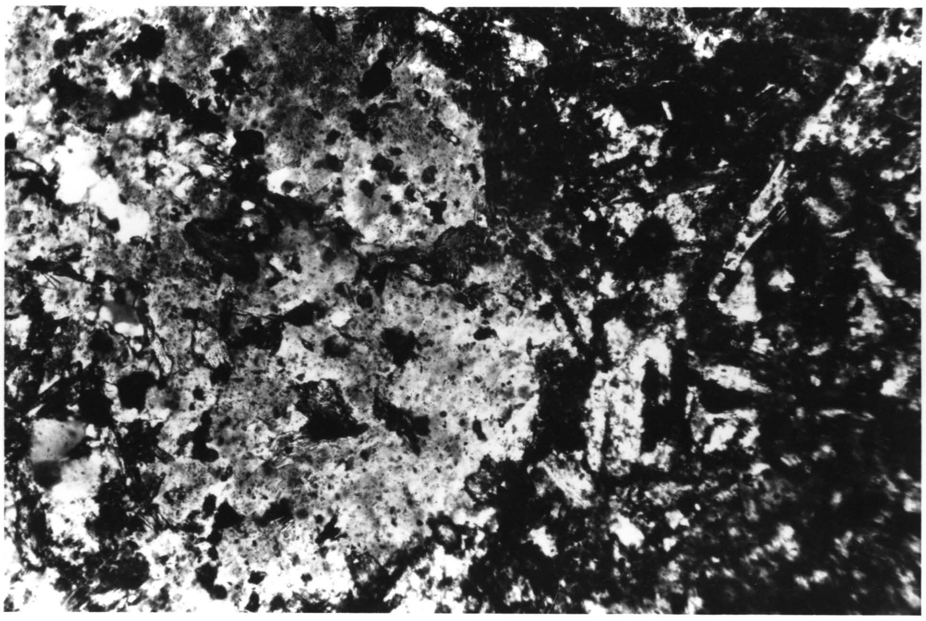


Fig. 17b: An extremely fine-grained and strongly corroded quartz-rich inclusion (grey) embedded in Amsterdam pyroclastics. Note growths of actinolite (dark grey) and secondary quartz (light grey) in the aphanitic matrix of the inclusion. Crossed nicols, X 100, Athole 392 IT (ECH 843c)

<u>Fig. 18a</u>: Flow structure in rhyolitic tuff at the base of the Amsterdam Formation. Athole 392 IT

<u>Fig. 18b</u>: Strongly spherulitic quartz-rich matrix in coarse-grained phase of the Athole rhyolitic tuff containing large grains of altered K-feldspar (top left corner) and quartz (dull grey, undulating extinction). Crossed nicols, X 100, Athole 392 IT (ECH 847)

where the strike is N 120° E and the dip 50° SW. This attitude can only be explained by intense contemporaneous deformation of the pile.

On the northwestern portion of Athole (A.2) several small outcrops (not more than 1 m^2 each) of an extremly coarse-grained porphyritic phase, resembling coarse granite in hand-specimen, can be seen in places in contact with the felsic tuff. The rock consists of large phenocrysts of quartz and altered K-feldspar, up to 15 mm across, set in a spherulitic, quartz-rich matrix (Fig. 18b). This coarse-grained rock is clearly not plutonic but volcanic in character, but the origin of the large closely packed phenocrysts in such a milieu remains a problem.

(ii) Mineralogy

Two semi-quantitative X-ray diffraction analyses of fresh samples, which were separated into a 15-25 micron fraction by sedimentation techniques and subsequently separated into a light and a heavy fraction by centrifuging in tetrabromoethane revealed the following mineralogical composition:

	Light fraction	Heavy fraction
quartz	XXXXX	XX
plagioclase (An_{10-20})	XXXX	X
stilpnomelane	XXX	XXX
actinolite	X	XXXX
augite	XX	XXXX
magnetite	X	XXXXX
chlorite	-	X

(X indicates relative abundance)

<u>Quartz</u> is present in the dacitic pyroclastic rocks of the Amsterdam Formation, either granophyrically intergrown with feldspar in the matrix, as fine crystallites or as euhedral crystals. It is also an abundant component of the rhyolite

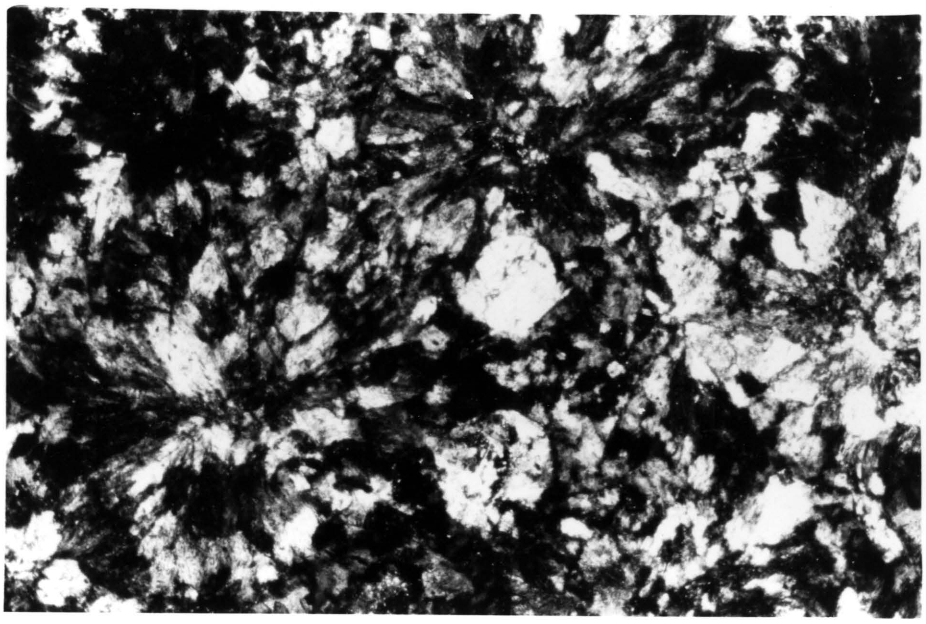
of the Athole Member, where it forms part of the usually devitrified glassy matrix (Fig. 19a), but where it may also occur in various other forms, e.g. in vesicules, in poorly developed glassy shards and as microlites.

The acicular microlites of quartz, which may be up to 0,5 mm long, are a most characteristic feature of this rock (Fig. 19b). The length to width ratio of the crystals varies between approximately 5:1 to 30:1 and they may be arranged in very intricate, interlocking patterns, sections of which are usually marked by different orientations. The microlites are certainly quartz paramorphs after tridymite and are identical to those described by Lombaard (1932, p. 135, Plate XII, Figs. 1 and 2) from Rooiberg Felsite and by Wager et al, (1935, p. 265) from a granophyre on the Isle of Skye.

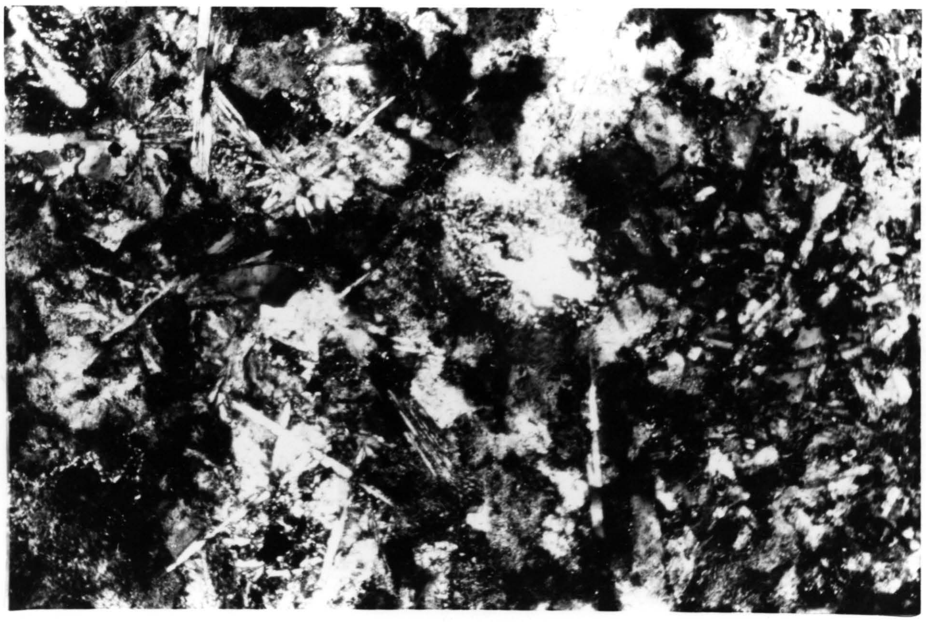
Needles of <u>plagioclase</u> in the dacitic rocks of the Amsterdam Formation are generally between 0,5 and 1 mm long but in exceptional cases even 2 mm. An analysis by electron microprobe shows that the needles consist of oligoclase (An_{30}) and a composition of An_{10-20} was obtained by X-ray diffraction analysis of two samples. One crystal fragment in the pyroclastic rock was found to be andesine (An_{40}) (Table 9). Plagioclase laths in the Amsterdam Formation are usually saussuritised.

<u>K-feldspar</u>. Tabular Carlsbad twins of sanidine (?) up to 2 mm long, occur in small amounts, especially in the Athole rhyolite, but the crystals are generally very altered. The best development of K-feldspar is in the porphyritic variety of the Athole Member, already referred to.

<u>Ferromagnesian minerals</u>. Augite occurs in small amounts in the dacitic tuff of the Amsterdam Formation. The composition was determined in two samples to be in the order of Mg_{22} Fe_{38} Ca_{40} (Table 9). Hornblende, pleochroic in dark



<u>Fig. 19a</u>: Spherulitic devitrification textures in fine-grained rhyolitic tuff of the Athole Member of the Amsterdam Formation. Crossed nicols, X 100, Athole 392 IT (ECH 624)



<u>Fig. 19b</u>: Quartz microlites and incipient granophyric texture (tiny light spots) in the rhyolitic Athole Member of the Amsterdam Formation. Crossed nicols, X 100, Athole 392 IT (ECH 588e)

Table 9 : Electron microprobe analyses of plagioclase and augite from the Amsterdam Formation

Chemical Composition

	1	2	3	4
SiO_2	61,64	59,48	50,53	46,84
TiO_2	-	-	2,15	2,03
Al_2O_3	23,69	24,21	0,04	0,52
FeO*	0,45	0,36	7,32	7,05
MgO	-	-	22,38	21,39
CaO	6,30	8,46	17,42	19,40
Na_2O	7,77	6,40	0,42	0,40
K_2O	0,40	0,41	0,00	0,33
Total	100,25	99,32	100,26	97,96

* Total Fe as FeO

Structural Formulae:
Number of oxygens:

	32		6	
Si	10,92	10,70	1,97	1,88
Ti	-	-	0,02	0,02
Al	4,95	5,14	0,10	0,10
Fe	0,07	0,08	0,73	0,72
Mg	-	-	0,42	0,42
Ca	1,20	1,63	0,73	0,82
Na	2,67	2,23	0,03	0,03
K	0,09	0,09	0,00	0,02

Z	15,87	15,84	2,00	2,00
W	-	-	0,76	0,87
X	3,96	3,95	1,16	1,18
Y	-	-	0,07	0,01

An	30	41	Mg:	22	21
Ab	67	56	Fe:	39	37
Or	3	3	Ca:	39	42

1. Plagioclase lath in dacitic tuff, Amsterdam Formation, Glen Eland 413 IT (ECH 529)
2. Plagioclase megacryst in dacitic tuff, Amsterdam Formation, Glen Eland 413 IT (ECH 529)
3. Augite in dacitic tuff, Amsterdam Formation, Tweepoort 404 IT (ECH 731)
4. Ditto

Analysts: Samples 1 and 2 R.C. Wallace and Samples 3 and 4 E.C.I. Hammerbeck, Geological Survey green and blue-green, is the most common amphibole present.

Accessory minerals. Magnetite and pyrite and subordinate apatite are the most common accessory minerals.

Secondary minerals. Chlorite, epidote, stilpnomelane, in the form of small flakes, and calcite are the usual secondary alteration products.

The dacitic tuff of the Amsterdam Formation is generally riddled with dark crystallites (Fig. 20a). The rock is very poorly translucent (Fig. 20b) and in order of importance this is caused by:

(i) ubiquitous dark crystallites in the matrix,

(ii) varying amounts of granophyric intergrowths, frequently only in incipient stages,

(iii) the generally fine-grained nature of the rock,

(iv) saussuritisation of the plagioclase, and

(v) varying amounts of ferromagnesian minerals (mainly amphibole) and accessory ore.

(iii) Chemical composition

The chemistry of the rocks of the Amsterdam Formation, as well as the CIPW norm, the Niggli equivalent norm and the Niggli values are reported in Table 10. Special care was taken, particularly with the samples of pyroclastic breccia to submit homogeneous and representative material for analysis.

The rocks of the Amsterdam Formation are very fine-grained and have a melanocratic appearance, as a result of which it is difficult to establish their true character without chemical data. In Table 11 an attempt is made to characterise the rock

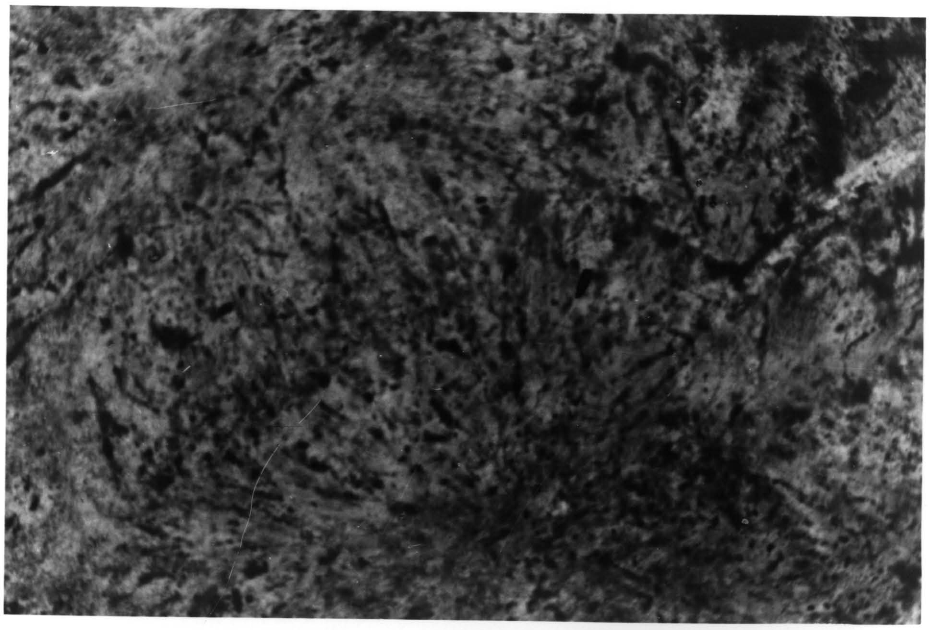


Fig. 20a: Dark crystallites typical of the Athole Rhyolite Member. Polarised light, X 40, Athole 392 IT (ECH 624)

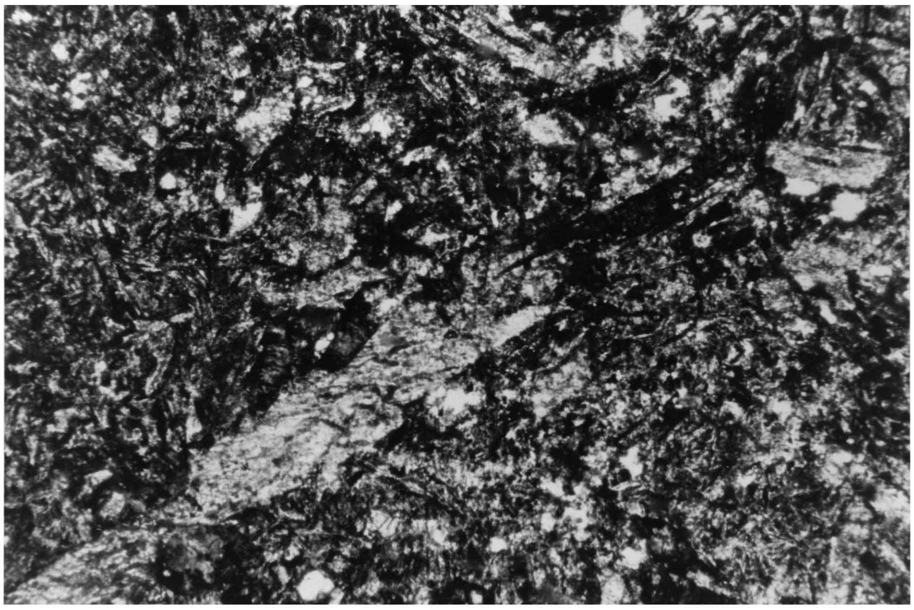


Fig. 20b: The fine-grained dacitic ash flow tuff of the Amsterdam Formation is riddled with dark crystallites. Note the fragmentary, strongly corroded and totally altered plagioclase (?) (light grey) and amphibole (dark grey). Polarised light, X 40, Amsterdam Townlands (ECH 714)

Table 10 : Chemical composition of rocks of the Amsterdam Formation

		1	2	3	4	5	6	7	8	9
Chemical composition	SiO_2	62,57	65,73	65,19	60,83	61,54	62,25	70,29	71,61	71,59
	TiO_2	0,90	0,82	0,85	1,02	1,03	1,07	0,51	0,24	0,54
	Al_2O_3	12,79	12,12	11,35	12,52	12,12	12,24	13,61	14,44	11,42
	Fe_2O_3	1,07	2,84	4,61	5,08	3,67	2,30	0,75	0,23	1,58
	FeO	6,40	5,29	5,29	6,69	7,20	8,21	2,43	2,21	3,76
	MnO	0,03	0,03	0,03	0,05	0,05	0,17	0,01	0,01	0,02
	MgO	2,63	0,86	2,30	1,64	1,26	0,58	1,33	0,79	1,06
	CaO	3,72	3,31	1,39	5,47	4,43	4,79	2,47	1,14	0,46
	Na_2O	2,15	3,23	3,13	3,33	3,27	2,86	3,39	4,29	2,99
	K_2O	3,55	3,02	3,12	2,15	2,32	3,04	3,57	2,85	3,53
	P_2O_5	0,14	0,16	0,15	0,13	0,16	0,16	0,16	0,02	0,07
	Cr_2O_3	0,02	0,01	0,04	0,01	0,01	-	0,02	0,01	-
	CO_2	0,96	0,07	0,05	0,09	0,05	0,30	0,31	0,67	0,11
	H_2O^+	2,05	1,38	1,48	0,67	1,42	1,53	1,09	1,04	1,48
	H_2O^-	0,00	0,04	0,02	0,00	0,05	0,12	0,04	0,00	0,00
	Total	98,97	98,90	98,99	99,68	98,57	99,61	99,91	99,54	98,60
CIPW Norm	Q	23,30	26,02	27,13	19,50	20,92	20,77	29,79	32,42	36,46
	c	1,20	0,00	0,77	0,00	0,00	0,00	0,84	3,82	2,26
	or	20,98	17,84	18,44	12,70	13,71	17,96	20,74	16,84	20,86
	ab	18,19	27,32	26,48	28,17	27,66	24,19	28,68	36,29	25,29
	an	11,47	9,65	5,60	12,86	11,54	11,58	9,24	1,28	1,12
	di wo	0,00	2,26	0,00	5,40	3,88	4,05	0,00	0,00	0,00
	di en	0,00	0,72	0,00	2,48	1,28	0,57	0,00	0,00	0,00
	di fs	0,00	1,53	0,00	2,91	2,60	3,48	0,00	0,00	0,00
	hy en	13,45	1,88	6,46	2,35	2,54	1,25	3,79	2,34	3,16
	hy fs	2,87	4,00	3,79	2,76	5,16	7,68	2,52	3,10	4,20
	mt	1,55	4,11	6,68	7,36	5,32	3,33	1,08	0,33	2,29
	cm	0,02	0,01	0,05	0,01	0,01	0,00	0,02	0,01	0,00
	ilm	1,70	1,55	1,61	1,93	1,95	2,03	0,96	0,45	1,02
	ap	0,33	0,37	0,35	0,30	0,37	0,37	0,37	0,04	0,16
	cc	2,18	0,15	0,11	0,20	0,11	0,68	0,70	1,52	0,25
	H_2O	2,04	1,41	1,49	0,66	1,46	1,64	1,12	1,03	1,47
	Total	98,97	98,90	98,99	99,67	98,57	99,62	99,91	99,54	98,60
Niggli values	al	29,00	30,24	27,22	24,80	26,22	27,06	38,57	44,98	36,77
	alk	16,73	21,41	20,44	15,46	17,06	17,67	26,57	31,58	28,14
	fm	38,93	33,34	46,29	40,04	39,31	36,02	22,13	16,99	32,40
	c	15,34	15,01	6,06	19,70	17,42	19,24	12,72	6,45	2,69
	si	240,72	278,21	265,18	204,44	225,81	233,45	337,97	378,38	391,08
	k	0,52	0,38	0,40	0,30	0,31	0,41	0,40	0,30	0,43
	mg	0,38	0,16	0,30	0,21	0,17	0,09	0,43	0,37	0,27
Katanorm	Q	20,34	24,72	25,20	17,97	19,75	19,19	27,04	26,99	33,22
	Or	22,37	18,83	19,46	13,26	14,58	19,05	21,29	17,28	22,02
	Ab	20,59	30,61	29,68	31,21	31,24	27,24	31,25	39,53	28,35
	An	15,75	10,20	6,35	13,44	12,29	12,30	11,62	5,68	1,98
	Wo	1,22	2,46	0,00	5,64	4,04	4,77	0,00	0,00	0,00
	En	7,74	2,51	5,99	4,73	3,70	1,70	3,67	0,00	0,79
	Hy	9,81	6,60	5,28	7,20	9,22	12,07	3,33	3,05	5,02
	Cord	0,00	0,00	1,97	0,00	0,00	0,00	0,28	6,15	6,33
	Mt	1,19	3,13	5,09	5,54	4,08	2,55	0,81	0,25	1,74
	Cp	0,29	0,33	0,31	0,27	0,33	0,33	0,32	0,04	0,14
	Ru	0,67	0,60	0,63	0,74	0,76	0,79	0,36	0,17	0,40
	Hm	1,39	1,39	1,39	1,39	1,39	0,00	1,39	1,39	1,39
	Cm	0,02	0,01	0,00	0,01	0,01	0,00	0,02	0,01	0,00

1. Dacitic tuff, Athole 392 IT (ECH 602c)
2. Dacitic tuff, Morgenstond 418 IT (ECH 689)
3. Dacitic tuff, Amsterdam 408 IT (ECH 714)
4. Dacitic tuff, Morgenstond 418 IT (ECH 680)
5. Dacitic tuff, Amsterdam 408 IT (ECH 535)
6. Dacitic tuff, Tweepoort 404 IT (ECH 731)
7. Pyroclastic breccia, Wolvenkop 427 IT (ECH 473c)
8. Pyroclastic breccia, Merriekloof 420 IT (ECH 510)
9. Rhyolite, Athole 392 IT (ECH 603a)

Analysts: National Institute for Metallurgy, and
General Superintendence Co., Johannesburg

types on chemical grounds.

The average chemical composition of the tuff of the Amsterdam Formation compares reasonably well with that of average dacite (Nockolds, 1954). The main discrepancies are a lower alumina content and a substantially higher total iron content of the former as compared with the average dacite. Considerable variations are observed in the chemistry of the dacitic tuff of the Amsterdam Formation (Table 10); hence the comparatively large standard deviations of the average values (Table 11). This can most likely be ascribed to its pyroclastic origin.

Streckeisen (1976) devised a method, based on the equivalent norm, to classify the volcanic rocks. The distinction is made primarily on the An/Or ratio and the composition of the normative feldspar: Or' = Or/(Or+Ab+An); Ab' = Ab/(Or+Ab+An); and An' = An/(Or+Ab+An). These parameters are plotted on a ternary diagram (Fig. 21) on which the rhyolite, rhyodacite and dacite fields are delimited by the An/Or ratios of 0-0,25; 0,25-0,67 and 0,67-1,5, respectively. Streckeisen (1976, p. 8) suggested a range of additional characteristic chemical criteria according to which a rock can be identified. Of these the following were selected and are listed in Table 11: SiO_2 and $Na_2O + K_2O$ (in mass per cent), normative quartz, and the normative An content of the plagioclase, i.e. An* = An/(Ab+An).

Also listed in Table 11 are the Rittmann norms in a further attempt to characterise the rocks of the Amsterdam Formation (Rittmann, 1973).

Although a comparison between the three methods of classification employed here, i.e. the Or'-Ab'-An' diagram (Fig. 21), the petrochemical criteria of Streckeisen and the Rittmann norm (Table 11), reveals a slight ambiguity in nomenclature it appears that three of the rocks can best be termed rhyodacite (No's. 7, 9 and 11), two dacite (No's. 10 and 12), one rhyolite

Table 11 : Rock types of the Amsterdam Formation in the light of their average composition compared with average dacite (Nockolds, 1954), petrochemical criteria of Streckeisen (1976) and the Rittmann norm (1973)

	1	2
SiO_2	63,02 ± 1,58	63,58
Al_2O_3	12,19 ± 0,44	16,67
Fe_2O_3	3,26 ± 1,37	2,24
FeO	6,51 ± 1,03	3,00
MgO	1,42 ± 0,75	2,12
CaO	3,85 ± 1,30	5,35
Na_2O	3,00 ± 0,41	3,98
K_2O	2,87 ± 0,48	1,40

1. Average composition of dacitic tuff, Amsterdam Formation
2. Average composition of dacite (Nockolds, 1954, p. 1015)
3. Petrochemical criteria of rhyodacite (Streckeisen, 1976, p.
4. Petrochemical criteria of dacite (Streckeisen, 1976, p. 9)
5. Petrochemical criteria of rhyolite (Streckeisen, 1976, p. 9
6. Petrochemical criteria of rhyolite (Streckeisen, 1976, p. 9
7. Petrochemical criteria of rhyodacite, Amsterdam Formation
8. Petrochemical criteria of dacite (?) Amsterdam Formation
9. Petrochemical criteria of rhyodacite, Amsterdam Formation
10. Petrochemical criteria of dacite, Amsterdam Formation
11. Petrochemical criteria of rhyodacite, Amsterdam Formation
12. Petrochemical criteria of dacite, Amsterdam Formation
13. Petrochemical criteria of rhyolite, Amsterdam Formation

	Sample No.	3	4	5	6	7 (731)	8 (602c)	9 (689)	10 (535)	11 (714)	12 (680)	13 (603a)
	SiO_2	66-73	63-70	70-77	70-76	62,3	62,6	65,7	61,5	65,2	60,8	71,6
	Na_2O+K_2O	7-9	6-7,5	7,5-9	8-9,5	5,9	5,7	6,3	5,6	6,3	5,5	6,5
	Q	17-28	17-25	24-35	27-35	19,2	20,3	24,7	19,8	26,1	18,0	36,1
	Or' (1)	43-46	20-35	42-53	40-50	33	38	32	25	34	23	40
	Ab' (1)	40-48	40-60	40-50	40-50	46	35	51	54	54	54	56
	An' (1)	10-20	15-30	6-10	0-10	21	27	17	21	12	23	4
	An* (2)	20-30	25-40	14-18	2-12	31	43	25	28	18	30	6
	An/Or	0,25-0,6	0,7-1,5	0,1-0,2	0-0,1	0,6	0,7	0,5	0,8	0,3	1,0	0,1
	Field (3)	3b	4	3a	2b	4	(?)	4	4	3b-4	4(?)	2b(?)
Rittmann Norm	Q	-	-	-	-	22,5	22,8	27,4	22,4	26,0	19,2	-
	San	-	-	-	-	30,6	33,9	30,8	21,4	34,2	18,5	-
	Plag	-	-	-	-	29,0	26,1	29,1	37,7	21,6	40,8	-
	Pyr	-	-	-	-	14,7	15,1	9,7	14,8	-	17,8	-
	Bi	-	-	-	-	-	-	-	-	14,9	-	-
	Mt	-	-	-	-	1,8	0,7	1,9	2,4	2,1	2,6	-
	Il	-	-	-	-	1,0	11,1	0,9	1,0	0,9	0,9	-
	Ap	-	-	-	-	0,3	0,3	0,2	0,3	0,3	0,3	-
	Field (3)	-	-	-	-	3b	7	3b	3b	3b	4	-
	Field (3) (Fig. 2f)					3b	3b-4	3b	4	3b	4	2-3a
	Rock type	Rhyodacite	Dacite	Rhyolite	Rhyolite	Rhyodacite	Dacite (?)	Rhyodacite	Dacite	Rhyodacite	Dacite	Rhyolite

(1) Normative feldspar: (see text)

(2) Normative An content of plagioclase; (see text)

(3) Field in QAPF diagram (Streckeisen, 1973)

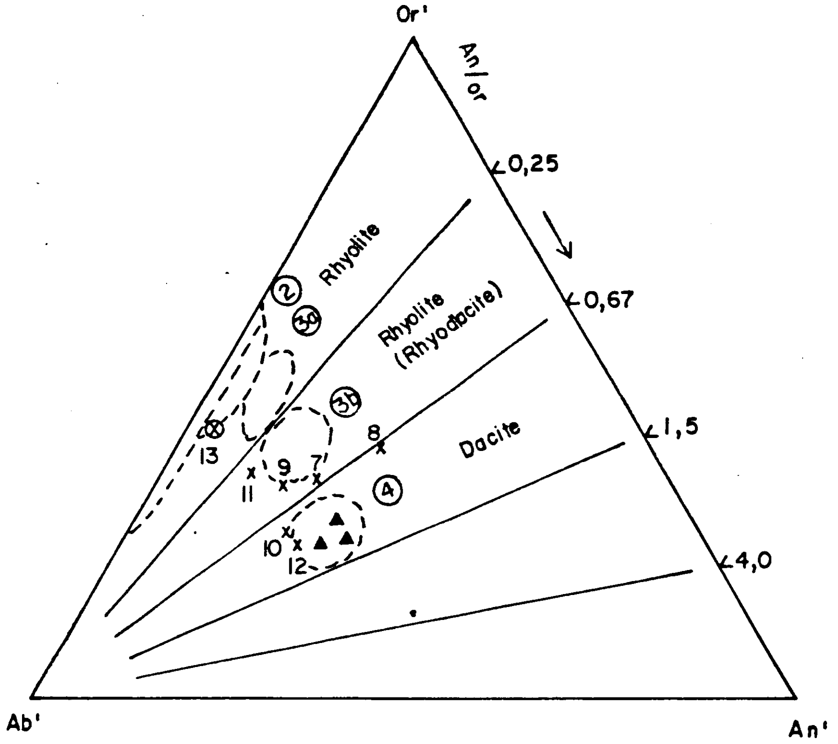


FIG. 21: Or'-Ab'-An' DIAGRAM SHOWING ROCK TYPES OF THE AMSTERDAM FORMATION. (NUMBERS OF SAMPLES AS IN TABLE 11, NUMBERS IN CIRCLES REFER TO STRECKEISEN QAPF DIAGRAM). TRIANGLE (▲) REPRESENT DACITE FROM TYPE LOCALITY IN TRANSILVANIA, ROMANIA (STRECKEISEN, 1976, P. 5).

(No. 13), while one (No. 8) remains enigmatic in that it cannot be classified conclusively on the QAPF diagram by any of the above methods, but it is probably of dacitic affinity (Fig. 21).

3. The Vaalkop Rhyolite Formation

a) Field relationships

(i) In the Piet Retief area

Rhyolite of the Vaalkop Formation first makes its appearance on Ishlelo 441 IT and Haarlem 443 IT (Folder IB, G-I.10) and extends from here uninterruptedly southeastwards in a belt of varying width to Strydkraal 477 IT and Potgieters Hoek 519 IT (N.13), where it swerves sharply eastwards into Swaziland. Its strike length is some 26 km on the Transvaal side of the border and it occupies an area of approximately 65 km^2. However, there is a second limb which branches off in a more southerly direction on Mooihoek 491 IT and extends first south-southeastwards and subsequently southeastwards to far beyond the southern boundary of the mapped area. Only one very small outcrop of Vaalkop rhyolite on Wolvenkop 427 IT (Folder IB, F.8) testifies of a probable originally greater extension in a northerly direction.

The rhyolite is massive, displays no signs of bedding, banding or flow structures and it is consequently difficult to determine its true attitude. The outcrop width of the eastern limb is very narrow between Vaalkop 482 IT and Mooihoek 491 IT and an almost vertical attitude is displayed on aerial photographs when viewed under a stereoscope. Here the Vaalkop Formation is sandwiched between granodiorite on the eastern side and Amsterdam pyroclastics in the west, and this locality could possibly represent the feeder of the rhyolite.

The field relationships of the Vaalkop rhyolite are in places markedly unconformable. On Rooksdrift 484 IT a marker horizon in the Amsterdam Formation, which is characterised by conspicuous plagioclase phenocrysts and which is even recognisable on aerial photos, disappears under the overlying rhyolite.

On Blesbokspruit 515 IT and Potgieters Hoek 519 IT the Vaalkop Formation overlies or lies in juxtaposition to Glen Eland quartzite and the Amsterdam Formation. The sharp easterly bend in the strike direction of the outcrop of the Vaalkop rhyolite on Strydkraal and Potgieters Hoek, as well as the separation of the outcrop into two limbs, are not difficult to explain if it is supposed that the Vaalkop rhyolite originally blanketed a much larger area and that its present outcrop represents erosion relicts. Small outliers of Vaalkop rhyolite, one on Basement granite on Strydkraal and another on Glen Eland quartzite on Rooksdrift 484 IT (L-M.13), between the two limbs of rhyolite, support this supposition.

(ii) Outside the mapped area

Humphrey and Krige (1931, p. 42-44) described the rocks of the Vaalkop Formation in the area south of Piet Retief as granophyre, which they considered to be intrusive and related to a "gabbro-granophyre magma" (p. 44). Several varieties, i.e. granophyre, microgranite, quartz prophyry, porphyritic granophyre and acid dykes were distinguished. The distinction between these varieties was mainly based on the amount of micropegmatite and feldspar phenocrysts present. On the Geological Survey map, Sheet 68 (Piet Retief) this granophyre is shown to occur in three separate areas. One is a continuous belt extending from Piet Retief southwards to Pipe Klip Berg 21 HU. The second outcrop occurs between the Pongola and Bivane Rivers and the third area is in southern Swaziland west of Mooihoek, where a sheet of quartz prophyry and porphyritic granophyre is reported to occur in the Mozaan Subgroup (Humphrey and Krige 1931, p. 43; see also Geological Map of

Swaziland, 1959). Only in the area mentioned first is the granophyre partly in contact with gabbroic rocks of the Usushwana Complex.

The main outcrop areas of granophyre in Swaziland are on the Makumulu Plateau and further north, immediately north of the Usutu River (Hunter, 1970a, p. 647). In both these areas the granophyre is associated with mafic rocks of the Usushwana Complex. Winter (1965, p. 10-11) noted variations in the granophyre in Swaziland and described coarse and fine-grained varieties.

The field relationships thus indicate that the Vaalkop rhyolite is not confined to the distribution of the gabbroic rocks of the Usushwana Complex and that it unconformably overlies some older formations at a low angle.

b) Petrography

(i) Macroscopical features and fabric

Macroscopically the Vaalkop Formation can be distinguished from the Amsterdam Formation by its distinctly red colour on weathered surfaces which are frequently strongly pock-marked. When fresh the rock varies from dark dull-grey, hardly distinguishable from the Amsterdam pyroclastic rocks, to a characteristic red variety.

These variations and differences are very subtle and only emerge from a detailed combined field and laboratory study.

The rhyolite is generally finely crystalline but it is markedly coarser grained than the Athole Member of the Amsterdam Formation. Accidental ejecta are only occasionally observed. Winter (1965, p. 10) reports partly brecciated quartzite xenoliths in the granophyre in Swaziland.

The amount of granophyric intergrowth in the Vaalkop rhyolite varies from place to place but may become very pronounced. In the most common rock type intergrowths constitute the matrix between scattered phenocrysts of altered feldspar and in places occur as radiating spherulitic aggregates. Similar textures are described from south of Piet Retief (Humphrey and Krige, 1931, p. 43). This rock locally merges into a porphyritic variety of the Vaalkop rhyolite. Euhedral to subhedral laths of totally saussuritised plagioclase (?) are set in a mesostasis of granophyric intergrowths (Fig. 22a). Elsewhere the rhyolite porphyry may contain much less micropegmatite and may even be devoid of it. Phenocrysts of anhedral crystals of quartz are also fairly common.

One variety of the Vaalkop rhyolite, conspicuously different from those described above, displays a typical felsitic texture in which anhedral phenocrysts, mainly of quartz are set in a microcrystalline mosaic of fine-grained quartz and alkali feldspar (?).

Crystallites are ubiquitous in the Vaalkop rhyolite in places. In some localities they are arranged in remarkable spherulitic growths around feldspar phenocrysts or other nucleii, in similar fashion as granophyric intergrowths (Fig. 22b). These textures are reminiscent of spherulites observed in the Athole rhyolite of the Amsterdam Formation.

(ii) Mineralogy

The mineralogy of the rocks of the Vaalkop Formation has been described by Humphrey and Krige (1931, p. 42-44) and Winter (1965, p. 10-11) and is therefore only briefly discussed below.

Quartz is a major constituent occurring mainly in the granophyric intergrowths and in the matrix of the felsitic variety. The grain size of the quartz in the matrix is

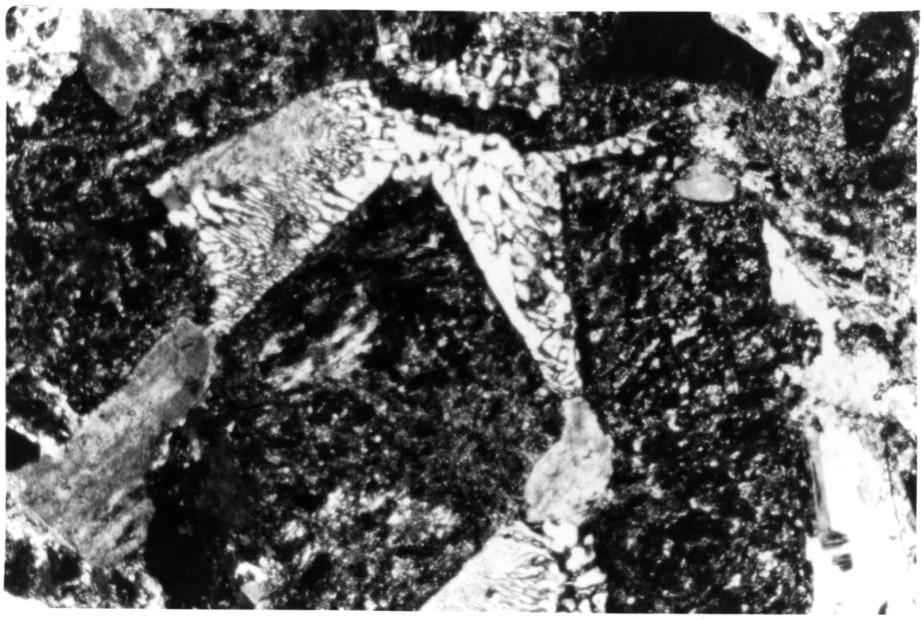


Fig. 22a: Altered plagioclase phenocrysts in a granophyric matrix of a porphyritic variety of the Vaalkop Rhyolite Formation. Crossed nicols, X 40, Haarlem 443 IT (ECH 718h)

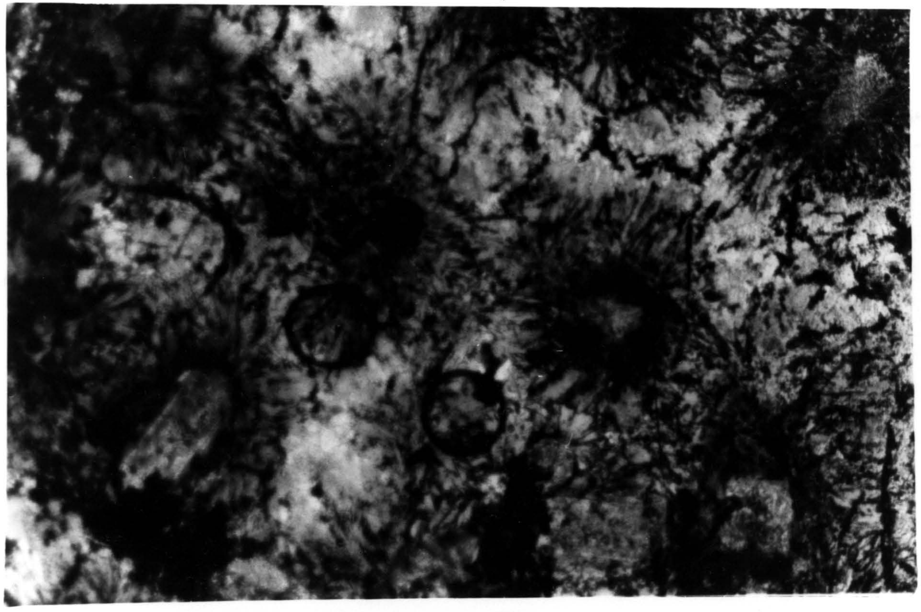


Fig. 22b: Spherulitic arrangement of crystallites around totally altered plagioclase (?) crystals in the Vaalkop Rhyolite Formation. Dark circles are air bubbles. Polarised light, X 40, Haarlem 443 IT (ECH 499)

in the order of 0,01 mm. Larger aggregates of quartz crystals occur as phenocrysts.

Plagioclase is present in the porphyritic variety of the Vaalkop Formation as euhedral laths (Fig. 22a) 1 to 2 mm long, set in a strongly micropegmatitic matrix. The crystals are almost invariably completely saussuritised.

K-feldspar is present mainly in the granophyric component and in the matrix of the felsitic rocks.

Ferromagnesian minerals. Strongly pleochroic dark green hornblende is usually present in small amounts.

Accessory minerals. Magnetite, ilmenite which is partly altered to leucoxene, and pyrite are the most important accessory minerals whereas sphene is observed in places.

Secondary alteration products. Chlorite, epidote and stilpnomelane are the most common low-grade metamorphic minerals in the Vaalkop rhyolite. Calcite is found in places.

(iii) Chemical composition

Seven samples of rhyolite from the Vaalkop Formation were chemically analysed. The results as well as the corresponding CIPW norms, the Niggli equivalent norm and the Niggli values are contained in Table 12. In Table 13 the average composition of these samples is compared with average compositions of calc-alkaline and alkaline granites and rhyolites. It emerges firstly, that on account of its average calcium content of 1,66 per cent the Vaalkop rhyolite compares more favourably with calc-alkaline granite and rhyolite than with alkaline rocks and secondly, that the most noteworthy discrepancies between the composition of the Vaalkop rhyolite and average granites and

Table 12 : Chemical composition of rhyolite of the Vaalkop Formations

		1	2	3	4	5	6	7
Chemical composition	SiO_2	71,63	70,83	73,27	73,00	71,31	72,10	71,72
	TiO_2	0,58	0,52	0,35	0,36	0,39	0,38	0,38
	Al_2O_3	12,04	12,37	11,74	11,87	11,90	11,64	12,06
	Fe_2O_3	2,56	2,95	3,13	2,66	3,10	2,84	2,37
	FeO	2,65	2,65	1,50	2,09	2,98	2,79	3,05
	MnO	0,02	0,08	0,06	0,08	0,09	0,09	0,09
	MgO	0,52	0,44	0,11	0,11	0,07	0,06	0,08
	CaO	1,98	1,78	1,24	1,24	1,77	1,86	1,78
	Na_2O	3,52	3,12	3,56	3,67	3,78	3,52	3,57
	K_2O	4,13	4,42	4,18	4,06	3,55	3,68	4,10
	P_2O_5	0,10	0,08	0,06	0,04	0,06	0,05	0,05
	Cr_2O_3	0,01	0,04	0,27	0,26	-	-	-
	CO_2	0,17	-	-	-	-	0,11	0,10
	H_2O^+	0,99	0,54	0,48	0,42	0,65	0,57	0,64
	H_2O^-	0,00	0,11	0,07	0,05	0,08	0,04	0,05
	Total	100,93	99,88	100,22	99,64	99,72	99,72	100,03
CIPW norm	Q	30,91	31,08	34,32	33,28	31,62	33,52	30,96
	c	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	or	24,41	26,12	24,70	23,99	20,98	21,75	24,23
	ab	29,78	26,39	30,12	31,05	31,98	29,78	30,20
	an	4,99	6,69	3,71	3,92	5,02	5,09	4,77
	di	2,59	1,35	1,18	1,69	2,96	2,74	2,73
	hy	1,81	2,13	0,00	0,58	1,04	1,01	1,94
	mt	3,71	4,27	4,01	3,85	4,49	4,11	3,43
	ilm	1,10	0,98	0,66	0,68	0,74	0,72	0,72
	ap	0,23	0,18	0,09	0,09	0,14	0,11	0,11
	cc	0,38	0,00	0,00	0,00	0,00	0,25	0,22
	H_2O	0,98	0,64	1,04	0,46	0,72	0,60	0,68
	Total	100,93	99,88	100,22	99,64	99,72	99,72	100,03
Niggli values	al	35,12	36,09	38,04	37,91	35,35	35,64	36,23
	alk	29,92	28,93	33,63	33,31	29,88	29,92	30,97
	fm	24,46	25,54	21,03	21,58	25,22	24,08	23,08
	c	10,49	9,44	7,30	7,20	9,56	10,35	9,72
	si	354,45	350,59	402,76	395,55	359,31	374,52	395,50
	k	0,44	0,49	0,44	0,42	0,38	0,41	0,43
	mg	0,16	0,13	0,04	0,04	0,02	0,02	0,02
Katanorm	Q	28,68	29,32	32,63	30,17	28,75	31,71	29,12
	Or	24,97	26,95	25,44	23,67	20,78	22,51	24,94
	Ab	32,35	28,91	32,93	32,52	33,63	32,72	33,01
	An	4,98	6,92	3,83	3,88	4,98	5,28	4,92
	Wo	1,79	0,69	0,91	0,78	1,35	1,59	1,55
	En	1,47	1,25	0,31	0,30	0,19	0,17	0,23
	Hy	2,40	2,24	0,24	1,49	2,57	2,57	3,31
	Mt	2,74	3,18	3,37	2,74	3,21	3,07	2,55
	Cp	0,20	0,16	0,08	0,08	0,21	0,10	0,10
	Ru	0,41	0,37	0,25	4,37	4,41	0,27	0,27
	Hm	1,39	1,39	1,39	1,39	1,39	1,39	1,39

Vaalkop Formation

1. Rhyolite, Haarlem 443 IT (ECH 499)
2. Rhyolite, Sterkwater 472 IT (ECH 812b)
3. Rhyolite, Sterkwater 472 IT (ECH 812h)
4. Rhyolite, Rooksdrift 484 IT (ECH 812k)
5. Rhyolite, Sterkwater 472 IT (ECH 808e)
6. Rhyolite, Sterkwater 472 IT (ECH 808f)
7. Rhyolite, Sterkwater 472 IT (ECH 808g)

Analysts: National Institute for Metallurgy and General Superintendence Co., Johannesburg rhyolites are a substantially higher iron content and a slightly lower alumina content of the former.

Table 13: Average composition of rhyolite of the Vaalkop Formation, compared with calc-alkaline and alkaline granites and rhyolites

	1	2	3	4	5
SiO_2	72,06 ± 0,98	72,08	73,66	73,86	74,57
Al_2O_3	11,95 ± 0,22	13,86	13,45	13,75	12,58
Fe_2O_3	2,80 ± 0,27	0,86	1,25	0,78	1,30
FeO	2,53 ± 0,51	1,67	0,75	1,13	1,02
MgO	0,20 ± 0,18	0,52	0,32	0,26	0,11
CaO	1,66 ± 0,28	1,33	1,13	0,72	0,61
Na_2O	3,53 ± 0,19	3,08	2,99	3,51	4,13
K_2O	4,02 ± 0,28	5,46	5,35	5,13	4,73

1. Average composition of rhyolite, Vaalkop Formation (7 samples)
2. Average calc-alkali granite, Nockolds (1954, p. 1012)
3. Average calc-alkali rhyolite, Nockolds (*ibid*)
4. Average alkali granite, Nockolds (*ibid*)
5. Average alkali rhyolite, Nockolds (*ibid*)

Chemically the rocks of the Vaalkop Formation are clearly of rhyolitic composition. The normative Or/An ratios of these rocks invariably fall in the range of 0-0,25, i.e. the rhyolite field of the Or'-Ab'-An' diagram of Streckeisen (1976) (See also Fig. 21).

4. Discussion

a) Morphological features and their genetic implications

Smith (1960, p. 806) lists two topographical criteria indicative of emplacement of pyroclastic rock by flowage, namely deposition in valleys or other topographical depressions and secondly, their level upper surfaces.

That the tuff of the Amsterdam Formation has been deposited on a paleo-landscape with considerable relief, can be demonstrated at a number of localities.

The pyroclastic rock has blanketed large parts of the Pongola Group which for instance can be observed south of Amsterdam where it transgresses over the Skurwerant quartzite (F.5/6). Only small inliers of quartzite protrude through this cover in and near the town.

North of Amsterdam a number of exposures of the Thole Formation are shown (Folder IA). They constitute isolated outcrops entirely surrounded by Amsterdam pyroclastics and no interconnection can be traced between the various bodies even in streambeds incised to considerably lower levels than the respective outcrops. The most acceptable explanation seems to be deposition on a paleo-relief in which the Thole pyroxenite formed more or less prominent morphological features. The small hill just north of the village is a case in point; it has a conspicuous sloping western flank, which actually represents a dip-slope of the Thole Formation, now largely blanketed by Amsterdam tuff (Fig. 23).

On Athole 393 IT (A.2/3) rhyolitic tuff of the Athole Member can be seen contiguous to Skurwerant quartzite which dips at a low angle of 15° southeast. However, no trace of this quartzite nor of the underlying Ngwempisi lava can be found in riverbeds, which are incised a couple of tens of metres into the pyroclastics, immediately north of this position. Again this relationship can only be explained satisfactorily by presupposing deposition of the ash-flow tuff on an uneven floor.

On the long, narrow extension of Forbes Athole 393 IT (B.2/3),

<u>Fig. 23</u>: A Thole pyroxenite sill (TF) blanketed by the Amsterdam Formation (AF) and transgressed by a dyke of porphyritic Karoo dolerite (Kd) (cf. Fig. 43b), immediately north of Amsterdam. Amsterdam Townlands

at its eastern border with Athole 392 IT, a marked flexure is observed in Skurwerant quartzite which, at this point, strikes due south and dips 5°E, as compared with its normal east-west strike and southerly dip in this area. The quartzite was presumably slightly domed as a result of the emplacement of the ultramafic rocks of the Thole Formation. The upper and western portions of the anticlinal fold were subsequently eroded away and were overlain by Athole rhyolitic tuff which presently can be observed in the narrow strip between the south-striking quartzite in the east and the Thole Formation in the west.

The Amsterdam Formation builds ranges of strongly dissected hills which are prominent because they are so conspicuously bare of trees and bushes, presumably as a result of the massive nature of these rocks. In the Amsterdam area the hills have a remarkably level upper surface over a distance of some 15-18 km. This surface does not correspond to that of the peneplained Basement granite. Northeast of Amsterdam and to the west of the Amsterdam syncline the elevation of the granite floor rises above that of the pyroclastic rocks, whereas the granite along the Amsterdam-Nerston road is topographically considerably lower than the Amsterdam Formation. The evidence thus indicates that this morphological feature could well represents the level upper surface of an ash flow deposit.

b) Age relationships

The unconformable overlap of the Amsterdam Formation over the entire Nsuze Subgroup and part of the Mozaan Subgroup in the Amsterdam area, as well as the lithic blocks and huge rafts of the Glen Eland quartzite in the pyroclastic breccia indicates that the Amsterdam Formation is of post-Pongola age. This relationship is also borne out by the fact that the volcanics were deposited on a paleo-relief, as described from south of Amsterdam and the northern part of Athole, thus indicating that a considerable time-lag must have occurred between the deposition of the two.

In the Piet Retief area outcrop conditions are less favourable, but in fact very similar conditions prevail. On Mooihoek 491 IT, Rooksdrift 484 IT and Blesbokspruit 515 IT the Amsterdam Formation cuts unconformably over Glen Eland quartzite between the two prominent outcrops of this formation. A smaller outlier of rhyolite on the top of the northern quartzite indicates the younger age of the Vaalkop Formation.

The mutual relationship between the Amsterdam Formation and the Vaalkop Formation is not very clear. In the Amsterdam area the top of the Amsterdam Formation is not clearly demarcated. As a result of crystallisation the texture of the tuff tends to become crystalline and granophyric intergrowths become more common higher up in the succession and in places the uppermost part of the formation is indistinguishable from the dark varieties of the Vaalkop Formation, further to the south. On Ishlelo 441 IT dark, recrystallised dacitic tuff can gradually be followed into reddish rhyolitic tuff, but on Rooksdrift 484 IT the transition appears to be relatively sharp.

The age of the Ngwempisi Formation was provisionally determined to be 3090 ± 90 m.y. (Burger and Coertze, 1973), and the granophyre of the Usushwana Complex yielded an age of 2847 ± 15 m.y. (Davies, 1971, p. 64-68).

c) Genetic implications of micropegmatite

Barker (1970, p. 3342-43) pointed out that granophyric intergrowths may originate in various ways. Micropegmatite textures can arise from cotectic crystallisation of quartz and alkali feldspar or may be attributed to metasomatic replacement or devitrification of glassy volcanics. Micropegmatite may either form the mesostasis, the last interstitial crystallisation products, or it may occur as megacrysts in acid extrusive rocks.

Cotectic granophyric intergrowths generally occur as mesostasis, and Fenner (1930, p. 161) described the unique conditions which prevail at the cotectic minimum, viz. firstly the temperature is fixed until crystallisation is complete, and secondly the composition of the final solidified phase is identical to that of the original liquid from which it crystallised.

Taylor (1968, p. 65-67) demonstrated that in many instances granophyric intergrowths exhibit a disequilibrium in oxygen isotope composition. Such rocks are invariably characterised by altered feldspar and this phenomenon is ascribed to deuteric oxygen exchange between feldspar, quartz and meteoric water, at relatively high temperatures. The feldspar phenocrysts in the rhyolite of the Vaalkop Formation are strongly altered and metasomatic processes, as postulated by Taylor, can be expected to have operated at the interface between the Vaalkop Formation and the intrusive gabbroic phase.

Micropegmatite in the Vaalkop rhyolite occurs interstitially with respect to quartz and feldspar phenocrysts, but in places it is present in larger amounts and may constitute the main mineral aggregate of the rock.

The groundmass granophyric intergrowths may be the result of cotectic crystallisation. However, in view of the fact that the micropegmatite content of the Vaalkop rhyolite varies considerably in places, it is unlikely that conditions outlined by Fenner (ibid) obtained only in some parts of the flow and therefore, cotectic crystallisation must be ruled out for that variety of the rhyolite which consists almost entirely of granophyric intergrowths.

It is therefore suggested that some of the micropegmatite is of secondary origin and resulted from the devitrification of originally glassy material of the Vaalkop rhyolite. The energy required for this transformation was provided by the emplacement of the intrusive phase of the Usushwana Complex. Du Plessis

(1976, p. 47) described a similar transition from a quartz-feldspar porphyry to porphyritic granophyre in the Bushveld Complex northwest of Warmbad and proposed a mechanism of increasing spherulitic devitrification.

d) Origin of the volcanic rocks

The rocks of the Amsterdam Formation do not consist of granophyre or altered Ngwempisi lava, as contended by Krige (1920-21) and Van Vuuren (1965), but the macroscopical and microscopical features of the dacitic and rhyolitic rocks are indicative of pyroclastic ash flows. Likewise, the acidic rocks of the Vaalkop Formation, which have in the past been described as granophyre, microgranite, quartz porphyry, etc., appear to be of volcanic origin and are here termed rhyolite. Although Hunter (1970a) considered these rocks to be part of the intrusive phase of the Usushwana Complex, he (p. 655) pointed out that the volume of granophyre present on the Makumulu Plateau in Swaziland is too large to be accounted for by differentiation from a gabbro intrusive and that it may have resulted from mobilisation of volcanic rocks of the Ngwempisi Formation.

In order to obtain more clarity on the origin of the pyroclastic rocks of the Usushwana Complex it is deemed necessary to compare the features displayed by typical ash flow deposits with those observed in the Amsterdam and Vaalkop Formations.

(i) Some general features of ash flows

The probable nuée ardente mode of origin of pyroclastic ash flows is discussed by Smith (1960, p. 802). Three different types of deposits, e.g. the Peléan type flows, the St. Vincent type flows and fissure type flows are distinguished. Each type has its distinctive features but as a result of the turbulent mode of transportation they have generally two characteristics in common, viz. poor sorting and poor bedding. The two types of deposits mentioned first are usually derived from volcanic cones and are more restricted in extent and volume, rarely exceeding 1 km^3 and 10 km^3 respectively, as compared with fissure eruptions which may be in excess of 100 km^3 (Füchtbauer, 1974, p. 175-176).

(ii) Rock types

Rhyolitic tuff is the most common type but quartz latitic, rhyodacitic, dacitic and even basaltic varieties have been described. Most of these rock types, except latite and basalt, are developed in the Amsterdam and Vaalkop Formations.

(iii) Field relationships

The aereal extent of ash flows may vary greatly. Rhyolite deposits covering more than 25 000 km^2 are known in New Zealand, Summatra and the Western United States, whereas the more basic types are less widespread, covering some 35 to 300 km^2 (Weyl, 1954, p. 11). Ash flow units may vary widely in thickness. While some ignimbrites are only about one metre thick or less, others may attain 100-150 m and Ross and Smith (1960, p. 20) are of the opinion that even 300 m is not impossible. Peterson (1959, p. 1740) reports a single pyroclastic dacitic flow in Arizona, U.S.A. which is in places almost 500 m thick.

The Amsterdam Formation unconformably overlies several formations of the Pongola Group and it is of relatively large aerial distribution. Assuming that the present outcrops of this rock in the northern part of the area mapped were originally linked, its total distribution could have been in the order of 400 km^2. If the thickness of the formation is taken to be 200-250 m the volume of pyroclastic material would be in the order of 80-100 km^3.

Rocks of the Vaalkop Formation are spread over a much larger area and it is not feasible to determine its possible original extent. Although the thickness of this rhyolite is in the order of 250 m, it is not known whether it comprises several flows or not.

Ash flows are characterised by very flat upper surfaces and have a horizontal attitude. Any uneveness in the floor is filled and the tuff may flow around obstacles or down the drainage patterns. Ash fall deposits in contrast are draped over the paleo-topography (Smith, 1960, p. 806-807). The upper surface of the Amsterdam Formation is very flat, but it is not known to what extent this may be due to subsequent peneplenation. The formation has been deposited on an uneven floor.

(iv) Macroscopical features

Typical ash flow tuffs are massive, non-sorted and non-bedded, although flowage features are observed in some deposits (Smith, 1960). Columnar prismatic jointing is a common feature. Clasts may exhibit a wide range in size but the predominant constituents are generally of ash-size (-4 mm) (Marshall, 1935, p. 360).

The rocks of the Amsterdam Formation are generally massive, unbedded and unsorted. Flow structures are in places observed near the floor of the Athole Member but no columnar prismatic jointing has been observed in any of these rocks. Lithic fragments of various sizes and shapes are very common in the dacitic and rhyolitic rocks of the Amsterdam Formation and in places the large pyroclasts are even surrounded by chilled margins in the matrix, indicating that they fell into hot, unconsolidated material.

The presence of pumice fragments appears to be the most important single criterion of a pyroclastic origin (Ross and Smith, 1960,

p. 18). No pumice has been observed in the dacitic tuff but the rhyolite of the Athole Member contains small, totally altered fragments reminiscent of pumice.

Lythophysae are reportedly less common in ash flows than in lavas because volatiles are retained longer in the former. In some deposits, however, lythophysae can be conspicuous and they can be very large, usually spherical but in some cases also flattened (Ross and Smith, 1960, p. 27). Slightly ellipsoidal lithophysae, the size of a hen's egg and larger, are found in places in the Athole rhyolite, whereas pegmatitic blebs in the Amsterdam Formation (Fig. 15a) conceivably represent similar but recrystallised lithophysae.

(v) Microscopical features

Welded glass shards, one of the most typical features of ignimbrites, were not observed in the rocks of the Amsterdam and Vaalkop Formations. This is not surprising since the rocks are almost 3000 m.y. old and have subsequently been subjected to metamorphism during the emplacement of the plutonic rocks of the complex. Consequently the rocks are usually totally devitrified and often display a microcrystalline texture. Only the rhyolite of the Athole Member contains some fragments which could be interpreted as shards of glass.

According to Ross and Smith (1960) ash flow tuffs completely free of phenocrysts are very rare. Rhyolitic tuffs always contain euhedral to subhedral phenocrysts of feldspar, mainly sanidine, and some contain quartz. Biotite and augite are less abundant in rhyolitic tuffs but are present in the more basic varieties. Magnetite is usually present in small amounts. Weyl (1954, p. 20) describes phenocrysts of plagioclase (An_{35-45}), ortho- and clinopyroxene and subordinate amounts of magnetite in rhyodacitic and dacitic ash flows of El Salvador, South America.

Phenocrysts of feldspar and amphibole are very common in the rocks of the Amsterdam Formation. Broken and corroded crystal fragments in the Athole Member, and to a lesser extent in Amsterdam dacitic tuff, are indicative of crystal tuffs. Elsewhere phenocrysts, mainly of feldspar, can be observed and in places flow textures are developed around such crystals. The abundance of euhedral plagioclase (?) laths and quartz crystals indicate that the Vaalkop Formation originally was a quartz-feldspar porphyry or related rhyolitic extrusive. Crystallites, in places arranged in spherulitic growths around feldspar or other nucleii in the rhyolite, are undoubtedly volcanic textures and are similar to those observed in the Athole rhyolite of the Amsterdam Formation, where they are very common.

According to Smith (1960, p. 828) and Ross and Smith (1960, p. 36-38 and 44-45) devitrification of the glass shards and groundmass as well as crystallisation of "vapour-phase minerals" are excellent diagnostic features of ash flow tuffs. Cristobalite and alkali feldspar commonly crystallise during the devitrification of glass, whereas tridymite and alkali feldspar are typical vapour-phase minerals, forming discrete crystals or crystal aggregates in pore spaces in the presence of volatiles. Primary quartz is found only in thick cooling units of rhyolite. It is a strange fact that cristobalite and tridymite have not inverted to quartz in most unaltered ash flows of Quaternary and Tertiary age. Fenner (1913, p. 343-346) drew attention to the fact that tridymite and crystobalite may be formed as metastable phases and that their presence in a rock not necessarily implies that they formed above the respective inversion points, i.e. 870° and 1470°C. Ramdohr (1954, p. 421) suggests that these modifications of tridymite and cristobalite are due to the incorporation of Ca, Na and K into the crystal lattice. Both tridymite and cristobalite have open structures and can easily accommodate ions of the alkali and alkaline earth groups (Deer, Howie and Zussman, 1960, IV, p. 192). Quartz microlites, paramorphous after tridymite, are common in the dacitic tuff of the

Amsterdam Formation and particularly in the Athole Rhyolite Member. Microlites were not observed in the Vaalkop Formation but Winter (1965, p. 10) reports that the granophyre in Swaziland contains "... microlites and vugs filled with quartz crystals and epidote".

The most severe effects of devitrification are seen in the development of spherulitic or rosette-like textures (Ross and Smith, 1960, p. 37) which may profoundly modify or even obliterate the original texture of the rock. Spherulitic textures observed in the Athole rhyolite and in places in the Vaalkop Formation, as well as the formation of the granophyric intergrowths in the latter are considered to be due to devitrification of originally glassy rocks.

e) Conclusions

Ross and Smith (1960, p. 18) stress the fact that the recognition of the original textures of pyroclastic ash flows in the case of thorough welding and devitrification represents probably the biggest problem in the correct identification of these rocks and that the field characteristics in such cases are of bigger importance than microscopical evidence. Hjelmqvist (1955, p. 8) points out some additional difficulties experienced when studying such rock types in Precambrian terrains. Some of the diagnostic field relationships, such as the columnar jointing, topographic control, etc. may be very difficult to recognise as a result of subsequent metamorphism, denudation etc. . The most characteristic features of pyroclastic flows which remain, under such circumstances, i.e. if microscopical evidence is inconcclusive, are the absence of bedding, lack of sorting and great aerial extent. Indeed, on the basis of these criteria most, if not all, large volcanic formations of rhyolitic and dacitic composition are considered to be pyroclastic ash flows (Cook, 1966, p. 157).

In the light of the evidence presented above it is believed that in the Amsterdam Formation diagnostic microscopical textures have been largely destroyed by advanced recrystallisation and devitrification and that these rocks can best be described as ash flow tuffs.

The extrusive origin of the Vaalkop Formation appears to be certain but its mode of origin e.g. rhyolitic lava or ash flow tuff, is less conclusive than in the case of the Amsterdam Formation.

D. The Plutonic Phase

In the present area of investigation the plutonic phase of the Usushwana Complex may be subdivided into a mafic group of rocks, i.e. the Piet Retief Suite, consisting of several types of gabbro, and acidic rocks, the Hlelo Suite, comprised of fine-grained granite and in places intermediate granodiorite, which is interposed between the two.

1. The Piet Retief Gabbro Suite

(a) Rock types and their field relationships

(i) Pyroxenite

With the single exception of one small plug, measuring a mere 20 x 30 m at the tip of a gabbro intrusive on the northern portion of Imbama 414 IT (Folder IA, A.6), no ultramafic bodies directly associated with the predominantly gabbroic rocks were found. This pyroxenite is different both in field relationships and in its petrographical properties from the ultramafic rocks of the Thole Formation and does not seem to be related to that intrusive episode, but likewise its association and age relationship with the adjacent quartz gabbro could not be demonstrated conclusively.

(ii) Quartz gabbro

This is a coarse to medium-grained, predominantly mesocratic rock in which quartz usually is a more or less conspicuous modal constituent, particularly in the two satellite bodies on Imbama 414 IT and Glen Eland 413 IT, in the two large bodies of gabbro southeast and north-east of Amsterdam, as well as elsewhere where the gabbro is in contact with the Basement granite. The quartz gabbro is typically a homogeneous rock displaying no rythmic layering. On Lions Glen 398 IT (G.1/2), immediately north of the homestead, a very coarse variety containing conspicuous hornblende crystals, 3 to 4 cm long, is developed along the contact with Basement granite.

The quartz-rich gabbro is by far the most abundant variety of the mafic rocks of the Usushwana Complex. Humphrey and Krige (1931, p. 42) described both melanocratic and leucocratic gabbros from the area south of Piet Retief but no indication is given about their relative abundance. On Cometje 13 HU, south of the area mapped, a cursory investigation of a traverse across the gabbroic zone revealed that it is only some 750 m wide here and that the gabbroic rocks consist mainly of quartz gabbro. Towards the overlying Vaalkop Formation a melanocratic variety is exposed at this locality in a road-cutting along the Piet Retief - Pongola road. This rock is also found elsewhere in the vicinity, where its suitability as dimension stone has reportedly received attention.

Van Vuuren (1965) considered two larger bodies of basic rocks which are intrusive into the Voorslag Formation, one located in rugged country on the border between Evergreen 425 IT and Redcliff 426 IT (H.8) and the other one on the western part of the latter farm (G.8), to be diabase sills. Cross-cutting intrusive relationships, though not very clear, are indicated especially for the former body, which transgresses northwards from ferruginous shale of the Voorslag Formation across the

Cascade Iron-formation Member into Skurwerant quartzite (Folder IA). These rocks cannot be distinguished from the medium-grained, quartz-rich gabbro found elsewhere in the area. Reddish plagioclase, which Van Vuuren (1965, p. 66) cited as being characteristic of the intrusive on Redcliff, can be observed also at other places in the quartz gabbro.

(iii) Ferrogabbro

The ferrogabbro, a predominantly melanocratic, medium- to fine-grained, magnetite-bearing gabbro is usually poorly exposed and, although its presence is indicated on the map it could not be mapped as a separate unit. It has its best development from Ishlelo 441 IT to Belfast 492 IT, along the western belt in the Piet Retief area. To the north it seems to terminate against the Haarlem fault, whereas to the south outcrop conditions are so poor that the presence of ferrogabbro on Athalie 520 IT, for instance, is indicated only by float material from a few exposures of magnetitite. Ferrogabbro is also observed in the eastern belt of gabbroic rocks in the Piet Retief area, where it is found along the western contact of this zone. Farther north, in the Amsterdam area this rock was observed on the southernmost part of Inhlovudwalile 421 IT (I.7) and on Tweepoort 404 IT where it appears to be chilled against granitic rocks of the complex.

Layering is a feature in places and a remarkable outcrop on Sterkwater 427 IT (K/L.12) shows layered ferrogabbro in an almost vertical disposition (Fig. 24a). An inclusion of light coloured gabbro is aligned parallel to the plane of layering.

Magnetite layers are developed at several localities in the ferrogabbro east and northeast of Piet Retief (Folder IB). Most of the occurrences are found in the western belt of gabbroic rocks, e.g., on Ishlelo 441 IT, Derby 444 IT, Belfast 492 IT and Athalie 520 IT. Only one definite small body of magnetite

Fig. 24a: Layered ferrogabbro of the Usushwana Complex in an almost vertical disposition. Note inclusion of a light coloured gabbro sub-parallel to the layering. Sterkwater 472 IT

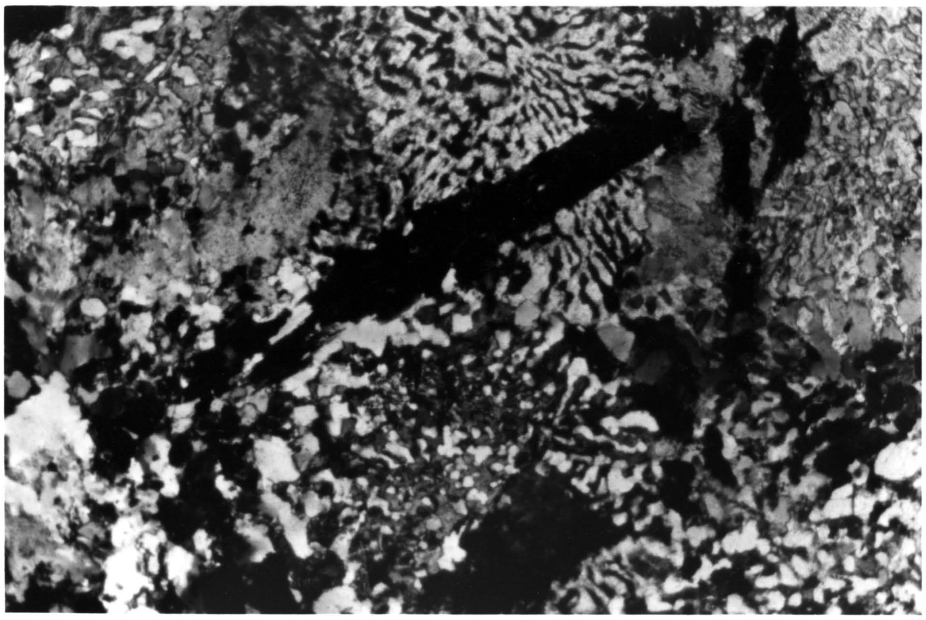


Fig. 24b: Pronounced granophyric texture in granodiorite. Note corroded needles of amphibole (black). Crossed nicols, X 40, Sterkwater 472 IT (ECH 808d)

is known along the eastern belt i.e. on Strydkraal 477 IT but its presence can be inferred from magnetite rubble in the soil elsewhere along this zone, as for instance on Rooipoort 481 IT and Burntop 445 IT. No magnetitite is known from the Amsterdam area.

The magnetitite occurs as disconnected lenses and segregations and at several localities two parallel layers can be observed only a few metres apart. The best development of this ore is on Derby 444 IT and Belfast 492 IT, near the common boundary of these two farms, where more or less continuous exposures can be traced over 2,5 km. Sporadic good outcrops can also be found on Ishlelo 441 IT.

The thickness of the layers is extremely variable and never exceeds 2 m. The dip varies from 15° to 30° east to northeast and occasionally restricted dip slopes are developed. Probable near-surface resources of magnetite iron ore of all the major occurrences on Ishlelo 441 IT, Derby 444 IT and Belfast 492 IT should not exceed 1 million tons. In Table 14 the chemical composition of two samples of magnetitite from Ishlelo is compared with that of magnetitite from the complex in Swaziland.

Table 14 : Chemical composition of magnetitite from the Usushwana Complex

	1	2	3	4
SiO_2	4,61	2,71	7,00	8,77
TiO_2	11,99	12,70	15,64	13,16
Al_2O_3	3,39	2,60	5,56	4,01
Fe_2O_3	51,24	53,71	39,56	39,60
FeO	25,04	25,40	29,14	28,78
MnO	-	-	0,26	0,52
MgO	0,56	0,43	0,82	0,08
CaO	0,05	0,05	2,17	2,42
Na_2O	0,03	0,03	0,22	0,05
K_2O	0,14	0,02	0,19	0,40
Cr_2O_3	0,07	0,04	0,02	0,01
V_2O_5	0,25	0,30	0,22	0,05
P_2O_5	-	-	0,17	0,06
Total	97,37	97,22	99,02	97,92

1. Ishlelo 441 IT (northernmost body, (ECH 483a).
   Analyst: National Institute for Metallurgy, Johannesburg
2. Ishlelo 441 IT (Hlelo River, ECH 489a).
   Analyst: National Institute for Metallurgy, Johannesburg

3 and 4. Swaziland, southeast of Mhlambanyati
(Hunter, 1970a, p. 653).

If the V_2O_5 and TiO_2 content of the magnetitite is considered as an indicator of the state of fractionation of the magma, as in the case of the Bushveld Complex (Willemse, 1969, p. 206), then the higher TiO_2 and lower V_2O_5 values of the magnetitite layers in Swaziland suggest that these either crystallised at a later stage or from a more fractionated magma than those of the Ishlelo area.

(iv) Gabbro

Rocks best described as gabbro are confined to the western belt of the gabbroic zone in the Piet Retief area. This gabbro is well exposed on Welgekozen 514 IT along the Piet Retief-Houtkop road, where it crosses the Farroloop and on the northeastern portion of the Piet Retief Townlands (Folder IB). Here it is a coarse-grained rock and intermittent outcrops can be seen over the entire width of the gabbroic zone which at this locality amounts to only 1,5 km. The gabbro is typically of light colour which is the result of advanced uralitisation of the pyroxenes.

Towards the south the gabbro could not be delimited with certainty and although ferrogabbro is present on Athalie gabbro certainly occurs further southwards beyond the mapped area. The northernmost exposure can be studied along the Piet Retief-Amsterdam road, where it enters the Usushwana Complex on Ishlelo 441 IT (G.10). Here only a very narrow strip of gabbro, some 150-200 m wide is wedged between Basement granite at its floor and ferrogabbro at its top. This strip could be followed for only a couple of hundred metres on either side of the road.

(v) Hyperite

A gabbroic rock marked by the presence of both clinopyroxene and orthopyroxene as well as accessory olivine occurs on Evergreen 425 IT (I.8) from where it extends south-eastwards into Swaziland. Outcrop conditions are poor but a number of detached exposures can be followed in a 500 m wide zone over a distance of some 4 km. The rock appears to be homogeneous throughout and no differentiation or layering is discernable. The hyperite is spatially unrelated to other exposures of the gabbroic rocks and its age relationship is therefore not known. A similar rock was observed on the eastern portion of Lions Glen 398 IT, some 12 km north-east of Amsterdam (G.1). Although the hyperite occurs together with ultramafic rocks typical of the Thole Formation at this locality its field and age relationships with neither the Thole ultramafics nor the quartz gabbro of the Usushwana Complex, both of which are exposed towards the west, could be established. A third small area with isolated outcrops of hyperite is found along the contact of the complex on the border between Blesbokspruit 515 IT and the Piet Retief Townlands (L.15). This exposure is marked by the presence of small amounts of disseminated sulphides which impart a characteristic iron staining to the weathered surface of the rocks. Another poorly exposed occurrence is found some 5 km further northwest of the latter locality, also at the contact of the Usushwana Complex and the Basement granite.

(b) The mafic suite in Swaziland

Winter (1965) and Hunter (1970a, p. 645-660) described the Usushwana Complex in Swaziland in some detail. Winter (1965) distinguished up to 10 varieties of gabbro in the nortern part of the complex in Swaziland, but he was unable to correlate them with those observed further south.

The most important points of correlation relevant to the present investigation are the following:

(i) Whereas the gabbroic rocks found in the southern and southwestern parts of the complex in Swaziland are comparable to those of the Piet Retief Suite, a much greater variety of rocks is developed along the northern limb of the complex, around Mhlambanyati (Hunter, 1970a, Table 1).

(ii) Quartz gabbro, devoid of layering, appears to be the most abundant variety in the southern and southwestern parts of the complex in Swaziland and in the Transvaal, where it is in places the only type present.

(iii) Titaniferous magnetitite is in places associated with the gabbroic rocks in southwestern Swaziland and in Transvaal.

(iv) Quartz gabbro is intrusive into pyroxenite in the northwestern part of the complex in Swaziland (Hunter, 1970a). A thickness of over 750 m of pyroxenite is reported, which is much more than that of any occurrence of Thole Formation mapped in the present area.

(v) Hypersthene gabbro is found at the base of the intrusive in the area bordering on the Transvaal but it has also been described from at least two zones higher up in the succession northwest of Mhlambanyati. Zones mineralised with copper and nickel sulphides are associated with this variety in Swaziland (Winter, 1965, p.11-13).

(c) Petrography

(i) Fabric and modal composition

The solitary outcrop of pyroxenite on Imbama 414 IT is a hypermelanic coarse-grained rock consisting essentially of ortho- and clinopyroxene and interstitial plagioclase. Hornblende is an abundant constituent of this rock. It forms large continuous crystals enclosing numerous relicts of pyroxene which it replaces.

The other members of the mafic suite are typical gabbroic cumulate rocks. Quartz gabbro, ferrogabbro and hyperite are normally medium-grained, but coarse-grained quartz gabbro occurs in the Amsterdam area. They are usually mesocratic rocks, the ferrogabbro being slightly darker than the quartz gabbro. Gabbro is as a rule of lighter colour and is also more coarse-grained.

In gabbro the plagioclase is the cumulus phase whereas pyroxene is intercumulus. In quartz gabbro and ferrogabbro both plagioclase and pyroxene are cumulus with late-stage micropegmatite as a conspicuous component of the intercumulus material, especially in the quartz gabbro. All these rocks are best described as mesocumulates (Wager, et al, 1960, p. 78).

Martini (1973) determined the modal composition of over 40 samples along a 2 km long traverse across the zone of gabbroic rocks on Ishlelo 441 IT (G.10). The results are presented in Figure 25. Large variations in modal composition are observed in places from one point to the next, but it has to be stressed that these may partly be ascribed to erroneous countings as a result of the strongly altered nature of the rocks, the reason why the ferromagnesian minerals were grouped together. The approximate average modal composition of the hyperite on Evergreen 425 IT (I.8), as determined by Van Vuuren (1965, p. 41), is as follows:

Plagioclase	38%
K-feldspar	8%
Augite	26%
Bronzite	18%
Quartz	8%
Amphibole, biotite and accessories	2%

(ii) Mineralogy

In addition to Van Vuuren's (1965) description of the mineralogy of three isolated gabbroic bodies southeast of Amsterdam, the composition of a large number of minerals were optically determined. Some of these determinations were subsequently corroborated by microprobe analyses (Tables 15, 16 and 17).

Olivine has been observed in only one thin section of

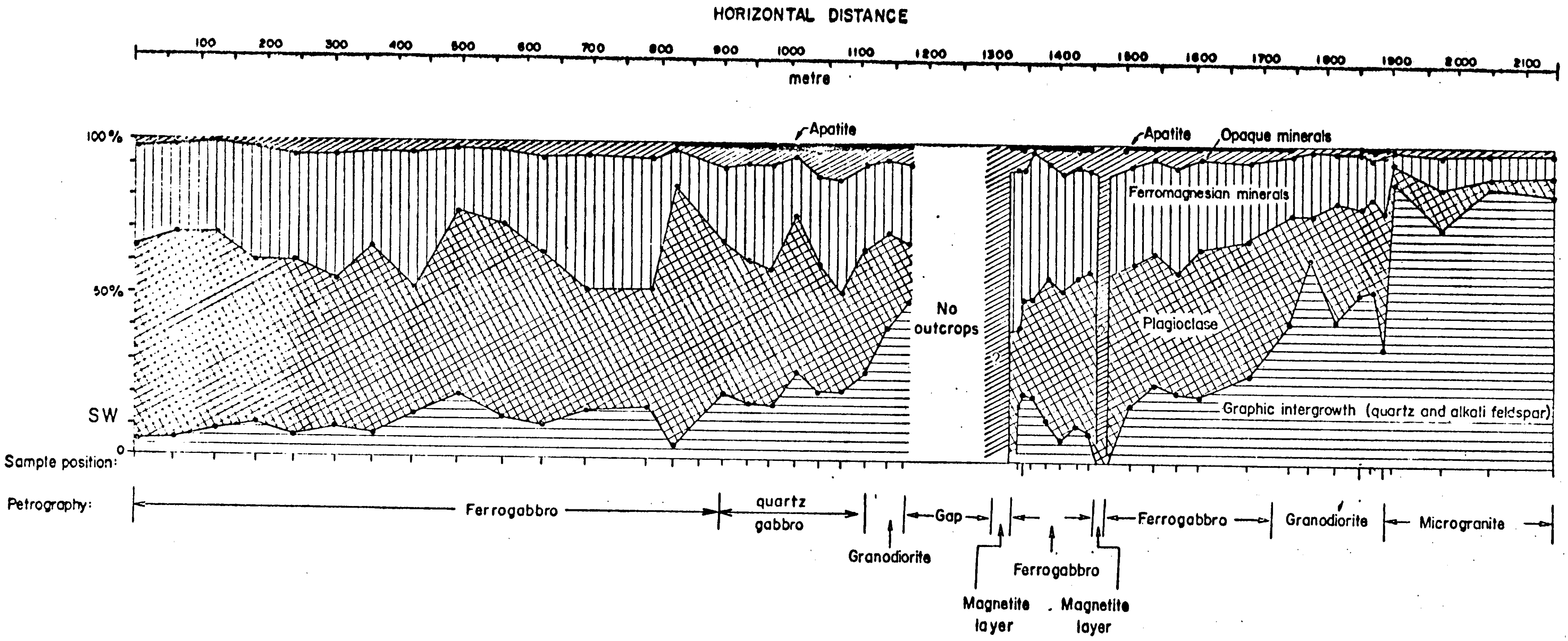


FIG.25: PETROGRAPHIC PROFILE ACROSS THE GABBROIC SUITE OF THE USUSHWANA COMPLEX ALONG THE HLELO RIVER (AFTER MARTINI, 1973) TRAVERSE IV, FOLDER IB.

hyperite (ECH 698b) which originates from Evergreen 425 IT. It was optically identified as chrysolite ($2V_z = \pm 90^o$).

Orthopyroxene of the pyroxenite from Imbama 414 IT was found on microprobe analysis to be bronzite (Mg_{78} Fe_{21} Ca_1) (Table 15). Large euhedral crystals of bronzite (Mg_{78-81} Fe_{16-21} Ca_{2-4}) are also developed in the hyperite. One analysis of orthopyroxene from quartz gabbro showed it to be ferrohypersthene (Mg_{40} Fe_{55} Ca_5) (Table 15). No orthopyroxene was observed in the light coloured gabbro.

Clinopyroxene. Optically the clinopyroxene was determined to be diopsidic augite ($c/Z = 40 - 41^o$ and $2V_z = 50\text{-}60^o$) but microprobe analyses indicate that in most cases it is a slightly more Fe-rich variety (Table 16). Two groups of clinopyroxenes can be distinguished mainly on the basis of their iron content. The one, normal augite, has a composition in the range of Mg_{34-57} Fe_{15-27} Ca_{29-43} and is found in gabbro and hyperite, whereas the other is ferroaugite (Mg_{26-42} Fe_{31-46} Ca_{31-36}) and is developed in the quartz gabbro and ferrogabbro. On the basis of the composition of the clinopyroxene the name ferrogabbro would thus apply to both the latter rock types.

Plotted on a pyroxene quadrilateral diagram the analyses of orthopyroxenes and clinopyroxenes fail to reveal a meaningful fractionation trend. This may be due to an unrepresentative suite of samples, owing to poor outcrop conditions.

Plagioclase. In the pyroxenite plagioclase occurs as a subordinate intercumulus mineral and has a composition of An_{58} Ab_{41} Or_1 (Table 17). The cumulus plagioclase of the quartz gabbro and ferrogabbro is normally labradorite (An_{51-53} Ab_{45-46} Or_{2-3}) but basic andesine is also present, for instance in quartz gabbro on Glen Eland 413 IT (ECH 635) and in ferrogabbro on Ishlelo 441 IT (ECH 488) (Table 17). Whereas basic labradorite (An_{65} Ab_{33} Or_2) is found in hyperite on the border of Blesbokspruit 515 IT and the Piet Retief Townlands, basic andesine (An_{48} Ab_{50} Or_2) is

Table 15 : Electron microprobe analyses of orthopyroxenes of gabbroic rocks of the Usushwana Complex

	1	2	3	4	5
SiO_2	50,29	53,45	54,60	51,92	52,56
Al_2O_3	0,81	1,33	1,48	0,68	0,49
Cr_2O_3	0,09	0,11	0,42	0,29	0,00
FeO*	32,15	14,02	14,03	25,03	14,49
MgO	13,51	28,88	27,43	20,11	29,93
CaO	2,12	1,63	1,85	2,09	0,79
NiO	0,27	0,36	0,32	0,05	0,05
Total	99,26	99,78	100,11	100,17	98,52

Structural Formula - Number of oxygens : 6

Si	1,97	1,92	1,95	1,95	1,92
Al	0,04	0,05	0,06	0,03	0,02
Cr	0,00	0,00	0,01	0,01	0,00
Fe	1,05	0,42	0,42	0,79	0,44
Mg	0,79	1,54	1,46	1,12	1,63
Ca	0,09	0,07	0,07	0,09	0,03
Ni	0,01	0,01	0,01	0,00	0,00
Z	2,00	2,00	2,00	2,00	2,00
W	0,11	0,08	0,08	0,09	0,03
X	1,88	1,96	1,90	1,93	2,01
Y	0,02	0,01	0,03	0,00	0,00
Mg	40	75	75	56	77
Fe	55	21	22	40	21
Ca	5	4	3	4	2

1. Quartz gabbro, Morgenstond 418 IT (ECH 505a)
2. Hyperite, Blesbokspruit 515 IT (ECH 754a)
3. Hyperite, Blesbokspruit 515 IT (ECH 755b)
4. Hyperite, Evergreen 425 IT (ECH 698c)
5. Pyroxenite, Imbama 414 IT (ECH 526)

Analyst: E. Hammerbeck, Geological Survey
(* Total iron reported as FeO)

Table 16 : Electron microprobe analyses of clinopyroxenes of gabbroic rocks of the Usushwana Complex

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	52,96	46,41	51,20	54,90	53,66	52,26	52,58	53,43	55,57	47,45	51,84	54,12	55,78	48,
TiO_2	0,18	0,63	0,07	0,19	0,57	0,72	0,87	0,31	0,70	0,34	0,25	0,29	0,11	0,
Al_2O_3	0,94	1,17	1,04	0,93	2,00	1,84	1,85	0,92	2,06	1,72	1,55	1,54	1,83	1,
Cr_2O_3	0,04	0,07	0,96	0,95	0,11	0,16	0,07	0,13	0,13	0,13	0,11	0,77	0,00	0,
FeO*	21,68	22,82	19,15	21,72	11,82	10,74	11,58	15,61	14,38	13,37	12,02	10,94	8,73	13,
MnO	0,00	0,47	0,00	0,00	0,50	0,44	0,47	0,60	0,33	1,33	0,41	0,07	0,18	0,
MgO	9,72	9,15	12,87	8,35	11,97	13,53	13,18	13,81	14,26	12,36	13,50	14,97	17,16	13,
CaO	14,38	18,22	14,63	12,78	19,29	20,00	20,54	14,77	12,88	21,90	19,89	17,60	15,78	19,
NiO	0,00	0,22	0,00	0,00	0,20	0,19	0,27	0,24	0,30	0,37	0,45	0,00	0,57	0,
Na_2O	0,19	0,52	0,20	0,13	0,48	0,49	0,33	0,21	0,30	0,23	0,41	0,66	0,41	0,
K_2O	0,03	0,06	0,00	0,00	0,05	0,06	0,05	0,06	0,08	0,07	0,04	0,01	0,02	0,
Total	100,12	99,75	100,12	99,95	100,65	100,43	101,81	100,09	101,01	99,27	100,48	100,97	100,57	98,

Structural Formula on the basis of 6 oxygens

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Si	2,03	1,87	1,96	2,09	2,00	1,95	1,95	2,01	2,03	1,86	1,95	1,99	2,02	1,
Ti	0,01	0,02	0,00	0,01	0,02	0,02	0,02	0,01	0,02	0,01	0,01	0,01	0,00	0,
Al	0,04	0,06	0,05	0,04	0,09	0,08	0,08	0,04	0,09	0,08	0,07	0,07	0,08	0,
Cr	0,00	0,00	0,03	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,
Fe^{2+}	0,70	0,77	0,61	0,69	0,37	0,34	0,36	0,49	0,44	0,44	0,38	0,34	0,26	0,
Mn	0,00	0,02	0,00	0,00	0,02	0,01	0,01	0,02	0,01	0,04	0,01	0,02	0,01	0,
Mg	0,56	0,55	0,74	0,48	0,66	0,75	0,73	0,77	0,78	0,72	0,76	0,82	0,93	0,
Ca	0,59	0,78	0,60	0,52	0,77	0,80	0,81	0,60	0,51	0,92	0,80	0,69	0,61	0,
Ni	0,00	0,01	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,02	0,
Na	0,01	0,04	0,02	0,01	0,03	0,04	0,02	0,02	0,02	0,02	0,03	0,05	0,03	0,
K	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,
Z	2,03	2,00	2,00	2,09	2,00	2,00	2,00	2,01	2,03	2,00	2,00	2,00	2,02	2,
W	0,60	0,82	0,62	0,53	0,80	0,84	0,83	0,62	0,53	0,94	0,83	0,74	0,64	0,
Y	0,05	0,00	0,04	0,08	0,11	0,05	0,05	0,05	0,11	0,00	0,03	0,07	0,08	0,
X	1,27	1,30	1,35	1,17	1,06	1,11	1,11	1,29	1,24	1,21	1,16	1,18	1,22	1,
Mg	30	25	38	28	36	40	38	41	45	34	39	44	51	3
Fe	38	38	31	41	22	18	20	27	26	23	20	18	15	2
Ca	32	36	31	31	42	42	42	32	29	43	41	38	34	4

1. Quartzgabbro, Kliprug 281 IT (ECH 635)
2. Quartzgabbro, Morgenstond 418 IT (ECH 505a)
3. Quartzgabbro, Morgenstond 418 IT (ECH 533b)
4. Ferrogabbro, Ishlelo 441 IT (ECH 488)
5. Gabbro, Piet Retief Townlands (ECH 810b)
6. Gabbro, Piet Retief Townlands (ECH 810c)
7. Gabbro, Piet Retief Townlands (ECH 810d)
8. Gabbro, Piet Retief Townlands (ECH 810e)
9. Gabbro, Piet Retief Townlands (ECH 810f)
10. Gabbro, Piet Retief Townlands (ECH 810g)
11. Hyperite, Blesbokspruit 515 IT (ECH 754a)
12. Hyperite, Evergeen 425 IT (ECH 698c)
13. Hyperite, Evergeen 425 IT (ECH 698c)
14. Basic dyke (altered) Glen Aggy 406 IT (ECH 574

Analyst: E. Hammerbeck, Geological Survey
(* Total iron reported as FeO)

Table 17 : Electron microprobe analyses of plagioclases from the gabbroic rocks of the Usushwana Complex

Sample No.	810a	810b	810c	810d	810e	810f	810g	810h	488	505a
SiO_2	52,83	55,58	52,25	53,96	54,17	53,18	53,33	51,71	55,90	54,38
Al_2O_3	30,18	28,27	28,85	27,99	28,23	29,35	28,76	29,87	26,52	27,59
FeO*	0,39	0,36	0,61	0,48	0,48	0,50	0,51	0,67	0,42	0,45
CaO	13,36	11,31	12,99	12,15	11,39	12,10	12,52	12,58	9,81	10,36
Na_2O	3,69	4,70	3,80	4,06	4,60	4,59	4,01	4,11	5,54	5,23
K_2O	0,37	0,50	0,39	0,42	0,56	0,50	0,42	0,42	0,36	0,52
Total	100,82	100,72	98,89	99,06	99,43	100,22	99,55	99,36	98,55	98,53

Structural formulae on the basis of 32 oxygen equivalents

	810a	810b	810c	810d	810e	810f	810g	810h	488	505a
Si	9,497	9,961	9,621	9,869	9,860	9,616	9,717	9,448	10,177	9,941
Al	6,394	5,971	6,254	6,025	6,056	6,256	6,176	6,433	5,690	5,945
Fe	0,058	0,053	0,093	0,067	0,073	0,077	0,077	0,102	0,064	0,068
Ca	2,575	2,172	2,563	2,375	2,222	2,333	2,444	2,462	1,913	2,030
Na	1,289	1,632	1,355	1,442	1,622	1,604	1,418	1,456	1,956	1,854
K	0,086	0,114	0,090	0,098	0,129	0,111	0,098	0,098	0,083	0,121
Z	15,89	15,93	15,88	15,89	15,92	15,87	15,89	15,88	15,87	15,89
X	3,950	3,918	4,008	3,915	3,973	4,048	3,960	4,016	3,952	4,005
An	65	55	64	61	56	57	62	62	48	51
Ab	33	42	34	37	41	40	36	36	50	46
Or	2	3	2	2	3	3	2	2	2	3

* Total iron as FeO

Analyst: R.C. Wallace, Geological Survey

continued/

Table 17 (continued)

Sample No.	533b	635	641	698c	732	754a	755b	526
SiO_2	55,22	56,58	55,11	55,20	54,92	51,83	51,75	52,76
Al_2O_3	28,62	26,58	27,32	27,56	27,27	30,58	29,35	30,02
FeO*	0,48	0,38	0,53	0,78	0,77	0,50	0,38	0,28
CaO	10,58	9,03	11,05	9,98	11,30	13,33	13,10	12,22
Na_2O	4,99	5,81	5,14	5,75	4,63	3,75	3,92	4,84
K_2O	0,53	0,57	0,46	0,39	0,41	0,37	0,42	0,15
Total	100,42	98,95	99,61	99,66	99,30	100,36	98,92	100,27

Structrual formulae on the basis of 32 oxygen equivalents

Si	9,901	10,249	9,993	9,989	9,983	9,379	9,518	9,52
Al	6,049	5,674	5,844	5,879	5,843	6,521	6,356	6,39
Fe	0,072	0,058	0,081	0,118	0,118	0,076	0,052	0,05
Ca	2,045	1,752	2,145	1,930	2,201	2,584	2,572	2,36
Na	1,740	2,041	1,806	2,018	1,631	1,315	1,331	1,69
K	0,125	0,132	0,106	0,089	0,096	0,086	0,086	0,03
Z	15,95	15,92	15,84	15,88	15,83	15,90	15,87	15,91
X	3,910	3,925	4,057	4,037	3,928	3,985	3,989	4,08
An	52	45	53	48	52	65	65	58
Ab	45	52	45	50	56	33	33	41
Or	3	3	2	2	2	2	2	1

* Total iron as FeO

Analyst: R.C. Wallace

808a-h, gabbro, Piet Retief Townlands
488, ferrogabbro, Ishlelo 441 IT
505a, quartz gabbro, Morgenstond 418 IT
533b, quartz gabbro, Morgenstond 418 IT
635, quartz gabbro, Glen Eland 413 IT
641, quartz gabbro, Tweepoort 404 IT
698c, hyperite, Evergreen 429 IT
732, ferrogabbro, Inhlovudwalile 421 IT
754a, hyperite, Blesbokspruit 515 IT
755b, hyperite, Blesbokspruit 515 IT
526, pyroxenite, Imbama 414IT

developed in these rocks on Evergreen 425 IT (Table 17). The composition of the plagioclase of the gabbro on the Piet Retief Townlands was found to vary between An_{55} Ab_{42} Or_3 and An_{65} Ab_{33} Or_2 (Table 17), indicating that this rock is slightly more basic than the other gabbroic varieties discussed above, excepting hyperite. Van Vuuren (1965, p. 38-42) reports values of An_{48-53} for plagioclase in quartz gabbro on Tweepoort 404 IT and the gabbroic bodies on Redcliff 426 IT and Evergreen 425 IT, An_{50-59} for ferrogabbro from the southern part of Inhlovudwalile 421 IT and An_{48-53} for hyperite from Evergreen.

Hornblende and biotite are in places conspicuous constituents of the gabbroic rocks. Hornblende is present in most of the thin sections studied: it is essentially a primary product but can in places also be seen to replace clinopyroxene. The hornblende is usually strongly pleochroic from very pale brown to light green and yellow brown.

Quartz is the most important intercumulus mineral. It is an ubiquitous constituent in quartz gabbro, ferrogabbro and hyperite, but distinctly less so in gabbro. Granophyric intergrowths are a common feature in the interstitial phase and can constitute 30 per cent or more of the rock.

Accessory minerals. Apatite, present in variable amounts, is the most ubiquitous accessory mineral. It occurs either in predominantly slender euhedral needles, which may in exceptional cases reach 0,3 mm in length, or in the form of rather anhedral grains. Euhedral to subhedral crystals of sphene, up to 0,3 mm in diameter, are noted in some sections but this mineral is a very minor constituent. Opaque minerals such as pyrite, magnetite, some pyrrhotite and very minor chalcopyrite are usually present in small amounts in the gabbroic rocks. In the ferrogabbro the opaque minerals, especially magnetite, may be present in amounts exceeding 10 per cent (Fig. 25).

Ilmenite occurs both in the form of more or less intimately intergrown grains and exsolution lamellae parallel to (111) in magnetite; ulvospinel could not be identified with certainty. The magnetite exhibits advanced maghemitisation and martitisation.

Secondary alteration products. In most specimens studied the saussuritisation of plagioclase and uralitisation of the pyroxenes has reached an advanced stage and frequently one or both of these minerals is entirely transformed to secondary minerals. In the gabbro the plagioclase is reasonably fresh but the clinopyroxene is largely altered to a fine fibrous aggregate of uralite. Elsewhere again the alteration has mainly affected the plagioclase which is transformed into an aggregate containing varying amounts of clinozoisite, zoisite, albite and sericite. Chlorite and epidote as well as green stilpnomelane, identified by X-ray diffraction analyses, are also commonly observed secondary minerals in all these rocks.

The effect of serpentinisation, of for instance ferrogabbro on Ishlelo 441 IT, can be seen by the formation of bastite, pseudomorphous after orthopyroxene. According to Tröger (1967, p. 621) bastite, in the above mode of occurrence, should have the composition of lizardite.

(iii) Chemical composition

A comparatively large number of chemical analyses were carried out on rocks of the mafic suite of the Usushwana Complex, in the first place to study the chemistry of the different rock types and their interrelationships in some detail, and secondly to establish any differentiation trends in the stratigraphic sequence of these rocks. The chemical composition of different gabbroic rocks of the complex, as well as the CIPW norms and Niggli equivalent norms and Niggli values are presented in Table 18.

In Table 19 the average composition of the major elements of some gabbroic rocks of the Usushwana Complex are compared with averages of certain rock types, computed by Nockolds (1954) and Barth (1962). The petrochemical characteristics of these rocks are further discussed in Chapter V.

2. The Hlelo Granite Suite

(a) Rock types and their field relationships

The acidic rocks related to the Usushwana Complex display considerable textural, mineralogical and chemical variations, but they can broadly be grouped into two categories, i.e. granodiorite and microgranite, although transitions between the two do occur.

(i) Granodiorite

The granodiorite occupies a position between the gabbroic rocks of the Piet Retief Suite and the roof rocks of the complex. The development of the granodiorite is practically restricted to the Piet Retief sector of the area mapped, i.e. from Ishlelo 441 IT southwards (Folder IB). Occurrences of rock resembling granodiorite in the Amsterdam area are believed to represent local varieties in the microgranite, which preponderates in this area.

There is a marked difference between granodiorite developed on

Table 18 : Chemical analyses of the gabbroic rocks of the Usushwana Complex

			1	2	3	4	5	6	7	8	9	10	11	12
Chemical analysis		SiO_2	52,83	52,95	52,34	52,17	52,76	53,07	52,48	52,29	51,57	52,31	53,02	57,63
		TiO_2	0,34	0,31	0,33	0,30	0,30	0,06	0,33	0,27	0,30	0,27	0,32	0,73
		Al_2O_3	18,27	17,25	17,45	16,26	18,06	17,52	17,60	17,76	18,19	17,81	18,60	15,24
		Fe_2O_3	1,54	1,92	2,08	2,03	0,72	1,30	1,33	1,41	1,59	1,36	1,38	1,49
		FeO	6,98	7,52	7,88	8,51	7,28	7,39	7,68	7,08	7,31	6,92	5,99	8,27
		MnO	0,16	0,18	0,19	0,21	0,18	0,18	0,18	0,17	0,18	0,17	0,14	0,05
		MgO	3,81	4,63	3,98	5,02	4,28	4,25	4,38	4,82	4,94	5,36	4,55	2,70
		CaO	10,52	10,79	10,64	10,72	10,59	11,03	11,14	11,00	11,21	10,84	10,78	7,49
		Na_2O	2,97	2,58	2,63	2,36	2,59	2,61	2,49	2,40	2,69	2,39	2,56	3,13
		K_2O	0,65	0,34	0,49	0,39	0,60	0,28	0,37	0,36	0,35	0,57	0,41	1,48
		P_2O_5	0,09	0,08	0,08	0,09	0,09	0,08	0,15	0,09	0,08	0,08	0,09	0,09
		CO_2	0,07	0,00	0,00	0,09	0,15	0,12	0,13	0,00	0,00	0,00	0,00	0,00
		H_2O^+	1,59	1,44	1,59	1,63	1,97	1,42	1,41	1,96	1,61	1,95	1,91	1,03
		H_2O^-	0.06	0.04	0.08	0.05	0.08	0.07	0.07	0.03	0.08	0.04	0,05	0,00
		Total	99,87	100,02	99,75	99,82	99,64	99,57	99,73	99,63	100,09	100,06	99,79	99,32
CIPW norm		Q	3,72	5,35	4,80	4,87	4,50	5,67	4,95	4,86	1,89	3,70	5,76	10,98
		or	3,84	2,00	2,89	2,30	3,54	1,67	2,18	2,12	2,06	3,36	2,42	8,74
		ab	25,12	21,82	22,25	19,96	21,91	22,08	21,06	20,30	22,75	20,22	21,65	26,48
		an	34,60	34,48	34,36	32,62	35,88	32,26	35,75	36,62	36,53	36,19	38,05	23,16
	di	wo	6,89	7,67	7,46	8,05	16,29	7,56	7,37	7,17	7,67	7,03	6,11	5,67
		en	3,64	4,30	3,80	4,43	3,33	4,00	3,90	4,16	4,45	4,28	3,72	2,33
		fs	3,25	3,37	3,66	3,62	2,95	3,55	3,46	3,01	3,22	2,74	2,38	3,34
	hy	en	7,37	8,84	7,66	10,08	9,01	8,19	8,67	9,63	9,66	10,90	9,09	5,65
		fs	6,53	7,02	7,35	8,25	7,99	7,26	7,69	6,97	6,99	6,97	5,81	8,15
		mt	2,23	2,78	3,01	2,94	1,04	1,88	1,92	2,04	2,30	1,97	2,00	2,16
		ilm	0,64	0,58	0,62	0,56	0,56	0,49	0,62	0,51	0,56	0,51	0,60	1,38
		ap	0,21	0,18	0,18	0,21	0,21	0,18	0,35	0,21	0,18	0,18	0,21	0,21
		cc	0,15	0,00	0,00	0,20	0,34	0,27	0,29	0,00	0,00	0,00	0,00	0,00
		H_2O	1,64	1,47	1,66	1,67	2,04	1,48	1,47	1,98	1,68	1,98	1,95	1,02
		Total	99,88	100,02	99,75	99,82	99,64	99,57	99,73	99,63	100,09	100,06	99,79	99,33
Niggli values		al	28,23	25,92	26,51	24,01	27,98	26,82	26,56	26,76	26,55	26,42	26,69	27,13
		alk	8,34	6,93	7,38	6,36	7,60	7,04	6,79	6,54	7,01	6,75	7,18	12,02
		fm	33,58	37,69	36,72	40,85	34,60	35,44	36,10	36,57	36,70	37,61	33,89	36,58
		c	29,55	29,47	29,39	28,78	29,82	30,69	30,56	30,13	29,74	29,23	30,23	24,25
		si	138,49	134,96	134,91	130,71	138,67	137,84	134,34	133,66	127,68	131,64	138,77	174,15
		k	0,13	0,08	0,11	0,99	0,13	0,07	0,09	0,09	0,08	0,14	0,10	0,24
		mg	0,44	0,47	0,42	0,46	0,49	0,46	0,46	0,50	0,49	0,54	0,52	0,33
Katanorm		Q	3,19	4,85	4,34	4,32	3,88	5,06	4,29	4,44	1,66	3,31	5,24	9,99
		Or	3,93	2,06	2,99	2,38	3,66	1,07	2,25	2,19	2,11	3,45	2,48	9,05
		Ab	27,33	23,74	24,38	21,89	23,99	24,13	23,00	22,22	24,65	21,96	23,58	29,09
		An	35,47	35,35	35,49	33,72	37,04	36,32	36,80	37,78	37,29	37,05	39,05	23,99
		Wo	6,99	7,61	7,41	8,28	6,65	7,82	7,66	7,18	7,60	7,01	6,11	5,57
		En	10,78	13,10	11,34	14,32	12,19	12,08	12,44	13,72	13,92	15,14	12,89	7,72
		Hy	10,24	10,86	11,41	12,50	11,41	11,14	11,58	10,57	10,71	10,27	8,76	12,27
		Mt	1,65	2,06	2,24	2,19	0,78	1,40	1,43	1,52	1,70	1,46	1,48	1,61
		Cp	0,18	0,16	0,16	0,18	0,18	0,16	0,03	0,18	0,16	0,16	0,18	0,18
		Ru	0,24	0,22	0,24	0,22	0,22	0,19	0,24	0,19	0,21	0,19	0,23	0,53

/continued

Table 18 (continued)

			13	14	15	16	17	18	19	20	21	22	23	24
Chemical composition		SiO_2	53,98	54,40	54,20	55,79	55,03	56,38	47,58	51,48	50,22	49,63	50,70	50,72
		TiO_2	0,57	0,37	0,62	0,61	0,62	1,44	2,33	1,83	1,04	1,39	0,11	0,31
		Al_2O_3	17,84	17,61	14,40	14,25	17,49	13,15	11,16	14,42	15,37	15,25	18,68	17,04
		Fe_2O_3	1,32	0,82	1,28	1,48	1,24	3,18	4,28	3,29	3,79	4,85	1,23	1,66
		FeO	7,78	7,34	8,27	8,17	7,28	9,82	15,38	11,49	9,52	9,81	4,71	6,64
		MnO	0,05	0,05	0,18	0,17	0,14	0,18	0,29	0,20	0,20	0,19	0,13	0,15
		MgO	2,92	4,33	5,35	4,18	2,94	1,17	5,64	3,11	3,41	3,75	7,40	6,36
		CaO	9,40	10,08	9,89	8,94	9,32	8,01	8,85	8,14	11,01	9,64	12,58	12,64
		Na_2O	3,23	2,98	2,38	2,52	3,09	2,71	2,15	5,52	2,66	2,32	2,31	1,98
		K_2O	0,68	0,61	1,04	1,26	0,95	1,44	0,54	0,97	0,52	0,47	0,08	0,16
		P_2O_5	0,03	0,03	0,13	0,12	0,15	0,23	0,09	0,12	0,09	0,12	0,08	0,10
		CO_2	0,00	0,00	0,05	0,18	0,14	0,23	0,36	0,32	0,24	0,10	-	-
		H_2O^+	1,10	1,24	1,28	2,06	1,42	1,67	1,28	0,73	1,71	1,98	1,96	2,09
		H_2O^-	0,00	0,00	0,09	0,03	0,06	0,10	0,09	0,10	0,03	0,06	0,09	0,04
		Total	98,91	99,87	99,88	99,75	99,86	99,70	100,46	99,75	99,80	99,55	100,05	99,88
CIPW norm		Q	5,64	4,83	6,41	9,80	7,47	15,12	1,57	2,71	4,26	6,78	0,33	2,86
		or	4,01	3,60	6,14	7,44	5,61	8,51	3,19	5,73	3,07	2,77	0,47	0,94
		ab	27,32	25,21	20,13	21,32	26,14	22,92	18,19	30,12	22,50	19,62	19,54	16,75
		an	32,17	32,87	25,54	23,85	31,05	19,46	20,43	20,50	28,46	29,81	40,37	37,14
	di	wo	6,46	7,04	9,25	7,75	5,60	7,50	8,65	7,23	10,09	6,93	8,67	10,17
		en	2,84	3,80	5,27	4,03	2,58	1,72	4,06	2,89	4,74	3,53	6,59	6,81
		fs	3,61	3,24	3,98	3,72	3,02	5,78	4,58	4,34	5,35	3,39	2,08	3,36
	hy	en	5,96	8,66	10,03	8,20	6,10	1,96	12,57	6,46	5,33	7,38	13,50	11,04
		fs	7,58	7,38	7,56	7,56	7,16	6,55	14,18	9,68	6,02	7,10	4,26	5,44
		mt	1,91	1,18	1,85	2,14	1,79	4,61	6,20	4,76	5,49	7,03	1,78	2,40
		ilm	1,08	0,70	1,17	1,15	1,17	2,73	4,42	3,47	1,97	2,63	0,20	0,58
		ap	0,07	0,07	0,30	0,28	0,35	0,54	0,21	0,28	0,21	0,28	0,18	0,23
		cc	0,00	0,00	0,11	0,40	0,31	0,52	0,81	0,72	0,54	0,22	0,00	0,00
		H_2O	1,09	1,23	2,09	2,08	1,47	1,76	1,36	0,82	1,73	2,03	2,04	2,12
		Total	98,89	99,86	99,88	99,75	99,87	99,70	100,46	99,75	99,80	99,55	100,05	99,88
Niggli values		al	29,16	27,51	22,30	23,63	29,11	23,94	15,74	22,26	22,75	22,77	25,73	23,91
		alk	9,89	8,69	7,81	9,13	10,17	10,95	5,58	10,66	7,30	6,46	5,35	4,81
		fm	33,02	35,17	42,05	40,28	32,53	38,61	56,88	44,24	40,33	44,60	37,40	39,05
		c	27,93	28,63	27,84	26,95	28,19	26,50	21,80	22,84	29,62	26,17	31,50	32,23
		si	149,68	144,20	142,40	156,95	155,36	174,12	109,40	134,83	126,07	125,74	118,50	120,71
		k	0,12	0,12	0,22	0,25	0,17	0,26	0,14	0,15	0,11	0,12	0,02	0,05
		mg	0,36	0,49	0,50	0,44	0,38	0,14	0,34	0,27	0,32	0,32	0,69	0,56
Katanorm		Q	4,98	4,29	5,62	8,77	6,47	13,52	0,00	0,85	3,05	5,49	0,23	2,49
		Or	4,15	3,67	6,36	7,76	5,77	9,06	3,37	5,97	3,22	2,95	0,48	0,97
		Ab	29,94	27,23	22,12	23,60	28,54	25,93	20,40	33,28	25,07	22,10	20,64	18,26
		An	33,23	33,47	26,45	24,88	31,96	20,75	21,60	21,36	29,89	31,14	40,77	38,16
		Wo	5,90	6,90	9,42	8,26	5,88	8,06	9,70	7,98	10,76	7,34	8,71	10,26
		En	8,32	12,17	15,29	12,03	8,35	3,44	13,79	8,94	9,88	10,98	20,63	18,03
		Hy	11,56	11,06	12,63	12,40	10,94	14,15	22,51	16,47	13,03	12,85	6,71	9,62
		Mt	1,42	0,87	1,39	1,61	1,33	3,54	4,73	3,58	4,16	5,38	1,30	1,78
		Cp	0,00	0,06	0,26	0,25	0,30	0,48	0,19	0,24	0,19	0,25	0,16	0,20
		Ru	0,41	0,26	0,45	0,44	0,44	1,07	1,72	1,33	0,76	1,03	6,08	0,22

/continued

Table 18 (continued)

			25	26	27	28	29	30	31	32	33	34	35
Chemical composition		SiO_2	52,19	51,76	51,89	51,59	52,29	51,84	55,53	55,96	51,93	56,60	50,56
		TiO_2	0,26	0,23	0,21	0,25	0,24	0,22	0,63	0,79	0,46	1,52	0,64
		Al_2O_3	21,18	19,15	18,95	19,42	18,29	16,82	13,43	9,07	12,87	12,20	6,57
		Fe_2O_3	0,83	1,22	1,11	0,89	0,72	1,57	1,19	1,12	0,61	5,79	1,26
		FeO	4,52	5,52	5,37	5,39	5,73	6,30	8,37	8,27	7,61	9,72	8,28
		MnO	0,10	0,13	0,14	0,12	0,14	0,16	0,19	0,05	0,03	0,20	0,18
		MgO	3,57	4,89	4,86	5,32	5,22	5,80	6,95	11,90	13,65	1,29	18,54
		CaO	12,15	12,27	12,49	12,08	11,81	12,26	8,37	7,72	10,14	5,31	10,74
		Na_2O	2,59	2,46	2,55	2,69	2,37	2,36	2,93	2,14	1,07	1,76	0,87
		K_2O	0,49	0,30	0,25	0,31	0,57	0,23	0,71	1,03	0,38	1,51	0,25
		P_2O_5	0,09	0,08	0,09	0,09	0,09	0,08	0,12	0,13	0,05	0,42	0,18
		CO_2	-	-	-	-	-	-	0,11	0,00	0,00	0,00	0,19
		H_2O^+	1,53	1,72	1,83	1,52	1,91	1,96	2,97	0,92	0,76	3,76	1,63
		H_2O^-	0,03	0,06	0,10	0,05	0,06	0,07	0,08	0,02	0,00	0,04	0,07
		Total	99,64	99,78	99,83	99,82	99,54	99,66	101,57	99,14	99,57	100,11	99,96
CIPW norm		Q	4,18	3,17	3,02	1,43	3,58	3,43	5,89	5,27	1,08	24,06	0,00
		or	2,89	1,77	1,47	1,83	3,36	1,35	4,19	6,08	2,24	8,92	1,47
		ab	21,91	20,81	21,57	22,75	20,05	19,96	24,79	18,10	9,05	14,89	7,36
		an	44,72	40,33	39,52	40,00	37,58	34,62	21,40	12,10	29,19	20,93	13,26
		wo	5,84	8,20	8,95	7,62	8,08	10,50	7,65	10,22	8,35	1,15	15,03
	di	en	3,62	5,33	5,81	5,02	5,17	6,93	4,82	7,77	6,59	0,32	12,32
		fs	2,22	2,87	3,13	2,59	2,91	3,57	2,83	2,45	1,75	0,82	2,70
		en	6,52	8,53	7,92	9,75	9,50	9,48	14,79	24,81	30,45	3,63	28,20
	hy	fs	3,99	4,59	4,26	5,02	5,35	4,88	8,69	7,83	8,09	9,32	6,19
		mt	1,20	1,76	1,60	1,29	1,04	2,27	1,72	1,62	0,88	8,39	1,82
		ilm	0,49	0,43	0,39	0,47	0,45	0,41	1,19	1,50	0,87	2,88	1,21
		ap	0,21	0,18	0,21	0,21	0,21	0,18	0,28	0,30	0,11	0,99	0,42
		cc	0,27	0,00	0,00	0,25	0,25	0,00	0,25	0,00	0,00	0,00	0,43
		H_2O	1,55	1,77	1,92	1,56	1,96	2,02	3,04	0,93	0,75	13,78	1,70
	ol	fo	-	-	-	-	-	-	-	-	-	-	6,39
		fa	-	-	-	-	-	-	-	-	-	-	1,40
		Total	99,64	99,78	99,83	99,82	99,54	99,66	101,57	99,03	99,46	100,11	99,92
Niggli values		al	32,74	28,26	28,01	28,33	27,41	24,32	20,51	12,73	16,12	23,87	7,44
		alk	7,40	6,45	6,60	6,94	6,77	5,97	8,53	6,50	2,72	8,86	1,93
		fm	25,72	32,37	31,82	32,69	33,65	37,50	47,71	61,07	58,08	48,39	68,52
		c	34,14	32,91	33,56	32,04	32,18	32,21	23,24	19,70	23,09	18,88	22,11
		si	136,85	129,58	130,14	127,68	132,95	127,12	143,89	133,25	110,34	187,86	97,16
		k	0,11	0,07	0,06	0,07	0,14	0,06	0,14	0,24	0,19	0,36	0,16
		mg	0,54	0,56	0,57	0,60	0,59	0,57	0,56	0,70	0,74	0,13	0,78
Katanorm		Q	3,60	2,82	2,70	1,02	3,08	3,12	4,97	4,34	0,66	23,31	0,00
		Or	2,95	1,81	1,51	1,85	3,45	1,40	4,28	6,16	2,24	9,82	1,48
		Ab	23,71	22,54	23,37	24,49	21,82	21,76	26,82	19,44	9,58	17,40	7,80
		An	45,61	41,17	40,35	40,57	38,55	35,57	21,83	12,25	29,13	23,05	13,27
		Wo	6,12	8,19	8,94	7,86	8,39	10,67	7,92	10,29	8,30	1,29	15,56
		En	10,05	13,78	13,69	14,89	14,77	16,44	19,56	33,23	37,59	3,92	36,91
		Hy	6,71	8,07	7,92	8,03	8,81	9,10	12,68	12,15	11,25	12,48	12,22
		Mt	0,88	1,30	1,18	0,94	0,77	1,69	1,27	1,18	0,64	6,66	1,32
		Cp	0,18	0,16	0,18	0,18	0,18	0,18	0,24	0,26	0,10	0,91	0,35
		Ru	0,18	0,16	0,15	0,18	0,17	0,16	0,45	0,56	0,32	1,17	0,45
		Fo	-	-	-	-	-	-	-	-	-	-	10,66

Table 18: (continued)

1.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809c)
2.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809d)
3.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809e)
4.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809f)
5.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809g)
6.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809h)
7.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809i)
8.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809j)
9.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809k)
10.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809l)
11.	Quartz gabbro,	Sterkwater	472 IT	(ECH 809m)
12.	Quartz gabbro,	Kliprug	281 IT	(ECH 635)
13.	Quartz gabbro,	Morgenstond	418 IT	(ECH 505a)
14.	Quartz gabbro,	Morgenstond	418 IT	(ECH 533b)
15.	Quartz gabbro,	Evergreen	425 IT	(ECH 492d)
16.	Quartz gabbro,	Tweepoort	404 IT	(ECH 641)
17.	Quartz gabbro,	Lions Glen	398 IT	(ECH 666d)
18.	Ferrogabbro,	Inhlovudwalile	421 IT	(ECH 732)
19.	Ferrogabbro,	Ishlelo	441 IT	(ECH 488)
20.	Ferrogabbro,	Inhlovudwalile	421 IT	(ECH 725)
21.	Ferrogabbro,	Sterkwater	472 IT	(ECH 809a)
22.	Ferrogabbro,	Sterkwater	472 IT	(ECH 809b)
23.	Gabbro,	Piet Retief Townlands		(ECH 810a)
24.	Gabbro,	Piet Retief Townlands		(ECH 810b)
25.	Gabbro,	Piet Retief Townlands		(ECH 810c)
26.	Gabbro,	Piet Retief Townlands		(ECH 810d)
27.	Gabbro,	Piet Retief Townlands		(ECH 810e)
28.	Gabbro,	Piet Retief Townlands		(ECH 810f)
29.	Gabbro,	Piet Retief Townlands		(ECH 810g)
30.	Gabbro,	Piet Retief Townlands		(ECH 810h)
31.	Quartz gabbro,	Redcliff	426 IT	(ECH 692)
32.	Hyperite,	Evergreen	425 IT	(ECH 695)
33.	Hyperite,	Lions Glen	398 IT	(ECH 666a)
34.	Ferrogabbro (chilled),	Tweepoort	404 IT	(ECH 730b)
35.	Pyroxenite,	Imbama	414 IT	(ECH 526)

Analysts: National Institute for Metallurgy and General Superintendence Co., Johannesburg.

Table 19: Average composition of some gabbroic rocks of the Usushwana Complex compared with average gabbros

	1	2	3
SiO_2	53,45 ± 1,51	51,06 ± 2,33	51,62 ± 0, 56
TiO_2	0,39 ± 0,17	1,61 ± 0,44	0,23 ± 0,03
Al_2O_3	17,15 ± 1,28	13,87 ± 1,57	18,69 ± 1,30
Fe_2O_3	1,43 ± 0,41	3,88 ± 0,39	1,15 ± 0,32
FeO	7,51 ± 0,60	11,20 ± 2,20	5,52 ± 0,57
MgO	4,26 ± 0,78	3,42 ± 1,43	5,43 ± 1,06
CaO	10,26 ± 0,85	9,13 ± 1,11	12,29 ± 0,26
Na_2O	2,68 ± 0,28	3,07 ± 1,34	2,41 ± 0,26
K_2O	0,64 + 0,34	0,78 + 0,37	0,30 + 0,15

	4	5	6
SiO_2	54,39	51,86	48,36
TiO_2	1,29	1,50	1,32
Al_2O_3	16,72	16,40	16,84
Fe_2O_3	2,49	2,73	2,55
FeO	7,15	6,97	7,92
MgO	4,15	6,12	8,08
CaO	6,68	8,40	11,07
Na_2O	3,15	3,36	2,26
K_2O	1,58	1,33	0,56

1. Quartz gabbro, Usushwana Complex (17 samples)
2. Ferrogabbro, Usushwana Complex (5 samples)
3. Gabbro, Usushwana Complex (8 samples)
4. Quartz gabbro, average after Barth (1962, p. 59)
5. Diorite, average after Nockolds (1954, p. 1019)
6. Gabbro, average after Nockolds (*ibid.*, p. 1020)

either side of the zone of roof rocks northeast of Piet Retief. Along the eastern side, where the gabbro is in contact with Vaalkop rhyolite, typical coarse granodiorite is developed as for instance on Sterkwater 472 IT (L.12), but in the west, where the rhyolite is partly underlain by rocks of the Amsterdam Formation, e.g. on the eastern part of Mooihoek 491 IT and Belfast 492 IT (J/K.13), a more fine-grained variety is present.

The granodiorite could not be traced all along the contact between the gabbroic rocks and the roof rocks but, on the other hand, it is only very rarely found in a position unrelated to this zone. Only one such occurrence is known on Ishlelo 441 IT along the Hlelo River in the hills immediately west of the magnetitite layer (G/H.10) and here it is believed to constitute a roof pendant of an originally larger overlying body of rhyolite and/or granodiorite which has subsequently been removed by erosion. That this is so can be demonstrated by the fact that granodiorite is found in a similar "stratigraphic" position at the base of the large body of microgranite just east of the Amsterdam - Piet Retief road, about 2,5 km northwest of the locality on the Hlelo River (G.9/10).

Xenoliths of quartzite, some tens of centimetres to several metres in extent, can frequently be seen in the granodiorite near the interface with its roof, e.g. on Ishlelo both at the above described locality and at the contact between the granodiorite and the main body of acid rocks east of the magnetitite exposures, as well as at the northeastern portion of Derby 444 IT and on Rooipoort 481 IT.

Two small outcrops of hornblendite, about 1,5 km apart, occur more or less on the contact of the granodiorite with ferrogabbro, on Kopje Alleen 479 IT and Rooipoort 481 IT. The outcrop on Rooipoort is very much smaller than that further north and occurs in a little donga in the immediate vicinity of a small exposure of magnetitite, rather in the fashion of a dyke. The rock is fine-grained and melanocratic, containing in places white phenocrysts of feldspar set in a dense network of hornblende crystals.

Transitional rocks situated between gabbro and "granophyre" have also been described from Swaziland, where Winter (1965, p. 10) and Hunter (1970a, p. 650) refer to them as hybrid gabbro. From their descriptions these rocks closely resemble those in the Piet Retief area. The actual thickness of the granodiorite could not be established with certainty in the present area but it does not attain a thickness of 330 m, as is reported from Swaziland.

(ii) Microgranite

Acidic rocks exhibiting a granitic texture are found in two belts along both limbs of the Usushwana Complex in the Amsterdam area. The western belt extends intermittently north and northwestwards from Kromrivier 145 IT in the south (I.11) to the common boundary of Glen Eland 413 IT and Kliprug 281 IT in the northwest (A.4) a total distance of almost 40 km. Along the eastern belt microgranite is present along the Swaziland border on Evergreen 425 IT and Haarlem 443 IT, south of the Ngwempisi River (I.8), and reappears again north of the river, from where it can be traced continuously over 15 km to the northern part of Tweepoort 404 IT (G.4).

The following field relationships are especially noteworthy:

(i) Granitic rocks do not always form the acidic counterpart of the mafic suite of the complex. They are always associated with gabbro but not *vice versa*. In the Amsterdam area the gabbro is frequently not accompanied by an acid phase, e.g. on the southern part of Kolwani and in the isolated gabbro intrusives on Imbama 414 IT, Glen Eland 413 IT, De Hoop 402 IT and Lions Glen 398 IT.

(ii) The granitic rocks appear to rest on top of the mafic rocks of the complex. This is best demonstrated on a regional scale by three prominent hills of microgranite which overly the gabbro at various "stratigraphic" positions (see Folder IB). The northernmost of these hills on Ishlelo 441 IT builds a prominent landmark immediately east of the Piet Retief-Amsterdam road. This outlier of microgranite overlies the basal part of the complex near its contact with the Basement granite. Only a narrow zone of gabbroic rocks, some 250 m wide, remains exposed between these two formations. Here the microgranite actually occurs in a position below the east and northeast dipping magnetitite layer. The central group of hills, on both flanks of the Hlelo River, is situated above the magnetitite layer which is found some 350 m farther south and dips at 30° north, underneath the microgranite hill. The southernmost hill, which constitutes the largest exposure of microgranite in this area, transgresses right across the magnetitite layer. On Ishlelo it is situated above it and on Derby and Kromrivier again below it, having again extended almost to the western contact of the complex with the Basement granite.

(iii) Small outliers of granitic rocks situated either on gabbro, as on the common boundary of Kromrivier, Leliefontein and Derby (I.11), or even on Basement granite close to the gabbro contact, as on Ishlelo (G.10) as well as Kromrivier and Leliefontein and Derby (I.11/14), are presumably erosion relicts of an originally continuous cover of these rocks. A similar outlier of Vaalkop rhyolite on Basement granite is found on Strydkraal 477 IT (M.13).

(iv) The contact between the gabbroic rocks and the micro-granite appears to be flat or undulating. This is borne out by the transgressive relationship discussed above and by exposures of gabbro adjacent to or within the microgabbro at topographically favourable positions. Such outcrops are found on Ishlelo immediately northeast of the southernmost magnetitite layer as well as in a small inlier of gabbro next to the Hlelo River. Farther north on Wolvenkop 427 IT and Morgenstond 418 IT gabbro is also found on both sides of the hills of microgranite (Folder IA). The present distribution of the granitic rocks thus appears to be the result of some morphological control quite unrelated to their relationship with the mafic suite of the complex.

(b) Petrography

(i) Fabric and modal composition

The granodiorite is not of uniform composition and gradations from a mesocratic to a more leucocratic variety can be observed. It does not differ much from the Vaalkop rhyolite, texturally and except for a markedly higher content of ferromagnesian minerals, it consists also of totally saussuritised plagioclase phenocrysts set in a more or less granophyrically intergrown matrix. Needle-like and irregular aggregates of hornblende, pleochroic mainly in brown-green to blue-green, occur in varying amounts (Fig. 24b). The proportion of amphibole present in the rock decreases higher up in the succession and is largely responsible for the observed variations in colour. These conspicuous amphibole "needles" are the most distinctive macroscopical feature of this rock.

The rocks described here as microgranite all have a fine- to medium-grained equigranular granitic texture and two main types may be distinguished. The first and most common variety is characterised by a high, though variable, content of micropegmatite. The second and less common type is a true granite exhibiting no or only insignificant amounts of granophyric intergrowths. All possible gradations between the above two varieties, and in fact between microgranite and granodiorite may be observed. Femic minerals, mainly hornblende, may or may not be present. In fresh hand specimens the microgranite usually has a distinctly red colour.

A wide range of variations in the modal composition of the granodiorite and of the microgranite is observed, both within each of these rock types and between the two (Table 20).

Table 20 : Modal composition of granodiorite and microgranite of the Hlelo Suite

	1	2	3	4	5	6	7	8	9	10
Quartz	-	11,9	-	11,0	26,0	21,8	35,7	35,3	36,0	33,0
K-feldspar	-	-	-	-	25,0	29,9	50,1	48,5	40,2	38,0
Plagioclase	13,0	29,7	23,6	24,5	28,0	3,0	2,0	5,3	7,7	16,0
Granophyric intergrowth	51,9	25,7	49,6	28,5	-	36,6	8,0	-	6,1	-
Ferromagnesian minerals	33,3	31,0	24,3	33,0	21,0	4,1	2,0	7,3	8,2	13,0
Accessories	0,8	1,7	2,5	3,0	-	1,6	2,2	3,6	1,8	-
Total	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

1. Granodiorite, Sterkwater 472 IT (ECH 808a)
2. Granodiorite, Sterkwater 472 IT (ECH 808b)
3. Granodiorite, Sterkwater 472 IT (ECH 808c)
4. Granodiorite, Sterkwater 472 IT (ECH 808d)
5. Granodiorite, Evergreen 425 IT (Van Vuuren, 1965, p. 28)
6. Microgranite, Haarlem 443 IT (ECH 501b)
7. Microgranite, Kromrivier 445 IT (ECH 495c)
8. Microgranite, Glen Eland 413 IT (ECH 527)
9. Microgranite, Wolvenkop 427 IT (ECH 473a)
10. Microgranite, Inhlovudwalile 421 IT (Van Vuuren, 1965, p. 28)

(ii) Mineralogy

Differences and similarities in the mineralogical composition of the granodiorite and the micrógranite are discussed below.

Quartz is always an important constituent in both the granodiorite and the microgranite. In granodiorite it is predominantly present in granophyric intergrowths which, however, may be relatively coarse in places. Free quartz in granodiorite from Sterkwater 771 IT exhibits a strongly undulatory extinction, indicating that this rock has been subjected to stress. Whereas quartz is a common constituent in the microgranite, this rock also contains a strongly variable component of granophyrically intergrown quartz and K-feldspar which, in exceptional cases, may constitute the bulk of the microgranite.

Alkali feldspar and plagioclase. In microgranite alkali feldspar, viz. perthitic orthoclase or microcline, preponderates over plagioclase which consists mainly of oligoclase and sodic andesine. The plagioclase crystals may be up to 1,5 mm in diameter, but they are almost invariably severely altered and for this reason no microprobe analyses were attempted. Except for a solitary twinned crystal, 5 mm in diameter, no K-feldspar was observed in the granodiorite other than that contained in the micropegmatite. Occasional plagioclase phenocrysts in the granodiorite are strongly saussuritised. The crystals are in places in the form of broken stumps and may be strongly corroded (Fig. 26a), thus indicating that they originated from an older rock which was incorporated in the granodiorite. There can be no doubt that this rock is the Vaalkop rhyolite which in places consists of altered feldspar phenocrysts set in a granophyric mesostasis (cf. Fig. 22a).

Ferromagnesian minerals. Hornblende, pleochroic in brown-

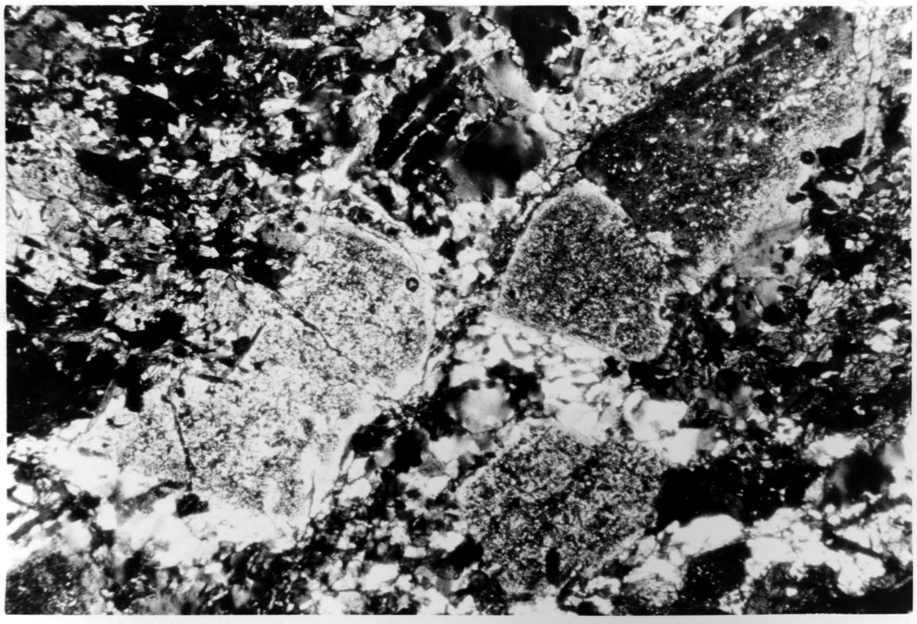


Fig. 26a: Corroded and deformed, totally saussuritised plagioclase crystals in a granophyric matrix of granodiorite. Crossed nicols, X 40, Sterkwater 472 IT (ECH 808b)

Fig. 26b: Intrusion breccia, consisting of fragments of lava of the Ngwempisi Formation in quartz gabbro of the Usushwana Complex. Morgenstond 418 IT

green to blue-green, is the most abundant amphibole in the microgranite. Its distribution is very erratic and it is found either in large, usually corroded, crystals or, in some cases, interstitially with respect to other minerals.

Other ferromagnesian minerals which are observed in places in the microgranite are remnants of altered biotite and in one sample green aegirine ($2V_x = 62^o$) was identified. The conspicuous amphibole needles of the granodiorite are composed of a similarly coloured variety of hornblende as described above. However, hornblende also occurs in this rock as minute elongated crystals, up to 0,3 mm long distributed in a criss-cross manner, mainly within strongly altered feldspar relicts.

The hornblendite which appears to be a local variety of the granodiorite consists predominantly of remarkably euhedral stout crystals of strongly pleochroic hornblende, frequently accompanied by deformed plagioclase, set in a groundmass of quartz, which has a strongly undulatory extinction.

Accessory and secondary minerals. Magnetite is the predominant accessory mineral in the granodiorite, being associated mainly with hornblende and sericite whereas chlorite and stilpnomelane are in places important secondary alteration products. In the microgranite apatite needles, sphene and ore (magnetite and pyrite) are the most common accessory minerals and epidote, sericite, chlorite and stilpnomelane are the usual secondary alteration products.

(iii) Chemical composition

Chemical analyses, CIPW norms, Niggli equivalent norms and

Table 21 : Chemical composition of rocks of the Hlelo Granite Suite, Usushwana Complex

		1	2	3	4	5	6	7	8
Chemical composition	SiO_2	70,46	69,28	70,56	72,44	62,05	60,52	65,61	63,47
	TiO_2	0,58	0,66	0,61	0,35	1,01	1,01	0,86	0,97
	Al_2O_3	11,91	11,49	11,82	11,72	11,94	12,90	12,32	11,95
	Fe_2O_3	2,27	6,76	2,59	2,70	6,19	7,90	6,20	7,10
	FeO	3,63	2,60	3,72	1,94	6,59	5,50	4,36	4,93
	MnO	0,09	0,03	0,02	0,02	0,18	0,19	0,15	0,16
	MgO	1,08	0,13	0,55	0,02	0,26	0,23	0,19	0,26
	CaO	1,10	1,64	1,11	1,51	4,35	4,65	3,67	3,89
	Na_2O	3,56	3,50	2,70	4,21	3,02	3,34	3,15	3,30
	K_2O	3,64	3,65	4,10	2,86	2,32	2,22	2,42	2,35
	P_2O_5	0,17	0,08	0,08	0,02	0,21	0,21	0,17	0,19
	CO_2	0,21	0,00	0,12	0,10	0,11	0,00	0,00	0,09
	H_2O^+	1,06	0,94	1,52	0,68	1,69	1,15	0,89	1,12
	H_2O^-	0,09	0,10	0,00	0,00	0,11	0,06	0,03	0,06
	Total	99,84	100,85	99,49	98,56	100,01	99,87	100,01	99,83
CIPW Norm	Q	31,08	32,06	34,83	34,18	25,80	23,58	30,59	27,91
	c	1,00	0,00	1,39	0,00	0,00	0,00	0,00	0,00
	or	21,51	21,57	24,23	16,90	13,71	13,12	14,30	13,88
	ab	30,12	29,61	22,84	35,62	25,55	28,25	26,65	27,92
	an	3,01	4,86	4,22	4,63	12,17	13,65	12,33	10,85
	di	0,00	0,69	0,00	1,50	6,43	5,48	4,10	4,93
	wo	0,00	0,77	0,00	0,16	0,00	0,70	0,00	0,36
	hy	6,68	0,00	5,06	0,00	2,91	0,00	0,09	0,00
	mt	3,29	6,54	3,75	3,91	8,97	11,45	8,98	10,29
	hm	-	2,24	-	-	-	-	-	-
	ilm	1,10	1,25	1,15	0,66	1,91	1,91	1,63	1,84
	ap	0,40	0,18	0,18	0,04	0,49	0,49	0,40	0,44
	cc	0,47	0,00	0,27	0,22	0,25	0,00	0,00	0,20
	H_2O	1,14	1,03	1,51	0,67	1,79	1,20	0,91	1,17
	Total	99,84	100,85	99,49	98,55	100,01	99,87	100,01	99,83
Niggli values	al	34,41	31,16	36,11	38,08	26,25	26,87	29,62	27,20
	alk	28,30	26,32	27,12	32,56	16,44	16,45	18,75	18,14
	fm	31,52	34,42	30,60	20,45	39,92	39,05	35,58	38,57
	c	5,78	8,09	6,16	8,92	17,39	17,61	16,04	16,09
	si	345,35	318,78	365,69	399,30	231,45	213,93	267,63	245,04
	k	0,40	0,41	0,50	0,31	0,34	0,30	0,34	0,31
	mg	0,25	0,03	0,14	0,01	0,34	0,03	0,03	0,03
Katanorm	Q	29,08	26,73	53,79	32,60	24,56	22,35	29,11	26,50
	Or	21,84	22,37	24,45	17,60	14,62	13,88	15,02	14,70
	Ab	33,11	32,61	25,52	39,29	28,92	31,74	29,71	31,37
	An	4,62	5,05	5,30	4,88	12,99	14,46	12,96	11,50
	Wo	0,00	1,16	0,00	1,12	3,48	3,46	2,05	3,10
	En	2,54	0,37	0,34	0,06	0,77	0,67	0,55	0,76
	Hy	4,33	4,23	4,19	1,19	6,57	3,51	2,80	3,11
	Mt	2,46	6,34	2,85	2,94	6,90	8,74	6,81	7,86
	Cp	0,35	0,16	0,17	0,04	0,44	0,44	0,35	0,39
	Ru	0,42	0,48	0,45	0,25	0,75	0,74	0,63	0,72

1. Microgranite, Inhlovudwalile 421 IT (ECH 723)
2. Microgranite, Wolvenkop 421 IT (ECH 467)
3. Microgranite, Glen Eland 413 IT (ECH 527)
4. Microgranite, Wolvenkop 427 IT (ECH 473a)
5. Granodiorite, Sterkwater 472 IT (ECH 808a)
6. Granodiorite, Sterkwater 472 IT (ECH 808b)
7. Granodiorite, Sterkwater 472 IT (ECH 808c)
8. Granodiorite, Sterkwater 472 IT (ECH 808d)

Analysts: National Institute for Metallurgy and General Superintendence Co., Johannesburg.

Niggli values of the acidic rocks of the Usushwana Complex appear in Table 21. The samples of microgranite come from different localities, but those of granodiorite constitute a suite of samples over one outcrop.

In Table 22 the average composition of the microgranite and granodiorite of the Usushwana Complex is compared with average compositions reported by Nockolds (1954).

Table 22 : Comparison between average composition of acidic rocks of the Usushwana Complex with average granite and granodiorite

	1	2	3	4
SiO_2	70,69 ± 1,13	73,86	62,91 ± 1,95	66,88
Al_2O_3	11,74 ± 0,16	13,75	12,28 ± 0,39	15,66
Fe_2O_3	3,54 ± 1,84	0,78	6,85 ± 0,71	1,33
FeO	2,97 ± 0,74	1,13	5,35 ± 0,82	2,59
MgO	0,45 ± 0,42	0,26	0,24 ± 0,03	1,57
CaO	1,34 ± 0,24	0,72	4,14 ± 0,38	3,56
Na_2O	3,49 ± 0,54	3,51	3,20 ± 0,13	3,84
K_2O	3,56 ± 0,45	5,13	2,33 ± 0,07	3,07

1. Average composition and standard deviation of microgranite, Usushwana Complex (4 samples)
2. Alkali granite, average after Nockolds (1954, p. 1012)
3. Average composition and standard deviation of granodiorite, Usushwana Complex (4 samples)
4. Granodiorite, average after Nockolds (*Ibid*, p. 1014)

Microgranite of the Usushwana Complex compares reasonably well with the average composition of alkali granite, which in turn is very similar to average alkali rhyolite (Table 22). Both the microgranite and the granodiorite of the Usushwana Complex are markedly enriched in iron as compared with the respective average compositions and both rock types are slightly depleted in silica and alumina in comparison with the average values. Granodiorite of the complex has a markedly lower MgO-content than average granodiorite.

3. Intrusive relationships

The gabbroic rocks are intrusive into the Basement Complex in which they may occur in the form of more or less isolated massifs, as for instance on Glen Eland 413 IT, Inhlovudwalile 421 IT and from De Hoop 403 IT to Lions Glen 398 IT. In places considerable disruption has been caused in the country rock in areas close to the contact, e.g. on Glen Eland and Imbama where schlieren of tonalitic material in the granite-gneiss are strongly deformed. Xenoliths of Basement granite can be seen in gabbro along the northeastern contact of the satellite intrusive on Glen Eland and on Cometjie 13 HU, south of the area mapped. The southern termination of the gabbro is marked by a prominent, altered intrusion breccia.

The gabbro is preferentially emplaced along the interface of the Basement granite and either the Vaalkop Formation (Folder IB) or the Pongola Group (Folder IA). In places however, it transgresses the roof rocks and is intrusive into the Pongola Group. The following intrusive relationships can be observed in the area (Folders IA and IB).

(i) A long narrow belt of quartz gabbro, extending over about 12 km on Glen Eland 413 IT and Kolwani 412 IT, is emplaced into the upper horizons of the Ngwempisi Formation. Along its southern tip a prominent zone of intrusion breccia is developed, consisting of fragments of amygdaloidal lava in various stages of digestion, set in a gabbroic matrix.

(ii) On Morgenstond 418 IT the northern termination of the extensive western gabbroic belt of the Usushwana

Complex cuts across the Evergreen-Morgenstond fault and abuts against almost the entire exposed pile of Ngwempisi lava. An intrusion breccia identical to that described above is developed along the southern contact of the cross-cutting, east-trending tongue of the gabbro (Fig. 26b).

(iii) On a more local scale the gabbro can be seen to be intrusive into the Glen Eland and Ngwempisi Formations along a zone of weakness associated with the emplacement of pyroclastic breccia of the Amsterdam Formation on De Hoop 402 IT, Sandbach 407 IT and Glen Aggy 406 IT (F.2).

(iv) Several large xenoliths of quartzite, certainly remnants of the Glen Eland Formation, are found in gabbro near the base of the complex along the Hlelo River on Ishlelo 441 IT.

(v) Isolated bodies of quartz gabbro, situated in the Voorslag Formation of the Mozaan Subgroup, are found on Redcliff 426 IT and Evergreen 425 IT.

(vi) An intrusive relationship is indicated between gabbro and the granitic rocks of the Hlelo Suite in the area east and southeast of Amsterdam. An analysis of a fine-grained (chilled) rock, observed at the contact between the gabbro and the microgranite in a highly weathered exposure in a road-cutting on Tweepoort 404 IT, along the Amsterdam-Nerston road, showed that it is of gabbroic composition (Table 18). About one 1 km south of this locality the gabbro cuts in dyke-like fashion right across the zone of microgranite and on the southern part of Inhlovudwalile 421 IT, just north of the Ngwempisi River, ferrogabbro is intrusive into both microgranite and Glen Eland quartzite (Folder IA).

(vii) On the other hand, dykes of granite aplite are seen intrusive into the gabbroic rocks at several localities, e.g. on Hebstlie 448 IT (J/K.11) and Kopje Alleen 493 IT (M.13) (Figs. 27a and 27b). At the Hebstlie occurrence, which is a prominent gabbro outcrop immediately west of the homestead, the aplite is in places repeatedly displaced by minor shear joints (Fig. 27a). At this locality as well as on Kopje Alleen 479 IT it can be seen to enclose fragments of the host rock (Fig. 27b). A similar relationship can be observed on Strydkraal 477 IT (M.13), where acidic rock embays and intrudes the gabbro.

The gabbroic rocks of the Piet Retief Suite thus clearly postdate the rocks of the Pongola Group and, moreover, in places even display an intrusive relationship with the granitic rocks of the Hlelo Suite. Acidic magmatism definitely younger than the gabbroic rocks is displayed by the aplitic veins in the gabbro.

4. Discussion

a) The diversity of rock types

(i) The Piet Retief Suite

Owing to poor exposures the Usushwana Complex does not lend itself to a detailed petrographic study and consequently the origin of the various gabbroic rock types observed in the area is poorly understood. There is no field or petrographic evidence relating to the genetic relationship of the pyroxenite and hyperite and likewise the gabbro and the quartz gabbro cannot be directly related to each other. Gabbro which is the more basic variety

Fig. 27a: Aplite vein in quartz gabbro deformed by subsequent movements. Hebstlie 448 IT

Fig. 27b: Inclusion of gabbro fragment in aplite vein. Hebstlie 448 IT

is observed only in two areas, situated in both cases at the floor of the complex. Towards the inner side of the intrusive the gabbro is bounded mainly by ferrogabbro. The general impression gained is that the gabbro constitutes an independant, earlier intrusion.

The development of ferrogabbro and especially of magnetite segregations in this rock affords the only example of differentiation *in situ*. Osborn (1962, p. 215-220), who studied the effect of oxygen fugacity on the differentiation of basaltic magma demonstrated that under constant, high oxygen pressure magnetite would crystallise from the melt leading to SiO_2 enrichment in the residual melt, whereas at low oxygen pressure the crystallisation of silicates, especially olivine, would be favoured, causing enrichment of iron in the residual liquid. Crystallisation of the quartz gabbro of the Usushwana Complex conceivably took place under low oxygen pressure with a resulting enrichment of iron in the melt to form ferrogabbro. Underneath the roof of the intrusive a local build-up of oxygen pressure was presumably effected with consequent enhanced crystallisation of magnetite and the formation of magnetite layers.

These layers are sporadically developed and of restricted extent. They exhibit considerable variations in dip from place to place and are in some instances slightly folded and displaced. For this reason they do not constitute a marker horizon which can be used to determine the attitude of the pile of gabbroic rocks nor to assess its thickness.

A similar mode of origin, based on cyclic fluctuations of fO_2, is also proposed for the Bushveld magnetitite layers (Von Gruenewaldt, 1973, p. 225; Molyneux, 1974, p. 338), but recently Ringwood (1975, p. 247-248) questioned the validity of some of Osborn's arguments concerning the source of the oxygen.

(ii) The Hlelo Suite

Field relationships and petrographic associations between the acidic rocks, i.e. granodiorite and microgranite on the one hand, and Vaalkop rhyolite on the other, indicate that these rocks are closely related to each other.

The granodiorite is considered to be a product of both differentiation of the mafic sequence of the complex and assimilation of its roof. Although the granodiorite, strictly speaking, is therefore part of the Piet Retief Suite it is grouped here with the Hlelo Suite, because it merges in places into the microgranite, from which it cannot always be readily distinguished in the field.

Martini (1973) interpreted the results of his petrographic study (Fig. 25) as being indicative of two differentiated cycles, the second of which commenced with the crystallisation of the first magnetite layer. However, it has been shown that the development of granodiorite below and above the magnetite layers is at the same topographic level and that, in view of the presence of quartzite xenoliths, both these occurrences were most likely part of a more extensive overlying body situated immediately below the roof of the complex. It is therefore suggested that the only effect of differentiation evident from Figure 25 is a gradual increase of micropegmatite towards the roof of the mafic sequence indicating that the granodiorite is part of the intrusive phase. The contact with the microgranite is marked by a very sharp increase in the micropegmatite content (Fig. 25).

The small xenoliths of quartzite, which are found in places in the granodiorite are further evidence of its intrusive nature. Mineralogically the granodiorite was shown to resemble the Vaalkop rhyolite in certain respects and to contain relicts of incorporated feldspar laths from the roof rocks (Fig's. 22a and 26a). These feldspar relicts and the high micropegmatite content of the granodiorite can most likely be ascribed to partial assimilation of Vaalkop rhyolite and possibly some quartzite by the basaltic magma of the Usushwana Complex.

The main factors which have therefore contributed to the genesis of the granodiorite are firstly, an increase of silica in the residual gabbroic melt as a result of the crystallisation of magnetite at relatively high oxygen pressure (Osborn, 1962), and secondly, assimilation of the roof rocks. Such a hypothesis would account for the general absence of granodiorite in areas where the plutonic rocks are not in contact with acidic roof rocks and where ferrogabbro is not developed.

As already pointed out the microgranite is always associated with gabbroic rocks but not vice versa. Where it is developed it seems to rest on the mafic rocks, and in small erosion relicts near the contact, even on the Basement granite floor. Relationships indicate that the gabbro is intrusive into the acidic rocks but, on the other hand, acidic veins are also intrusive into the basic rocks. These veins of granite aplite could represent downward injections of remobilised granitic melt into the gabbroic rocks.

In discussing the roof rocks of the Bushveld Complex, Von Gruenewaldt (1972, p. 124-128) demonstrated that the origin of the granophyre is best ascribed to partial melting of Rooiberg felsite and that these liquids were injected into the roof. The calculations of Irvine (1970) were called upon to explain the mode of origin of the granophyre. Irvine (p. 1034) demonstrated that the roof of a layered intrusive would be continuously subjected to the maximum temperature of the magma, as a result of convection currents, and that loss of heat during crystallisation would be effected mainly through the roof. Consequently (p. 1046) partial or complete fusion of the roof rocks should occur as a result of this contact metamorphism, unless the melting temperature of the roof rocks is higher than that of the gabbroic magma. Von Gruenewaldt (ibid., p. 125) argued that, in the presence of H_2O and HF and a pressure of at least 1500 bars, the melting point of the Rooiberg felsite would be as much as 400°C lower than that of the mafic liquid and that more than 1000 m of roof rocks could have been melted by the mafic intrusion.

These observations reflect the conditions in the present area very closely but the relationships are less clear where Vaalkop rhyolite is not developed, e.g. in the Amsterdam area. One small outcrop on Wolvenkop 427 IT, however, shows that the Vaalkop Formation originally extended farther northwards than is presently observed. Moreover, similar conditions would have prevailed underneath a roof of Athole rhyolite and the rhyodacite of the Amsterdam Formation.

b) Comparative aspects of the plutonic rocks

The plutonic suite of the Usushwana Complex cannot be described as a stratiform complex because the intrusive lacks characteristic rythmic and cryptic layering. Differentiation and crystallisation of the gabbroic magma could apparently not proceed unimpeded, with the result that layering could not develop. The magnetitite layers are the most distinctive manifestations of such processes, but these layers have been shown to be only sporadically developed and to be deformed in places, indicating movement of the partially consolidated crystal mush.

Whereas the association between quartz gabbro and ferrogabbro can be explained in terms of differentiation and fluctuating oxygen pressure, no direct relationship with the other types of gabbro is discernible, e.g. gabbro and hyperite. The latter rocks occur in more or less isolated bodies and possibly constitute separate intrusives.

Thayer (1971, p. 240) classified ultramafic and gabbroic rocks into three main groups, viz. authigenic, polygenic and allogenic. The stratiform complexes are described as authigenic and typical examples are the Bushveld and Stillwater Complexes and the Great Dyke. Alpine-type complexes, kimberlite and similar ultramafic intrusives are termed allogenic. A large intermediate group is described as polygenic rocks. The rocks of this group in some respects resemble either the stratiform or alpine-type deposits, but also exhibit characteristics indicating a complex genetic history. Thayer (p. 244) considers the Duluth Complex, Minnesota, as a typical polygenic-type intrusive.

Recent work on the Duluth Complex revealed that it is a multiple intrusion consisting of anorthositic gabbro, which forms the upper part of the complex, intruded by a layered sequence of troctolite and gabbro. A third intrusive event is seen in cross-cutting ferrogranodiorite and granophyre and late stage basalt and aplite dykes (Phinney, 1972, p. 333).

In view of the above considerations the Usushwana Complex can best be described as a polygenic-type intrusive.

c) Relationship between acidic rocks

In the past all acidic rocks of the Usushwana Complex were grouped together as "granophyre". However, although closely related to each other these rocks are of varied nature and origin and therefore the generalised term "granophyre" is not recommended. The main arguments pertaining to the origin of these rocks as put forward in the preceding chapters are briefly as follows.

Firstly, the distribution of the "granophyre" is not confined to the occurrences of the gabbroic rocks, indicating that it is not an in situ differentiation product. Moreover, the volume of acidic rocks was shown by Hunter (1970, p. 665) to be at variance with such an origin. A volcanic origin for the Vaalkop Formation is indicated by its low-angle unconformable relationship with the Pongola Group and its fine-grained texture, typical of extrusive rocks.

Secondly, the acidic rocks in places acted as roof for the intrusive phase. This is borne out by xenoliths of quartzite at the interface between the Vaalkop Formation and granodiorite as well as by intrusive relationships of gabbro into microgranite.

Thirdly, microgranite closely resembles Vaalkop rhyolite in its field relationships and chemistry (cf. also Chapter V.D.2). In the field these rocks are in places difficult to distinguish. The development of granitic textures may result from increasing granophyrisation and recrystallisation of felsic rocks and it is argued in the preceding chapter that the microgranite is a product of partial remelting of acidic roof rocks. The aplite veins in the gabbro are considered to be a further manifestation of this process.

E. Metamorphic effects

Apart from the partial melting of the acidic roof rocks described above very little other contact metamorphic effects of the Usushwana Complex are observed. In the Amsterdam area the gabbroic rocks occur as isolated bodies of comparatively small volume. They rarely lie in contact with rocks amenable to metamorphic reconstitution, the only exceptions being the quartz gabbro intrusives on Evergreen 425 IT and Redcliff 426 IT where, possibly due to the lack of good exposure, no metamorphism of the surrounding ferruginous shale was observed.

Sericite is developed in a volcanic ash bed in Ngwempisi lava on Bothashoop 521 IT, east of Piet Retief. Around Amsterdam pyrophylite is found in the Amsterdam as well as in the Voorslag Formations and its origin must be ascribed to the emplacement of ultramafic sheets of the Thole Formation.

The Ngwempisi lava in the area east of Piet Retief is strongly sheared which is most probably due to the structural deformation prior to and during the emplacement of the Usushwana Complex.

The only area where the argillaceous sediments of the Nsuze Subgroup are subjected to appreciable contact metamorphism is south of Piet Retief, where rocks of the Assegaai Formation have been converted into andalusite-mica shist (Humphrey and Krige, 1931, p. 24 and 33). It has been shown that this Formation is not developed in the area north of Piet Retief.

Secondary minerals like epidote, chlorite, stilpnomelane, tremolite, zoisite and sericite, as well as serpentine and chrysotile, which are all observed in some of the rocks of the Usushwana Complex are all indicative of greenshist-facies regional metamorphism to which the area, and in fact most Precambrian rocks in Southern Africa, have been subjected.

V. PETROCHEMICAL ASPECTS OF THE USUSHWANA COMPLEX

A. Stratigraphical variation in the plutonic rocks

1. The Piet Retief Gabbro Suite

In order to study any variation in the chemistry of the quartz gabbro and the ferrogabbro 13 samples were collected along a traverse on Sterkwater 472 IT over gabbroic rocks of the eastern limb of the complex, proceeding from the contact with the roof rocks eastwards towards the floor (Folder IB, Traverse V). The first two samples, viz. 809a and b Table 18) are from the ferrogabbro zone and eleven samples (809c - m) are spread over approximately 1,5 km covering the quartz gabbro. Because of poor exposures the traverse had to be off-set several times as is shown in Folder IB. Although this has introduced wide gaps in some places and possibly duplication in others, any broad variation should emerge. In Figure 28a the major oxides SiO_2, Al_2O_3, Fe_2O_3 + FeO, MgO, CaO and Na_2O + K_2O are plotted against the stratigraphical position of the samples. The quartz gabbro is chemically remarkably homogeneous, and with the possible exception of iron, not the slightest indication of any differentiation trend is perceptible from the base or outer contact of the complex to the ferrogabbro zone in the centre. The ferrogabbro manifests itself by a significantly higher total iron content and a concurring decrease in SiO_2 and Al_2O_3. Because of poor exposures and a resulting large gap of approximately 400 m between the sample points 809b and c it is not possible to conclude whether this variation is due to differentiation in situ, to a rapid change in the magma chemistry or to an upsurge of new magma. One explanation for the uniform chemical composition could be that the quartz gabbro in this area is shallow-dipping and that accordingly only a very small part of the succession was sampled. However, whereas the dip of the quartz gabbro could not be ascertained, the ferrogabbro zone dips almost vertically at this point, as is indicated by layering in

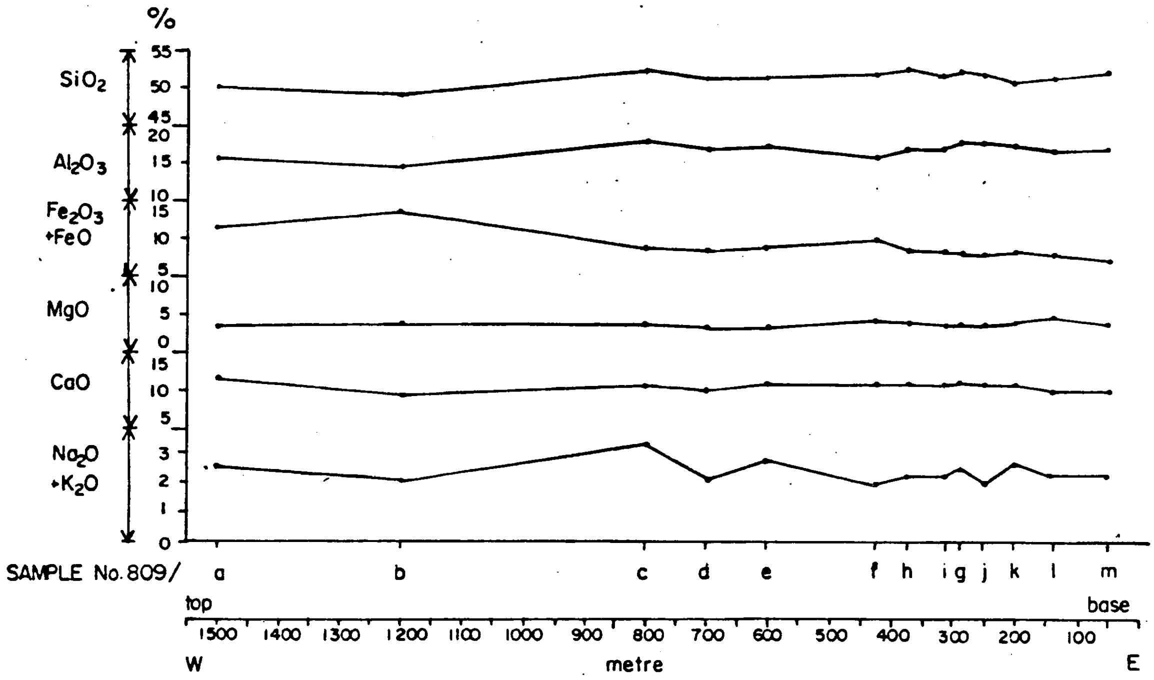


FIG. 28a: CHEMICAL VARIATION ALONG ALONG TRAVERSE V; SAMPLES 809 a-b ARE FERROGABBRO AND 809 c-m ARE QUARTZ GABBRO (c.f. TABLE 18). STERKWATER 472 IT.

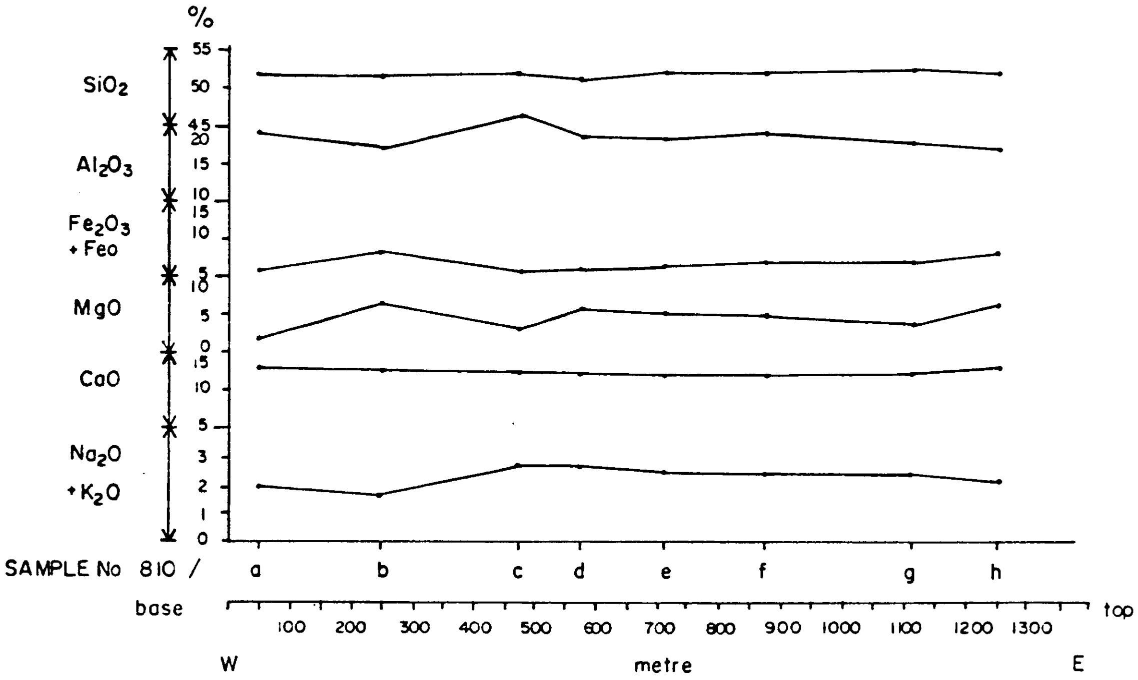


FIG 28b : CHEMICAL VARIATION OF GABBRO ALONG TRAVERSE VII. (c.f. TABLE 18). PIET RETIEF TOWNLANDS an exposure on Sterkwater 472 IT, about 500 m south of sample position 809a (Fig. 24a).

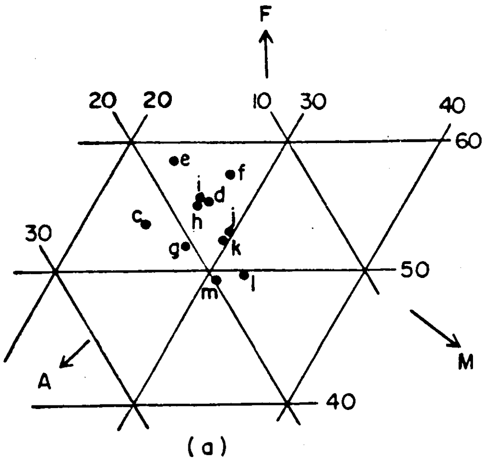
In order to study variations in composition of the gabbro, eight samples were collected along Traverse VII (Folder IB) on the Piet Retief Townlands at intervals of 120 - 250 m, depending on the distribution of the outcrops. The concentration of the main elements plotted against their stratigraphical position is depicted in Figure 28b. Likewise, the gabbro displays very little differentiation across the width of the zone. The chemical composition is in fact very similar to that of the quartz gabbro but a slight decrease in alumina and combined alkalies and a concomitant increase in total iron and magnesia are indicated. A small break appears in the succession between samples 810 b and c which accentuates these trends.

The fact that neither the quartz gabbro nor the gabbro display any marked differentiation is further illustrated by studying the distribution of the samples from the above two traverses, i.e. quartz gabbro of Traverse V and gabbro of Traverse VII, on detailed AFM diagrams (Fig's. 29a and 29b respectively). Sample numbers correspond to those in Figures 28a and b respectively.

The haphazard distribution of the points within each field becomes immediately obvious and no differentiation trend is discernible. The two figures have only one feature in common; the sample nearest to the floor of the complex, i.e. points m and l in Figure 29a and point a in Figure 29b are the most magnesium-rich and are thus the only manifestations of incipient differentiation at the base of these two groups of rocks.

2. The Hlelo Granite Suite and the Vaalkop Formation

Traverse VI (Folder IB) was designed to investigate the grano-



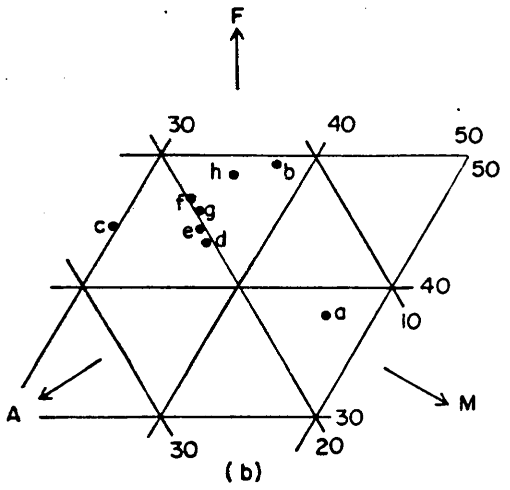


FIG. 29a: AFM DIAGRAM SHOWING DISTRIBUTION OF SAMPLES 809 c-m (TRAVERSE V) IN DETAIL. STERKWATER 472 IT.

FIG. 29b: AFM DIAGRAM SHOWING DISTRIBUTION OF SAMPLES 810 a-h (TRAVERSE VII) IN DETAIL. PIET RETIEF TOWNLANDS.

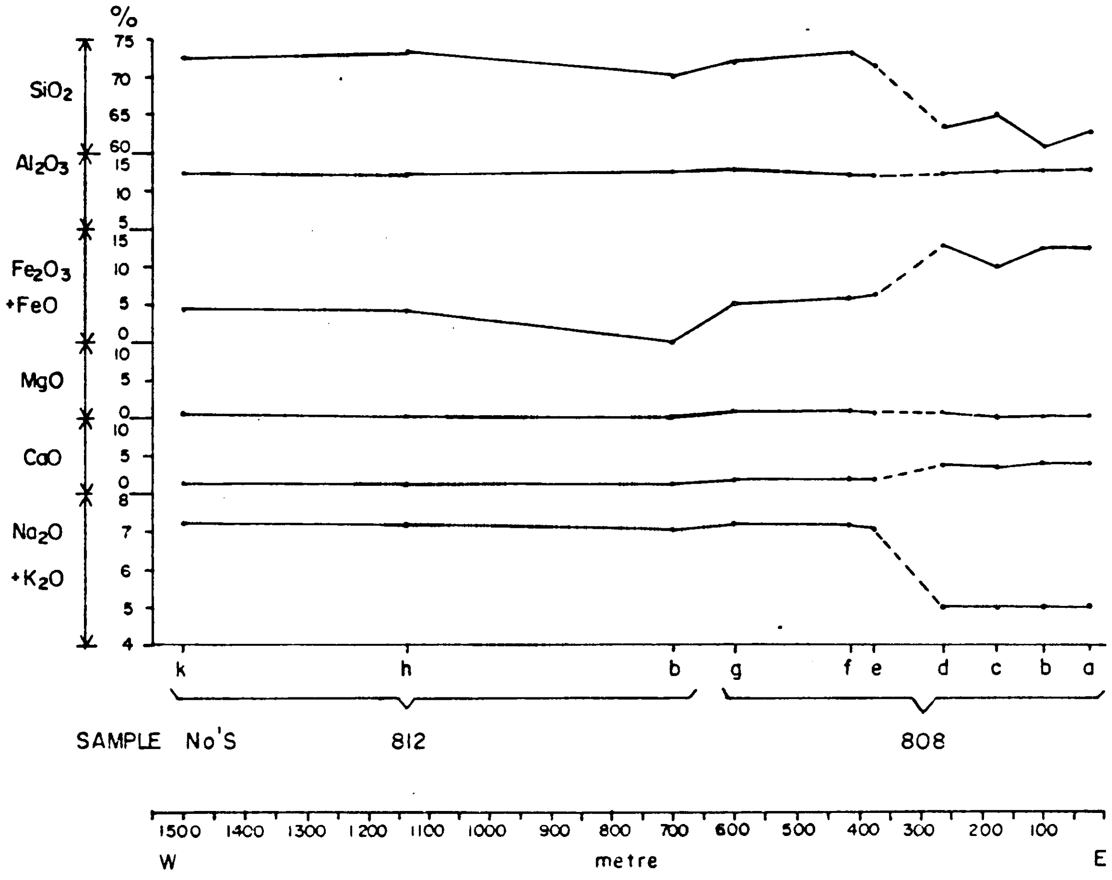


FIG 29c: CHEMICAL VARIATION ALONG TRAVERSE VI. SAMPLES 808 a-d ARE GRANODIORITE AND 808 e-g AS WELL AS 812 b,h,k VAALKOP RHYOLITE. STERKWATER 472 IT AND ROOKSDRIFT 484 IT.

diorite and its relationship with the Vaalkop Formation on Sterkwater 472 IT. The traverse was off-set in the middle by about 100 m, but this proved to coincide with a very abrupt change into Vaalkop rhyolite, a fact not realised in the field. A separate series of samples was collected across the prominent mountain of Vaalkop Formation on Sterkwater 472 IT and Rooksdrift 484 IT, and three samples, one from the eastern flank near the contact with gabbroic rocks of the Piet Retief Suite, one from the top of the mountain and one from the western flank were analysed chemically. For the purpose of this investigation these three samples are considered to constitute an extension of traverse VI. The chemical variation of these samples, plotted in the consecutive order in which they were collected, is depicted in Figure 29c. A very marked break appears at the contact between the granodiorite and the Vaalkop rhyolite in the case of SiO_2, total iron, $Na_2O + K_2O$ and to a lesser extent of CaO. The indications are thus that this contact is chemically well defined, lending further support to the field and petrographic finding that this is an intrusive contact, as already discussed in previous chapters.

B. Generalised variation trends

The generalised trend in a composite AFM-diagram, utilizing all available whole rock chemical data on pyroxenites, gabbroic rocks, granitic rocks as well as the volcanic formations from the present area and from Swaziland is in agreement with the well established differentiation trends of tholeiitic igneous complexes, i.e. initial enrichment in iron and subsequent enrichment in alkalies (Fig. 30a). The different rock types which can be distinguished on various criteria fall into well-defined areas, depicted as fields I to IX in the diagram. However, the boundaries between these fields are somewhat arbitrary and are largely based on available petrographic data.

Field I includes the ultramafic rocks, mainly those of the

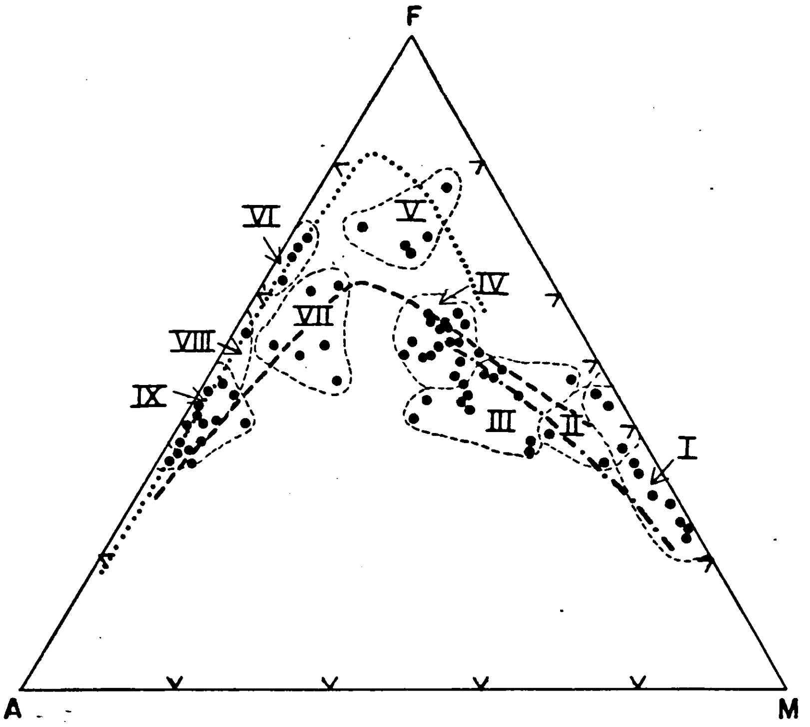


Fig. 30a: Composite AFM diagram of rocks of the Usushwana Complex. I = pyroxenite, II = hyperite, III = gabbro, IV = quartz gabbro, V = ferrogabbro, VI = granodiorite, VII = dacitic tuff, VIII = microgranite and IX = rhyolite; Tholeiitic magma trends:······ Skaergaard, ---- Tasmanian dolerites, —·—·— Mt Davies (Giles Complex) Australia (After Nesbitt et al, 1970)

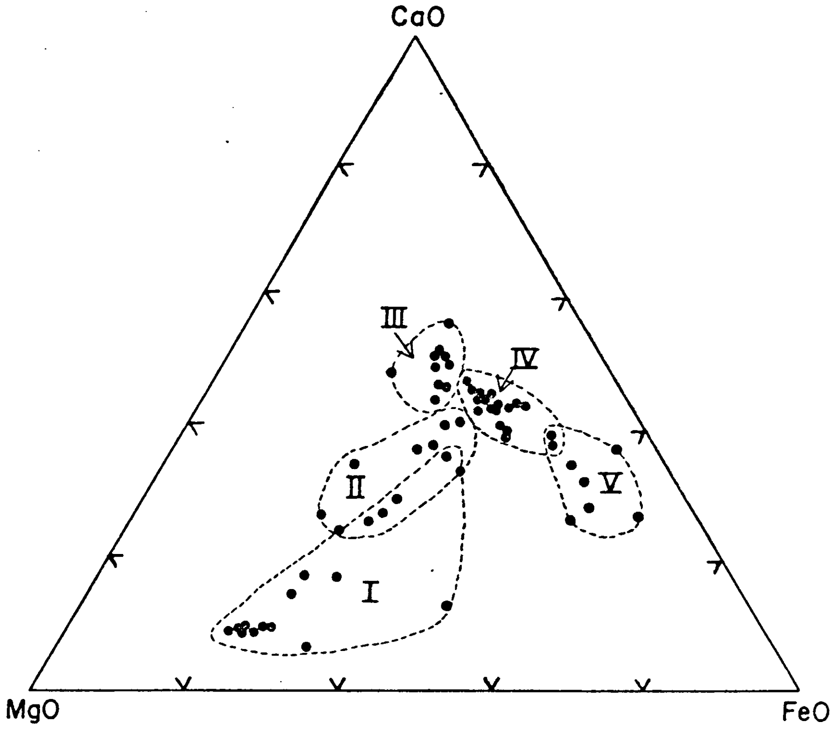


Fig. 30b: FeO - CaO - MgO Diagram of the basic rocks of the Usushwana Complex (notations as above)

Thole Formation, but also pyroxenites from Swaziland (Hunter, 1970a, p. 656). It is not known whether the latter are of a similar type as those from the Thole Formation of the present area or whether they are more directly related to the gabbroic suite of the complex. The pyroxenite from the small isolated plug an Imbama 414 IT plots inside this field.

Field II embraces two samples of hyperite from the present area, a gabbroic dyke described from Swaziland, and also three samples of the uppermost portions of Thole Formation sills from Forbes Athole 393 IT, Westoe 394 IT, and Evergreen 425 IT. Fields I and II are shown to overlap because the relationship between the hyperite and the ultramafic rocks of the Thole Formation and from Swaziland is obscure.

Fields III, IV and V depict the main gabbroic rock types of the complex, i.e. gabbro, quartz gabbro and ferrogabbro, respectively. Again the boundary between these fields is not based solely on this diagram but also on field and other evidence. Despite its leucocratic appearance the gabbro is evidently decidedly more mafic in composition than the quartz gabbro and the ferrogabbro. The ferrogabbro falls into a distinct field of its own.

The trend observed in Figure 30a, depicting an initial iron-enrichment and a subsequent enrichment in alkalies in the granodiorite and the microgranite, is in agreement with the magmatic differentiation trend exhibited in stratiform complexes like the Bushveld, Skaergaard intrusion and other complexes (Bowes, et al 1970, Nesbitt et al, 1970).

Apart from its higher iron and titanium content the ferrogabbro has been shown to be chemically very simiiar to quartz gabbro. The absence of rocks of intermediate composition between that of quartz gabbro and ferrogabbro can probably be ascribed to insufficient sampling, although such a break may also be attributed to a sudden appearance of several per cent magnetite.

Only four analyses of granodiorite from a traverse of samples across the margin of the acid phase on Sterkwater 472 IT (Traverse V) are available and form a distinct group of their own (Field VI). Field VII, which embraces the dacitic pyroclastics of the Amsterdam Formation, occupies an intermediate position and does not seem to fall on the fractionation trend. Microgranite (Field VIII) and the rhyolite rocks of the Vaalkop Formation and the Athole Member (Field IX), overlap considerably, demonstrating that these rocks are chemically very similar.

The above grouping of the basic rocks into fields I-V is corroborated in a FeO- CaO- MgO diagram (Fig. 30b). The distribution of points can be subdivided into two separate areas, one comprising the ultramafic rocks and the hyperite, i.e. fields I and II, and secondly the gabbroic suite, i.e. fields III, IV and V. Again fields I and II overlap and the topmost samples of three traverses across sills of the Thole Formation all plot within the hyperite field which could therefore be considered to be a differentiation product of the ultramafic rocks. Four samples reported from Swaziland (Hunter 1970a, H1663, H1665, H1667 and H1668) also plot into the hyperite field. Three of these samples are associated with the Cu-Ni-Co bearing gabbroic zones described from Mhlambanyati and Embo (Winter, 1965, p. 16-22).

The variation diagrams discussed above do not take any changes in the silica content into account and for this reason the analytical data of rocks of the Usushwana Complex in the area under discussion is plotted on QLM diagrams (Fig. 31a). Diagram (i) depicts the various plutonic rock types, and diagram (ii) the volcanic rocks. The same distribution pattern as described above emerges, except that the members of the gabbroic suite cannot be distinguished from one another and are thus grouped together. It is interesting to note that the pyroxenites fall into a separate field (I) and that their upper differentiates do not approach the positions of the hyperite, as

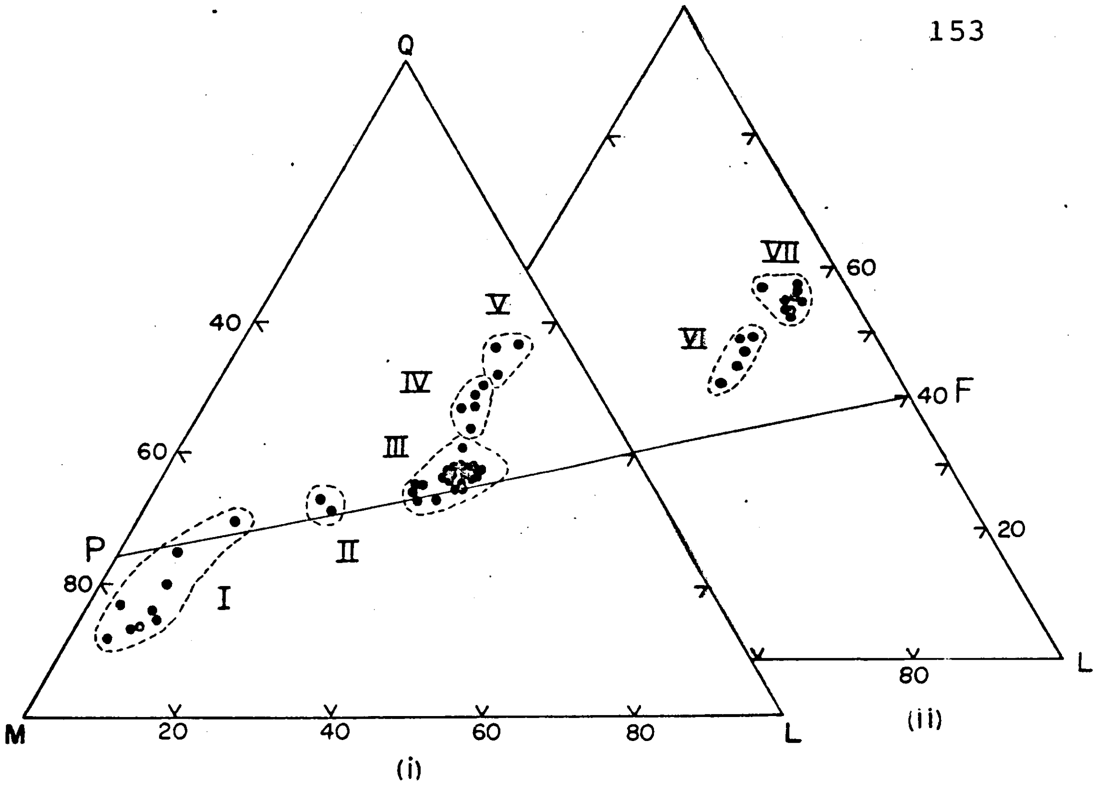


Fig. 3la: QLM Diagrams for rocks of the Usushwana Complex; (i) plutonic rocks: I = pyroxenite, II = hyperite, III = gabbroic suite, IV = granodiorite and V = microgranite; (ii) volcanic rocks: VI = dacitic tuff and VII = Athole rhyolite, Vaalkop rhyolite and pyroclastic breccia.

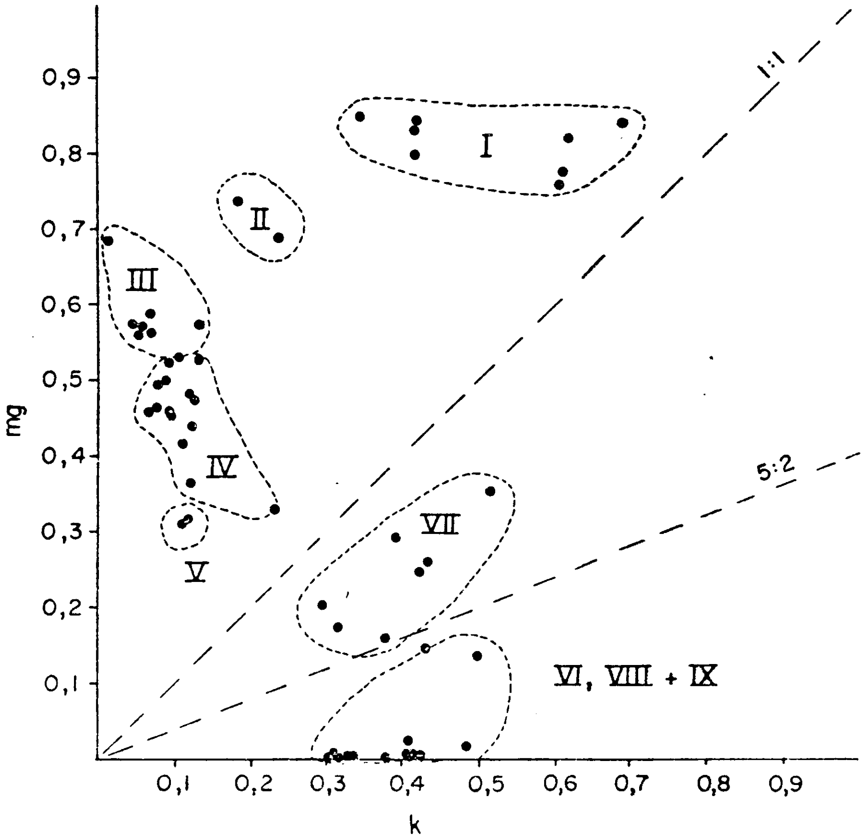


Fig. 3lb: k / mg Diagram for rocks of the Usushwana Complex (notations as in figure 3la) was the case with the diagrams discussed above; hence only two points fall into the latter field (II). The acid rocks of the plutonic series, e.g. granodiorite and microgranite of fields IV and V, respectively, coincide with the respective fields of the volcanic rocks, viz. dacitic tuff (VI), rhyolite and pyroclastic breccia VII of diagram (ii) (Fig. 31a).

The basic rocks outlined by fields I-V in figure 31a can also be clearly defined in a k/mg diagram (Fig. 31b). The dacite of the Amsterdam Formation again falls into a field of its own, bounded by k:mg ratios of 5:2 and 1:1. It is interesting to note that a sample of the Athole Member (Table 10, Sample 9), a rhyolite which from field evidence is considered to be associated with the dacite, plots in the centre of this field. In contrast to the QLM diagram, in which the granodiorite and the dacitic tuff of the Amsterdam Formation could not be distinguished from each other, these two rock types are clearly separated in the k/mg plot. The granodiorite falls into the field of the microgranite and the rhyolite below the 5:2 ratio line, but the various rock types in this field cannot be distinguished from each other.

Two samples of pyroclastic breccia fall exactly onto the dividing line between the basic and the acid rocks. The relatively high magnesium content of these rocks is remarkable since they are in other respects comparable with the more acid rocks in the area.

C. Classification of the volcanic rocks

Chemical classifications of the volcanic rocks in the Amsterdam-Piet Retief area were attempted according to methods suggested by Rittmann (1962 and 1973), Irvine and Baragar (1971) and Middlemost (1973).

1. The Rittmann Classification

According to Rittmann (1962, p. 106-110) magma types are characterised by a certain alkali/silica ratio, termed the Suite Index and this ratio as well as the slope of the graph on a SiO_2 / (Na_2O + K_2O) diagram defines the petrographic suite to which the magma belongs. The volcanics of the area under investigation have the following Suite Indexes:

	Range	Average Suite Index	Number of samples
Ngwempisi Formation	0,6-1,1	0,8	12
Tobolsk Member	-	2,0	1
Amsterdam Formation	1,4-1,8	1,7	6
Athole Member	-	1,2	1
Pyroclastic breccia	1,7-1,8	1,75	2
Vaalkop Formation	1,8-2,1	2,0	7

Calc-alkaline rocks have a Suite Index of 1 to 5 (Rittmann, 1962, p. 110 and Barth, 1962, p. 172) and according to this classification the volcanic rocks associated with the Pongola Group and the Usushwana Complex would be of strong calc-alkaline character.

Rittmann (1973) devised a method to calculate the assemblage of minerals which would crystallise from magmas within a certain range of physical conditions and which would characterise specific igneous facies. Volcanic, plutonic and carbonate facies are recognised, depending on pressure and temperature conditions (ibid., p. 16).

The Rittmann norm for the "dry" volcanic facies, i.e. at relatively low pressure, has been calculated for a number of analyses of volcanic rocks studied during the present investigation. The Rittmann norms of some rocks of the Amsterdam Formation were already reported in Chapter IV.C.b (Table 11) and it was concluded that these rocks were of dacitic to rhyodacitic composition.

2. The Classification of Irvine and Baragar

Based on a comprehensive literature study Irvine and Baragar (1971) devised a classification scheme which incorporates the most important schools of thought, save for the work of Rittmann.

Employing the same alkali-silica diagram as Rittmann, Irvine and Baragar (1971, p. 532) distinguish an alkaline and a sub-alkaline field, the latter one of which in turn is subdivided into a tholeiitic basalt series and an calc-alkaline series (ibid., p. 524). The volcanic rocks of the present area clearly fall into the sub-alkaline field (Fig. 32a) and, plotted on an AFM diagram (Fig. 32b) and an Ab-An-Or diagram (Fig. 33a) they are shown to be of tholeiitic composition. The latter association is confirmed by the fact that the rocks almost invariably have Opx and Q in the CIPW norm, one of the distinctive characteristics postulated by Irvine and Baragar (ibid., p. 530).

The chemical classification into various rock types is accomplished by plotting the cation normative colour index against the cation normative plagioclase composition (Fig. 33b). Two adjustments of the chemical analyses are required in order to allow unbiased comparisons in cases where the rocks appear to have been altered. Firstly, if the Fe_2O_3/FeO ratio deviates from that of fresh rocks of comparable composition it has to be corrected and, based on a statistical analysis of a large number of analyses, Irvine and Baragar (1971, p. 526) propose that the upper limit of Fe_2O_3 should be set at TiO_2 + 1,5 and that excess Fe_2O_3 be converted to FeO. Secondly the analyses are recalculated to 100 per cent after exclusion of H_2O and CO_2. The katanorms of the volcanic rocks of the present area, adjusted according to the above-mentioned criteria, are reported in

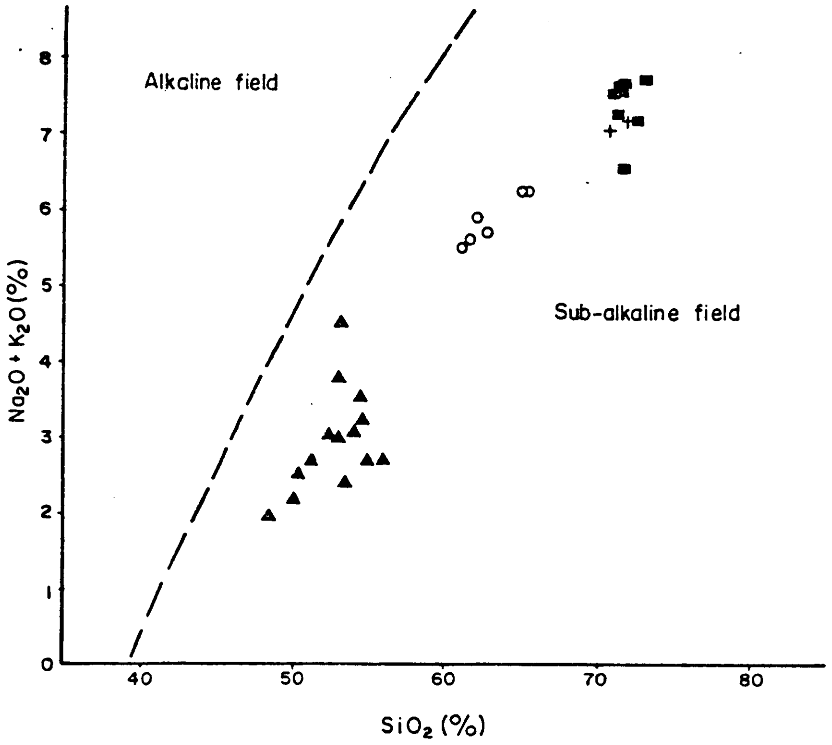


FIG. 32a: VARIATION DIAGRAM OF ALKALIES VS SILICA (MASS PER CENT) SHOWING THE SUB-ALKALINE NATURE OF THE VOLCANIC SUITE; ▲ =NGWEMPISI BASALT/ANDESITE, o = AMSTERDAM DACITIC TUFF, ■= VAALKOP AND ATHOLE RHYOLITE AND + = PYROCLASTIC BRECCIA.

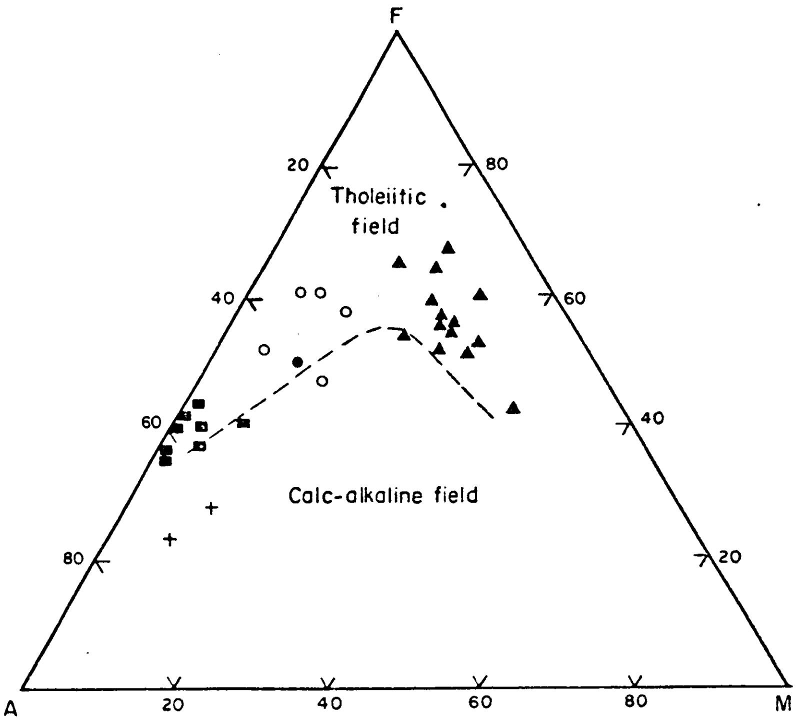


FIG. 32b: AFM (MASS PER CENT) VARIATION DIAGRAM (AFTER IRVINE AND BARAGAR, 1971), SHOWING THE THOLEIITIC AFFILIATION OF THE VOLCANIC SUITE; NOTATIONS AS IN FIG. 32a.

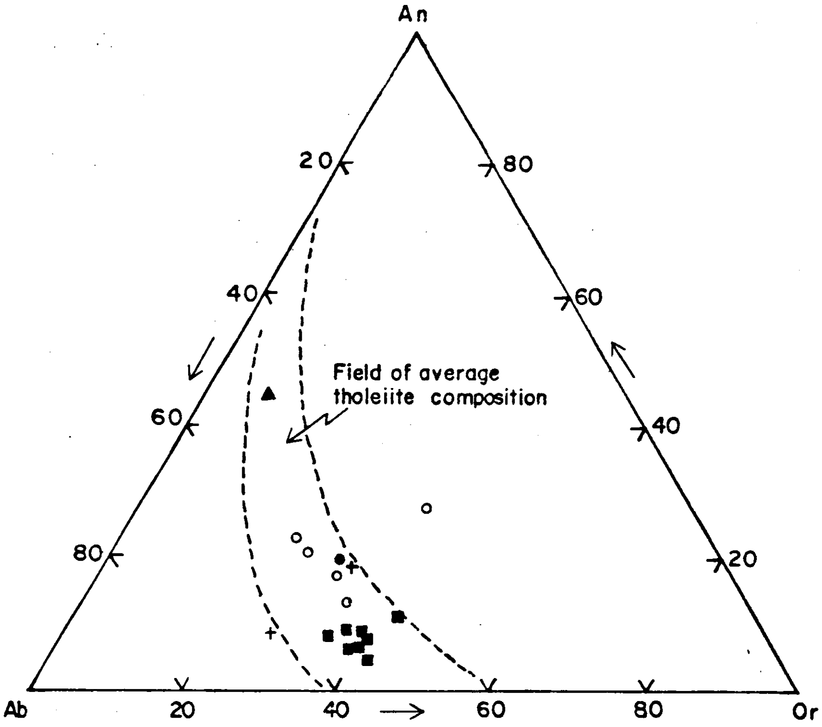


FIG. 33a: VARIATION DIAGRAM OF NORMATIVE Or-An-Ab-(AFTER IRVINE AND BARAGAR, 1971) OF THE VOLCANIC SUITE; NOTATIONS AS IN FIG. 32a.

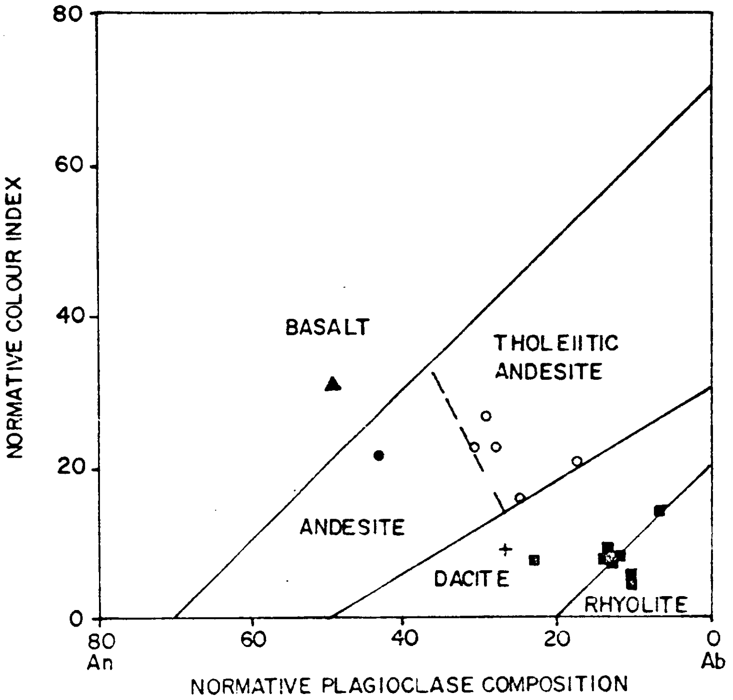


FIG. 33b: VARIATION DIAGRAM OF NORMATIVE PLAGIOCLASE COMPOSITION VS NORMATIVE COLOUR INDEX FOR THE VOLCANIC SUITE; NOTATIONS AS IN FIG. 32a. (AFTER IRVINE AND BARAGAR, 1971).

Table 23. The normative colour index is expressed as Wo + En + Hy + Mt + Cp + Ru and the normative plagioclase composition as 100 An/(An + Ab).

According to this method of classification one sample of the Ngwempisi Formation for which the adjusted katanorm is available plots in the basaltic field, the pyroclastics of the Amsterdam Formation are predominantly tholeiitic andesite and the more acid Vaalkop Formation is dacitic to rhyolitic although the silica content is normally above 70 per cent. The Athole Member of the Amsterdam Formation falls on the boundary of the rhyolite and dacite fields (Fig. 33b).

3. The Classification of Middlemost

Middlemost (1973) devised a simple method of classification based on the relationship of SiO_2 and $Na_2O + K_2O$ which is basically the same silica/alkali diagram used by Rittmann and Irvine and Baragar. Average SiO_2 values are calculated and the standard deviation is determined according to which each type of volcanic rock is delimited. Seven main types of volcanic rocks are distinguished on account of their silica content. For the purpose of this investigation only the more common types are of interest, namely:

Basalt : SiO_2 range 45-53,5%
Andesite : SiO_2 range 53,5-62%
Dacite : SiO_2 range 62-70%
Rhyolite : SiO_2 range 70-75%

Middlemost attempted to subdivide the main groups further on account of the CaO and Al_2O_3 content of the respective lavas, but the separation achieved is not as satisfactory as in the variation diagrams proposed by Irvine and Baragar.

The volcanic rocks of the Pongola Group and the Usushwana Complex plotted on this diagram (Fig. 34) can be subdivided into (i)

Table 23 : Adjusted katanorms of volcanic rocks of the Amsterdam-Piet Retief area

Sample No.	731	602c	689	714	535	680	473c	498c	808e	808f	808g	812b	812h	812k	499	603a
Q	18,26	20,09	23,90	23,76	18,19	14,57	27,10	6,73	29,03	30,84	28,57	28,29	31,74	30,87	28,03	33,15
Or	19,25	22,45	19,00	19,60	14,80	13,55	21,25	5,35	21,85	22,70	25,10	26,85	25,60	24,80	25,10	22,05
Ab	27,60	20,65	30,90	29,90	31,65	32,00	31,25	28,65	35,35	33,00	33,20	28,80	33,15	34,05	32,55	28,41
An	12,43	15,80	10,25	6,45	12,48	13,25	11,55	27,68	5,25	5,28	4,93	8,55	3,88	4,08	5,15	2,10
Wo	4,82	1,24	2,50	-	4,12	6,76	-	2,92	1,40	1,62	1,56	0,02	0,90	0,80	1,74	-
En	1,70	7,76	2,52	6,04	3,76	4,84	3,62	10,62	0,20	0,16	0,22	1,24	0,28	0,32	1,48	0,82
Hy	12,22	9,86	7,42	8,72	11,04	11,18	3,34	13,76	4,46	3,98	4,02	3,56	2,10	2,72	3,10	5,04
Cord	-	-	-	1,98	-	-	0,39	-	-	-	-	-	-	-	-	6,19
Mt	2,58	1,20	2,58	2,61	2,87	2,82	0,81	2,86	2,06	2,05	2,03	2,18	0,90	2,01	2,24	1,74
Cp	0,33	0,28	0,33	0,30	0,31	0,28	0,33	0,40	0,13	0,10	0,10	0,15	0,08	0,08	0,20	0,10
Ru	0,83	0,67	0,61	0,63	0,77	0,76	0,37	1,03	0,28	0,27	0,27	0,37	0,25	0,27	0,41	0,40
Total	99,99	100,00	100,01	99,99	99,99	100,01	100,01	100,00	100,01	100,00	99,99	100,01	99,99	100,00	100,00	100,00
Normative																
CI	22,5	21,0	16,0	20,3	22,9	26,6	8,9	31,6	8,5	8,2	8,2	7,5	4,5	6,2	9,2	14,3
Plagioclase	31,1	43,3	24,9	17,7	28,3	29,3	27,0	49,1	12,9	13,8	12,9	22,9	10,5	10,7	13,7	6,9

Samples 731-680: Dacitic tuff, Amsterdam Formation, for localities see Table 10
Sample 473c: Pyroclastic breccia, Amsterdam Formation, for locality see Table 10
Sample 498c: basaltic lava, Ngwempisi Formation, for locality see Table 4
Samples 808e-g, and 812h-k and 499: Rhyolite, Vaalkop Formation for localities see Table 12
Sample 603a, Rhyolitic tuff, Amsterdam Formation (Athole Member), for locality see Table 10

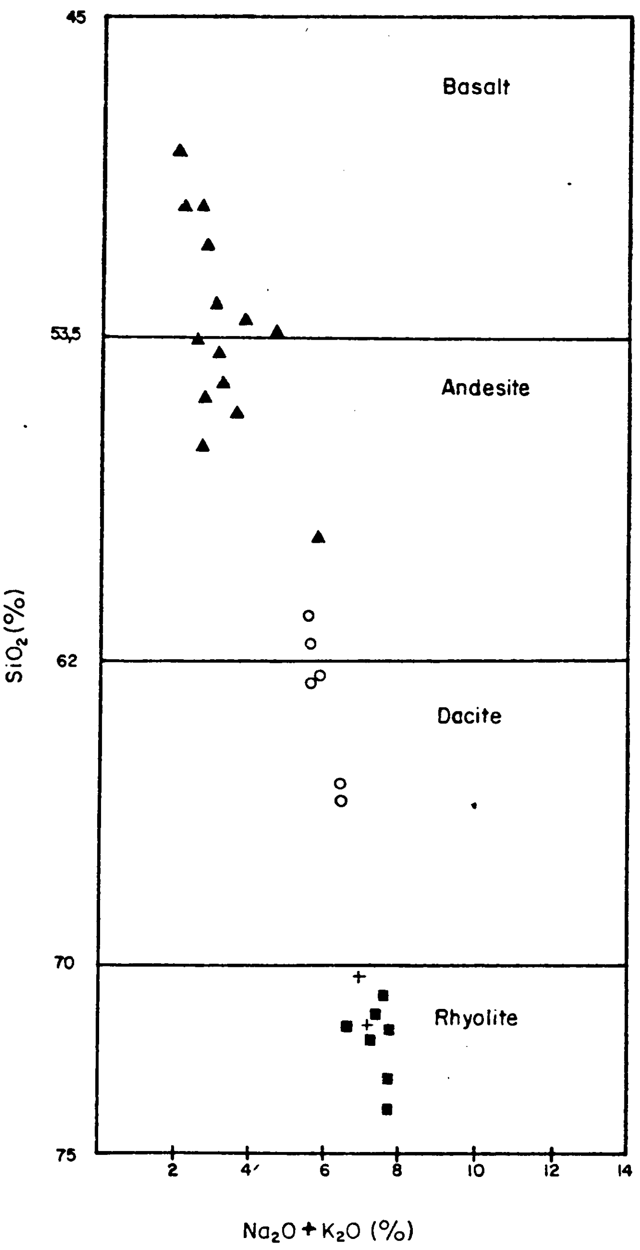


FIG. 34: ALKALI : SILICA DIAGRAM (AFTER MIDDLEMOST 1973), ILLUSTRATING THE CLASSIFICATION OF THE VOLCANIC ROCKS : NOTATIONS AS IN FIG. 32 a.

basalt and andesite of the Ngwempisi Formation, (ii) andesite and dacite of the Amsterdam Formation, and (iii) rhyolite of the Athole Member and the Vaalkop Formation.

4. Discussion

Two main ambiguites emerge from a comparison of the different methods of classification described above. Firstly, the volcanic suite can be classified as tholeiitic according to the Irvine and Baragar scheme and as calc-alkaline by the Rittmann Suite Index and secondly, rock types are more basic according to the Irvine-Baragar classification than suggested by the Rittmann/Streckeisen and the Middlemost methods of classification.

The first discrepancy mentioned above arises from the fact that Rittmann's Suite Index is based on the school of thought of Peacock (1931) who defined the calc-alkali series as rocks containing 56 to 61 per cent SiO_2 and, in which (Na_2O + K_2O) exceeds CaO (Barth, 1962, p. 172). Neither the alumina nor the iron content is taken into consideration in this classification. Regarding the alumina content of basaltic rocks Irvine and Baragar (1971, p.535) point out that the calc-alkaline rocks are distinguished by an alumina content of 16 to 20 per cent, whereas their tholeiitic counterparts contain only 12 to 16 per cent Al_2O_3.

Analyses of samples from the Ngwempisi Formation (Matthews, unpubl. information) and of the Tobolsk Member of the Bergplaats Formation (?) (Visser, 1964, p. 133) show that the Al_2O_3 content is below 16 per cent demonstrating that these rocks belong to the tholeiitic basalt series. Moreover, the amount of iron enrichment in the rock-suite determines its trend of variation in the AFM diagram according to which the rocks of the Usushwana Complex are distinguished as being of tholeiitic affiliation (Fig. 32b).

The reason for the second ambiquity referred to above must probably be sought in the facts that, firstly the rocks of the Vaalkop and Amsterdam Formations contain considerably more iron and titanium than average rocks of similar composition, which results in a higher colour index, and secondly that they are not fresh and that the alteration these rocks have suffered may have affected their alkali-content which would result in anamalous normative plagioclase values. It is probably not advisable to use this diagram for the classification of pyroclastic rocks, particularly ash flow deposits, since these are subjected to relatively long periods of crystallisation from gases contained in the tuff.

The volcanic rocks of the present area are best defined by the classification of Middlemost which agrees better with the petrographic data than the other schemes discussed. According to this method the volcanics of the Pongola Group are basalt and andesite, the Amsterdam Formation predominantly dacite and the Athole Member and the Vaalkop Formation rhyolite. Since all these rocks were shown to be of tholeiitic affiliation it is tempting to relate the volcanic rocks of the Pongola Group and the rocks of the Usushwana Complex to the same petrogenic province (as defined by Carmichael, et al, 1974, p. 40).

D. Petrogenetic implications

1. Excess of alumina

Excess of alumina, redefined by Burri (1959, p. 63-64) as $t = al - (c + alk) > 0$, rarely occurs in fresh, truely igneous rocks, and if it does, it indicates a possible origin by syntexis. $T = al - alk > 0$ indicates the amount of alumina available for the formation of anorthite. Following this reasoning Watson and Snyman (1975, p. 141) used these values to study the relationship between leptite and felsite of the Bushveld Complex and concluded that, on petrochemical grounds, the two are indistinguishable since the former rarely has an excess in alumina.

Employing the same method to study the relationship between various types of volcanic rocks and different granites of the Amsterdam-Piet Retief area (Fig. 35), the following facts emerge:

(i) All the rocks studied have positive T-values.

(ii) The dacitic rocks of the Amsterdam Formation have mostly negative t-values and occupy a closely defined field intermediate between the Ngwempisi basalt and the Vaalkop rhyolite.

(iii) The pyroclastic breccia of the Amsterdam Formation normally has positive t-values which appears to be due to contamination by a variety of Basement granite exhibiting a positive t-value, possibly the Homogeneous Hood granite.

(iv) One sample each of Amsterdam dacitic tuff and Athole rhyolite show an alumina excess which again, bearing their pyroclastic origin in mind, may be due to contamination.

(v) The Vaalkop rhyolite and the microgranite of the Usushwana Complex are petrochemically very similar, but whereas the former appears to have as a rule negative t-values alumina excess does occur in the microgranite.

(vi) The granodiorite plots in a position very similar to that of the Amsterdam Formation.

(vii) Two trends for granitic rocks emerge from Figure 35. Homogeneous Hood granite, Nelspruit migmatite, Pongola granite and microgranite of the Usushwana Complex fall on a trend defined by mainly positive t-values in the range of -5 to +20, in contrast with the tonalite and granodiorite from the Ancient Gneiss Complex and granodiorite of the Usushwana Complex which in comparison show no alumina excess.

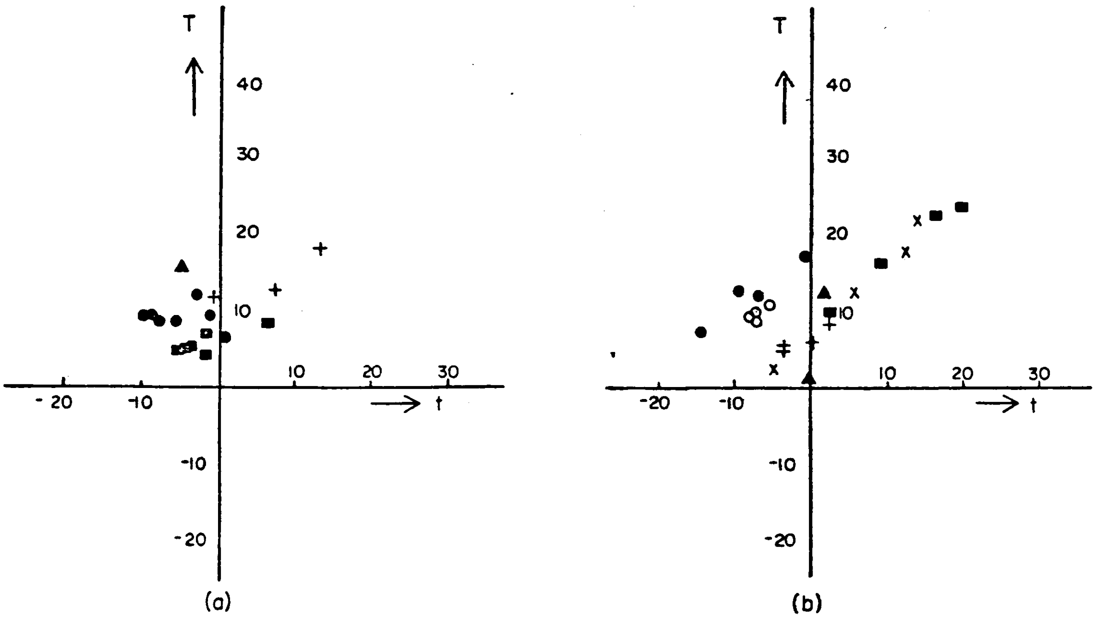


FIGURE 35 : DIAGRAMS OF T=(al-alk) VS t=(al-(c+alk));

(a) : EFFUSIVE ROCKS (+ = PYROCLASTIC BRECCIA, ● = DACITIC TUFF, ■ = RHYOLITE, AND ▲ = BASALT AND ANDESITE.

(b) : GRANITIC ROCKS (o = GRANODIORITE AND + = MICROGRANITE, USUSHWANA COMPLEX; x = PONGOLA GRANITE; ■ = HOMOGENEOUS HOOD GRANITE, ▲ = NELSPRUIT GNEISS AND MIGMATITE AND ● = ANCIENT GNEISS COMPLEX)

2. Petrochemical comparison between Vaalkop rhyolite and microgranite

The Vaalkop rhyolite and the microgranite of the Usushwana Complex are chemically closely related. A migration of only between 3,6 to 6,1 ions per standard cell would be required to transform the rhyolite into microgranite (Table 24). Similarly, the chemical composition of the granodiorite, which is interposed between the gabbro of the complex and the Vaalkop rhyolite, is very similar to that of the dacite of the Amsterdam Formation and the substance transfer required to transform the dacite into granodiorite proved in a number of examples to be in the order of 5,6 to 15,5 ions per standard cell.

It may be reasoned from the above that the Vaalkop rhyolite and the microgranite of the Usushwana Complex are chemically indistinguishable, lending further support to the petrographical and field observations indicating that the microgranite is a partially melted product of the Vaalkop rhyolite.

Table 24 : Substance transfer (ions per standard cell) required to transform Vaalkop rhyolite into microgranite

	Barth standard cell															
	Sample No's 723	467	473a	527	499	808f	808g	812b	812h	499-723	808f -467	808g -473a	812b -527	812h -723	499 -467	812h -527
Si^{4+}	62,29	61,35	64,14	62,21	62,62	63,80	63,40	62,85	63,84	-0,3	-2,4	+0,7	-0,6	-1,5	-1,3	-1,6
Ti^{4+}	0,39	0,44	0,23	0,40	0,38	0,25	0,25	0,35	0,23	0,0	+0,2	0,0	0,0	+0,2	+0,1	+0,2
Al^{3+}	12,41	12,00	12,23	12,28	12,41	12,14	12,57	12,94	12,06	0,0	-0,1	-0,1	-0,7	+0,3	-0,4	+0,2
Fe^{3+}	1,51	4,51	1,80	1,72	1,68	1,89	1,58	1,97	2,05	-0,2	+2,6	+0,2	-0,2	-0,5	+2,8	-0,3
Fe^{2+}	2,68	1,93	1,44	2,74	1,94	2,07	2,55	1,97	1,09	+0,8	-0,1	-1,1	+0,8	+1,6	0,0	+1,6
Mn^{2+}	0,07	0,02	0,02	0,02	0,02	0,07	0,07	0,06	0,04	+0,1	-0,1	-0,1	0,0	0,0	0,0	0,0
Mg^{2+}	1,42	0,17	0,03	0,72	0,68	0,08	0,11	0,58	0,14	+0,7	+0,1	-0,1	+0,1	+1,3	-0,5	+0,6
Ca^{2+}	1,04	1,56	1,43	1,05	1,86	1,76	1,69	1,69	1,16	-0,8	-0,2	-0,2	-0,6	-0,1	-0,3	-0,1
Na^{+}	6,10	6,01	7,23	4,62	5,97	6,04	6,12	5,38	6,02	+0,2	-0,1	+1,1	-0,8	+0,1	0,0	-1,4
K^{+}	4,11	4,12	3,23	4,61	4,61	4,15	4,62	5,00	4,65	-0,5	-0,1	-1,4	-0,4	-0,5	-0,5	-0,1
$(OH)^{-}$	6,25	5,55	4,02	8,94	5,77	3,36	3,77	3,20	5,69	+0,5	+2,2	+0,2	+5,7	+0,6	-0,2	+3,2
For sample localities see Tables 12 and 21					Total transfer of metallic ions					3,6	6,0	5,0	4,2	6,1	5,9	6,1
					Nett transfer of metallic ions					0,0	-0,2	-1,0	-2,4	+0,9	-0,1	-0,9

Samples 723, 467, 473a and 527 are microgranite

Samples 499, 808f, 808g, 812b and 812h are Vaalkop rhyolite

VI. EMPLACEMENT OF THE USUSHWANA COMPLEX

A. Theoretical Considerations

1. Origin of basaltic magma

Fractional crystallisation and partial melting are the processes considered to be responsible for the diversity of basaltic rocks. The primary hearth of magma from the peridotitic substratum is according to Ringwood, (1975, p. 147 and 222-227) at a depth of 70-150 km in the "low-velocity zone" or "upper asthenosphere", also termed the "seismic waveguide" by Beloussov (1971, p. 57). The reduced seismic velocity in this zone is caused by the presence of mobile peridotite, termed pyrolite by Ringwood (1975, p. 180), which is in a state of incipient melting. Ringwood (1975, p. 146) envisages that pyrolite may rise diapirically due to gravitational instability in the mantle and that, as a result of a pronounced difference between the adiabatic and melting point gradients within the diapir, partial melting of the pyrolite will increase with increasing height. As long as the liquid thus produced remains in contact with the residual pyrolite it remains in chemical equilibrium with its host and its composition is determined by the amount of partial melting which has taken place. Magma segregation (Ringwood, ibid.) takes place when this melt is separated from the unmelted pyrolite and the composition of the magma thus generated depends directly on the depth of magma segregation. Alkali-olivine basalt originates from greater depths than high-alumina basalt, whereas magma segregation at very shallow levels gives rise to quartz tholeiite.

In view of the fact that the gravimetric survey militates against the presence of a large hidden part of the complex, it must be assumed that the exposed gabbroic rocks were generated by magma segregation from a pyrolite diapir at relatively shallow levels and that in situ fractional crystallisation of a more mafic magma did not seem to have taken place.

Partial melting in the low velocity zone results in a decrease in density and a concomittant increase in volume which causes lighter material to rise and denser material from the roof to subside. As a result of this the segregated magma may rise at a comparatively high rate where deep structures are present in the lithosphere.

Where no such weak zones are present the magma ascends by way of melting and stoping of the roof. Sufficient heat to facilitate melting and stoping on a large scale can only be generated in big magma chambers. If only comparatively small volumes of magma are available melting of the lithosphere is insignificant and the magma can only rise where deep structural zones present suitable avenues. The final height of ascent is determined by an equilibrium between the rate of rise which depends on the density relations between the magma and the crustal rocks, and the cooling rate. Beloussov (ibid. p. 62) estimates that "the mean overall volume of erupted rocks comes to only an insignificant portion (about 15 per cent) of the total volume of basaltic asthenoliths rising from the upper mantle. The major portion utilises slower mechanisms of rise and comes to a halt at various depths without reaching the surface."

It has been shown that the structural setting of the Usushwana Complex conforms to the regional structure of the area. Hunter (1970a) pointed out that the sedimentary and volcanic rocks of the Pongola Group are confined to the same area as the Usushwana Complex in the area north of the Usutu River in Swaziland, and he attributes this to subsidence in a graben, along which the plutonic rocks were emplaced. Similar conditions seem to prevail in the Amsterdam area. In places, as for instance in the area north of the Amsterdam-Nerston road, the Basement granite is strongly sheared along the contact with the rocks of the Pongola Group and this weak zone was presumably exploited by the gabbroic intrusive. Further south and also along the western contact of the intrusive the gabbro is emplaced into the basement rocks, in places giving rise to seemingly isolated gabbro massifs and to roof-pendants of granite-gneiss, interposed between rocks of the Pongola Group and the gabbroic rocks.

Field evidence from Swaziland (Hunter, 1970a) and the present area therefore indicates that the emplacement of the Usushwana Complex is structurally controlled and consequently deep structures which facilitated the rise of the magma appear to be present.

2. Relationships between basaltic and rhyolitic magma

Factional melting is called upon by Yoder (1973, p. 164-169) to explain the origin of basaltic and rhyolitic magmas from a common source. The universal uniformity in composition of basaltic and rhyolitic rocks and the paucity of rocks of intermediate composition are manifestations of certain controlling physical and chemical conditions in the generation of these magmas and, moreover, experimental results have shown that fractional melting will yield liquids of relatively uniform composition, irrespective of any heterogeneity in the original mantle material (Yoder and Tilley, 1962, p. 578).

All rocks derived from a common source by either fractional crystallisation or partial melting, and without contamination by foreign material, have the same or a similar initial Sr^{87}/Sr^{86} ratio (Faure and Powell, 1972, p. 26-27; Yoder, 1973, p. 168). In the case of the Usushwana Complex Davies (1971, p. 131) determined average initial Sr^{87}/Sr^{86} ratios of 0,7029 ± 0,0018 and 0,7031 ± 0,0014 for granophyre

(Vaalkop Formation?) and gabbroic rocks from Swaziland, respectively, and estimated the age of the Vaalkop Formation at 2784 ± 30 m.y. It is clear that these values do not deviate significantly from each other, from which Davies concluded that both these rocks were derived from a common source. Oceanic basalts have initial Sr^{87}/Sr^{86} ratios in the range of 0,702-0,706, averaging 0,7037, whereas those of the continental crust are significantly higher and the average ratio is estimated at 0,719 (Faure and Powell, 1972, p. 24-26), for example Allsop (1961, p. 1504) obtained an initial Sr^{87}/Sr^{86} ratio of 0,7106 ± 0,030 for Basement granite from the Johannesburg dome. Based on a given age of 2784 ± 30 m.y. the initial Sr^{87}/Sr^{86} ratio of the rocks of the Usushwana Complex is slightly higher than that of oceanic basalt (Faure and Powell, 1972, p. 26) which is probably due to contamination. Nevertheless, the strontium isotope geochemistry of the rocks of the Usushwana Complex suggests that the magma from which they were derived, originated in the mantle.

Blake et al. (1965, p. 35-42) discussed the relationships between acid and basic rocks in the so-called "net-veined intrusive complexes" which often display relationships ranging from intimate acid veining in basic rocks to basic inclusions in acid rocks. Examples are described, for instance from the Guernsey diorite complex, Channel Island (p. 35), where diorite is apparently chilled against acid rock which veins it in a highly irregular fashion. Flow textures in the acid veins indicate that the viscosity of the rhyolitic magma was reduced, possibly as a result of superheating by the basic magma. At Austerhorn in Iceland (p. 36) "pillows" of basic rock are found in granophyre. These pillows generally have sharp contacts with the granophyre and they grade from fine-grained basalt at the margin to ophitic dolerite in the centre. The associations of acid and basic rocks are evidence of local mixing of magmas, which is also known from some composite dykes in Iceland (Carmichael et al, 1974, p. 67). On the strength of these arguments and supporting evidence abstracted from the literature Blake et al (ibid.) argued firstly that acid and basic magma in these complexes may co-exist, secondly that the basic rocks are commonly chilled against acid rocks even where the latter vein the basic rocks, thirdly that some complexes (p. 40) may have resulted from the mobilisation of pre-existing acid rocks by a basic intrusion in which case the mobilised acid material would then have back-veined the basic intrusion; and finally (p. 41) that "... the presence of basic magma may, indeed, be essential to the uprise ...., of acid magma". Co-existing magmas of contrasting composition are thus considered to occur where basic magma meets contemporaneous viscous acid magma. The mobility of the latter may thereby be increased and the acid magma may in turn intrude the unconsolidated basic magma.

In the description of the intrusive relationships between the basic and acidic rock of the Usushwana Complex it was shown that gabbro is chilled against microgranite and, moreover, that at several localities veins of aplite are noted in the gabbroic rocks, indicating that a mobile acid phase existed after the emplacement of the gabbro. Although certainly not a "net-veined" complex in the sense of Blake, et al (ibid.), it may be argued that the contiguous acid and basic rocks of the Usushwana Complex crystallised from contemporaneous magma phases, which originally were derived through fractionational crystallisation in depth of basaltic liquids generated from the mantle by processes of partial melting, with contamination by partial melting of crust to produce the comparatively large amount of acid liquids.

B. Sequence of magmatic events

A more or less continuous record of magmatic activity, which culminated in the emplacement of the plutonic phase of the Usushwana Complex, is observed in the stratigraphical record. The envisaged sequence of events can be summarised briefly as follows:

(i) Extrusion of basaltic and andesitic lava at three periods during the depositional cycle of the Pongola Group, i.e. an initial phase (the Mpama Member), a main phase (the Ngwempisi Formation) and a final phase (the Tobolsk Member). The regional scale of these lava flows, especially of the Ngwempisi Formation, indicates that they are fissure eruptions, which according to Rittmann (1962, p. 129) are characterised by the emission of basaltic lava.

(ii) These events were followed by the emplacement of ultramafic sills of the Thole Formation, mainly into rocks of the Mozaan Subgroup, during or shortly after the structural deformation of the Pongola Group. This is borne out by the conformable relationships between the ultramafic sills and the Skurwerant quartzite, where they have been folded together in the formation of the Amsterdam syncline, viz. on Athole 392 IT and Forbes Athole 393 IT, and on the other hand, by discordant relations along the Kranskop fault.

(iii) After an erosional hiatus, during which a marked relief must have developed, renewed volcanic activity ensued, giving rise to the Amsterdam Formation which has many characteristics of ash-flow deposits. The Vaalkop rhyolite is considered to be a related volcanic phase.

(iv) The emplacement of the plutonic phase of the Usushwana Complex concludes the magmatic cycle. Various types of gabbroic rocks can be distinguished; gabbro appears to be oldest, followed by quartz gabbro and ferrogabbro, which are the most common varieties. The age relationships of the hyperite are not clear and chemically it occupies a position intermediate between the gabbroic rocks and the ultramafic rocks of the Thole Formation.

(v) The origin of the granodiorite, which is interposed between the roof rocks of the complex and the gabbroic rocks is considered to be the product of a combination of magmatic differentiation and assimilation of the acidic roof rocks.

(vi) It has been demonstrated that the acidic rocks of the Usushwana Complex, i.e. Vaalkop rhyolite and microgranite are closely related in their field relationship and that they are chemically indistinguishable. Arguments put forward by Blake et al. (1965) for the consanguinity of basic and acid magmas are called upon to explain interrelationships between the gabbro and the Vaalkop rhyolite. The origin of the microgranite is largely ascribed to remobilisation of the Vaalkop rhyolite.

The presumed mode of emplacement of the Usushwana Complex is illustrated by way of three generalised profiles in Figure 36. Profile A-B shows a cross-section of the northern part of the Amsterdam syncline. Gabbroic rocks are emplaced along the interface of the Basement granite and the rocks of the Pongola Group. In the southwestern portion the gabbro is intrusive into the Pongola Group itself, probably due to the presence of a structurally weak zone. A possible near-surface link between the gabbroic intrusive on either side of the Amsterdam syncline is not implied by the available field and gravity data in this area. Further south, this situation appears to be different as is depicted in profile C-D. Here gabbroic rocks are emplaced high up into the pile of rocks of the Pongola Group. Such conditions are indicated by the regional gravity data as well as by the occurrence of gabbro in the Voorslag Formation on Redcliff 426 IT and Evergreen 425 IT. The Evergreen-Morgenstond fault has probably facilitated the rise of the magma into the higher levels. In this area a common root of different gabbroic intrusives, which again mainly exploited the contacts between the different formations, is envisaged. This observation is compatible with the gravity data along the Kromrivier-Derby-Roburnia traverse, where only one intrusive is surmised (cf. Fig. 5a). Profile E-F represents a section across the Usushwana Complex in the Piet Retief area. Two dyke-like gabbroic intrusives are apparent from the field relationships and this is corroborated by the gravity data (Fig. 5b). No large strike faults are known in this part of the area but they may have been a factor in the emplacement of the gabbroic rocks, especially along the western intrusive, because of the long, straight and narrow course of the western limb of the complex, particularly to the south of the area mapped.

C. Age of the Complex

Bivan:

The rocks of the Usushwana Complex and the Ngwempisi Formation were shown to be all of tholeiitic parentage and it is not inconceivable that they originated from a common magma hearth which was reactivated from time to time. Based on the two radiometric ages available, i.e. 3100 ± 90 m.y. for the Ngwempisi lava and 2874 ± 30 m.y. for the Vaalkop Formation, the indicated time-span between these events is very large. However, not too much reliance should be placed on the radiometric ages. In a comparison of radiometric ages of a wide range of predominant basic complexes Brooks et al. (1976, p. 1088) observed that continental volcanic rocks may inherit a Sr-isotopic composition from the lithosphere, which would increase the age. The isochron-plot for the granophyre of the Usushwana Complex reported by Davies et al. (1970, p. 583-585) is strongly dependent on a sample of aplite (UC 11) the genetic association of which is uncertain. These authors report that the spread in the initial Sr^{87}/Sr^{86} ratio is relatively large, especially if sample UC 11 is omitted. A steeper isochron plot could conceivably be arrived at if sample UC 11 is omitted which would result in a greater age than 2874 ± 30 m.y. for the Vaalkop Formation.

VII. ECONOMIC MINERAL POTENTIAL

A. Geochemical stream sediment survey

1. Orientation survey

a) Field procedures

In order to assess the economic mineral potential of the Usushwana Complex a reconnaissance geochemical survey was carried out to delineate areas which may warrant more intensive exploration. Since no sulphide mineral deposits are known in the area under consideration the actual effect of mineralisation on soil or stream sediments could not be ascertained and the orientation survey was therefore rather of general nature.

Initial mapping had revealed disseminated sulphides, mainly pyrite, in Ngwempisi lava on Haarlem 443 IT (Folder IB) and accordingly an area of some 15 km^2 was chosen on this farm to test the most practical way of prospecting. For comparison a second area, some 30 km^2 in extent, was chosen on Paardekop 428 IT and Morgenstond 418 IT (Folder IB). This area is underlain by Basement granite, which forms the floor of the complex, quartz gabbro, microgranite, and portions of the roof pendant, which in this area again constitutes mainly Basement granite. The area on Haarlem is situated in very mountainous terrain whereas the area on Paardekop and Morgenstond is moderately undulating.

The feasibility of conducting a stream sediment survey, which appeared to be the most practical method in this area, was tested by two sets each of ridge-and-spur soil samples and of stream sediment samples in the two test areas:

	Ridge-and-spur	Active stream sediment
Haarlem	53 samples	29 samples
Paardekop/Morgenstond	76 samples	26 samples

Where disseminated sulphides were noted in the rocks, above-background concentrations of Cu and Ni in the ridge-and-spur samples were fairly well reflected in the stream sediments, particularly in the case of nickel.

b) Geochemical indicators

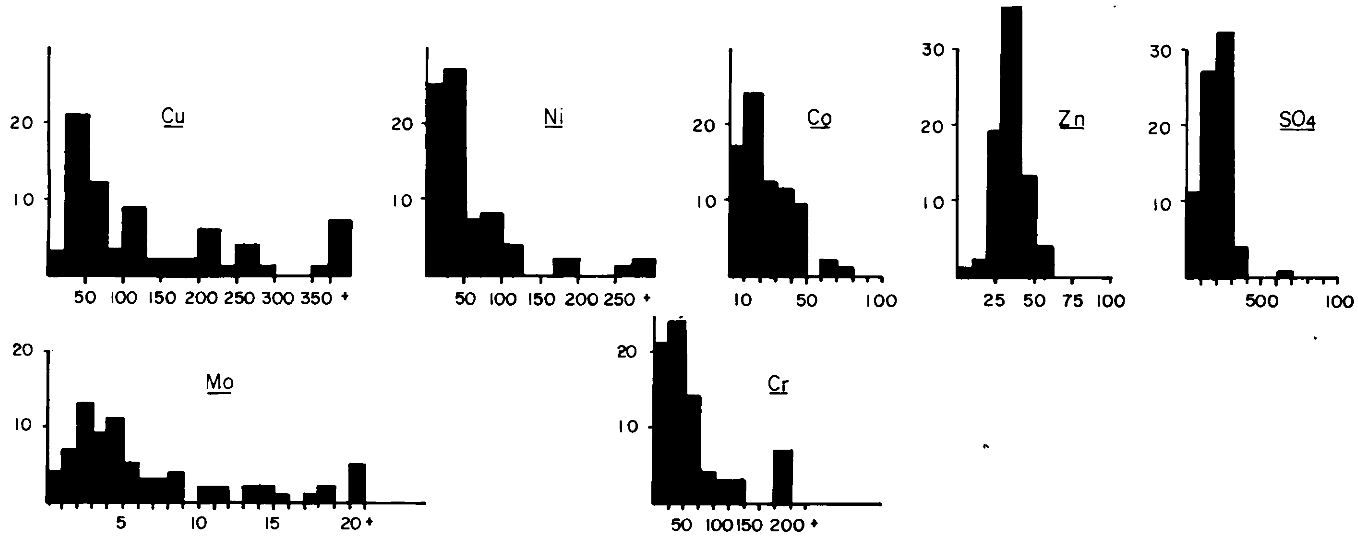
The - 80 mesh fraction of all samples was submitted for analysis and Cu, Ni, Co, Zn, Cr, Sn, Sb, Mo, Cd and S were determined by optical spectography and by X-ray fluorescence spectroscopy (XRF).

The values obtained for Sn, Sb and Cd invariably lay below their respective detection limits and were thus excluded from the regional program. The frequency distribution of the remaining elements is reported in Figure 37. Although the high solubility of sulphates makes sulphur a good indicator of sulphide mineralisation the results of this survey were disappointing since the distribution of sulphur in the different sets of samples approaches normality. The results for Mo proved to be unreliable and big discrepancies were found in the analyses of duplicate samples. The test for Mo is very sensitive and the observed values were generally very low and this element was disregarded during the subsequent program. Similarly the Co content was generally very low and assay for Co was therefore not deemed necessary in the regional survey.

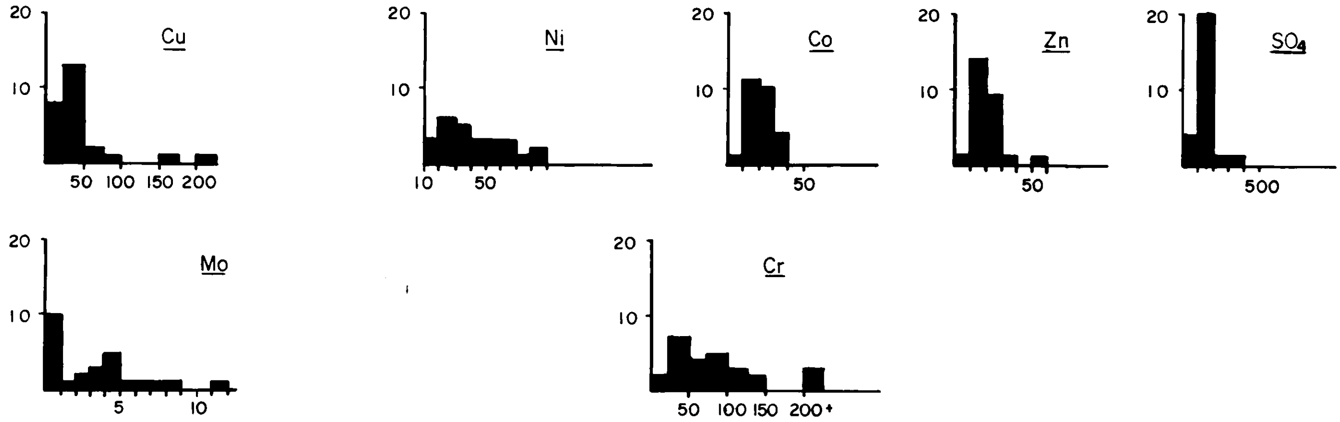
Useful results were obtained for Cu, Ni, Zn and Cr.

c) Discussion

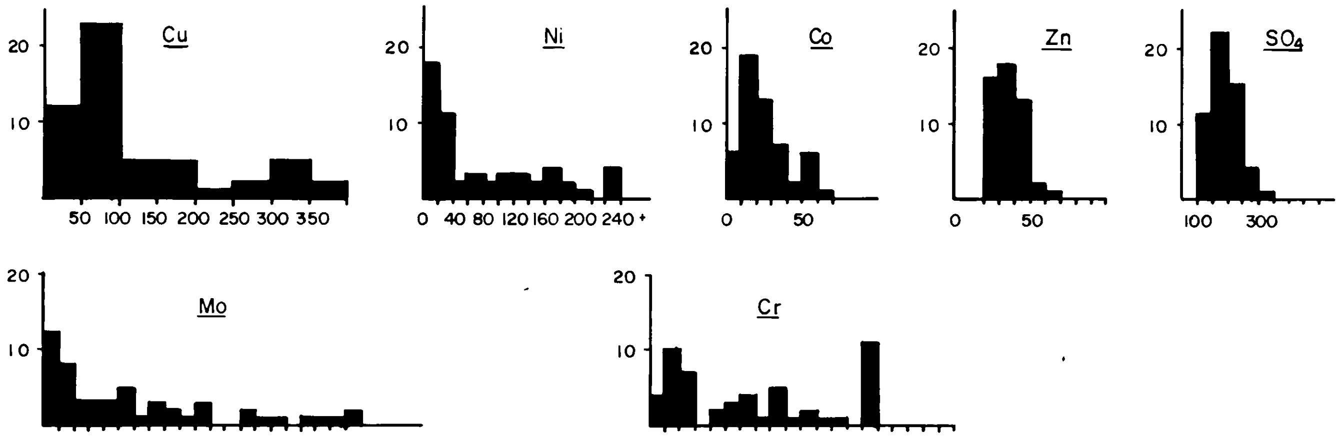
Based on the findings of the above investigations a stream sediment survey could thus be expected to yield satisfactory results if sulphide mineralisation were present. Bearing in mind that in a stream survey only one half to one third of the number of samples would yield a similar coverage as a ridge-



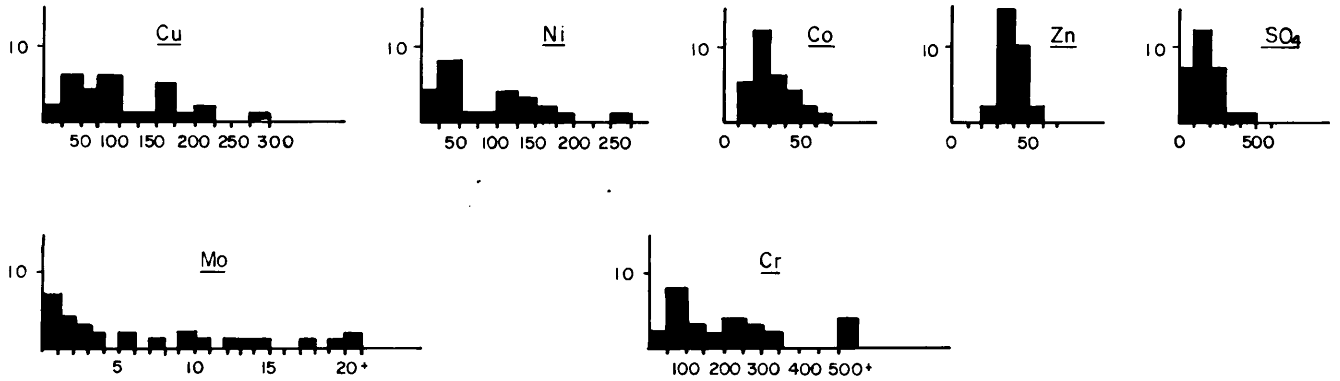
1. Paardekop-Morgenstond: Ridge-and-spur samples



I. Paardekop-Morgenstond: Stream sediment samples



2. Haarlem : Ridge-and-spur samples



2. Haarlem: Stream sediment samples

FIG. 37 · COMPARISON OF THE TRACE ELEMENT DISTRIBUTION IN RIDGE-AND-SPUR AND STREAM SEDIMENT SAMPLES IN TWO SELECTED AREAS OF THE USUSHWANA COMPLEX.

and-spur soil survey the regional program was carried out along the following lines:

(i) Samples of active stream sediment were collected at a sampling density of approximately two samples per square kilometre.

(ii) The -80 mesh fractions of all samples was analysed for the elements Cu, Ni and Zn. Although useful Cr values were obtained during the orientation survey this element was disregarded, firstly because of its insolubility both in nature and in the laboratory and secondly, because no near-surface chromium deposits were expected. Detrital grains of chromite are the only phase in which this element is observed in soils and since these are generally conspicuous, the need to search for it geochemically is usually impracticable (Hawkes and Webb, 1965, p. 363).

2. Regional survey and follow-up

Some 1600 stream-sediment samples were collected from December 1971 to February 1972 and from May 1972 to July 1972, over an area of about 750 km^2 around the village of Amsterdam. The sampled area is approximately delimited by latitudes 26°30'S and 26°45'S and by longitudes 30°30'E and 30°47'E, covering the greater part of the 1:50 000 topographical sheets 2630 DA and 2630 DB (up to the Swaziland border). The mapped area also includes portions of sheets 2630 DC and 2630 DD, to the north and northeast of Piet Retief. The geochemical survey was however not extended farther south because the findings in the Amsterdam area did not seem to warrant it. It was also discovered that a large part of the drainage system northeast of Piet Retief is contaminated by effluent from a paper mill in the area, the effect of which would have had to be studied in detail.

The resulting raw data of the geochemical survey are presented on Folders II, III and IV. The undifferentiated values for Cu, Ni and Zn have been grouped into the following classes, employing the statistics mode (Mo) and standard deviation (s):

0-49	ppm:	normal or background values (Mo + 2s)
50-69	ppm:	threshold values (Mo + 3s)
70-89	ppm:	possibly anomalous values
90+	ppm:	probably anomalous values

This grouping results from the overall distribution of the results regardless of the lithological control (Fig. 38). It is however, obvious that the different lithological units have a marked effect on the trace-element distribution and the background therefore has to be adjusted to counter such differences.

Some apparently anomalous concentrations of Cu, Ni and Zn obtained during the reconnaissance survey were followed up by means of soil samples, generally taken at depths of 15-20 cm along traverses at right angles across the strike of the formation. The results are reported in Figure 39 and the following observations can be made:

(i) Above-background concentrations of Cu, Ni and Zn are found in Ngwempisi lava and three areas were investigated in greater detail by traverses I, III and VIII. Disseminated sulphides can be observed in the lava in each case; the highest concentration appears to be towards the lower contact of the formation. However, analyses of rock samples from these areas reveal insignificant concentrations of Cu, Ni and Zn (Table 26).

(ii) High values of Cu, Ni and Zn are found in the Amsterdam Formation at various places. In order

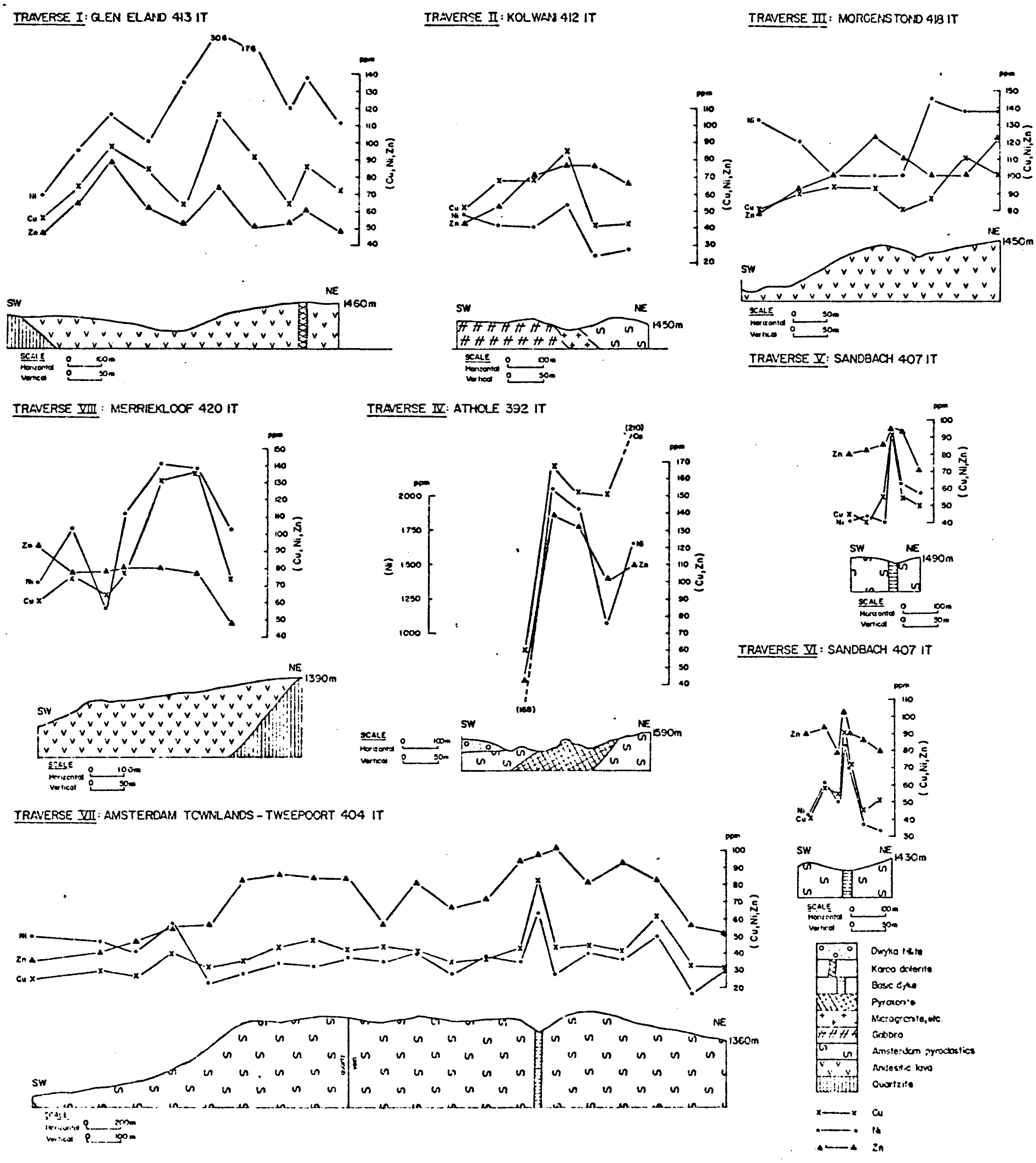


FIG. 39 : SELECTED GEOCHEMICAL FOLLOW-UP STUDIES IN THE AMSTERDAM AREA (c.f. FOLDERS II, III & IV)

to establish possible concentrations of these elements along specific horizons of this volcanic formation it was sampled at intervals of approximately 200 m along a 4,5 km traverse across its entire outcrop width southeast of Amsterdam (Fig. 39, Traverse VII). No noteworthy concentration of these trace elements is observed apart from a marked increase of nickel and copper values over a basic dyke, which contains specks of sulphides. The same dyke was also investigated further north in traverses V and VI and the same element pattern emerged. Whereas the Cu and Ni concentrations are markedly higher in the dyke than in the country rock, Zn differs only marginally. The Zn level in the three areas is roughly the same and must be regarded as background.

(iii) A concentration of higher Zn values on Kolwani 412 IT was tested in traverse II, which was designed to cut across the contact zones between gabbro, micrograniteand dacitic tuff. Cu and Ni appear to be somewhat enriched at this contact and Zn decreases in the gabbro. This observation corroborates the finding that the Amsterdam Formation has a higher zinc background than the other rock types, as will be shown below.

(iv) A train of high Ni values in a stream on the northern part of Athole 392 IT led to an exposure of pyroxenite and dacitic tuff in a deeply incised streambed surrounded mainly by Karoo rocks.

A soil survey across this exposure confirmed the origin of the high nickel values (Traverse IV) and in addition an anomalous copper value was revealed near the base of the pyroxenite. However, this copper anomaly stems from a single sample and should be re-investigated in order to assess its significance.

3. Interpretation of results

a) Reproducibility of results

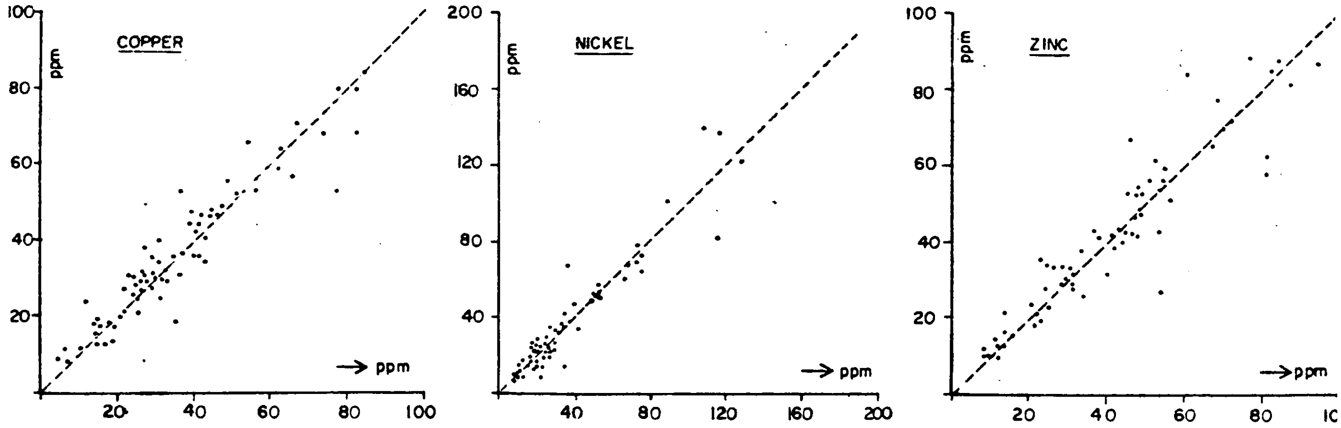
In geochemical exploration two criteria are of interest in determining the reproducibility of results, e.g. (i) the precision of the analytical technique and (ii) the precision of the sampling method.

(i) Analytical technique

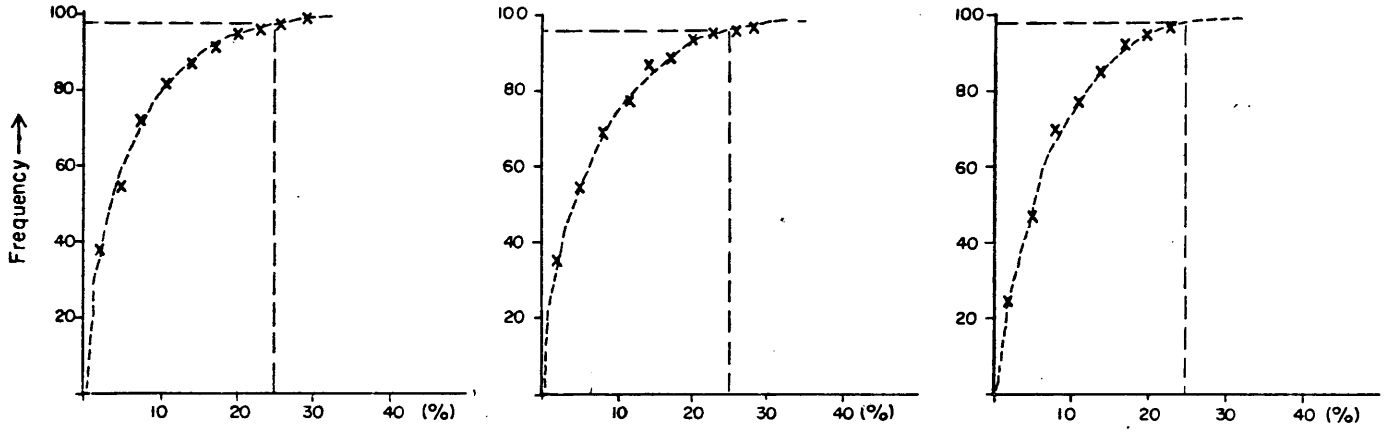
In judging the acceptability of an analytical technique clear distinction must be made between the accuracy and the precision of the method, which together account for the total error.

The accuracy of the analytical method, i.e. the deviation of the result obtained from the true value is not of much concern in geochemical exploration. The precision of the method on the other hand, must be high to ensure consistency of results.

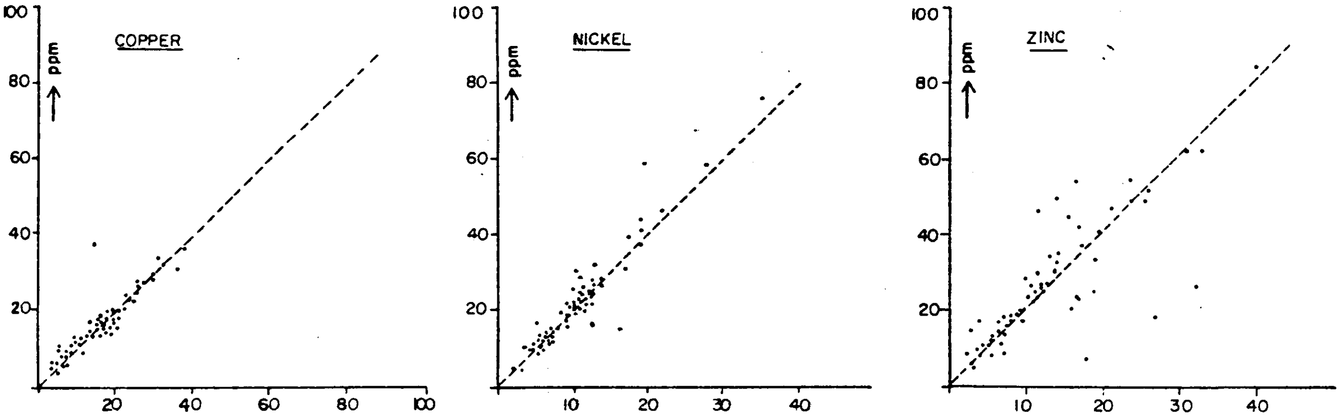
In order to assess the precision of the analytical method 65 samples were halved and submitted for analysis under separate numbers. The determined values of each sample pair are plotted against each other and the percentage deviation from the mean was calculated and plotted in cumulative frequency distribution curves (Fig. 40 iii and iv). The distribution of the percentage deviation for the three elements concerned are of the J-line type, since the smallest deviations occur most frequently, and such distributions do not lend themselves to further statistical analysis. However, from the cumulative frequency distribution the percentage deviation from the



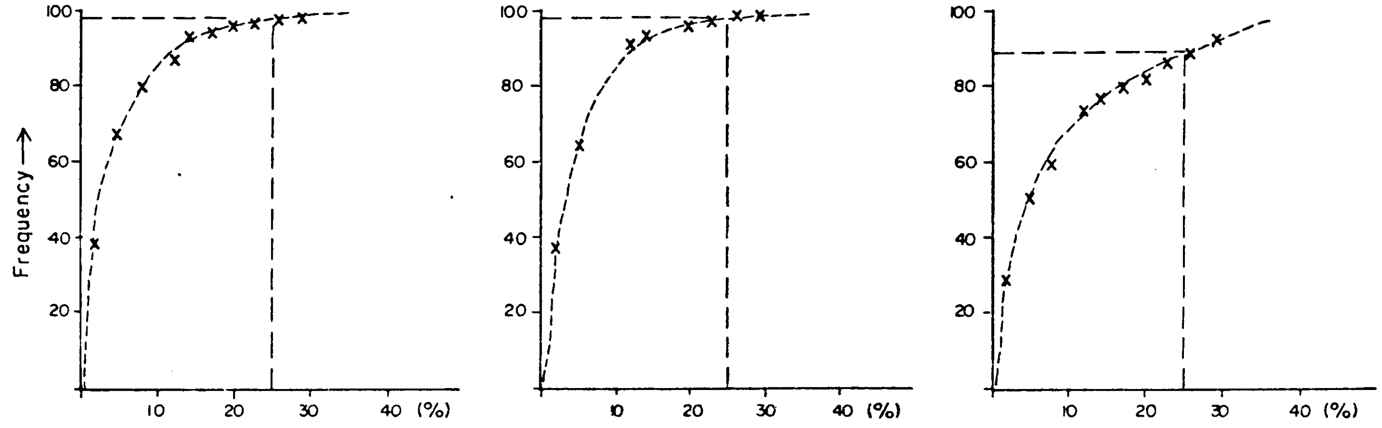
(i) Analysis of duplicate field samples



(ii) Cumulative frequency distribution of percentage deviation from mean of duplicate field analysis



(iii) Analysis of duplicate laboratory samples



(iv) Cumulative frequency distribution of percentage deviation from mean duplicate laboratory samples

FIG. 40 PRECISION AND REPRODUCIBILITY OF GEOCHEMICAL STREAM SEDIMENT SAMPLES FROM THE AMSTERDAM AREA mean of a sample pair can be determined for certain proportions of the population (Fig. 40).

A bulk sample, taken at the beginning of the sampling operations, has been subdivided into 24 portions and these have been submitted for analysis in lots of 8 samples at three stages during the course of the program, all under separate numbers.

The variation within each batch of samples remained within satisfactory limits, compared with the above-set standard. However, considerable deviation was observed between the three stages of the program, especially in the second phase, which necessitated that a large number of analyses had to be repeated.

(ii) Sampling procedure

In order to test if any one sample is representative of its environment and to assess whether the variability of the analytical results was in accordance with that of the sampling procedure, 60 pairs of samples were taken in duplicate in the field, at a distance of 1 to 2 m apart. Plotting the values of each pair of samples against each other reveals a very good correlation for each of the three elements. Again the distribution is of the J-line type and this results in the abnormal cumulative frequency distributions (Fig. 40 i and ii).

b) Environmental parameters

During the present study the following observations were made at each sample point in order to study the possible effects of various geological and other parameters on the trace element content of the samples:

(i) type of sample, e.g. silt, sand and soil (The latter in cases where no active sediment was present)

(ii) Colour of sample, e.g. dark brown, brown, red-brown, yellow-brown or grey

(iii) Morphology of streambed, e.g. steep gradient, intermediate gradient or shallow gradient

(iv) Embankment, e.g. shallow or deeply incised streambed which could cause dilution of the sample

(v) Streambed, e.g. outcrops common, outcrops scarce or no outcrops

(vi) Geology, e.g. various lithological units, and

(vii) Possible sources of contamination, e.g. roads, buildings and constructions, powerlines, etc.

The effect of the lithological units on the trace-elements distribution is presented in Figure 38, in which the overall distribution, considering the undifferentiated data as a whole, is compared with that observed over various rock types or formations.

The undifferentiated data exhibits a slightly positive skew distribution and a value of 50 ppm, approximately encompassing the mode of the distribution plus 2 standard deviations, defines the background satisfactorily for the elements copper, nickel and zinc. In the case of zinc the background distribution is less well-defined which can be ascribed to a second, superimposed population.

For copper the 50 ppm background level applies to all the individual rock types studied, with a possible exception of Karoo dolerite, where the distribution is somewhat erractic.

For nickel the 50 ppm level defines the background for all rock types with the definite exception of the Thole Formation, where two populations are superimposed (Figure 38). One population complies with the generalised 50 ppm background concentration and yields anomalous values of 100 ppm and higher. The second and main population greatly exceeds the 190 ppm Ni level yielding erractic values up to 1800 ppm. The latter population is considered to represent the Thole Formation. Owing to the erractic distribution of nickel in this population the background concentration could not be calculated but this level is believed to be very high. Most "anomalous" nickel values related to the Thole Formation reported in Folder III are therefore considered to be of no economic significance. The relatively low nickel values, in samples of the population mentioned first, are most likely due to contamination from neighbouring rock types and resulting dilution of the nickel concentrations in the stream sediment samples.

The nickel distribution in the rocks of the Pongola Group shows two distinct populations one of which reflects the overall background concentration and the other one a possibly anomalous concentration of this element. The higher Ni-values in the Ngwempisi Formation can be related to observed disseminated sulphides but in the case of the sedimentary rocks the significance of this anomaly remains unexplained.

The wider spread of the overall zinc distribution, referred to above, results from the higher background content of this element in the Amsterdam Formation and the Ngwempisi Formation. The former shows a normal zinc distribution; the mode of the distribution is around 40 ppm and the background level can thus be defined as 70 ppm. It is thus clear that only values exceeding 90 ppm can be considered as being possibly anomalous. It appears from Figure 38 that three per cent of the population falls into this category. The zinc distribution in the Ngwempisi lava is less well-defined, but the background concentration is comparable with that of the Amsterdam Formation, and only samples exceeding a concentration of 90 ppm Zn can be considered to be possibly anomalous, which comprises nine per cent of the total population.

Figure 41 depicts the distribution of Cu, Ni and Zn in different types of material sampled as well as the distribution according to the colour of the sample. It is evident that neither of these parameters exert a marked effect on the trace element content of the samples. Similarly no such control was observed for any of the other parameters referred to above and in particular no contamination from any unnatural source was observed. In both above cases the distribution of zinc is less well-defined than that of copper and nickel, which is in agreement with the overall zinc distribution shown in Figure 38.

c) Discussion

The cumulative frequency distribution provides a quick and explicit method of comparing the variability of the data and of estimating which percentiles of the distribution answer specific requirements in analytical precision. Selecting a 25 per cent deviation from the mean value as an acceptable level, which must not be exceeded by say 95 per cent of the population, the following results are obtained:

	Duplicate analysis	Duplicate field samples
Cu	98%	98%
Ni	98%	96%
Zn	89%	98%

With the only exception of zinc for duplicate laboratory analysis, all the results fall well within the limits set out above. The results prove that precision of the sampling procedure is very good and each sample can be regarded as being representative of its immediate environment, and this finding also stresses the point that in general a high precision in the analytical technique is called for. The precision achieved in the analytical technique was very good for Cu and Ni, but less so for Zn, where 7 samples out of the total of 65 exceed the 25 per cent deviation limit and some by a very large margin. It has to be stressed therefore that the significance of any one high value is always questionable and should be reinvestigated unless the geochemical anomaly is supported by more than one value. The greater the number of supporting values the greater the significance of the anomaly, and this especially applies where the recorded values are only marginally anomalous.

The method to estimate and compare the analytical and the procedural precision, which is applied above has the disadvantage that a relatively insignificant variation of say 6 and 10 ppm in a sample pair introduces a high percentage error, e.g. 25 per cent deviation from the mean in this example. Out of a total of 18 errors of 25 per cent and more, in the statistical population employed in this study, 5 involved insignificant pairs of values of less than 20 ppm.

However, the method is quick and easy to apply and the results confirm that even including a couple of errors which are of little significance the overall data still complies with or approaches the limitation that 95 per cent of the population should not deviate by more than 25 per cent from the mean value of the sample-pairs.

A study was made of the possible effect of a number of environmental controls on the trace element distribution. In the area under consideration it was found that most of these parameters can be disregarded. The only significant exceptions are the lithological control of the Thole Formation and to some extent of the Ngwempisi lava and the Pongola sediments on the nickel distribution and that of the Amsterdam and Ngwempisi Formations on the zinc concentration. In view of the general absence of sulphides in the exposed parts of the

Thole Formation the high nickel values must be ascribed to camouflaging of nickel in the ferromagnesian minerals in this rock.

The 50 ppm trace-element level employed in Folders II, III and IV thus satisfactorily defines the general background with the few modifications that all nickel values related to the Thole Formation are eliminated and that the zinc background of the Amsterdam and Ngwempisi Formations is taken as 70 ppm.

B. Sulphide Minerals

Sulphides occur very sparingly in rocks related to the Usushwana Complex. They are invariably finely dispersed and no horizon or trend of mineralisation could be established. The only localities containing sulphides in noteworthy amounts were found in an outcrop of hyperite along the contact of the Usushwana Complex and Basement granite east of Piet Retief on the border between the Piet Retief Townlands and Blesbokspruit 515 IT (Folder IB), and to a lesser extent in the northern body of quartz gabbro along the road to Panbult on Glen Eland 413 IT (Folder IA), as well as in an altered basic dyke intrusive into the Amsterdam Formation east of Amsterdam on Merriekloof 420 IT and on Westoe 394 IT. The Ngwempisi lava of the Nsuze Subgroup appears to be richer in sulphides than the gabbroic rocks of the Usushwana Complex and several above-background concentrations of Cu, Ni and Zn could be identified by the geochemical survey covering this formation. Although decidedly uneconomic, this lava appears to hold more promise for future exploration than the Usushwana Complex itself. Three such geochemical anomalies were followed up by traverses of soil sample, but the results were not encouraging. Sulphides are conspicuously absent in the exposed sheets of the Thole Formation.

The ore minerals in various rock types are briefly summarised in Table 25. Pyrite is the most frequent sulphide and preponderates almost throughout. Pyrrhotite is a minor disseminated constituent which is observed in a number of polished sections, but always in very small amounts. The hyperite east of Piet Retief contains noteworthy amounts of this mineral. The origin is clearly late-magmatic, since the pyrrhotite fills cracks in the silicates and is often seen to replace pyroxene along twin planes and exsolution lamellae. Chalcopyrite is widely distributed but it occurs invariably in extremely small amounts and in some sections only isolated, minute grains could be detected. Sphalerite has been observed in some sections, notably associated with chalcopyrite, but the amounts present are always very small.

C. Some Trace Elements in rocks related to the Usushwana Complex

A number of samples were analysed for Cu, Ni, Zn, Cr and S in order to study any possible economic potential of the rock formations in the area under investigation (Table 26). The reported values reflect the actual trace element content of the rocks and do not necessarily have a direct bearing on attendant sulphide mineralisation, in which case cold extraction methods of leaching should have been employed. Cameron et al (1971, p. 307) studied the trace element content of ultramafic bodies in Canada and came to the conclusions that firstly, ultramafic bodies associated with copper-nickel sulphide deposits have a distinctly higher content in these elements than unmineralised intrusives, and secondly, mineralised ultramafic bodies have a mean sulphur content of 0,11 to 1,92 per cent S, as compared with a range of 0,01 to 0,10 per cent S in barren ultramafic rocks.

Except for one possible exception the trace element concentrations observed in rocks related to the Usushwana Complex are

Table 25 : The sulphide minerals in some rocks from the Amsterdam - Piet Retief area

Locality		Sample Number	Rock-type	Pyrite	Pyrrhotite	Chalco-pyrite	Sphalerite
Usushwana Complex (Piet Retief Suite)							
Blesbokspruit	515 IT	ECH 754a	Hyperite	-	XXX	XX	-
Blesbokspruit	515 IT	ECH 754b	Hyperite	-	XXX	XX	-
Blesbokspruit	515 IT	ECH 755a	Hyperite	-	XX	XX	-
Sandbach	407 IT	ECH 700	Basic dyke	XX	-	X	-
Merriekloof	420 IT	ECH 712b	Basic dyke	XX	XXX	XX	X
Westoe	394 IT	ECH 585	Basic dyke	XXX	-	X	-
Wolvenkop	427 IT	ECH 465a	Quartz gabbro	XXX	-	XX	-
Springvalley	429 IT	ECH 507b	Quartz gabbro	XX	-	X	-
Wolvenkop	427 IT	ECH 466	Quartz gabbro	XX	-	X	-
Usushwana Complex (Hlelo Suite and Amsterdam Formation)							
Forbes Athole	393 IT	ECH 627	Rhyolite	XXX	-	-	-
De Hoop	402 IT	ECH 658	Rhyolite	XX	X	X	-
Mooihoek	491 IT	ECH 763	Rhyolite	-	XX	X	-
Wolvenkop	419 IT	ECH 473b	Microgranite	XX	-	X	-
Merriekloof	420 IT	ECH 539	Dacitic tuff	XXX	-	XX	XX
Morgenstond	418 IT	ECH 509d	Pyroclastic breccia	XX	XXX	XX	X
Ngwempisi Formation							
Haarlem	443 IT	ECH 498h	Andesitic lava	XX	XXX	XX	-
Morgenstond	418 IT	ECH 509a	Andesitic lava	XXX	-	XX	-
Morgenstond	418 IT	ECH 676	Andesitic lava	XX	XX	XXX	X
Morgenstond	418 IT	ECH 677	Andesitic lava	XX	X	X	-
Morgenstond	418 IT	ECH 678	Andesitic lava	-	XX	X	-
Merriekloof	420 IT	ECH 712a	Andesitic lava	-	XX	-	-
Glen Eland	413 IT	ECH 637	Andesitic lava	-	XXX	XX	XX
Athole	392 IT	ECH 604	Andesitic lava	XXX	-	X	-
Other							
Wolvenkop	427 IT	ECH 464a	Tonalite, Basement	X	XX	X	-
Forbes Athole	393 IT	ECH 617	Dolerite, Karoo	XX	-	X	-
Wolvenkop	427 IT	ECH 476	Dolerite, Karoo	XX	-	X	-
Glen Eland	413 IT	ECH 562	Dolerite, Karoo	XXX	X	X	-

XXX = frequent ore mineral
XX = minor ore mineral
X = trace

Table 26: Some trace elements in selected rocks of the Usushwana Complex and related Formations

Locality	Rock-type	Sample Numbers	Cu	Ni	Zn	Cr	S	S
			ppm	ppm	ppm	ppm	ppm	%
Sterkwater 472 IT	quartz gabbro	ECH 809c	22	25	34	155	-	0,006
Sterkwater 472 IT	quartz gabbro	ECH 809d	37	23	30	122	-	0,004
Sterkwater 472 IT	quartz gabbro	ECH 809e	128	22	32	103	-	0,005
Sterkwater 472 IT	quartz gabbro	ECH 809f	43	19	25	108	-	0,007
Sterkwater 472 IT	quartz gabbro	ECH 809g	42	18	22	150	-	0,008
Sterkwater 472 IT	quartz gabbro	ECH 809h	37	28	33	145	-	0,009
Sterkwater 472 IT	quartz gabbro	ECH 809i	36	26	32	141	-	0,011
Sterkwater 472 IT	quartz gabbro	ECH 809j	29	19	21	98	-	0,005
Sterkwater 472 IT	quartz gabbro	ECH 809k	28	25	30	81	-	0,005
Sterkwater 472 IT	quartz gabbro	ECH 809l	27	23	26	103	-	0,006
Sterkwater 472 IT	quartz gabbro	ECH 809m	26	22	24	122	-	0,006
Morgenstond 418 IT	quartz gabbro	ECH 533b	-	36	-	-	465	-
Tweepoort 404 IT	quartz gabbro	ECH 641	-	41	-	-	698	-
Lions Glen 398 IT	quartz gabbro	ECH 666d	-	38	-	-	470	-
Glen Eland 413 IT	quartz gabbro	ECH 524	93	52	88	7	-	0,47
Redcliff 426 IT	quartz gabbro	ECH 692	-	130	-	-	446	-
Evergeen 425 IT	quartz gabbro	ECH 492d	-	74	-	-	447	-
Tweepoort 404 IT	ferrogabbro	ECH 730b	41	12	57	156	-	0,12
Sterkwater 472 IT	ferrogabbro	ECH 809a	86	13	37	122	-	0,048
Sterkwater 472 IT	ferrogabbro	ECH 809b	317	40	58	120	-	0,007
Ishlelo 441 IT	ferrogabbro	ECH 488	-	38	-	-	874	-
Inhlovudwalile 421 IT	ferrogabbro	ECH 725	-	28	-	-	849	-
Inhlovudwalile 421 IT	ferrogabbro	ECH 732	-	36	-	-	732	-
Merriekloof 420 IT	basic dyke	ECH 712b	92	76	154	111	-	0,70
Lions Glen 398 IT	hyperite	ECH 666a	43	254	71	1257	-	0,023
Evergreen 425 IT	hyperite	ECH 695	67	349	87	846	-	0,032
Blesbokspruit 515 IT	hyperite	ECH 754b	1670	980	24	277	-	0,29
Piet Retief Townlands	gabbro	ECH 810a	86	80	18	306	-	0,018
Piet Retief Townlands	gabbro	ECH 810b	113	51	34	122	-	0,035
Piet Retief Townlands	gabbro	ECH 810c	46	32	22	122	-	0,020
Piet Retief Townlands	gabbro	ECH 810d	51	28	20	138	-	0,009
Piet Retief Townlands	gabbro	ECH 810e	28	26	22	104	-	0,023
Piet Retief Townlands	gabbro	ECH 810f	30	29	26	214	-	0,014
Piet Retief Townlands	gabbro	ECH 810g	63	22	16	104	-	0,008
Piet Retief Townlands	gabbro	ECH 810h	56	32	19	98	-	0,021
Imbama 414 IT	peridotite	ECH 526	-	415	-	-	636	-

Table 26 (cont. next page)

Table 26 (continued)

Locality		Rock-type	Sample Numbers	Cu	Ni	Zn	Cr	S	S
				ppm	ppm	ppm	ppm	ppm	%
Sterkwater	472 IT	granodiorite	ECH 808a	19	12	139	179	-	0,008
Sterkwater	472 IT	granodiorite	ECH 808b	16	11	148	155	-	0,003
Sterkwater	472 IT	granodiorite	ECH 808c	37	10	131	169	-	0,006
Sterkwater	472 IT	granodiorite	ECH 808d	39	11	119	241	-	0,005
Wolvenkop	427 IT	microgranite	ECH 473a	12	26	122	-	-	-
Glen Eland	413 IT	microgranite	ECH 527	11	31	111	-	-	-
Inhlovudwalile	421 IT	microgranite	ECH 723	-	15	-	-	366	-
Morgenstond	418 IT	dacitic tuff	ECH 680	63	27	60	-	-	-
Amsterdam	408 IT	dacitic tuff	ECH 535	29	31	108	-	-	-
Amsterdam	408 IT	dacitic tuff	ECH 714	9	13	69	229	-	0,007
Tweepoort	404 IT	dacitic tuff	ECH 731	31	11	87	174	-	0,029
Rooksdrift	484 IT	dacitic tuff	ECH 813b	44	12	87	141	-	0,007
Athole	392 IT	rhyolitic tuff	ECH 603a	6	11	85	-	-	-
Haarlem	443 IT	rhyolite (Vaalkop)	ECH 499	15	12	84	422	-	0,008
Sterkwater	472 IT	rhyolite (Vaalkop)	ECH 808e	23	7	138	254	-	0,007
Sterkwater	472 IT	rhyolite (Vaalkop)	ECH 808f	24	8	103	318	-	0,005
Sterkwater	472 IT	rhyolite (Vaalkop)	ECH 808g	28	7	91	254	-	0,003
Sterkwater	472 IT	rhyolite (Vaalkop)	ECH 812b	15	9	88	241	-	0,007
Sterkwater	472 IT	rhyolite (Vaalkop)	ECH 812h	22	7	85	272	-	0,006
Sterkwater	472 IT	rhyolite (Vaalkop)	ECH 812b	15	7	98	258	-	0,007
Haarlem	443 IT	andesite/basalt	ECH 498c	60	88	67	-	-	-
Haarlem	443 IT	andesite/basalt	ECH 498d	67	134	112	343	-	0,13
Haarlem	443 IT	andesite/basalt	ECH 498h	30	17	92	7	-	0,11
Morgenstond	418 IT	andesite/basalt	ECH 676	26	55	121	132	-	0,013
Morgenstond	418 IT	andesite/basalt	ECH 677a	74	111	121	111	-	0,28
Morgenstond	418 IT	andesite/basalt	ECH 677b	75	54	129	57	-	0,19
Morgenstond	418 IT	andesite/basalt	ECH 678	41	39	94	50	-	0,05
Morgenstond	418 IT	andesite/basalt	ECH 691	59	78	159	111	-	0,05
Merriekloof	420 IT	andesite/basalt	ECH 712a	63	94	126	132	-	0,17
Merriekloof	420 IT	andesite/basalt	ECH 712c	103	143	151	89	-	0,25
Forbes Athole	393 IT	pyroxenite (Thole)	ECH 593a	-	79	-	-	396	-
Forbes Athole	393 IT	pyroxenite (Thole)	ECH 593b	22	920	78	2011	-	0,013
Forbes Athole	393 IT	pyroxenite (Thole)	ECH 593f	20	1970	75	1804	-	0,01
Amsterdam	408 IT	pyroxenite (Thole)	ECH 534	18	2320	89	2111	-	0,012
Glen Aggy	406 IT	pyroxenite (Thole)	ECH 560	105	1360	99	2136	-	0,018
Glen Aggy	406 IT	basic dyke	ECH 561	74	93	124	91	-	0,014
Westoe	394 IT	basic dyke	ECH 585b	50	188	162	171	-	0,079

Analysts: National Institute for Metallurgy and General
Superintendence Co. Ltd., Johannesburg

very low, especially as far as sulphur is concerned, and it may be concluded that the magma of the Usushwana Complex was deficient in this constituent. Samples from most of the localities in which sulphides have been observed are slightly enriched in sulphur and in most cases the trace element analyses corroborates the observed ore mineral assemblage. High nickel values in the Thole ultramafics must be ascribed to the silicate phase and are of the same order as those observed during the geochemical stream sediment survey. The only exception, where over 1600 ppm Cu, almost 1000 ppm Ni and almost 0,3 per cent S was observed, is the outcrop of hyperite east of Piet Retief referred to above. The copper-nickel mineralisation reported from Swaziland by Winter (1962) and Hunter (1970a) was found in a similar rock type.

Fire assay for platinum group metals and gold of a number of samples of Thole Formation invariably lay below the detection limit of 0,1 ppm.

D. Discussion

The investigation of the Usushwana Complex did not reveal any significant indications of mineralisation and apparently the geological setting did not afford favourable conditions for the formation of ore deposits.

In discussing nickeliferous ultrabasic intrusives in Canada, Kilburn et al. (1969, p. 281) distinguished an Orogenic and a Volcanic group. The former constitute structurally controlled intrusives, whereas the latter, as the name implies, are closely related to volcanic sequences. Sulphide ores are found in both categories. In the orogenic rocks they occur mainly disseminated throughout the intrusive, or certain parts thereof, and in the volcanic variety contact deposits appear to be more characteristic. Wall rock deposits appear to be rare in both types.

In the Amsterdam area the intrusive/host rock relationships of the Thole Formation are somewhat obscured since it is partly buried by both the Amsterdam Formation and the Dwyka Formation. The Thole Formation post-dates the Pongola volcanism and precedes the extrusion of the Amsterdam pyroclastics. This demonstrates its volcanic association, but on the other hand it is also related to the structural episode leading to the emplacement of the Usushwana Complex.

Most of the sills of the Thole Formation are concordantly emplaced into the Pongola Group and are usually well differentiated, ranging from harzburgite at the base through pyroxenite to hyperite and gabbro or norite at the top. These intrusives thus in fact constitute authigenic deposits, as defined by Thayer (1971, p. 240-242). Naldrett, as quoted by Thayer (p. 245) expressed the opinion that well differentiated intrusives of this type only rarely hold promise for sulphide ores.

Naldrett and Gasparrini (1971, p. 214-220) studied the compatibility of sulphide melts with peridotite magma at the Marbridge nickel deposits in Canada. Sulphur is very reactive and will under normal conditions react with iron in the magma to form pyrite and the iron content of the melt will consequently diminish. It is argued on experimental and theoretical grounds that, at a temperature of 940°C at which the Marbridge sulphide melt would have remained liquid, and an assumed lithostatic pressure of 1000 bar to contain the liquid sulphur, the SO_2 fugacity would be too high for thermodynamic equilibrium. Consequently, at Marbridge such a sulphur-rich melt would be incompatible with the average observed composition of the olivine. However, optimum pressure-temperature conditions must exist where sulphur-rich melts are in equilibrium with their host and this can either be in peridotites which have an abnormally low Fe : Mg ratio, or in specific zones of normal peridotites containing olivine with an unusually low Fe/Mg ratio. The composition of the olivine compatible with the Marbridge sulphur-rich melts was estimated by Naldrett and Gasparrini (ibid) to be in the order of 97-98 per cent fosterite. The harzburgite of the Thole Formation contains abundant unserpentinised olivine kernels which have a remarkably constant composition of Mg_{81-84}; also in vertical succession virtually no variation is discernible in various levels of those sills which were studied in more detail.

In the light of the above, it appears that the chemical milieu of the Thole Formation, and particularly its basal harzburgite, was not conducive for the formation of sulphide melts and it was shown already that the magma in fact appears to have been deficient in sulphur. The sills are believed to be near-surface intrusives and the above limitations on the confining pressure were presumably not met. Similar conditions possibly prevailed for the Onverwacht komatiites, some of which are believed to be of extrusive origin (Viljoen and Viljoen, 1969a, b) and it is significant that these so far have not yet yielded promising sulphide mineralisation.

The volcanicity of the Pongola Group and that of the Amsterdam and Vaalkop Formations, as well as the plutonic rocks of the Usushwana Complex, were shown to be of tholeiitic parentage and it forms, though with at least one erosional hiatus, a prolonged magmatic cycle. As such it is comparable with similar Precambrian volcanic complexes, some of which contain important mineral deposits. Examples are the Porcupine, Kirkland Lake and Noranda Complexes in the Canadian Shield, in which Goodwin (1965, p. 956) distinguished the following generalised sequence of events, which he considers to be a "standard extrusive cycle":

(i) extended quiet extrusion of basic lava into subsiding basins with intercalated flows or pyroclastic formations of intermediate composition,

(ii) structural disruption and violent extrusion of felsic pyroclastic rocks,

(iii) an erosional and sedimentary cycle,

(iv) intrusives emplaced into this sequence may represent sub-surface equivalents of the volcanic rocks and they may be important ore bearers.

Conditions in the present area reflect the above concept remarkably well with the exception that the events (ii) and (iii) are reversed. The sedimentary cycle of the Voorslag Formation followed directly on the extrusion of the basic lava of the Ngwempisi Formation and after an erosional hiatus this was followed by the extrusion of the Amsterdam Formation and the Vaalkop Rhyolite Formation.

Vein-type precious and massive base metal deposits in the above-mentioned Canadian volcanic complexes are found in the following settings (Goodwin 1965, p. 964-965):

(i) Most deposits are associated with andesite-rhyolite assemblages;

(ii) massive sulphide deposits occur predominantly in volcanic breccias and tuffs. Ore bodies are found either within rhyolitic breccias or in the upper parts thereof, or in brecciated and silicified andesite and tuff, and

(iii) the mineralisation is structurally controlled and is restricted to domes and arches, which may result from underlying intrusives, or antiforms.

The structural setting in the Amsterdam area is one of synclinal warping in a graben-like feature, which then perhaps precludes the presence of important massive sulphide mineralisation. In addition, the Canadian deposits mentioned above occur in an oceanic environment whereas that of the present area is continental. However, although the results of the present investigation are not encouraging, the felsic pyroclastics and especially the pyroclastic breccia bodies in the Amsterdam Formation warrant further research in view of the otherwise favourable comparison with the Canadian occurrences.

VIII. FORMATIONS POST-DATING THE USUSHWANA COMPLEX

A. Basic Dykes

a) Field relationships

A relatively large number of pre-Karoo diabase dykes are observed mainly in the northeastern part of the area mapped, but only some of the more prominent ones are shown on Folders IA and IB. The dykes are especially numerous in the granitic terrain east of Amsterdam but are also intrusive into the Pongola Group, the Amsterdam Formation and farther south on Haarlem 443 IT and Ishlelo 441 IT, into the Vaalkop Formation.

The relationship of the dykes with the plutonic rocks of the Usushwana Complex is not very clear. At two localities, viz. on Redcliff 426 IT (G.8) and on the border between Dingleside 97 IT and Deepdene 395 IT, about 10 km north-northeast of Amsterdam (F.1) diabase dykes are observed in association with quartz gabbro of the complex. However, on Redcliff the nature of the contact between the dyke and the gabbro is obscured by poor outcrop conditions and intensive afforestation. At the second occurrence mentioned above a dyke seems to branch off from the gabbro and intrudes Basement granite in a north-westerly direction for some 3 km towards the Usutu River, where it terminates abruptly in the granite. Texturally this dyke resembles a porphyritic basic dyke found on Westoe 394 IT and Glen Aggy 306 IT, but near the contact with the gabbro it can hardly be distinguished from the quartz gabbro and therefore the intrusive relationship remains inconclusive. In the area east of Amsterdam the diabase cuts the dyke-like occurrences of the Amsterdam Formation e.g. on De Hoop 402 IT, Tweepoort 404 IT and Avoca 403 IT. In places the basic dykes show peculiar relationships with the dacitic tuff and the pyroclastic breccia of the Amsterdam Formation. On De Hoop the latter stands out in a little ridge and is apparently underlain by a diabasic dyke and on Tweepoort a small capping of dacitic tuff, containing typical recrystallised lithophysae (?), appears to overly such a dyke.

b) Petrography

The dykes display considerable textural variations ranging from a fine to medium grained rock, with ubiquitous slender crystals of plagioclase, to a poikilitic variety which in places contains clinopyroxene crystals up to 1 cm in diameter.

Van Vuuren (1965, p. 66-67 and Table 4) described the mineralogy of the diabase dykes in detail. His results were briefly as follows.

> Plagioclase is in many places almost totally saussuritised and a large variation in composition, ranging from andesine to labradorite is observed.
>
> Augite is the principal pyroxene and the optical properties are $2V_z = 45\text{-}56^\circ$ and $c/Z = 38\text{-}42^\circ$. Hypersthene is in places present in fair amounts. The pyroxene is as a rule uralitised to varying degrees.
>
> Hornblende and biotite are present in places and quartz is the most abundant accessory mineral, followed by magnetite and leucoxene and skeletal ilmenite crystals.

During the present investigation one sample from a dyke on Glen Aggy 406 IT was analysed chemically (Table 27), but unfortunately it displays an anomalous chemical composition in that it is extremely silica-rich and resembles its host, i.e. the dacitic tuff of the Amsterdam Formation, more closely than a gabbroic rock (cf. Tables 10 and 18). The reason for this remains problematical, but could possibly be due to contamination.

Table 27 : Chemical composition and CIPW norm of a basic dyke related to the Usushwana Complex

		CIPW Norm	
SiO_2	64,60		
TiO_2	0,91	Q	31,12
Al_2O_3	11,67	or	18,49
Fe_2O_3	2,85	ab	23,60
FeO	5,18	an	0,32
MnO	0,03	di	0,00
MgO	1,70	hy	9,93
CaO	2,34	mt	4,13
Na_2O	2,79	ilm	1,72
K_2O	3,13		
P_2O_5	0,17		
CO_2	1,61		
H_2O^+	2,04		
H_2O^-	0,00		
Total	99,02		

Analyst: General Superintendence Laboratory, Johannesburg

B. The Sicunusa Granite Pluton

1. Distribution and field relationships

Hunter (1973, p. 139) described six granite plutons in Swaziland, which he termed "Younger plutons" and which are intrusive into the Basement Complex. This type of granite is generally known as the Pongola granite (Geol. map Republic of S. Afr. 1970). One of the plutons in Swaziland, the so-called Sicunusa pluton (Hunter, ibid, p. 139) extends into the present area and is briefly discussed here.

The westernmost portion of this massif builds a prominent, densely vegetated hill on Houdkop 475 IT and Strydkraal 477 IT

(M/N. 12), close to the Swaziland border. Apart from this pluton, which is intrusive into the Usushwana Complex farther eastwards in Swaziland, a number of granitic dykes, consisting of a similar porphyritic rock, are present in the area east of Piet Retief (Folder IB).

In the Amsterdam area a comparable rock was noted in several isolated outcrops on Glen Eland 413 IT, along the road from Amsterdam to Sheepmoor, past the Jericho Dam, just outside the mapped area. The granite is found close to the northernmost extension of the quartz gabbro of the Usushwana Complex and the quartzite of the Glen Eland Formation, but their mutual field relationships could not be established owing to the poor outcrop conditions and afforestation in the area.

2. Petrography

a) Fabric

The granite is medium to coarse-grained and is characterised by extremely abundant and conspicuously euhedral K-feldspar phenocrysts, up to 20 mm long. Towards the westernmost contact of the pluton an area of approximately 1 km^2 within the pluton consists of a much finer-grained variety displaying only sporadic small feldspar phenocrysts.

b) Mineralogy

The mineralogy of the granite is fairly simple and has been described by Hunter (1973, p. 139).

Quartz occurs both in the matrix and as larger anhedral crystals. In the fine-grained variety the latter are much less common.

Feldspar. Microcline is most strikingly developed as large euhedral phenocrysts which are frequently twinned and in some instances mantled with altered plagioclase. Plagioclase is developed in subordinate amounts only and is ususally saussuritised. The indications are that alteration of the feldspar in the fine-grained zone of the Sicunusa pluton is more advanced than in the main body.

Ferromagnesian minerals, i.e. hornblende and biotite and accessory sphene and zircon are present in minor amounts only.

c) Petrochemistry

The chemical composition of both the fine-grained and the normal varieties of the Sicunusa granite, as well as that of the two dykes of this rock are presented in Table 28. The analyses compare well with the average composition of similar rocks in Swaziland (Hunter, 1973, p. 139). In Figure 42 the Na_2O/K_2O ratio of this granite is compared with that of some other "Younger plutons" and the "Older plutons" of Swaziland (Hunter, ibid, p. 139). Its affiliation with the former is obvious.

Chemically the fine-grained variety resembles the coarse porphyritic granite of the pluton, from which it differs only in a somewhat higher normative quartz content and a correspondingly lower normative albite content (Table 28). This rock therefore most likely represents a chilled roof facies of the Sicunusa granite.

C. The Karoo Sequence

1. Dwyka Formation and Ecca Group

a) Distribution and field relationships

The southern extremities of the Karoo cover to the north and northwest of the present area extends from Bankkop in the

Table 28 : Chemical composition of Pongola granite, Piet Retief area

	1	2	3	4
SiO_2	74,47	74,86	75,03	73,26
TiO_2	0,25	0,22	0,13	0,28
Al_2O_3	13,51	13,02	13,95	12,84
Fe_2O_3*	2,72	2,55	1,92	3,05
MnO	0,04	0,04	0,04	0,06
MgO	0,28	0,01	0,01	0,12
CaO	1,21	1,13	0,79	1,28
Na_2O	0,97	2,17	1,93	3,71
K_2O	5,42	5,43	5,43	5,50
P_2O_5	0,01	0,01	0,01	0,01
Total	98,88	99,44	99,24	100,16
CIPW norm				
Q	45,09	39,04	41,33	28,67
or	32,03	32,09	32,09	32,25
ab	8,20	18,36	16,32	31,44
an	5,93	5,54	3,85	2,22
di	0,69	0,02	0,02	2,04
c	3,87	1,54	3,48	0,00
hm	2,71	2,54	1,91	3,20
ru	0,28	0,25	0,16	0,32
ap	0,02	0,02	0,02	0,02
Total	98,82	99,40	99,18	100,16

1. Coarse porphyritic granite dyke, Strydkraal 477 IT (ECH 771)
2. Coarse porphyritic granite, Sicunusa pluton, Strydkraal 477 IT (ECH 794b)
3. Fine-grained granite, Sicunusa pluton, Strydkraal 477 IT (ECH 794a)
4. Coarse porphyritic granite dyke, Morgenzon 88 IT (ECH 778)

Analyst: Geological Survey Laboratory

(* Total iron reported as Fe_2O_3)

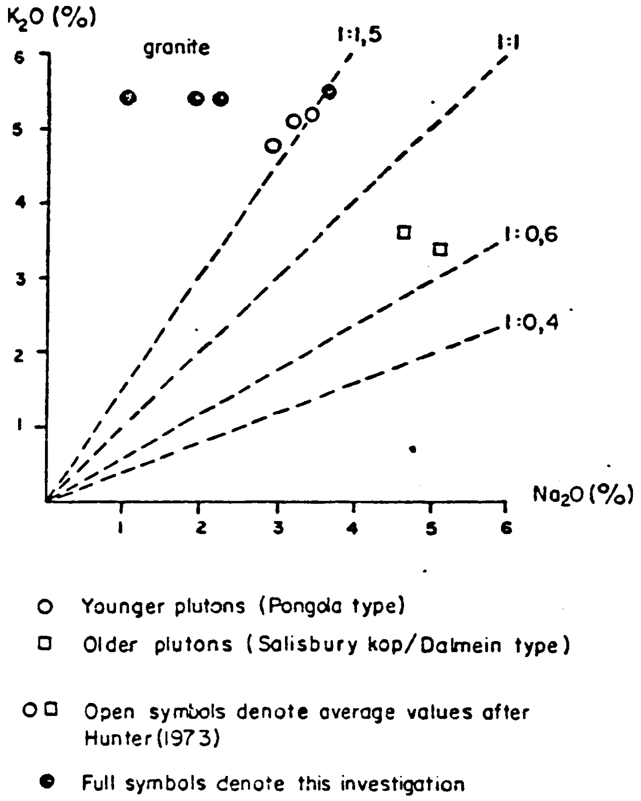


FIG. 42 : Na_2O / K_2O VARIATION DIAGRAM ILLUSTRATING THE RELATIONSHIP OF GRANITE PLUTONS OF SWAZILAND AND EASTERN TRANSVAAL.

west to the Westoe Dam, 12 km north of Amsterdam, and beyond, and blankets the underlying Basement granite, Pongola Group and Usushwana Complex. South of this line the Karoo cover has been eroded, except in the Amsterdam valley, the floor of which is up to 300 m lower than the surrounding country-side. Dwyka tillite and some fine-grained fluvioglacial deposits are much in evidence, overlain by lower Ecca shale and dolerite sheets, intrusive into the latter (Folder IA). Outside this valley only a few isolated outcrops of Dwyka tillite remain south of the above-mentioned line, e.g. on Imbama 414 IT and Ishlelo 441 IT.

Van Vuuren (1965) has adequately described the Dwyka Formation and Ecca Group in the southern part of the Amsterdam valley and this needs not be repeated here.

b) Glaciated pavements

Beautiful, small roches moutonneés and striated floors, carved into Skurwerant quartzite and the Amsterdam pyroclastics, are exposed northwest of Amsterdam on the southeastern portion of Athole 392 IT and the eastern part of Forbes Athole 393 IT (C/D.3). A small striated pavement was observed on the Amsterdam Townlands, just outside the village and less well preserved floors occur on Kolwani 412 IT (C.5) and on Athole (B/C.3) (Fig. 43a). The direction of the ice movement was from NNW to SSE and the striations are orientated N 145°E to N 160°E.

Humphrey and Krige (1931) reported similar glacial floors from the Vryheid area, but as far as could be ascertained those at Amsterdam are the only glaciated pavements known in the Eastern Transvaal. These occurrences were first reported by Visser, et al, (1949).

Fig. 43a: A striated roche moutonnée of Amsterdam pyroclastics as a result of Dwyka glaciation. Athole 392 IT

Fig. 43b: Large phenocrysts of altered plagioclase in porphyritic dolerite. Amsterdam Townlands

2. Karoo Dolerite

Karoo dolerite is present both in the form of sills and dykes.

Within the Amsterdam syncline (Folder IA) two extensive sills are emplaced into the Ecca Group on Forbes Athole 393 IT, where it forms a small plateau, and further south on Sterkfontein 419 IT, Kranskop 422 IT and Wolvenkop 427 IT. In the Piet Retief area relatively small dolerite intrusives are found in Ngwempisi lava and the Skurwerant Formation, mainly on Blesbokspruit 515 IT and Athalie 520 IT (M.14/15), but these appear to have transgressive relationships with the country rock. They are also more coarse-grained and display a diabasic texture, in contrast with the normally fine-grained dolerite sills of the Amsterdam area. The latter are usually marked by tiny plagioclase phenocrysts, but one occurrence on the eastern corridor-like extension of Glen Eland 413 IT, immediately south of the Amsterdam-Ermelo road, is of a coarse-grained nature.

Dolerite dykes are found mainly in the northern part of the mapped area where they preferentially strike northeast and almost due north (Folder IA). Only the more prominent dykes are shown on the map. The dykes are characterised by conspicuous euhedral plagioclase phenocrysts, up to 1 cm long. Two remarkable sub-parallel dykes, some 200 to 250 m apart, are literally packed with exceedingly large anhedral to subhedral phenocrysts, which may attain lengths of 6 to 8 cm (Fig. 43b). In places a faint banding is discernible in this rock caused by layering of the phenocrysts. Another remarkable fact about these dykes is their persistency; they can be traced intermittently from Morgenstond 418 IT where they are found in Basement granite, past Amsterdam, where one dyke is well exposed on the northern slope of a prominent hill immediately north of the village (Fig. 23), to Lions Glen 398 IT, again in the Basement Complex, a total distance of almost 30 km. They can most probably be traced beyond the boundaries of the mapped area.

The Karoo dolerite is always very fresh but in the abovementioned porphyritic dyke the plagioclase phenocrysts are completely saussuritised.

IX. SUMMARY AND CONCLUSIONS

The Usushwana Complex in the southeastern Transvaal consists of a suite of volcanic and plutonic rocks which are younger than the Pongola Group and are in turn intruded by Sicunusa granite. The intrusive has the form of a dyke, about 100 km long, with a bearing of N 140°E. In the mapped area a western and an eastern belt of intrusive rocks can be recognised, separated either by rocks of the Pongola Group in the Amsterdam syncline or by acid roof rocks farther south. The best development of the gabbroic suite is 15 to 20 km due north of Piet Retief, where only one gabbro zone is present, which, according to a gravity survey of this area, is more than 4000 m thick.

The sequence of events leading to the development of the complex is as follows: (i) Deposition of the sedimentary rocks of the Pongola Group with attendant basic volcanicity; (ii) emplacement of ultramafic sills of the Thole Formation, mainly into the Mozaan Subgroup; (iii) extrusion of mainly pyroclastic rhyolitic to dacitic rocks of the Amsterdam Formation and rhyolite of the Vaalkop Formation and (iv) emplacement of the gabbroic rocks of the Usushwana Complex and the formation of an acidic phase, which consists of granodiorite and microgranite.

The sills of the Thole Formation are as a rule well differentiated, consisting of harzburgite at the base which grades upwards into pyroxenite and in places even into gabbro or norite. Pyroxenite is the most widespread and carries large crystals, mainly of orthopyroxene up to 1 cm in diameter. The sills are only in the order of 50 m thick, but they may be quite extensive. In the northern part of the Amsterdam syncline one sill appears to form a continuous feature 6 to 9 km wide and over 20 km long, in which case its central unexposed portion might be of greater thickness.

The Thole Formation is the most basic rock type in the area, but appears to be completely barren of sulphide mineralisation. The magma seems to have been deficient in sulphur and moreover, its chemical composition and mode of emplacement appears to be unfavourable for the formation of sulphide deposits.

The pyroclastic rocks of the Amsterdam Formation exhibit many features indicative of ash-flow deposits. This formation is found in the northern part of the Amsterdam syncline and consists of a predominantly fine-grained, completely massive, dark coloured rock type, containing many accidental ejecta of granite and quartzite as well as blebs of coarsely crystalline quartz and K-feldspar, up to 12 cm in diameter. The latter are reminiscent of altered lithophysae. In places the foreign material may become so plentiful as to constitute pyroclastic breccia bodies. Towards the centre of the syncline the dark tuffaceous rock grades into a distinctly red rhyolitic variety in which fragments of foreign material, mainly quartzite, are ubiquitous. Devitrification textures such as spherulites can be observed even in handspecimen and flow structures are developed in some places.

The dark pyroclastic rocks of the Amsterdam Formation are dacitic in composition and generally contain tiny needles of plagioclase, corroded in places, and acicular aggregates of amphibole, set in a fine-grained matrix riddled with dark crystallites. This, in addition to complete saussuritisation of the plagioclase and incipient granophyric intergrowths, results in the melanocratic appearance of the rock. Rocks of the Amsterdam Formation in places resemble fine-grained igneous rocks and it is concluded that the ignimbritic texture has been destroyed by advanced devitrification and recrystallisation.

All the acidic rocks of the Usushwana Complex have in the past been referred to as granophyre. However, rocks of the Vaalkop Formation are believed to be of volcanic origin, essentially rhyolite, and are separated from the microgranite and granodiorite of the intrusive phase.

Macroscopically the Vaalkop rhyolite is distinguished from the Amsterdam pyroclastics by its distinctly red weathered surface, which is frequently pock-marked. It is usually a fine-grained crystalline rock, though markedly coarser than the rhyolitic Athole Member of the Amsterdam Formation, but when fresh it may vary from dark grey, resembling the Amsterdam Formation, to a red variety. The former is a holocrystalline rock consisting of altered plagioclase set in granophyric matrix, whereas the red type is a felsitic variety totally devoid of granophyric intergrowths. The Vaalkop Formation in places constitutes the roof of the intrusive phase of the complex.

The main types of basic rocks which can be distinguished are quartz gabbro, ferrogabbro, gabbro and hyperite. The quartz gabbro is a homogeneous coarse to medium-grained predominantly mesocratic rock in which quartz is usually a conspicuous modal constituent. It is by far the most common type and constitutes the main body of the mafic phase of the complex. No signs of rhythmic layering are discernible. The only indications that differentiation took place during the development of the intrusive is in the formation of a zone of ferrogabbro which displays weakly developed layering in places as well as a considerably higher iron and titanium content. Magnetite layers occur in the form of disconnected lenses and segregations at several localities in the ferrogabbro to the east and northeast of Piet Retief. The thickness of the layers is extremely variable, but never exceeds 2 m, and occasionally small dip-slopes are developed. Probable near-surface resources of magnetite iron ore of all the major occurrences are unlikely to exceed one million ton. The chemical composition of the magnetite is in the order of 55 per cent Fe, 12 per cent TiO_2 and 0,25 per cent V_2O_5.

Gabbro is relatively scarce and owes its light coloured appearance to the advanced uralitisation of the ferromagnesian components although it is in fact more basic in composition than the other two varieties.

The hyperite is comparable to the hypersthene gabbro described from Swaziland, where it is associated with low-grade copper-nickel mineralisation. It is significant that the only noteworthy sulphides found in the present area occur in this rock. Chemically the hyperite is intermediate in composition between the ultramafic rocks of the Thole Formation and the gabbroic rocks of the complex.

The development of the complex in depth and the presence of any more basic differentiates and possible ore deposits, for instance of chromite, should be investigated by a deep borehole, which could best be sited near the boundary between Burntop 446 IT and Derby 444 IT (Folder IB, I.11). A gravity survey showed that the complex consists here only of one limb and that it is over 4000 m thick.

The acidic rocks of the intrusive phase display considerable variations, ranging from granodiorite to microgranite. Granodiorite, when present, occupies a position between the gabbroic rocks of the complex and its roof of Vaalkop rhyolite. Small xenoliths of quartzite are frequently found in the granodiorite at this interface. The granodiorite is partly a differentiation product of the gabbroic suite of the complex, but assimilation of rhyolitic roof rocks has contributed to its origin.

Microgranite is intermittently present along both limbs of the complex in the Amsterdam area. The amount of femic minerals varies greatly and in places the rock approaches the granodiorite in appearance and mineralogical composition, although in other places it can hardly be distinguished from Vaalkop rhyolite. The field relationships indicate that the zone of granitic rocks overlies the gabbroic rocks. They do not always form the acidic counterpart of the mafic rocks and in places the latter is in fact chilled against, or intrusive into, the acidic rock. Chemically the granitic rocks are indistinguishable from the Vaalkop rhyolite and they are considered to be partly a product of remelting of the rhyolite.

A geochemical stream sediment survey of the area around Amsterdam produced a number of apparently anomalous concentrations of copper, nickel and zinc. However, where these were investigated in the field only insignificant amounts of sulphides were noted. Disseminated sulphides occur in the Ngwempisi lava in places, but the concentration of copper, nickel and zinc in these rocks is rarely higher than 100 ppm. Sulphides occur very sparingly in the Amsterdam and Vaalkop Formations and this is reflected in the low concentrations of copper, nickel and zinc in these rocks. This also applies to the pyroclastic breccia bodies.

This investigation did not reveal any significant indications of mineralisation and it appears that the geological setting of the Usushwana Complex did not afford favourable conditions for the formation of ore deposits.

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