THE BUSHVELD GRANITES AND ASSOCIATED ROCKS IN THE AREA NORTH-WEST OF WARMBATHS, TRANSVAAL

by

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ABSTRACT

From mapping and subsequent petrological and chemical investigation the existence of two separate phases of granitic rocks of the Bushveld Complex in the Warmbaths area was established; viz:

(i) the Baviaansberg granite suite and
(ii) the Verongelukspruit granophyre suite.

Field relationships indicate a definite age-difference between the two granitic phases. The older Verongelukspruit granophyre suite is represented by a series of rocks ranging from granite porphyry through porphyritic micro-granophyre and porphyritic granophyre to granophyre. The younger Baviaansberg granite suite essentially consists of a coarse-grained main facies, which shows some textural variations, and a fine-grained contact facies.

A comparison between the granitic rocks of the Warmbaths area and those at Zaaiplaats indicates many similarities and a tentative correlation is given.

The older Verongelukspruit granophyre suite is considered to represent the first phase of granitic intrusion of the Bushveld Complex. The petrological characteristics of this rock suite indicate that it owes its present character to metamorphic recrystallization. This metamorphism is considered to be the result of the intrusive activity of the younger, main phase of granitic intrusion viz. that of the Baviaansberg granite suite.

The Rooiberg felsite attains a thickness of 3000 m and is subdivided into two units:

(i) the upper felsite unit, and
(ii) the lower felsite unit.

The lower unit consists of various types of felsite whereas the upper unit also includes a volcanic breccia, tuff and an ash-flow tuff.

The recognition of a twofold subdivision in the Rooiberg felsite and the mapping of the separate units has greatly aided in unravelling the structure of the area, which indicates that two major periods of deformation dominated the structural evolution of the area viz.

(i) a pre- and early-Waterberg period of deformation, and

(ii) a post- and possibly syn-Waterberg period of deformation.

SAMEVATTENDE OORSIG

Deur kartering en daaropvolgende petrologiese en chemiese ondersoeke is die bestaan van twee aparte fases van granitiese gesteentes van die Bosveldkompleks in die Warmbadgebied vasgestel nl.:

(i) die Baviaansberggraniet-suite en

(ii) die Verongelukspruitgranofier- suite

Veldverhoudings dui op 'n definitiewe ouderdomsverskil tussen die twee granitiese fases. Die ouer Verongelukspruitgranofier-suite word verteenwoordig deur 'n reeks gesteentes wat strek vanaf granietporfier deur porfiritiese mikrogranofier en porfiritiese granofier tot granofier. Die jonger Baviaansberggraniet-suite bestaan wesentlik uit 'n grofkorrelrige, hooffase, wat teksturele variasies toon en 'n fynkorrelrige kontakfase.

'n Vergelyking tussen die granitiese gesteentes van die Warmbadgebied en die van Zaaiplaats toon vele ooreenkomste en 'n tentatiewe korrelasie tussen die gesteentes van die twee gebiede word gegee.

Die ouer Verongelukspruitgranofier-suite word beskou as die verteenwoordiger van die eerste fase van granitiese indringing van die Bosveldkompleks. Die petrologiese kenmerke van hierdie gesteentereeks dui daarop dat hul huidige karakter te wyte is aan metamorfe rekristallisasie. Hierdie metamorfose word beskou die gevolg te wees van die intrusiewe aktiwiteit van die jonger hooffase van granitiese indringing nl. die van die Baviaansberggraniet-suite.

Die Rooibergfelsiet bereik 'n dikte van 3000 m en word onderverdeel in twee eenhede:

(i) die boonste felsieteenheid, en

(ii) die onderste felsieteenheid.

Die onderste eenheid bestaan uit verskillende tipes felsiet terwyl die boonste eenheid ook 'n vulkaniese breksie en tuf sowel as 'n asvloeituf insluit.

Die herkenning van die onderverdeling in die Rooibergfelsiet en die meegaande uitkartering daarvan het baie bygedra tot die ontrafeling van die struktuur van die gebied wat aantoon dat die strukturele ontwikkeling van die gebied deur twee hoof periodes van vervorming oorheers is, nl.

(i) 'n voor- en vroeg-Waterbergperiode van vervorming, en

(ii) 'n na-Waterberg en moontlike Waterbergperiode van vervorming.

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1. INTRODUCTION

During the winter months of 1971 and 1972 an area measuring approximately 640 km^2, and situated north-west of Warmbaths, was mapped as part of the mapping program of the Geological Survey for sheet 2428 C (Nylstroom). The mapping was done on aerial photographs (scale approximately 1 : 36,000) and the data obtained were compiled on a map on a scale of 1 : 50,000 (Folder 1).

The area, roughly rectangular in shape, is largely underlain by Bushveld granite and Rooiberg felsite. While this investigation was in progress the Geological Survey started a research program on a regional basis on the various aspects of the salic phase (Bushveld granite, Rooiberg felsite and related rocks) of the Bushveld Complex. Since then the author had the privilege of visiting different parts (including the Zaaiplaats area) of the Bushveld Complex where these rocks are developed, and as a result came to realise the problems concerning the mode of formation, correlation, and the general relationships between these various rock-types.

It was then decided that a more detailed study of the numerous aspects concerning these formations in the investigated area might lead to a better understanding of the salic phase of the Bushveld Complex in general.

2. TOPOGRAPHY AND DRAINAGE

The topography of the area exhibits a certain degree of geological control and is dominated by two main features. Rooiberg felsite and granophyre on the one hand, being fine-grained and resistant, build hill-ranges, usually deeply incised by streams, whereas Bushveld granite on the other hand, being less resistant to weathering, mainly occupies low-lying country.

The central-western part of the area is characterised by the above-mentioned low-lying, slightly rolling granite country, broken only once by a west-north-westerly trending ridge of felsite on Kareefontein 432 KR and Newburg 437 KR. This relatively flat area extends eastwards along two narrow anticlinal structures towards Nylstroom and Warmbaths respectively. Towards the west and the south-west it links up with the Springbok Flats which dominates the topography southwards almost as far as Pretoria.

Bordering this central-western part to the north and east, hill-ranges, generally formed by Rooiberg felsite but also by granophyre on Elandsfontein 401 KR, rise steeply to form the outer rim of the Waterberg plateau which extends northwards and eastwards from the investigated area. In the south a single west-north-westerly trending ridge from Warmbaths to Cyferfontein 434 KR, formed by felsite and rocks of the Transvaal System, separates the central low-lying area from the plains to the south.

The drainage pattern of the area may be divided into four separate portions viz.

(i) a southern or south-western portion with a NW-SE trending watershed from Kareefontein 432 KR to Roodepoort 457 KR. This area is drained to the south and south-west. The streams usually peter out where they enter the Springbok Flats to the south, except for the Kareespruit, which forms a tributary of the Pienaars River.

(ii) a south-eastern portion which drains eastwards and north-eastwards into the Buffelspruit, which, in the vicinity of Warmbaths swings south and becomes the Plat River, a tributary of the Pienaars River.

(iii) a north-western portion with watersheds being the Hoekberge to the north and the north-south striking hill-range on Elandsfontein 401 KR to the east. This area is drained to the west and north-west by tributaries of the westward flowing Sand River.

(iv) a north-eastern portion in which the drainage is to the east and north-east with an EW trending watershed on Schrikkloof 428 KR and Witfontein 430 KR. The streams draining this area are tributaries of the Sand River which drains northwards.

3. PREVIOUS WORK

The area was previously investigated by H. Kynaston and E.T. Mellor during 1909. Kynaston who mapped the southern portion, recognised the existence of the Zwartkloof anticline (Kynaston, 1910, plate VII) west-north-west of Warmbaths and the overthrust of dolomite, banded ironstone, quartzite and micaceous quartzitic rocks of the Transvaal System over younger formations (ibid., p. 26). He reported the presence of an overturned sequence of Waterberg sediments, Rooiberg felsite and Bushveld granite against a NW-SE striking strike-fault along the southern limb of the anticline.

Commenting on the Rooiberg felsite, Kynaston stated that it is older than the Bushveld granite which shows intrusive relationships to the felsite, which in turn, shows considerable partial recrystallization. He described the felsite as generally uniform in character with different flows or types being recognisable in places. He further reported the occurrence of a bluish-black shale on Baviaansberg 422 KR and Witfontein 430 KR which he correlated with the Sterk River Shales, and a persistent agglomerate near the base of the felsite (ibid., p. 31-32).

The Bushveld granite he described as being a coarse, red biotite granite which invariably passes into a fine-grained, locally porphyritic phase on approaching the contact with the felsite. This contact phase was reported to contain as a rule granophyric textures, though frequently not to a degree sufficient to warrant the use of the term granophyre (ibid., p. 35)

Mellor (1910, p. 47), after investigating a small portion in the north-eastern part of the area, described the presence of a second anticlinal structure on Rietpoort 390 KR and referred to it as the Rietpoort anticline. Like Kynaston he recognised different types of the Rooiberg felsite, which however, were distinguishable over short distances only. He mentioned the presence of shale in the felsite only a short distance above the contact with the granite on De Naauwte 393 KR and ascribed their relative positions to the fact that the granite occupies a higher horizon in the felsite than usual (ibid., p. 47-48).

Referring to the Bushveld granite he reported the presence of typical "Red Granite" with fine-grained, sometimes bluish or greenish marginal phases on Rhenosterpoort 402 KR, the granite further west being coarser and more massive than usual (ibid., p. 50).

Previously, during 1908, these two investigators made a study of the tin-deposits in the Waterberg area. Discussing the origin of the tin they remarked that the intrusive activity of the magma of the Bushveld granite probably extended over a considerable period of time, the most active and wide-spread phase (as regards the Waterberg tin-fields), commencing immediately after the out-pouring of the Rooiberg felsite (Kynaston, et al., 1909, p. 99).

Since these early investigations the only work on record done by the Geological Survey in this area is that by L.E. Kent who investigated a cobalt-nickel occurrence to the west of Warmbaths on the farm Roodepoort 467 KR. During the first half of the nineteen forties the area was partly surveyed on aerial photographs by L.E. Kent and F.C. Truter. This project, however, was stopped before completion and no report was compiled.

4. GEOLOGICAL FORMATIONS

The following geological formations are present in the investigated area:

RECENT FORMATIONS	Alluvium, sand, soil, gravel, scree and ferricrete.
KAROO SYSTEM	
STORMBERG SERIES	
DRAKENSBERG STAGE	BUSHVELD AMYGDALOID: Amygdaloidal basaltic lava.
CAVE SANDSTONE STAGE	BUSHVELD SANDSTONE: Cream-coloured to red, fine-grained sandstone.
ECCA SERIES	Yellowish-brown fine-grained sandstone and grit.
POST-WATERBERG INTRUSIVES	Diabase, granophyric diabase.
WATERBERG SYSTEM	
NYLSTROOM SERIES	
SWAERSHOEK STAGE	Siltstone, conglomerate, sandstone and pebble-sandstone.
BUSHVELD COMPLEX	
BAVIAANSBERG GRANITE SUITE	Medium- to coarse-grained, even-grained, and porphyritic granite with dykes and sheets of aplite and a fine-grained to medium-grained contact phase.
VERONGELUKSPRUIT GRANOPHYRE SUITE	Granite porphyry, spherulitic granite porphyry, micro-granophyre, porphyritic granophyre and granophyre.

ROOIBERG FELSITE	
UPPER FELSITE UNIT	Ash-flow tuff, felsite, tuff, volcanic breccia and quartzite xenoliths.
LOWER FELSITE UNIT	Felsite and quartzite xenoliths.
TRANSVAAL SYSTEM	
PRETORIA SERIES	
TIMEBALL HILL STAGE	Quartz-feldspar-biotite schist, quartz-mica schist, and quartzite.
DOLOMITE SERIES	
BAND IRONSTONE STAGE	Banded ironstone.
MAIN DOLOMITE STAGE	Dolomite and chert.

5. THE TRANSVAAL SYSTEM

5.1 DISTRIBUTION AND FIELD RELATIONSHIPS

Rocks of the Transvaal System occupy a narrow zone extending from the immediate vicinity of Warmbaths in a west-north-westerly direction to Cyferfontein 434 KR, and form part of the overthrusted mass of the Droogekloof Thrust. The Transvaal System is bordered to the north by the thrust-plane and generally dips in a southerly direction underneath Bushveld granite, forming the floor of the latter. Due to poor exposures the contact relationships between Bushveld granite and the Transvaal rocks could not be studied in detail. An intrusive relationship, however, is indicated by the presence of a number of xenoliths on Cyferfontein 434 KR which are considered to represent inclusions of the Transvaal System in the Bushveld granite.

Along the Droogekloof Thrust the rocks of the Transvaal System have been pushed over Rooiberg felsite, Bushveld granite and sediments of the Waterberg System.

Only portions of the Dolomite and Pretoria Series are represented in a number of scattered occurrences. This rendered correlation and subdivision very difficult. The various rock-types have been subjected to considerable deformation, as indicated by severe folding and brecciation. As may be expected, they also show effects of dynamic metamorphism, whereas indications of thermal or contact metamorphism, due to intrusion of the Bushveld granite, are less conspicuous.

5.2 THE DOLOMITE SERIES

The main occurrence of the Dolomite Series is on Zwartkloof 470 KR where two prominent hills, on either side of the road leading to the Zwartkloof Fluorspar Mine, are formed by dolomite and banded ironstone. Isolated outcrops of both dolomite and banded ironstone extend eastwards and westwards onto the adjoining farms Herman 468 KR, Roodepoort 467 KR and Droogekloof 471 KR. On Zwartkloof 470 KR and the eastern portion of Droogekloof 471 KR the

Dolomite Series has been deformed into a number of folds which probably have been further affected by minor faulting. Further to the west, on Droogekloof 471 KR, the structural relationships of these formations are less complicated and a normal succession of the Dolomite Series dips at 30-45 degrees south under the overlying quartzite of the Pretoria Series.

From the western portion of Droogekloof 471 KR and further westwards along the Droogekloof Thrust the dolomite and banded ironstone have been faulted out and the fault gradually intersects higher levels in the Transvaal beds. However, on Cyferfontein 434 KR a number of occurrences of banded ironstone and dolomite are again developed south of the fault-line.

Nowhere in the present area is there an extensive development of the Dolomite Series. It is subdivided into the **Main Dolomite Stage** and the **Banded Ironstone Stage**, the Upper Dolomite Stage – as developed elsewhere in the Transvaal – appears to be absent. The thickness of these formations is difficult to determine as the base of the dolomite is not exposed and the succession is intensively disturbed. On Droogekloof 471 KR where a normal succession is developed the thickness of the banded ironstone has been estimated at approximately 75-100 m.

5.2.1 Dolomite and Chert

The dolomite crops out sporadically and is easily recognised on account of its characteristic weathering. Layers of varying thickness of chert tend to increase in thickness and abundance towards the top of the dolomite and crop out as low ridges in the area.

Under the microscope the dolomite is seen to consist mainly of anhedral grains of recrystallized dolomite – as a rule twinned, kinked and bent – and subordinate amounts of quartz, chlorite and iron-oxides. Long, needle-shaped tremolite crystals which stand out on weathered surfaces are present in a sample from Zwartkloof 470 KR, whereas serpentine is reported to be developed in places in the dolomite on Zwartkloof 470 KR (I.C. Pringle, pers. comm.). In another sample, slightly elongated grains of dolomite show a parallel orientation, which according to Spry (1969, p. 267) is indicative of rapid deformation at low temperature. Twinning, kinking and bending of dolomite crystals and the described dimensional preferred orientation point to metamorphic alteration under stress during overthrusting. The development of tremolite is probably due to the contact metamorphism by the Bushveld granite.

As a rule the chert is white or yellowish-white and partly or entirely recrystallized. It contains moderate amounts of iron-oxides.

5.2.2 Banded Ironstone

The banded ironstone forms conspicuous outcrops which can be easily traced on aerial photographs due to the fact that it supports a very dense, bushy vegetation. It consists of thin layers of magnetite or hematite or ferruginous shale alternating with cherty or quartzitic layers. On weathered surfaces the quartzitic/cherty layers are stained red or yellow whereas the magnetite/hematite layers are reddish-brown. On fresh surfaces, however, the quartzitic/cherty layers are white and the magnetite/hematite layers bluish-black in colour.

5.3 THE PRETORIA SERIES

The beds of the Pretoria Series attain their best development immediately north of the farmhouse on Boschpoort 473 KR, where they form an isolated hill along the line of the Droogekloof thrust-fault. The occurrence consists of irregular outcrops of white quartzite interbedded with purple, quartzitic, schistose rocks. The beds dip at 25^{o} to 65^{o} in a southerly direction and are highly brecciated, faulted and folded with the result that subdivision of the Pretoria Series or lateral correlation is very difficult. However, at least three separate quartzite layers seem to be present. The lowest is a hard, massive quartzite and is present directly along the thrust-plane. Overlying this quartzite, and separated from it by quartz-mica schist, a bluish-grey quartzite with thin layers rich in iron-oxides can be distinguished. This quartzite, is in turn, overlain by purple schist and another massive white quartzite which forms the crest of the ridge. A number of other isolated occurrences of quartzite and schist are present south of the Droogekloof Thrust on Boschpoort 473 KR and the two neighbouring farms (see Folder 1).

In view of the fact that quartzite and schist (altered shale) are present immediately above the banded ironstone of the Dolomite Series in areas where a normal succession is developed (Droogekloof 471 KR), as well as the presence of ferruginous quartzite on Boschpoort 473 KR, all the aforementioned formations are correlated with the Timeball Hill Stage of the Pretoria Series.

In the north-western part of Cyferfontein 434 KR and on Vaalwal 525 KQ a white quartzite south of the Droogekloof Thrust dips to the south at 40^{o} to 75^{o}. This quartzite was correlated with the Magaliesberg Stage by Ianello (1969, p. 4), who mapped the adjoining area to the west. However, a correlation with either the Black Reef Series or the Timeball Hill Stage of the Pretoria Series would be more justified if the relative positions of outcrops of dolomite and banded ironstone to the south-east are taken into account.

Near the north-western corner of Olievenfontein 475 KR a white, coarse- to fine-grained quartzite crops out. This quartzite probably represents a xenolith in the Bushveld granite, and its correlation is therefore uncertain.

5.3.1 Quartz-feldspar-biotite Schist

In the bed of the Droëkloofspruit the quartz-feldspar-biotite schist occurs between banded ironstone of the Dolomite Series and quartzite of the Pretoria Series. In other parts of the area where the Timeball Hill quartzite and the banded ironstone crop out in close proximity, they are usually separated by a small area devoid of outcrops. These areas are probably underlain by the quartz-feldspar-biotite schist. This view appears to be supported by the presence of quartz-feldspar-biotite schist, in direct contact with banded ironstone, in the core of the syncline formed by banded ironstone and dolomite on Zwartkloof 470 KR, where it is believed to form the basal member of the Pretoria

Series. It may, however, also represent a lense of altered shaly material in the banded ironstone, a feature described by Coertze (1961, p. 57) of other areas in the Transvaal.

Mica, readily recognisable in hand-specimen, imparts a pronounced schistosity to this rock which is greenish-grey in colour. In the core of the syncline on Zwartkloof 470 KR the schist is reddish-grey, which is probably due to secondary staining by iron-oxides derived from the banded ironstone.

In thin section, the schist shows a pronounced parallel orientation of mica flakes, with xenoblastic, granular quartz and feldspar between the layers of mica. The constituents are quartz, biotite, feldspar (plagioclase and microcline) and iron-oxides. Small acicular crystals of tourmaline which are pleochroic from yellowish-green to colourless are also present.

5.3.2 Quartz-mica Schist

The quartz-mica schist is present between the different quartzites on Boschpoort 473 KR and at two other localities (see Folder 1). In hand-specimen, it is purple in colour and is characterized by the present of mica which, however, does not show a marked schistosity. In places it grades into a micaceous quartzite and it generally contains a higher amount of iron-oxides than the quartz-feldspar-biotite schist. It consists of quartz and colourless mica, small amounts of acicular crystals of yellowish-green pleochroic tourmaline and scattered grains of iron-oxides.

5.3.3 Quartzite

The quartzite of the Pretoria Series is white to cream-coloured, medium- to fine-grained and massive. Generally it consists of recrystallized quartz and subordinate amounts of small, intergranular grains of colourless mica. Accessories are iron-oxides and a few grains of broken and corroded, optically undeterminable, minerals of detrital origin. Many of the quartz grains display undulose extinction, numerous cracks and very irregular boundaries, in particular in samples collected near the Droogekloof Thrust.

A slaty quartzite in the Droëkloofspruit on Droogekloof 471 KR shows a marked elongation and parallel orientation of quartz grains. Bluish-white, ferruginous quartzite on Boschpoort 473 KR shows parallel orientation of elongated flakes or grains of iron-oxides, slightly elongated quartz and colourless mica. It contains a few highly corroded grains of greenish-blue, pleochroic tourmaline, probably of detrital origin. The quartzite from the isolated outcrop near the eastern boundary of Olievenfontein 475 KR is coarsely recrystallized and consists of xenoblastic quartz with undulose extinction and irregular boundaries and colourless mica. The quartz contains needles of rutile and the mica occurs intergranularly and as small inclusions in the quartz grains.

Original detrital accessories are represented by a few grains of zircon and magnetite. One sample contains moderate amounts of colourless apatite.

5.4 XENOLITHS IN THE BUSHVELD GRANITE

On Cyferfontein 434 KR a number of small outcrops of highly altered sediments are present as xenoliths in the Bushveld granite. These xenoliths represent fragments of the underlying sediments of the Transvaal System which crop out in the near vicinity along the line of the Droogekloof Thrust. They are found mainly along the bed of the Rietspruit and vary considerably in size, the biggest being only a few metres in diameter. Variation in petrographical character and composition from one xenolith to another indicates a variety of original parent-rocks. In a few cases original quartzitic or shaly material is still recognisable and in some xenoliths layering is still detectable. The Bushveld granite in contact with and surrounding the xenoliths varies considerably from the granite generally found in this area.

The original sedimentary rocks have been subjected to a reasonably high grade of metamorphism, a fact which is proved by the granoblastic texture and the formation of the following minerals, which are present in varying amounts, depending on the composition of the original rock:

(a) minerals of the epidote group, both biaxial negative and positive and probably epidote and clinozoisite.

(b) minerals of the amphibole group, biaxial negative, pleochroic in greenish colours and probably hornblende, actinolite and/or tremolite.

(c) feldspars (plagioclase and perthite).

(d) chlorite and biotite

(e) sericite

(f) apatite

(g) pyroxenes mostly altered to amphibole and chlorite.

Some of these minerals, e.g. those of the epidote group, chlorite and sericite were probably formed during retrograde metamorphism.

6. THE ROOIBERG FELSITE

6.1 REVIEW

Ever since Lombaard's (1932) treatise on the felsites and their relations in the Bushveld Complex, in which he proposed a classification for the Rooiberg or Bushveld felsites (Table 1), this classification has been used with only slight modification by different workers.

TABLE 1

CLASSIFICATION OF ROOIBERG FELSITE

(Lombaard, 1932, p. 159)

1. Non-Porphyritic Felsites	2. Porphyritic Felsites Insets are:		3. Felsites with directed textures	4. Pyroclastic Felsites
	Albite	Microperthite		
Pseudo-spherulitic			Trachytic	Volcanic breccia
Granophyric			Flow-banded	Tuffs
Felsitic (Glassy)			Amygdaloidal	

Wolhuter (1954, p. 6) states that "except for trachytic and porphyritic varieties carrying phenocrysts of microperthite, examples of all the remaining felsites are found" in the country surrounding Loskop Dam, Transvaal. He also proposed to rename Lombaard's "pyroclastic felsite" to "felsitic pyroclastic rocks". His subdivision and classification of the felsite and associated sediments is summarized in Table 2.

TABLE 2

CLASSIFICATION OF ROOIBERG FELSITE USED BY WOLHUTER

(1954, pp. 5-11)

1. FELSITIC LAVA		2. FELSITIC PYROCLASTIC ROCKS	3. CONTEMPORANEOUS SEDIMENTS
TYPES	VARIETIES		
Pseudospherulitic and granophyric felsite	Slightly porphyritic Amygdaloidal Non-porphyritic	Crystallithic tuff Lithic tuff	Quartzite Sandstone Shale
Granophyric felsite	Porphyritic Non-porphyritic		
Uniformly fine-grained (glassy) felsite	Porphyritic Non-porphyritic		
Felsite with directed textures	Amygdaloidal Flow-banded		

Glathaar (1956, p. 5) after investigating an area south-east of Rust der Winter Dam remarks that felsites exhibiting all the characteristics described by Lombaard are present in that area and he classifies the felsites as follows (Table 3).

TABLE 3

CLASSIFICATION OF ROOIBERG FELSITE USED BY GLATHAAR

(1956, pp. 5-11)

1. FELSITE LAVA	2. PYROCLASTS	3. SEDIMENTS
Pseudospherulitic granophyric felsite	Basal Tuff	Quartzite
Pseudospherulitic felsite	Glass Tuff (i) multi-coloured (ii) black	
Felsitic Perlite	Agglomerate	

More recently Menge (1963, pp. 5-17) suggested a threefold subdivision for the Rooiberg felsite developed in an area west of Naboomspruit viz:-

(iii) Upper felsite
(ii) Ignimbrite and shale
(i) Lower felsite.

At approximately the same time agglomerate and tuff were reported to be present in the Rooiberg felsite north-west and south-west of Potgietersrust (Wilke, 1963 p. 14-16, De Villiers, 1963, p. 10-12). Both workers also reported the presence of xenoliths of quartzite in the Rooiberg felsite (Wilke 1963, p. 6 & 7; De Villiers 1963, p. 7 & 8).

Von Gruenewaldt (1966, p. 11) stated that the designations proposed by Lombaard are generally applicable to the felsite in the area north of Middelburg. After a review of such terms as "granophyric", "micrographic" and "micropegmatitic" he proposed the following subdivision of the Rooiberg felsite in the area under consideration (Table 4):

TABLE 4

SUBDIVISION AND CLASSIFICATION OF THE ROOIBERG FELSITE USED BY VON GRUENEWALDT (1966, p. 29 and 1968, p. 159)

<table>
<tr><th>WATERVAL 184 JS</th><th colspan="2">ROODEWAL 193 JS AND AVONTUUR 195 JS</th></tr>
<tr><td rowspan="5">NOT INVESTIGATED</td><td rowspan="4">UPPER FELSITE</td><td>Not mapped. At least another 1200ft of felsite on Klipnek 199 JS</td></tr>
<tr><td>Porphyritic felsite</td></tr>
<tr><td>Shale</td></tr>
<tr><td>Agglomerate
Porphyritic felsite</td></tr>
<tr><td colspan="2">VARIABLE FELSITE (Amygdaloidal and pseudospherulitic felsite and microgranophyre)</td></tr>
<tr><td>LOWER FELSITE (non-porphyritic, porphyritic and micrographic)</td><td colspan="2">Microgranophyre, granophyre and microgranite</td></tr>
</table>

Recently Coetzee (1970, p. 312-325) investigated a portion of the Rooiberg felsite along the northern limb of the so-called Zwaershoek anticline (Jansen 1969, p. 59) north of Nylstroom and subdivided the felsite as given in Table 5. He stressed that none of the evidence presented by Menge in favour of his "ignimbrite" is unequivocal proof that the rock is an ignimbrite and not an agglomerate.

TABLE 5

SUBDIVISION OF THE ROOIBERG FELSITE AS USED BY COETZEE

(1970, p. 318)

SYSTEM	SERIES	FORMATION
TRANSVAAL	ROOIBERG	Quartz-feldspar porphyry
		Upper sedimentary zone
		"Pale" felsite and porphyritic felsite
		"Union Tin" shale
		"Pale" felsite
		Agglomerate
		Variable felsite
		"Pale" felsite
		Porphyritic felsite

6.2 THE ROOIBERG FELSITE NORTH-WEST OF WARMBATHS

6.2.1 Distribution and Field Relationships

A large portion of the investigated area is underlain by Rooiberg felsite. In general it forms the outer rim of the Waterberg basin which is developed to the north and east of the area surveyed. In broad outline the felsite occupies the limbs of two anticlinal structures viz. the Loubad anticline (Jansen, 1969, p.59) previously referred to as the Rietpoort anticline (Mellor, 1910, p. 47), south of Loubad, and the Zwartkloof anticline north-west of Warmbaths. Between these two structures the felsite forms the western rim of the Nylstroom syncline (Jansen 1969, p. 59). Both anticlines, however, have been affected by faulting. At a number of localities on Witfontein 430 KR, Elandsfontein 440 KR, Kareefontein 432 KR and Boekenhoutplaat 436 KR, Rooiberg felsite occurs as erosional remnants on top of the Bushveld granite (see Folder 1).

Along the northern limb of the Loubad anticline and westwards in the Hoekberge the felsite dips northwards at 55 to 75 degrees, whereas on Rietpoort 391 KR, in the nose of the anticline, dips vary between 30^{o} and 65^{o} in north-easterly directions. The felsite has been displaced from Rietpoort 390 KR to Rhenosterpoort 402 KR, and from here to Newburg 437 KR it strikes north-south and dips eastwards at 30-35 degrees. On Newburg 437 KR the strike changes to WNW-ESE and the dip increases to $55^{o} - 75^{o}$ to the north-east along the north-eastern limb of the Zwartkloof anticline. On Zwartkloof 470 KR in the nose of the anticline the dip varies between 60^{o} and 25^{o} in a general easterly direction. Along the southern limb, up to the Boschpoort fault, no dips could be measured but the felsite is estimated to dip at $60^{o} - 70^{o}$ southwards. South of the Boschpoort fault Rooiberg felsite strikes WNW-ESE and although not measured, rather high overturned dips are indicated.

The Rooiberg felsite overlies Bushveld granite with an intrusive, locally irregular contact. On a regional scale, however, the granite apparently intruded to more or less the same niveau in the felsite, except south of the Boschpoort fault where the granite intruded to a higher level. In places the felsite is overlain conformably by sediments of the Waterberg System, as indicated by dips in the felsite, but over large areas an unconformable relationship exists (see Folder 1). The presence of a pyroclastic zone, consisting of a volcanic breccia overlain by a layer of tuffaceous material in the Rooiberg felsite, made it possible to subdivide the felsite into two major units referred to as the upper and lower felsite units. A generalized schematic section representing this subdivision and indicating approximate thicknesses of these units is given in Fig. 1.

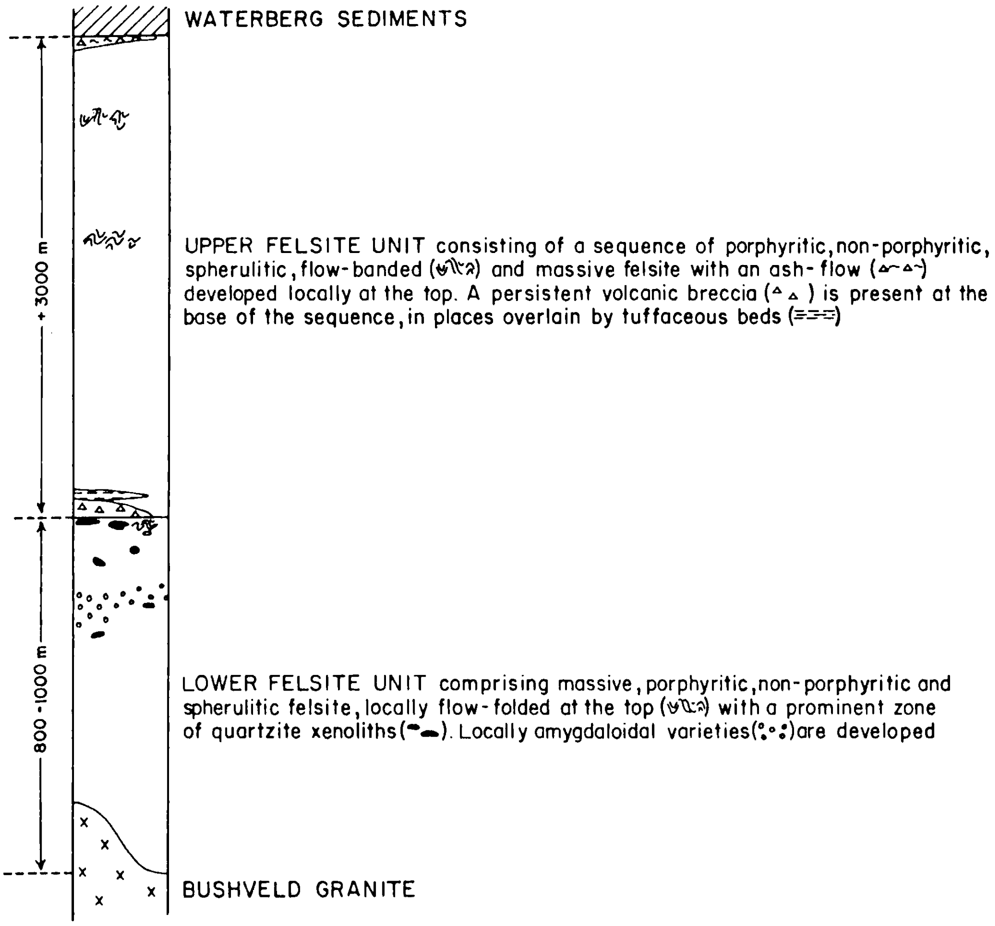

FIG. I. - Schematic stratigraphic section of the Rooiberg felsite

As indicated in Figure 1, the upper portion of the lower felsite unit is characterized by the preponderance of numerous quartzite xenoliths, often forming a definite stratigraphic horizon. In areas where the basal volcanoclastic sediments of the upper unit are absent these xenoliths aided in the subdivision and mapping o the separate units, the contact between the upper and lower felsite being drawn immediately above the level in the felsite sequence where these xenoliths occur.

6.2.2 The Lower Felsite Unit

The lower felsite unit is mainly developed north of the Boschpoort fault. The erosional remnants of felsite in the Bushveld granite on Kareefontein 432 KR and the adjoining farms are tentatively considered as part of the lower felsite unit. The presence of quartzite xenoliths in the felsite remnant on Witfontein 430 KR and Kareefontein 432 KR is regarded as positive evidence of this assumption. The lower unit is very well exposed on Witfontein 430 KR and Newburg 432 KR where both the relationship with Bushveld granite and the overlying upper felsite unit can be observed. The original thickness of the lower unit cannot be determined and the present average thickness is approximately 800 to 1000 m.

The lower unit commonly comprises granular felsite, in part porphyritic and in places spherulitic. In hand-specimen the felsite of this unit generally ranges from black to dark grey in colour which changes to a dull ocreous red upon weathering. It has a fine-grained groundmass (0,01-0,25 mm) consisting mainly of quartz, feldspar, abundant chlorite and iron-oxides. Phenocrysts of rounded quartz and anhedral to subhedral feldspar (albite) are frequently present. The albite phenocrysts are mostly highly chloritized and sericitized. A number of samples contain carbonate and epidote in addition.

Metamorphism of the felsite by the Bushveld granite resulted in recrystallization near the contact and the formation of a coarser matrix. In some places micrographophyric varieties were formed probably from original, spherulitic felsite. The lower felsite unit is characterized by the presence of xenoliths of quartzite, abundant chlorite (of metamorphic origin due to the Bushveld granite) and also the apparent scarcity of flow-banding and clastic or other intercalations. Although observations during field-work indicated possible variation within the lower felsite unit, no attempt was made to further subdivide it. However, varieties of felsite and the quartzite zenoliths need further elaboration.

(a) Black Porphyritic Variety

Outcrops of this rock-type have been found on Witfontein 430 KR and Kareefontein 432 KR approximately in the middle of the lower unit. It is pitch-black in colour, is usually fresher than the more common felsite of the lower unit and contains many phenocrysts. The fine-grained groundmass consists of quartz, feldspar (needle-shaped microlites) hornblende, and iron-oxides. The phenocrysts are albite and corroded quartz.

(b) Amygdaloidal Variety

This rock-type commonly occurs in the upper portion of the lower unit The amygdales are often elongated, usually not more than a few millemetres in diameter, and consist of quartz (Fig. 2). The matrix does not seem to vary much from that of the common felsite of the lower unit.

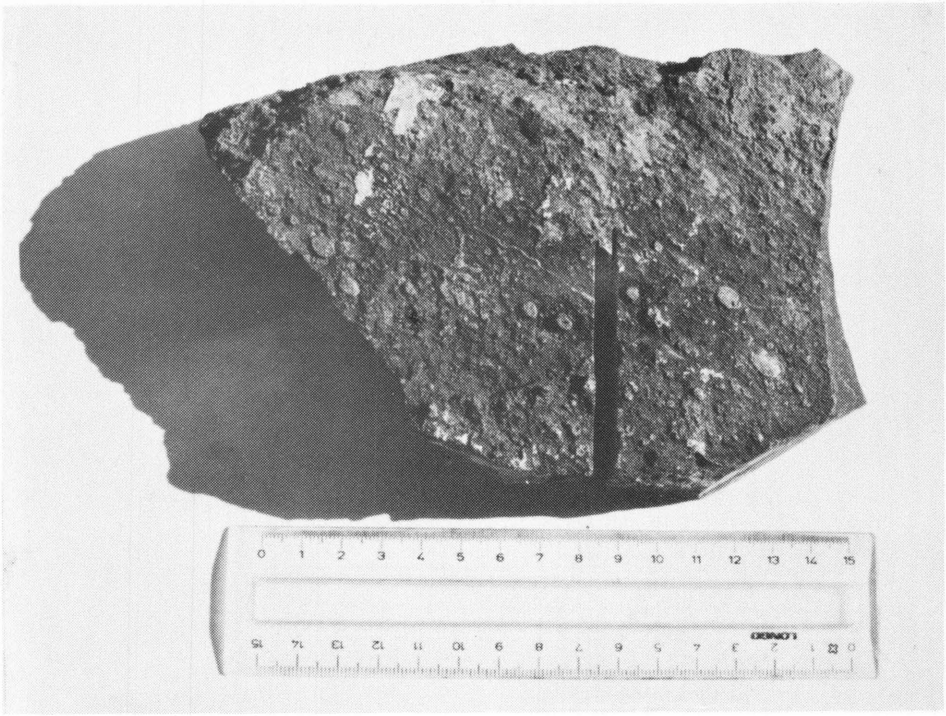

Fig. 2 – Amygdaloidal felsite from the upper portion of the lower felsite unit (Zwartkloof 470KR)

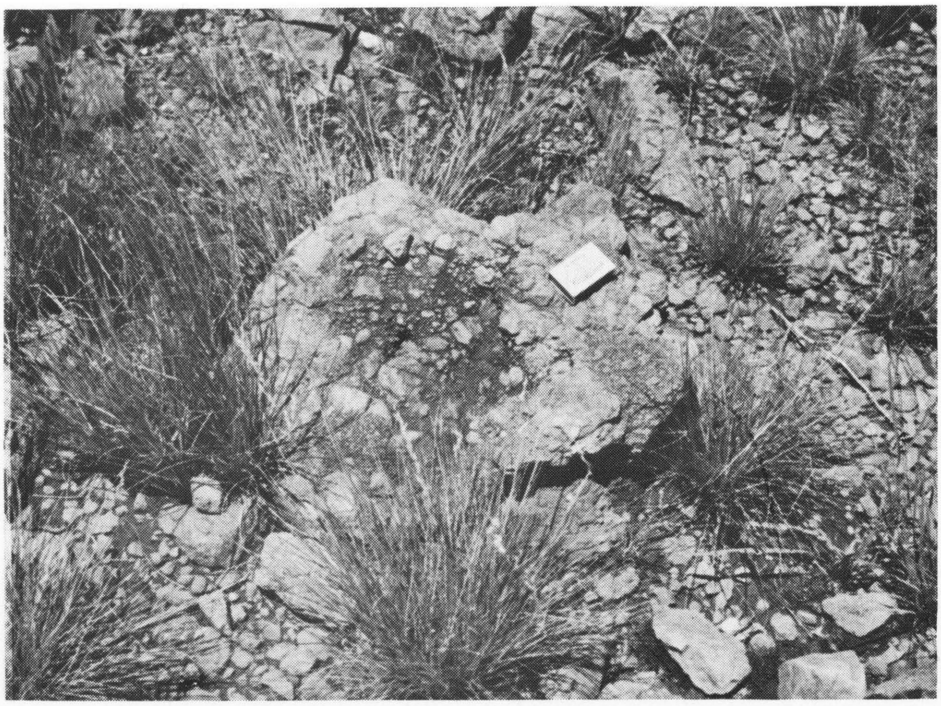

Fig. 3 – Outcrops of xenoliths of quartzite in the lower felsite unit on Middelfontein 391 KR. Note the brecciated nature and the texture which gives the impression of partial fusion

(c) Quartzite Xenoliths

Blocks and lenses of quartzite and quartzite-breccia of differing sizes are randomly distributed in the upper portion of the lower unit with a maximum frequency below the volcanic breccia of the upper unit. They occur throughout the investigated area and attain their best development on Zandrivier 397 KR. The quartzite is commonly recrystallized and shows signs of partial fusion (Fig. 3). On Witfontein 430 KR and at other localities, especially south of the Boschpoort fault, the xenoliths also occur in the upper felsite unit. However, there are some lithological differences between the quartzites of the lower unit and those of the upper unit (Table 6).

TABLE 6

LITHOLOGICAL DIFFERENCES BETWEEN QUARTZITE OF THE UPPER AND LOWER FELSITE UNITS

QUARTZITE OF THE LOWER FELSITE UNIT	QUARTZITE OF THE UPPER FELSITE UNIT
1. Entirely recrystallized	1. Partly recrystallized
2. Quartz grains highly irregular and strained	2. Quartz grains often rounded
3. Contains intergranular mica	3. Quartz grains cemented by quartz
4. Commonly white in colour	4 Buff; reddish-brown and in places green in colour
5. Contains no felsite fragments	5. Contains felsite fragments
6. Feldspar minor constituent	6. Abundant feldspar

Two hypotheses were put forward to explain the presence of quartzite in the Rooiberg felsite viz. (i) they represent accidental inclusions of rocks of the Transvaal System; (ii) they are contemporaneous sediments (Von Gruenewaldt 1968, p. 158). If the lithological differences listed in Table 6 are considered the quartzite in the lower unit may represent accidental inclusion whereas those in the upper unit may represent contemporaneous sediments.

6.2.3 The Upper Felsite Unit

Conformably overlying the lower felsite unit is a sequence of felsite flows, preceded by a volcanic breccia and a layer of tuffaceous material, all of which constitute the upper felsite unit. At the very top of the upper unit – below the sediments of the Waterberg System – on Rhenosterpoort 402 KR, a breccia, which was identified as a partly welded ash-flow tuff (ignimbrite), is present. Similar rocks were encountered on the same horizon on Droogekloof 471 KR and Elandsfontein 427 KR.

(a) The Volcanic Breccia

The xenolith-rich zone at the top of the lower felsite unit is overlain by a persistent volcanic breccia or agglomerate. In general the breccia forms good exposures, often causing small ledges in the gently sloping felsite country. It may be followed along strike for considerable distances and is absent only along small portions of both the Zwartkloof and the Loubad anticlines, as well as in parts of the felsite south of the Boschpoort fault (see Folder 1). On Witfontein 430 KR where it is well exposed the thickness is estimated at 60 m.

The breccia is a cream- or grey-coloured rock studded with dark angular fragments (Fig. 4). On fresh surfaces it is dark-grey or black and the brecciated nature is difficult to discern. It consists of a felsitic groundmass in which fragments of microcrystalline, .often flow-banded, felsite and sporadic fragments of quartzite are embedded. The fragments vary in dimension i.e. from a few millimetres to 30 millimetres and more in diameter.

(b) Tuff

The volcanic breccia is almost invariably overlain by a layer of tuffaceous material (Fig. 5). However, in places, a thin flow of felsite intervenes between the breccia and the tuff. As opposed to the volcanic breccia and the felsite, the tuff weathers negatively and the best outcrops of tuff are therefore found in valleys cutting across the felsite. Good exposures are found on Rietpoort 390 KR,

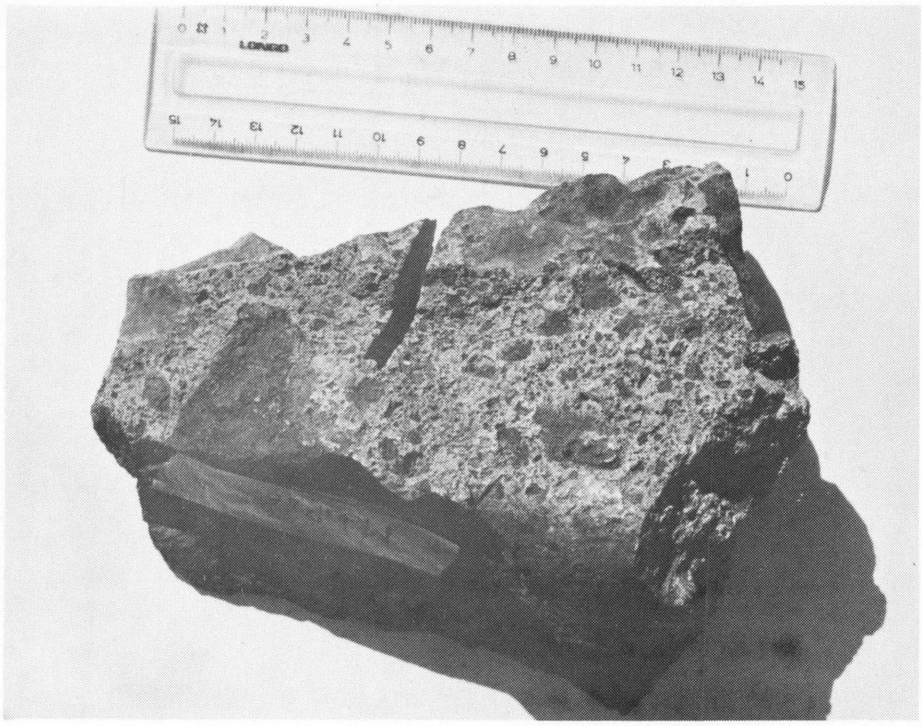

Fig. 4 – Volcanic breccia with dark angular fragments of various sizes in a light, cream-coloured, fine-grained felsitic groundmass

Fig. 5 – Outcrops of tuff along the nose of the Loubad anticline, Rietpoort 390KR

Zandrivier 397 KR, Witfontein 430 KR, Newburg 437 KR, Baviaansberg 442 KR and Zwartkloof 470 KR On the eastern portion of Zwartkloof 470 KR tuff and volcanic breccia crop out concentrically around a small stock of Bushveld granite. Along the south-western limb of the Zwartkloof anticline the tuff seems to be absent. The same applies to the felsite south of the Boschpoort fault. The tuff is mostly light-brown to grey or purple in colour, fine-grained and massive although in places it is thinly bedded (Fig. 6). Locally rounded lapilli of pumice were observed in the massive tuff. In general it seems as if the tuff is massive in the lower portion and laminated in the upper portion.

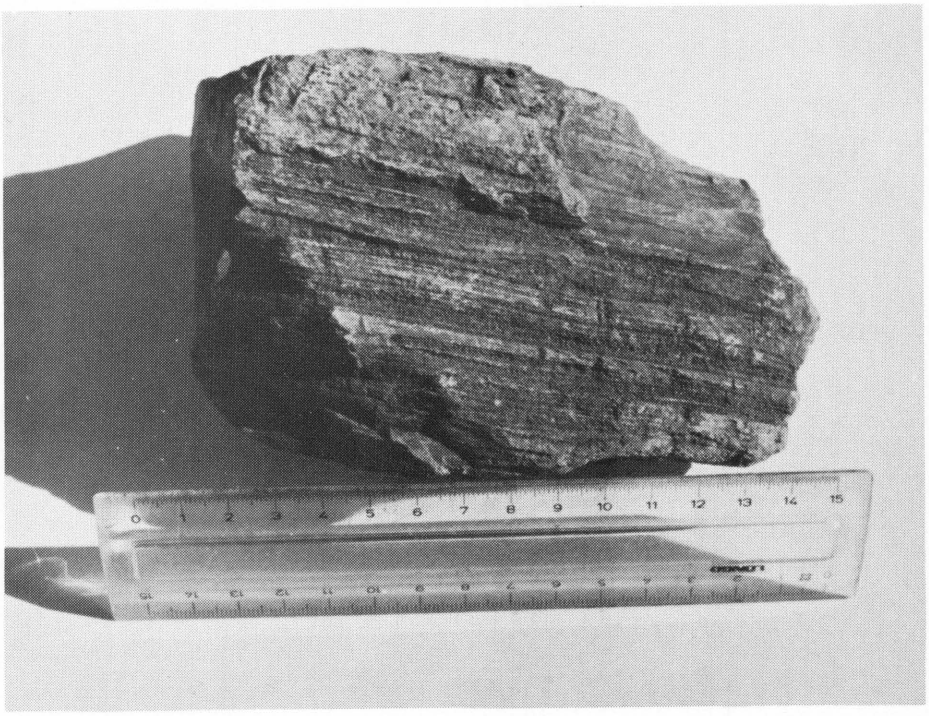

Fig. 6 – Thinly laminated tuff, Newburg 437 KR

The tuff is highly sericitized and contains small, angular fragments of quartz and large amounts of iron-oxides in a fine-grained sericitic groundmass. In the laminated varieties thin layers of dark, sericitic material alternate with layers of light quartzitic material. The laminated tuff from Newburg 437 KR and Baviaansberg 442 KR is dark-grey to black in colour and seems to have been partly transformed into hornfels, probably as a result of metamorphism by the Bushveld granite. The metamorphosed tuff contains small amounts of biotite.

(c) Felsite

As is the case with the lower felsite unit, the felsite of the upper unit comprises different varieties as well as different flows, but they were not mapped separately. Porphyritic, spherulitic, micro-granophyric and granular varieties are present and in general no significant lithological differences between the felsites of the upper and lower units seem to exist. Indications are that chlorite is more abundant in the lower felsite unit and that flow-banded felsite is more characteristic of the upper felsite unit.

(d) Ash-flow Tuff

This rock is discussed separately because its occurrence is rather unique. The presence of a still recognisable welded ash-flow tuff (ignimbrite) in rocks generally accepted to be approximately 2000 My. old is in itself an exceptional feature, (Ross and Smith, 1961, p. 49). The texture of the rock under discussion is typical of an ash-flow (Figs. 7 and 8). Whether it belongs to the Rooiberg felsite or to the volcanics of the Nylstroom Series of the Waterberg System is uncertain but as it occurs at the top of the upper felsite unit, it is incorporated in the latter.

In hand-specimen the ash-flow tuff is light-grey in colour, often with a purple or reddish discolouration. In thin section indications of welding and a well developed eutaxitic texture are displayed.

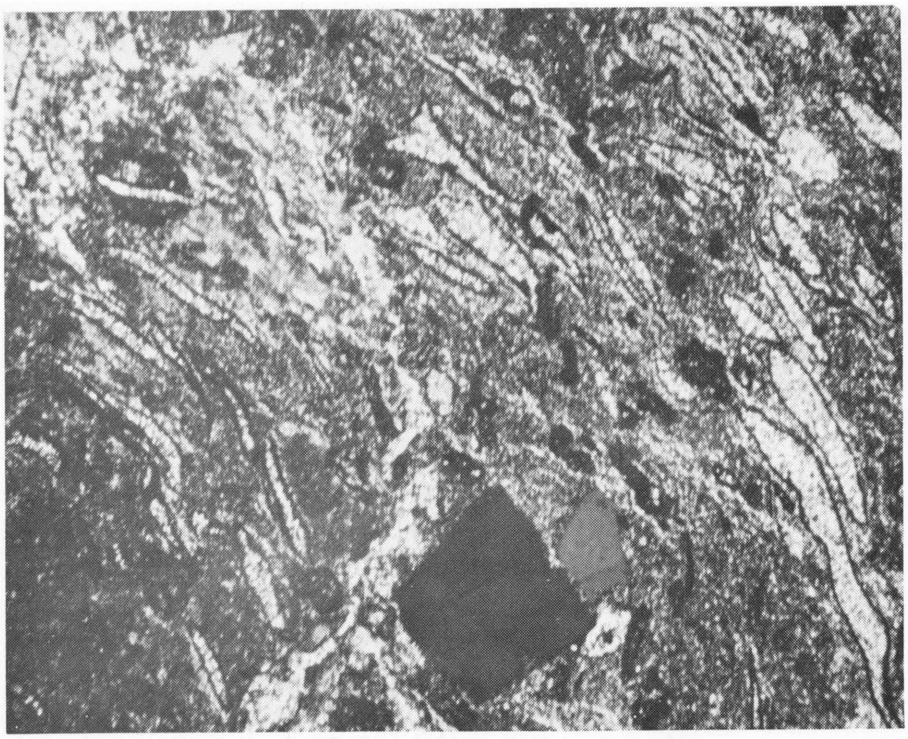

Fig 7 – Welded ash-flow tuff at the top of the upper felsite unit Subhedral crystals of quartz in a devitrified groundmass with a well-developed eutaxitic texture Note the fork-shaped shard near the centre of the photograph (crossed nicols, x 30) (M du P 3/71) Rhenosterpoort 402KR

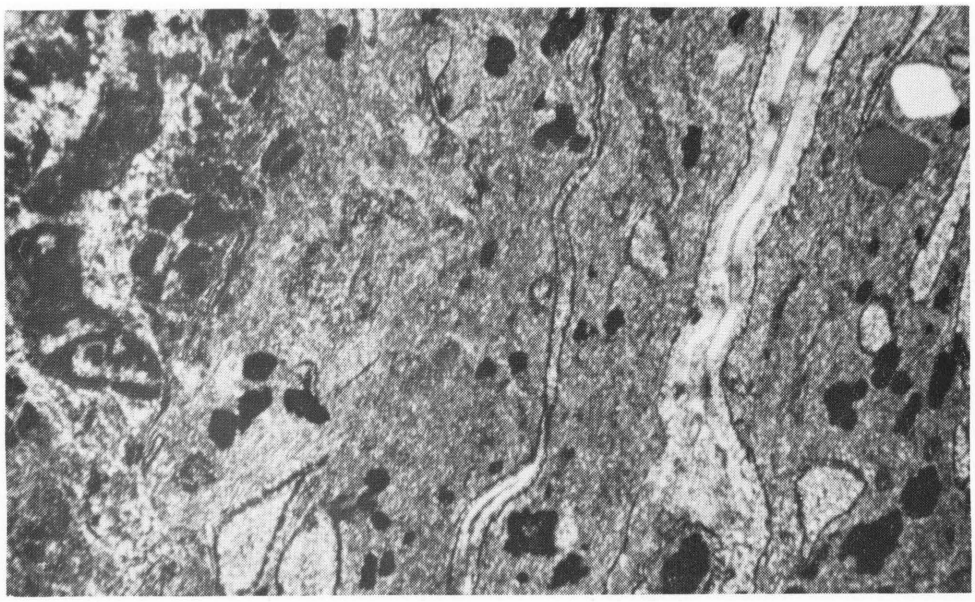

Fig 8 – Vitric ash-flow tuff showing a well-developed eutaxitic groundmass Note the flattened fragment of pumice in the right-hand side of the photograph (crossed nicols, x 30) (MduP 146/72) Droogekloof 471KR

Original fragments of pumice are flattened due to welding and cavities are filled with relatively coarse-grained quartz and alkali-feldspar. The centres of fragments of pumice are altered to micro-crystalline material which is too fine-grained for optical resolution. It may be sericitic in composition. The groundmass is highly recrystallized and primary textures are poorly preserved. In places it is weakly sperulitic, and some recrystallized axiolites are present. The amount and size of phenocrysts are small, so that the rock should be regarded as a welded, vitric ash-flow tuff.

6.3 CONCLUSIONS

In the present investigation a subdivision for the Rooiberg felsite, based on field evidence and constituting major mapable units, was sought. The subdivision also had to serve as a basis for regional correlation and for a structural analysis of the investigated area. If the present subdivision (Fig. 1) is compared with those of Menge and Coetzee (Table 5) and the observations of Wilke and De Villiers are kept in mind, regional correlation within the "Waterberg display" (Hall, 1932, p. 243) seems feasible. Although the late Dr. R.C. Rhodes (pers comm.) suggested a similar subdivision for the Rooiberg felsite west of Loskop Dam, the author would not attempt a definite correlation with the Rooiberg felsite of the "Middelburg display" (Hall, 1932, p. 243) without firsthand knowledge.

Most of the types and varieties of felsite distinguished by Lombaard (1932, p. 159) could be recognised during the present investigation and his classification seems to have a reasonably wide application. Field evidence, micro-scopy and the existing literature on Rooiberg felsite indicate that all gradations exist between such textures as felsitic, spherulitic (pseudo-spherulitic), micro-granophyric and granophyric. The experimental results by Lofgren (1971, p. 111-123) underline the existence of such gradations, on which he remarks, "thus the cooling history of a natural glass could affect its subsequent rate of devitrification, the number of sperulite nucleation sites, and ultimately the general appearance of the final texture" (ibid., p. 121). Therefore, the author considers that the existing classifications, based on textural variations, are indicative of certain domains within lava flows and that they reflect the history since solidification of those specific flows or parts of flows. Furthermore, if the origin of a term such as "pseudosperulitic" is compared with the definition of the term "spherulite" (Howell, J.V., 1960, p. 275) reconsideration of the existing classification for the Rooiberg felsite seems necessary.

In conclusion it is suggested that future studies on the Rooiberg felsite should be concentrated on detailed mapping, combined with intensive petrological and geochemical investigation of selected portions within the framework of a regionally applicable subdivision (as presented here) in order to provide a classification based on petrochemical, lithological and genetic evidence.

7. THE BUSHVELD GRANITE AND ASSOCIATED ROCKS

7.1 REVIEW

The historical development of our knowledge of the acid phase of the Bushveld Complex is marked by three distinct periods during which the acid rocks received detailed attention. The three periods may be demarcated as follows:-

(i) a first period from 1904 until 1928
(ii) a second period between 1944 and 1956
(iii) a third period which started in 1964 and which is still in progress.

The information gathered during the **first period** was largely the result of an extensive mapping programme, primarily aimed at mapping the Bushveld Complex. It was conducted by the Geological Survey of the Transvaal and later by the Geological Survey of the Union of South Africa. This project resulted in the appearance of a large number of publications mainly in the form of official reports and sheet explanations, and culminated in the visit of the Shaler Memorial Expedition in 1922.

In 1908 Kynaston investigated an area situated north-west of Potgietersrust including the Zaaiplaats Tin-mining area. Since the geology of this area has played a major part in the development of the present views on the classification and mode of occurrence of the Bushveld granite, his results are summarized below.

Kynaston (1909 p. 20) subdivided the Bushveld granite of the Zaaiplaats area into five zones from the contact with the mafic rocks upwards viz.

(i) zone of fine-grained granites, aplites and diorites
(ii) zone of coarse, massive granite
(iii) zone of medium-grained, granulitic granite
(iv) zone of pegmatite
(v) zone of red granophyre.

According to Kynaston the **zone of fine-grained granites, aplites and diorites** is not always developed and consists essentially of different varieties of fine-grained biotite-granite and aplite, often forming a type of breccia with a more dioritic type, where the dioritic variety forms the fragments in the breccia.

The zone of fine-grained granites is succeeded by the **zone of coarse, massive granite** constituting the main mass of the Bushveld granite. This coarse granite grades upwards into a more medium-grained variety representing the **zone of medium-grained, granulitic granite.**

The zone of pegmatite immediately overlies the medium-grained granite and consists essentially of one or several bands of very coarse pegmatite separated by granite. This zone is succeeded by the **zone of red granophyre** which according to Kynaston, shows a well marked platy or pseudo-bedded structure in its lower portions and which due to the consistent development of micropegmatite, deserves the name of granophyre rather than granite.

The year 1928 marked the conclusion of the first period after which Daly (1928) and Hall (1932) compiled the information acquired during this period – mainly by Kynaston, Mellor, Hall, Humphrey, Wagner and Du Toit – and effectively summarized their views on the various aspects of the Complex.

The **second period** started, when Strauss and Truter (1944) and Strauss (1954) recognized the existence of granites of three different ages in the Zaaiplaats area and proposed a classification which he compared with those of Kynaston and Wagner (Table 7).

TABLE 7

COMPARISON OF THE CLASSIFICATIONS OF BUSHVELD GRANITE FOR THE ZAAIPLAATS AREA AS PROPOSED BY STRAUSS, WAGNER AND KYNASTON (STRAUSS AND TRUTER, 1944, p. 49) AND (STRAUSS, 1954, p. 25)

	STRAUSS	WAGNER	KYNASTON
BOBBEJAANKOP GRANITE AND ASSOCIATED LEASE MICROGRANITE (3)	Pegmatite	Pegmatite	Pegmatite
	Lease microgranite	Aplitic granite (in part) Fine-grained, aplitic granite	Medium-grained granulitic granite
	Bobbejaankop granite	Coarse-grained, pink and red granite (in part) Miarolitic granite	Coarse-grained, massive granite (in part)
(2)	Foothills granite	Porphyritic granite Aplitic granite (in part)	Fine-grained granites, etc. (in part)
MAIN GRANITE (1)	Contact micro-granite Granophyric granite succeeded by or intercalated with granophyre and granite porphyry	Granophyric rocks	Red granophyre
	Coarse-grained, grey, leococratic granite Coarse-grained, grey mesotype granite	Coarse-grained pink and red granite (in part)	Coarse-grained, massive granite (in part)
	Intrusive contact Metamorphosed Rooiberg sediments		Fine-grained granites, etc. (in part)

As indicated in Table 7 Strauss's **Main granite** or oldest granite consists of a variety of granitic rocks which are arranged in different zones resulting in a pseudostratification (1954, p. 26) which conforms to the roof and the floor of the sheet-like intrusion.

The **coarse-grained, grey, mesotype granite** mainly occupies the base of the Main granite where it intrudes Rooiberg sediments in the form of large apophyses, veins and dykes. The amount of hornblende in this variety apparently decreases away from the underlying sediments and upwards in the succession with the result that this variety grades upwards into the **coarse-grained, grey, leucocratic granite.**

The grain-size of the coarse leucocratic granite decreases progressively upwards in the sequence, and micropegmatite appears which gradually increases in amount with the result that this rock-type eventually grades into a granophyric variety. This **granophyric granite** again grades into **granophyre (Bushveld granophyre)** which exhibits a delicate micrographic texture throughout (ibid., p. 28) A variety of the granophyre referred to as a "porphyritic granophyre" contains numerous grains of euhedral or slightly corroded quartz and feldspar in a fine-grained, micrographic groundmass.

Flatlying lenses of **granite porphyry** (ibid., pp. 31,32) are in contact with felsite or with granophyric granite immediately below the felsite. The granite porphyry usually grades into granophyric granite within a very short distance. This rock-type consists of phenocrysts of quartz and feldspar in a groundmass of felsitic material. The phenocrysts (ibid., p. 32) are surrounded by radially intergrown or spherulitic orthoclase. Where neither the granophyre nor the granite porphyry is in contact with the Rooiberg felsite a **zone of microgranite** forms the contact zone and in places a thin zone of pegmatite is developed along this contact with the felsite.

The second oldest or **Foothills granite** (ibid., pp. 33-35) is typically a porphyritic granite with a fine-grained aplitic groundmass and insets of quartz and feldspar. It occurs as transgressive sheets and shows complex intrusive relationships with both the Main granite and the altered rocks of the Rooiberg Series and also intrudes the mafic rocks of the Complex.

The youngest or **Bobbejaankop granite** (ibid., pp. 37, 38) is characterized

by

(i) its coarse texture

(ii) its deep, red colour

(iii) the fact that its quartz is well segregated and forms chains and clusters

(iv) the red colour and dull, earthy appearance of its feldspars

(v) the development of miarolitic cavities

(vi) the development of spherulitic clusters of tourmaline and

(vii) its homogeneity

The **Lease granite** (ibid., pp. 39, 40), a fine-grained granite, is always associated with the Bobbejaankop granite. It is localized predominantly along the upper contact of the Bobbejaankop granite as lenticular, sheet-like masses between the latter and the granophyric granite of the Main granite. It also forms veins, dykes and sheets in the Bobbejaankop granite. The Lease granite is intrusive into the granophyric variety of the Main granite and the contact is marked by a zone of flat, concordant pegmatite bodies referred to as the **Contact pegmatite** (ibid., p. 40).

During the second period a number of other investigators also contributed to our present knowledge. In 1950 Steyn (1950, p. 41) argued in favour of contemporaneity of the Main Bushveld granite and the isolated granite mass of Magnet Heights. Kuschke (1950) recognised the existence of three varieties of the Bushveld granite in an area north-west of Brits viz.:-

(i) coarse-grained (Main) granite

(ii) porphyritic granite

(iii) fine-grained granite.

He recognized the presence of two different granophyres, a Bushveld granophyre and a pseudogranophyre and concluded that these granophyric rocks originated by metamorphism and metasomatism of pre-existing sediments.

M.v.R. Steyn (1955), p.69) concluded that the emplacement of granophyre, in an area north-west of Pretoria, post-dates the gabbroidal rocks of the Bushveld Complex and also that the granite of that area attained its present stratigraphic position by intrusion (therefore implying a magmatic origin).

J.G.D. Steyn (1956, p. 20) argued in favour of a similar origin for the granite and granophyre in the Stavoren area and advocated a magmatic origin, but stated that a metasomatic origin is not precluded for the granophyre unless a magmatic origin for the granite is proved.

The **third period**, although actually gaining momentum a few years later, started when Willemse (1964, p. 102) grouped granophyre, Rooiberg felsite and leptite together in what he called the Epicrustal Phase of the Bushveld Complex, and concluded that "although metasomatism of sedimentary rocks may have resulted in the formation of some of the granophyres it never-the-less is clear that in places granophyre has consolidated from its own magma" (Willemse, 1964, p. 115). He adopted Strauss's classification for the granites and stated that there is no doubt that the isolated masses of granite such as those at Magnet Heights and Steelpoort Park are of the same age as the Main granite. He also listed evidence that the granites are younger than the dioritic rocks (ibid., p. 112) and proposed processes of granitization, assimilation and anatexis (ibid., p. 118) to explain the origin of the Bushveld granite.

Hammerbeck (1965, p. 85) corroborated the earlier statement by Willemse when he concluded that the granite of Steelpoort Park links up in depth with the main mass of granite.

Von Gruenewaldt (1968, p. 164) found evidence to substantiate the view that several types of granophyre occur in the Bushveld Complex viz.

(i) Rooiberg granophyre – a palingenetic product of the Rooiberg felsite
(ii) granophyric granite and granophyre related to the Bushveld granite
(iii) Stavoren granophyre – a granophyre developed between the Bushveld granite and quartzites of the roof

He also presented evidence suggesting that the granophyre of the Loskop Dam area (Rooiberg granophyre) is a palingenetic product of the Rooiberg felsite.

Fourie (1969) concluded that the granites may be distinguished or differentiated from the granophyres, felsites and leptites on the basis of their geochemistry.

Ianello (1970, p. 12) recognized the following granitic rocks as being part of the felsic portion of the Bushveld Complex, in an area situated to the west of Rooiberg:

(i) Koedoeskop granite

(ii) Main granite (sensu lato)
Slipfontein variety
Porphyritic variety
Main granite (sensu stricto)

(iii) Granophyric granite

(iv) Bushveld granophyre

(v) Rooiberg granophyre

He (ibid., 1970, p. 113) regarded the Koedoeskop granite as being younger than the Main granite and considered it to be the equivalent of the Bobbejaankop granite. Statistical analysis (ibid., p. 62) of the modal composition of the Main granite suggested a metasomatic and partially anatectic origin for the Main granite and a metasomatic origin for the granophyric rocks.

Recently the Economic Geology Research Unit at the University of the Witwatersrand became actively involved in the investigation of the felsic portion of the complex when a research project on the Bushveld Complex was initiated. The results of this investigation were published by Hunter and Lenthall (1971), Lenthall (1972a, 1972b), Hunter (1973, 1974), Lenthall and Hunter (1973, 1974). Lenthall and Hunter (1973, p. 30) proposed the following classification for the acid phase of the Complex.

TABLE 8

PROPOSED CLASSIFICATION OF THE ACID PHASE OF THE BUSHVELD COMPLEX BY LENTHALL AND HUNTER (1973, p. 30)

3. Bobbejaankop Granite	Coarse-grained, red granites, locally miarolitic; fine-grained microgranites
2. Sekukuni Granite	Coarse-grained, grey, mesocratic to leucocratic granites, locally rapakivic; finer-grained, red granophyric granites; granophyres; aplites; porphyritic granites; quartz and quartz-feldspar porphyries
1. Rooiberg Felsite	Massive cryptocrystalline lavas, locally porphyritic and amygdaloidal, occasionally displaying granophyric textures

They also proposed that:

(i) the term Bobbejaankop granite be retained for younger, intrusive, mineralized Bushveld granites and the associated hood facies (Lease granite)

(ii) the distinction of an episode of Foothills granite appears to be unjustified

(iii) the term "Main" be discarded and replaced by the term "Sekukuni" for all non-mineralized granites and their textural varieties.

Lenthall (1973, p. 76) also proposed a subdivision for the granophyres of the Complex – based on their stratigraphic position – in an attempt to systematize the nomenclature (Table 9).

TABLE 9

PROPOSED SUBDIVISION AND CLASSIFICATION OF GRANOPHYRES OF THE BUSHVELD COMPLEX (LENTHALL, 1973, p. 76)

NATURE OF GRANOPHYRE	PROPOSED NAME	TYPE AREA	PREVIOUS NAME
1. Developed along the contact of the Mafic Phase and the overlying felsite	Waterval Granophyre	The farm Waterval, east of Loskop Dam	Rooiberg Granophyre
2. Developed as lenses and cross-cutting bodies in felsite	Paardekop Granophyre	Near the trigonometrical beacon Paardekop, Tautes Heights.	
3. Developed along the contacts of Bushveld granite and overlying felsite	Sterk River Granophyre	Sterk River, Zaaiplaats tin-mining area	Bushveld Granophyre
4. Developed along the base of the Bushveld granites at the contact with the Mafic Phase	Blinkwater Granophyre	The farm Blinkwater, Zaaiplaats tin-mining area	Pseudogranophyre Bushveld granophyre
5. Developed in the Bushveld granites along the contact with the Mafic Phase	Groenfontein Granophyre	The farm Groenfontein, Zaaiplaats tin-mining area	
6. Developed in the Bushveld granites adjacent to dykes and sheets of diabase, dolerite etc.	Welgevonden Granophyre	The farm Welgevonden, Zaaiplaats tin-mining area	

Von Gruenewaldt (1972) found evidence to corroborate his earlier views on the origin of the Rooiberg granophyre and presented a mechanism to explain the origin of the granophyre and other roof-rocks of the area around Tauteshoogte.

The validity of Strauss's classic subdivision and classification of the granitic rocks of the Zaaiplaats area became subject to possible reconsideration when De Waal (1972, p. 143) also proposed a classification (Table 10) for these rocks and presented data to indicate that the rocks of the "Main Suite" belong to the Epicrustal Phase of the Complex and that they owe their present petrographic and textural nature to subsequent metamorphism by the Layered Mafic Sequence and possibly also the Bobbejaankop granite.

TABLE 10

REVISED CLASSIFICATION OF THE GRANITE AND ASSOCIATED ROCKS OF THE ZAAIPLAATS AREA (DE WAAL, 1972, p. 143)

LATE PLUTONIC PHASE	BOBBEJAANKOP GRANITE, PEGMATITE AND APLITE; FOOTHILLS GRANITE
PLUTONIC PHASE	Layered Mafic Sequence
EPICRUSTAL PHASE	MAIN SUITE composed of granulite, granophyric granulite, granophyre, porphyritic granophyre and porphyry Rooiberg Felsite, shale and agglomerate (flow breccia)

Recently Rhodes (1974) and Rhodes and Bornhorst (1975) examined the geochemical relationships between the granites, felsites and granophyres of the Complex and concluded that the granite and felsite form two geochemically distinct populations.

De Bruiyn (in press) used textural analysis to investigate the granophyre between the Bushveld granite and the Rooiberg felsite in the Moloto area, and concluded that this granophyre originated by metamorphic recrystallization of Rooiberg felsite as a result of the intrusion of the Bushveld granite.

De Bruiyn and Rhodes (1975) also recognized the existence of a new type of Bushveld granite - referred to as the Makhutso granite – and presented textural and chemical data to differentiate between this granite and other types hitherto recognized.

7.2 THE GRANITIC ROCKS NORTH-WEST OF WARMBATHS

7.2.1 Subdivision

Based on field relationships, lithology and petrography, the granitic rocks of the investigated area can be subdivided into two main units representing two distinct events during the emplacement of the Bushveld Complex. To avoid any possible confusion with the existing nomenclature for the granitic rocks, local names have been assigned to both these units. Within each of the units different facies and varieties have been recognized as shown in Table 11. The varieties, most of which show gradational relationships with one another, have been recognized mainly on the basis of textural variation.

TABLE 11

SUBDIVISION OF THE GRANITIC ROCKS OF THE WARMBATHS AREA

UNIT	TYPE/VARIETY	CHARACTERISTICS
2. BAVIAANSBERG GRANITE SUITE	(c) Aplite facies	1. Fine-grained, aplitic 2. Dykes and sills intrusive in (b) 3. Essentially the same petrological composition as (b) – in places associated with quartz-tourmaline aggregates and pegmatite. 4. Intruded along joints and fractures in (b)
	(b) Main facies (i) even-grained variety (ii) porphyritic variety	1. Essentially a biotite granite 2. Red to grey in colour 3. Medium- to coarse-grained 4. Shows textural variation 5. Contains miarolitic cavities 6. Quartz-tourmaline aggregates present 7. Grades into (a)
	(a) Contact facies	1. Fine- to medium-grained 2. Often exhibits interlocking laths of quartz and feldspar 3. Contact pegmatite developed at or near gradational contact with (b) 4. Sometimes porphyritic 5. Grades into (b)
	Intrusive contact	
1. VERONGELUKSPRUIT GRANOPHYRE SUITE	(b) Granophyre (a) Granite Porphyry	1. Essentially a gradational rock series grading from granite porphyry through spherulitic granite porphyry and porphyritic microgranophyre to granophyre

7.2.2 The Verongelukspruit Granophyre Suite

(a) Distribution and Field relationships

On Elandsfontein 401 KR and the adjoining farms Rhenosterpoort 402 KR, Witfontein 430 KR and Kareefontein 432 KR a body of granophyre and granite porphyry, striking more or less north-south and varying in width, is developed. Both rock-types weather to small rounded boulders leaving a thin soil-cover which supports a poor vegetation very similar to that of the Rooiberg felsite.

In many places a well-developed set of low-dipping joints impart a pseudo-bedded structure to these rocks which suggests that they have the same attitude as the Rooiberg felsite to the east on Elandsfontein 401 KR and Elandsfontein 427 KR. This is further supported by the fact that the granophyre and the granite porphyry forms an escarpment with steep slopes towards the west and south and more gentle slopes towards the north and especially the east.

The granite porphyry occupies the centre of the body and is surrounded by granophyre with which it shows gradational contacts. The granophyre in turn is surrounded with a sharp intrusive contact by fine-grained contact facies of the Baviaansberg granite. These contact relationships are best exposed along the western and south-western slopes of the escarpment where it can be seen that the Baviaansberg granite has been chilled against the granophyre. This suggests a definite lapse of time between the emplacement of the two main granitic rock-suites. The northern and eastern contacts are more difficult to locate owing to the more gradual slopes and the striking similarity between the weathering of the granophyre and the Baviaansberg contact granite.

(b) Petrography

(i) Granite Porphyry

The granite porphyry is a dark reddish-brown to chocolate-brown or black, massive rock. In hand specimen it displays phenocrysts of pink or grey feldspar (1-4 mm in diameter) and of glassy quartz (as a rule smaller than the feldspar phenocrysts) in a microcrystalline and often spherulitic groundmass.

Weathering of the feldspar phenocrysts produces a pitted surface of small cavities.

In thin section the granite porphyry exhibits a fine-grained, granular groundmass of quartz, feldspar (perthite, orthoclase and plagioclase) and hornblende with accessory magnetite, zircon, sphene, fluorite, and epidote. The phenocrysts are quartz and perthite The phenocrysts of feldspar in contrast with those of quartz, which as a rule are rounded and highly corroded, are euhedral to subhedral. Fine-grained spherulitic intergrowths of quartz and feldspar are developed in the groundmass and as a rule have phenocrysts as growth-centres (Fig 9). The amount and size of the intergrowths vary (Fig. 10) and in samples with a higher amount of spherulitic intergrowths, the femic minerals tend to be concentrated in large, interstitial aggregates or nodules. The feldspars (both groundmass and phenocrysts) are turbid due to numerous small inclusions and secondary alteration

In addition, carbonate of secondary origin is present in a few samples.

(ii) Granophyre

As a rule the granophyre is red or reddish-grey in colour, fine- to medium-grained and massive. The granophyric intergrowths are easily distinguished with the aid of a handlens. The ferromagnesian minerals are usually present as large isolated patches. Microscopically the granophyre exhibits large amounts of micropegmatitic intergrowths of quartz and feldspar (orthoclase and perthite) as well as scattered phenocrysts of quartz and perthite (Fig 11). The feldspars are turbid owing to numerous small inclusions of iron-oxides and secondary alteration products. Ferromagnesian minerals, mainly hornblende altered to chlorite and white mica, form isolated interstitial aggregates. Accessories commonly associated with the ferromagnesian minerals are magnetite, fluorite, cassiterite, sphene and epidote.

(iii) Transition between granite porphyry and granophyre

The two rocks described above actually represent the two end-members of a transitional rock-series. Microscopic evidence indicates a gradual transition from granite porphyry to granophyre, characterized by the following:-

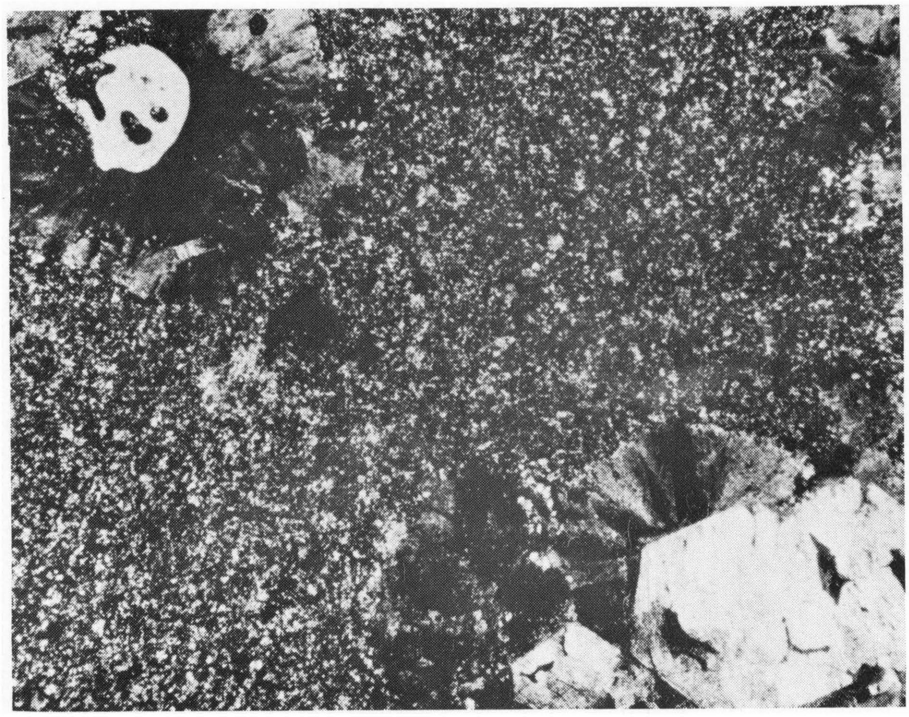

Fig. 9 – Verongeluksprui t granite porphyry showing a rounded and corroded quartz phenocryst and a euhedral phenocryst of perthite, partially surrounded by spherulitic intergrowths of quartz and feldspar in a fine-grained groundmass (crossed nicols x 16) (M du P 118/71) Elandsfontein 401KR

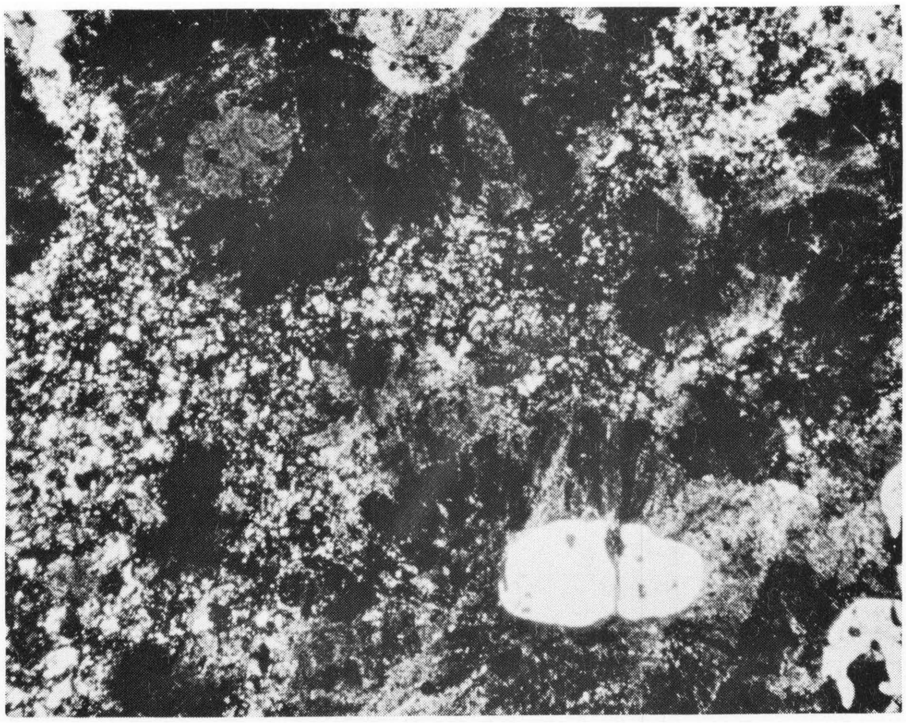

Fig. 10 – Verongelukspruit granite porphyry showing increased spherulitic growth around phenocrysts and a smaller amount of groundmass (crossed nicols x 16) (M du P 12/72) Kareefontein 432 KR

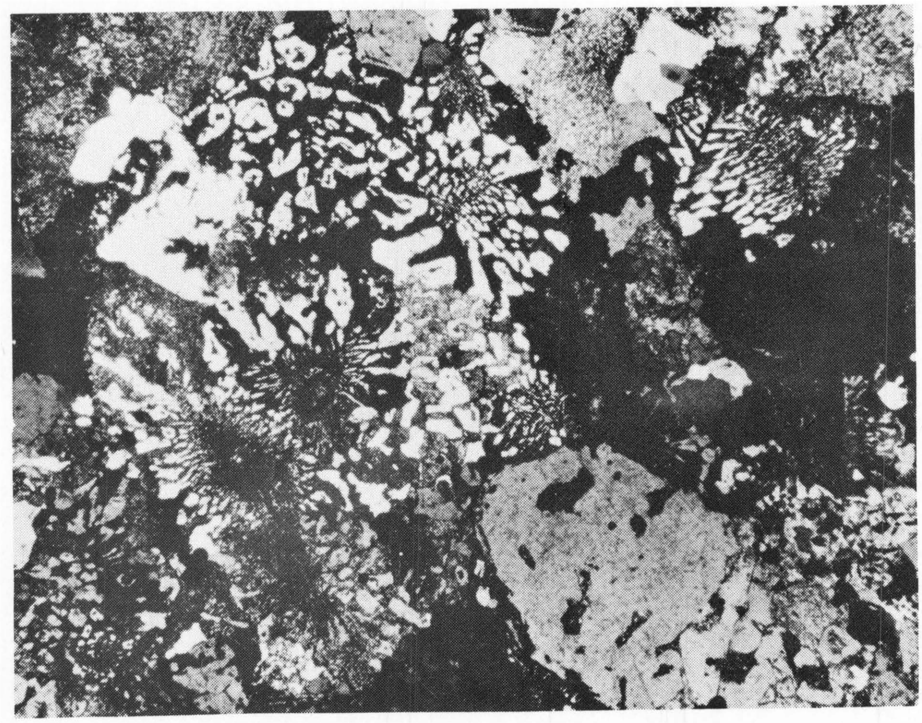

Fig. 11 – Verongeluksspruit granophyre. Phenocrysts of quartz and feldspar surrounded by granophyric intergrowths (crossed nicols x 16) (M du P 98/71) Elandsfontein 401KR

(a) The original rock is represented by **granite porphyry**, consisting essentially of a microcrystalline matrix with insets of euhedral to subhedral feldspar (orthoclase, perthite and plagioclase) and quartz (Fig. 12a).

(b) The first step during the transformation was the formation of sperulitic intergrowths in the groundmass of quartz and feldspar which grew outwards from growth-centres, as a rule phenocrysts (Fig. 12b). The result is a rock which may be called a **spherulitic granite porphyry.** Since little or no femic-minerals are incorporated in the spherulitic intergrowths, they are pushed out into the remaining microcrystalline matrix

(c) As the metamorphic recrystallization proceded the spherulites increased in size and the amount of microcrystalline groundmass was reduced with a sympathetic increase in the concentration of the femic minerals into clusters. Owing to the increase in the size of the spherulites, individual minerals in the spherulites simultaneously became coarser grained, resulting in a rock which may be called a **blastoporphyritic micro-granophyre** (Figs. 12c, d)

(d) Continued metamorphic recrystallization eventually resulted in almost all the granular matrix being incorporated into spherulitic intergrowths which increased in size to such an extent that the individual grains of quartz and feldspar can be recognized as the components of a micrographic or granophyric intergrowth. The femic minerals have been concentrated in large interstitial aggregates or clusters The original phenocrysts of feldspar and quartz are surrounded by granophyric intergrowths, with the result that this rock-type may be called a **porphyritic granophyre** or **granophyre** (Figs. 12e, f).

7.2.3 Baviaansberg Granite Suite

(a) Field Relationships and Distribution

The rocks of the Baviaansberg granite suite, comprising the three facies as defined in Table 11, underlie a considerable part of the area north of the

Boschpoort fault. The major part of this area is underlain by the Main facies, which has been intruded by dykes and sheets of the aplite facies and which grades into the contact facies on approaching the roof of the granite i.e. the overlying Rooiberg felsite and the rocks of the Verongelukspruit granophyre suite. In the northern part of this area on Diepdrift 431 KR and in the core of the Loubad anticline the main facies crops out as isolated patches in a flat-lying area characterized by yellow, sandy or gritty soil supporting a bushy vegetation. Outcrops are found as low dome-like koppies and also along streambeds. The contact facies crops out sporadically along the scree-covered foothills of the felsite ranges which form the Hoekberge and the rim of the Loubad anticline. Further south on Kareefontein 432 KR and in the core of the Zwartkloof anticline, outcrops of both the main facies and the contact facies are better, with smaller intervening areas covered by sand and soil.

Between the Droogekloof thrust and the Boschpoort fault (Folder 1) Baviaansberg granite, represented by the contact facies and the main facies, crops out along the southern foothills of the range formed by felsite on Cyferfontein 434 KR, Boschpoort 473 KR and Droogekloof 471 KR. The entire succession, between the Boschpoort fault and the Droogekloof Thrust, has been overturned with the result that the granite is overlying the Rooiberg felsite. Further eastwards along this section on Roodepoort 467 KR and in the township of Warmbaths, Baviaansberg granite forms very poor exposures.

In the south-western corner of the investigated area the main facies of the Baviaansberg granite underlies a flat-lying, soil-covered area on Cyferfontein 434 KR and Rietspruit 527 KQ. Here exposures are poor and occur chiefly along streambeds. The granite forms part of the overthrusted mass of the Droogekloof thrust and is intrusive into rocks of the Transvaal System which dip southwards and form the floor of the granite. In the adjoining area to the west, Ianello (1969, p. 11) described the presence of what he called the Koedoeskop granite in contact with quartzite of the Transvaal System. It is, however, the author's opinion that the granite of this particular occurrence is the result of assimilation of rocks of the Transvaal System by the Baviaansberg granite. Evidence supporting this view may be found on Cyferfontein 434 KR where a number of xenoliths of Transvaal sediments occur in the granite and where the granite surrounding these xenoliths is altered to a graphic granite poor in femic minerals.

The bulk of the granitic rocks developed in the area shows many features which are considered to be characteristic of typical, red Bushveld granite. In addition to more common features such as the red colour, absence of directional features, coarse granularity, etc., features such as miarolitic cavities and the presence of roundish intergrowths of quartz and tourmaline have also been observed.

The Baviaansberg contact granite is developed almost continuously along the contact between granite and Rooiberg felsite and also between granite and the Verongelukspruit granophyre. It commonly occupies elevated areas along the foothills of the felsite-ranges and is usually characterized by weathering into small rounded boulders. It forms a zone of variable width between the main facies of the Baviaansberg granite suite and the older rocks and grades almost imperceptibly into the rocks of the main facies.

Pegmatites occur frequently and at random in the Baviaansberg granite in particular on Zwartkloof 470 KR, Newburg 437 KR, Baviaansberg 442KR and Droogekloof 471 KR. A zone of pegmatite, considered to be a contact pegmatite, is commonly developed at or near the gradational contact between the main and contact facies of the Baviaansberg suite. This zone occupies a definite stratigraphic horizon and may be followed over considerable distances.

(b) Petrography

(i) The Baviaansberg contact facies

The Baviaansberg contact granite is a dark red, grey or red coloured rock, usually fine- to medium-grained and in places porphyritic with sporadic phenocrysts of quartz and feldspar. It consists of quartz, microperthite, minor amounts of microcline perthite, plagioclase and hornblende, the latter mostly altered to biotite and/or chlorite. A large amount of very small inclusions and of secondary chlorite and epidote causes the turbidity of the feldspar; the orthoclase more so than the plagioclase. In many places the quartz and feldspar form a characteristic interlocking

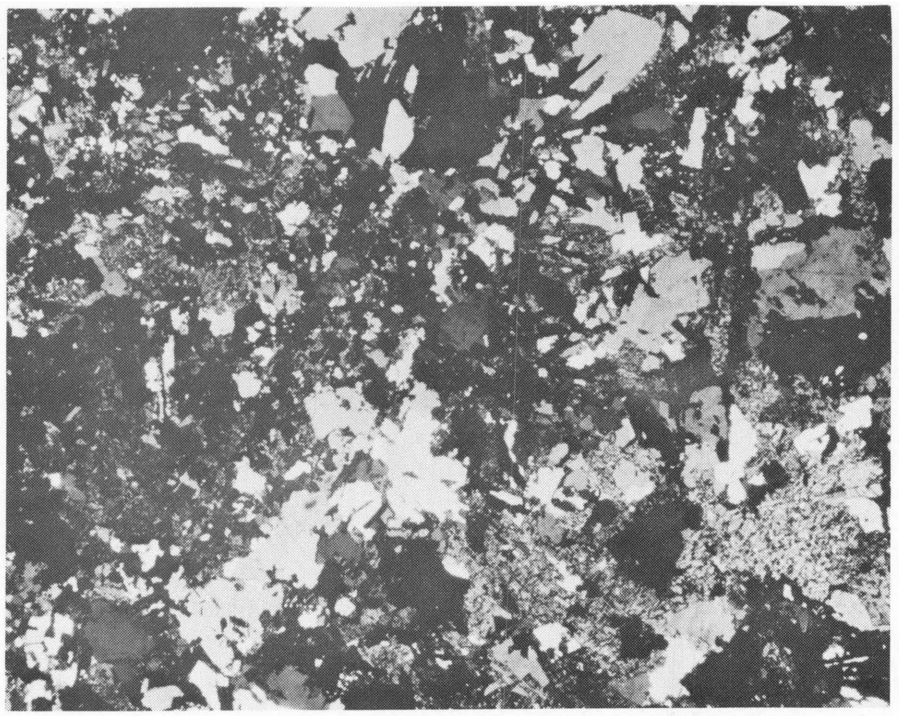

Fig. 13 – Baviaansberg contact granite with interlocking laths of quartz and feldspar. The texture in a way resembles a graphic intergrowth (crossed nicols x 8) (M du P 66/72) Witfontein 430KR

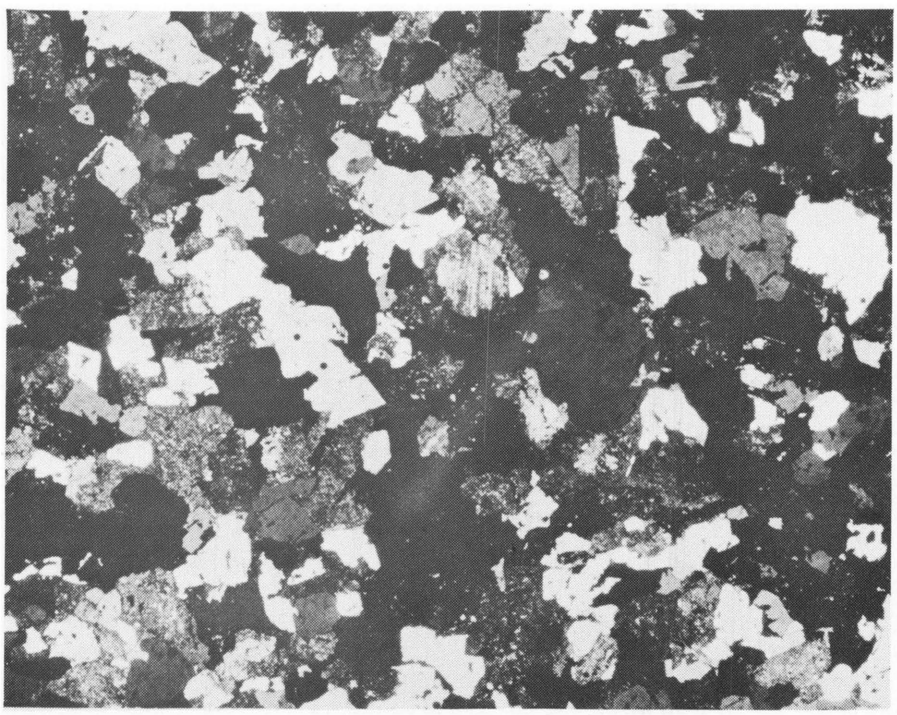

Fig. 14 – Baviaansberg contact granite in which the characteristic interlocking lath-texture is less obvious (crossed nicols x 8)(M du P 94/71) Elandsfontein 401KR

texture of lath-like crystals which in a way resembles a graphic intergrowth (Figs. 13 and 14). The femic minerals occur as isolated grains in small interstices among the interlocking feldspar and quartz grains. Fluorite and magnetic are the most common accessories while epidote, zircon and cassiterite are also present. The accessory minerals are usually intimately associated with the femic minerals.

(ii) The Baviaansberg main facies

The main facies of the Baviaansberg granite suite shows considerable variation in texture with an even-grained variety and a porphyritic variety as the two extremes.

(a) The even-grained variety

This variety predominates and is widespread in the investigated area. It varies in colour from red to grey and is as a rule medium- to coarse-grained.

Microscopically it displays an equigranular hypidiomorphic to allotriomorphic texture and it consists mainly of anhedral to subhedral quartz, perthite, minor amounts of microcline perthite, plagioclase as well as biotite and chlorite (Fig. 15). Similar to the contact granite, the feldspar is turbid due to numerous small inclusions and secondary alterations. The primary femic mineral is biotite which is often extensively altered to chlorite. Fluorite, magnetite and zircon are the main accessories whereas sphene, epidote and cassiterite are present in extremely small amounts.

(b) The porphyritic variety

The porphyritic variety is intimately associated with the even-grained variety and gradations between the two are common. It differs only in texture from the even-grained variety, and consists of a fine- to medium-grained groundmass of quartz, perthite, minor amounts of microline perthite, plagioclase, biotite and chlorite with phenocrysts of perthite and of quartz (Fig. 16). Owing to the variation in the relative amounts of the groundmass and phenocrysts and the variation in the relative sizes of phenocrysts and groundmass, all gradations between

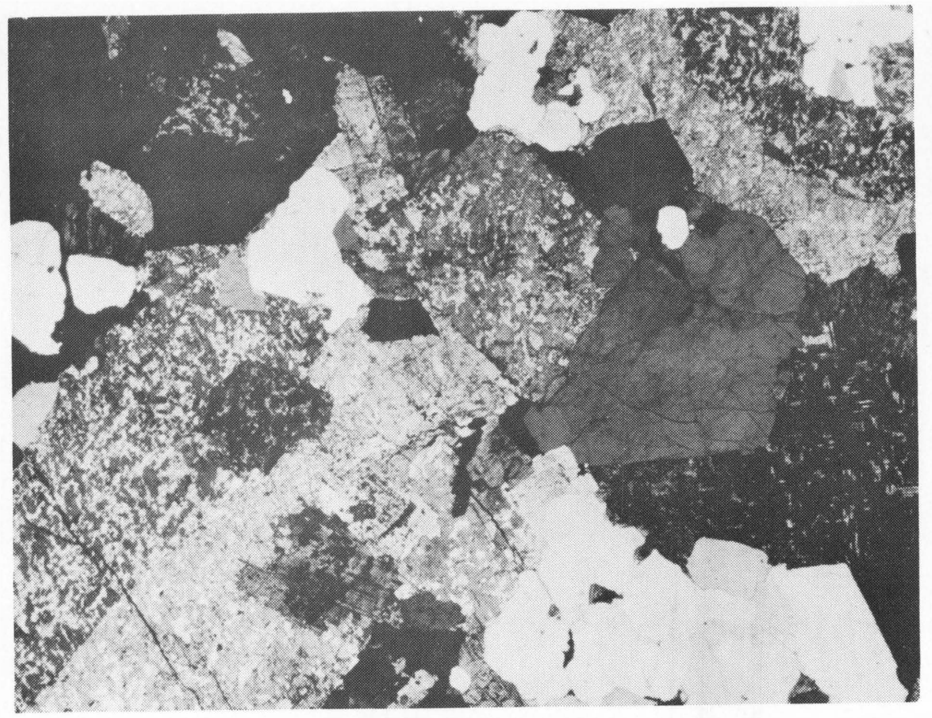

Fig. 15 – The even-grained variety of the Baviaansberg main facies. Note the small plagioclase crystal enclosed in the larger crystal of perthite (crossed nicols x 8) (M du P 16/72) Kareefontein 432 KR

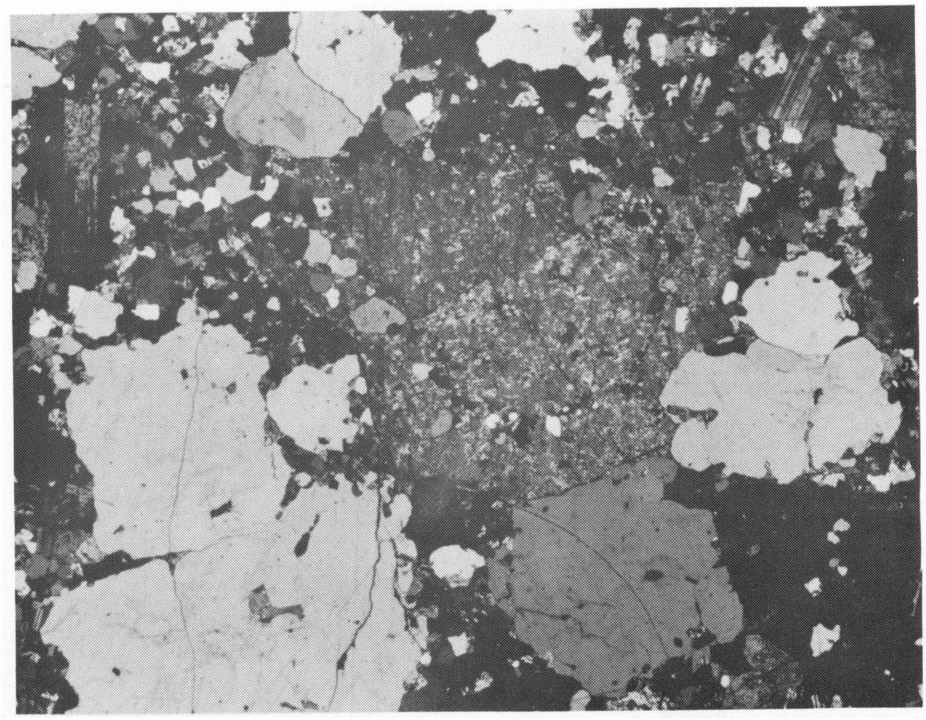

Fig. 16 – The porphyritic variety of the Baviaansberg main facies. Large crystals of quartz and perthite are surrounded by small crystals of perthite, quartz and plagioclase (crossed nicols x 8) (M du P 50/72) Gorcum 435 KR

the typical porphyritic granite and the even-grained variety have been observed.

(iii) The Baviaansberg aplite facies

This facies is represented by a light-red or grey, fine-grained or aplitic granite which has a mineralogical composition similar to the Baviaansberg main granite. Being a product of the final stages of crystallization the aplites intruded along joints and fractures in the Baviaansberg main granite and are also associated with segregation pegmatites.

7.3 CHEMISTRY OF THE GRANITE AND ASSOCIATED ROCKS

As part of the investigation, a number of rock-samples of which the localities are indicated on Folder 1 were submitted for chemical analysis. These analyses together with the content of some selected minor elements and the C.I.P.W.-norms are listed in Table 12. Three analyses of Rooiberg felsite are included for comparative purposes.

These analyses form the basis of a number of diagrams (Figs. 17-24) selected from the literature, for the comparison of the granitic rocks from the Warmbaths area with those of other localities.

The following may be concluded from the various diagrams:

(a) Figures 17 and 18 verify the observation of Von Gruenewaldt (1968, p. 165) viz. that the Bushveld granite and Rooiberg felsite can be distinguished by a diagram of their femic constituents vs potassium contents and also on a triangular diagram $Si^{4+} - (Na^{+} + K^{+}) - (Fe^{3+} + Fe^{2+} + Mg^{2+} + Mn^{2+})$.

(b) The rocks of the Verongelukspruit granophyre suite plot in the granite field (Figs. 17 and 18) which suggests that these rocks are more closely related to the granitic phase of the Bushveld Complex than to the Rooiberg felsite.

(c) The results of Figures 19-22 are in agreement with the following observations by Rhodes (1974, p. 94):

(i) "Analyses of the Bushveld granite are generally closely grouped and display well-defined variation trends, suggesting a co-magmatic origin for the various granites analysed"

(ii) Analyses of the Rooiberg felsite are widely scattered and do not conform to any single differentiation trend.

(d) The variation in the minor element content (Figs. 23 and 24) indicates that most of the analyses fall in the field of the Main granite whereas only two analyses plot in the field of the Bobbejaankop granite. This result becomes more meaningful if it is taken into account that the two samples in the field of the Bobbejaankop granite were taken in an area where the granite is known to be mineralized. This is in accordance with Lenthall's (1972 , p. 29) conclusion that the acid phase of the Bushveld Complex may be subdivied into three components on the basis of trace and minor element content viz:

(i) Rooiberg felsite

(ii) non-mineralized granites and associated granophyres

(iii) mineralized granites

7.4 DISCUSSION

7.4.1 Mode of emplacement of the granitic rocks

Any model for the emplacement of the granitic rocks of the Bushveld Complex for the Warmbaths area should take the following facts into account:

(a) the gradual transition of the rocks of the Verongeluksspruit granophyre suite outwards from a core of granite porphyry through porphyritic micrograngranophyre to porphyritic granophyre and granophyre.

TABLE 12

RESULTS OF CHEMICAL ANALYSES AND C.I.P.W.-NORM CALCULATIONS OF GRANITIC ROCKS AND ROOIBERG FELSITE FROM THE AREA NORTH-WEST OF WARMBATHS (ANALYSES BY THE NATIONAL INSTITUTE FOR METALLURGY)

SAMPLE NUMBER	W1	W2	W3	E1	E2	E3	E4	K1	K2	N1	N2	R1
SiO_2	75,57	70,42	73,34	74,20	73,57	74,92	74,22	76,36	75,44	76,41	75,10	74,53
Al_2O_3	13,17	11,94	11,65	11,86	12,42	11,65	11,70	12,53	11,88	11,93	12,56	12,14
Fe_2O_3	0,34	2,49	0,81	0,52	0,57	1,19	1,46	0,54	1,12	0,69	0,42	5,87
FeO	1,81	3,89	2,22	2,14	2,49	1,58	1,78	0,86	1,46	0,14	1,23	0,43
MgO	0,13	0,12	0,15	0,31	0,09	0,26	0,22	0,14	0,28	0,18	0,28	0,32
CaO	0,38	1,96	0,98	1,05	1,09	0,71	1,27	0,63	0,51	0,03	0,15	0,04
Na_2O	6,23	2,56	2,86	3,26	2,99	3,12	2,22	5,37	3,14	0,57	3,34	0,22
K_2O	0,29	5,23	5,07	4,90	4,77	5,12	5,03	2,21	4,68	8,93	5,32	3,61
TiO_2	0,40	0,37	0,16	0,21	0,23	0,19	0,24	0,24	0,16	0,06	0,08	0,09
P_2O_5	0,01	0,11	0,05	0,07	0,06	0,06	0,06	0,07	0,08	0,04	0,04	0,07
Mn_3O_4	0,03	0,13	0,04	0,04	0,03	0,02	0,08	0,02	0,02	0,01	0,08	0,02
H_2O-	0,10	0,12	0,10	0,15	0,02	0,14	0,13	0,08	0,19	0,39	0,15	0,37
H_2O+	0,65	0,55	0,76	0,62	0,71	0,66	0,63	0,69	0,69	0,20	0,42	1,80
CO_2	0,22	0,05	0,57	0,31	0,60	0,44	1,26	0,42	0,20	0,17	0,65	0,02
TOTAL	99,33	99,94	98,76	99,64	99,64	100,07	100,27	100,16	99,85	99,75	99,82	99,53

C.I.P.W.-NORMS

	W1	W2	W3	E1	E2	E3	E4	K1	K2	N1	N2	R1
Q	36,73	30,08	35,40	33,34	35,53	35,89	42,23	36,10	37,82	39,41	36,36	59,20
c	2,45	–	1,11	0,17	1,89	0,84	3,35	1,30	1,37	1,76	2,63	8,01
or	1,71	30,91	29,96	28,96	28,19	30,26	29,72	13,06	27,66	52,78	31,44	21,33
ab	52,71	21,65	24,19	27,58	25,29	26,39	18,78	45,43	26,56	4,82	28,25	1,86
an	0,42	5,64	0,93	2,79	1,22	0,34	–	0,01	0,74	–	–	–
di	–	2,68	–	–	–	–	–	–	–	–	–	–
hy	2,76	3,59	3,59	3,99	4,00	2,28	1,55	1,12	2,22	0,01	1,12	0,65
mt	0,49	3,60	1,17	0,75	0,82	1,72	2,11	0,73	1,62	0,30	0,60	1,19
hm	–	–	–	–	–	–	–	–	–	0,47	–	5,04
il	0,75	0,70	0,30	0,39	0,43	0,36	0,45	0,45	0,30	0,11	0,15	0,17
hap	0,02	0,25	0,11	0,16	0,14	0,14	0,14	0,16	0,18	0,09	0,09	0,16
cc	0,50	0,11	1,29	0,70	1,36	1,00	2,12	0,95	0,45	–	0,17	–
magn	–	–	–	–	–	–	0,46	–	–	0,35	0,58	0,11
chaly	–	–	–	–	–	–	0,22	–	–	–	0,70	–
H_2O+	0,64	0,54	0,75	0,61	0,70	0,65	0,62	0,68	0,68	0,19	0,41	1,79
H_2O-	0,10	0,12	0,10	0,15	0,02	0,14	0,13	0,08	0,19	0,39	0,15	0,37
TOTAL	99,28	99,87	98,90	99,59	99,59	100,01	101,88	100,07	99,79	100,68	102,70	99,88

MINOR ELEMENTS IN P.P.M.

	W1	W2	W3	E1	E2	E3	E4	K1	K2	N1	N2	R1
Zn	15	130	25	65	25	30	95	20	25	5	20	185
Ba	200	1260	500	850	1140	660	1080	660	520	530	250	520
Zr	520	420	310	420	490	420	480	500	250	280	280	480
Sr	40	115	30	40	50	20	40	95	40	10	10	30
Rb	50	220	300	200	190	280	260	140	230	590	430	280
F	120	690	3220	1390	1670	980	940	140	1570	20	780	60
Sn	15	–	–	19	–	48	–	20	–	–	–	–

W1 Rooiberg felsite (lower unit)
W2 Black porphyritic felsite (lower unit)
W3 Baviaansberg contact granite
E1 Verongelukspruit granophyre
E2 Verongelukspruit granite porphyry
E3 Baviaansberg contact granite
E4 Verongelukspruit porphyritic microgranophyre
K1 Verongelukspruit granophyre
K2 Baviaansberg main granite
N1 Baviaansberg main granite
N2 Baviaansberg main granite
R1 Rooiberg felsite (upper unit)

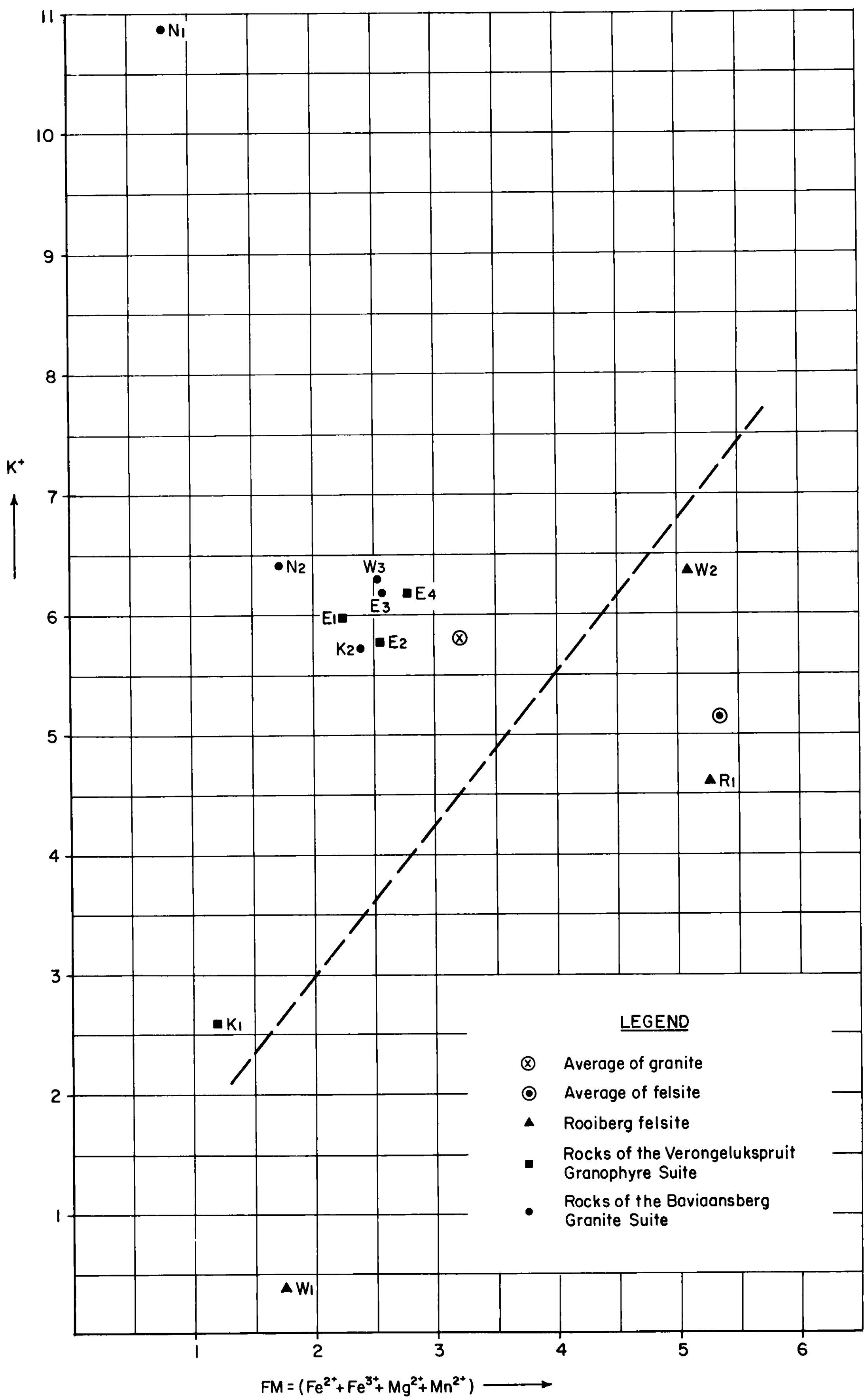

FIG. 17.- K-FM diagram for Rooiberg felsite and granitic rocks from the Warmbaths area (after von Gruenewaldt 1968, p. 167)

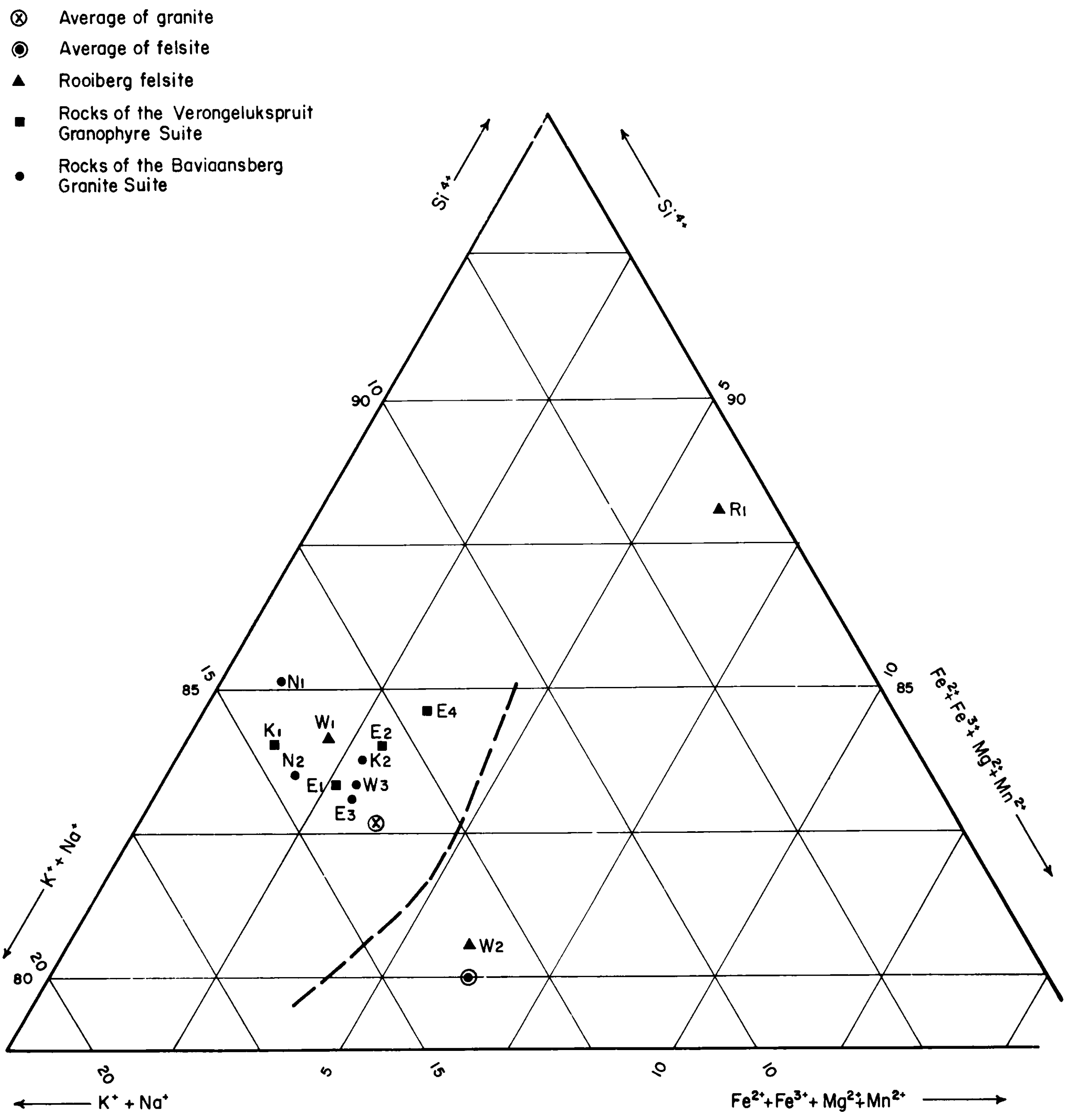

FIG.18.- Variation in composition of Rooiberg felsite and granitic rocks from the Warmbaths area (after von Gruenewaldt 1968, p.168)

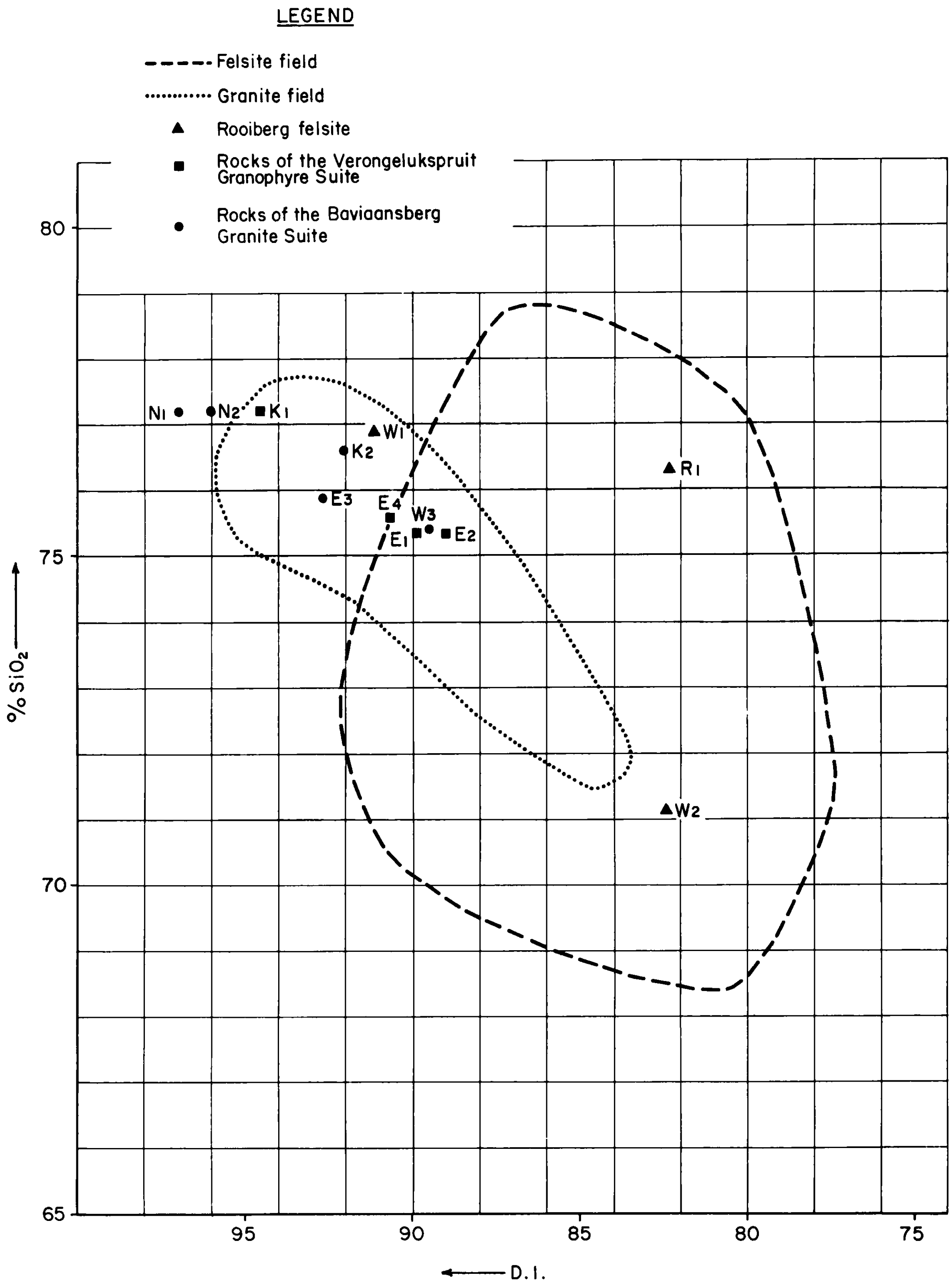

FIG.19.- Variation diagram of SiO_2 vs D.I. for Rooiberg felsite and granitic rocks from the Warmbaths area (adapted from Rhodes 1974, p.94). D.I.-differentiation index. The felsite and granite fields were drawn to include 87,5% of the analyses plotted by Rhodes

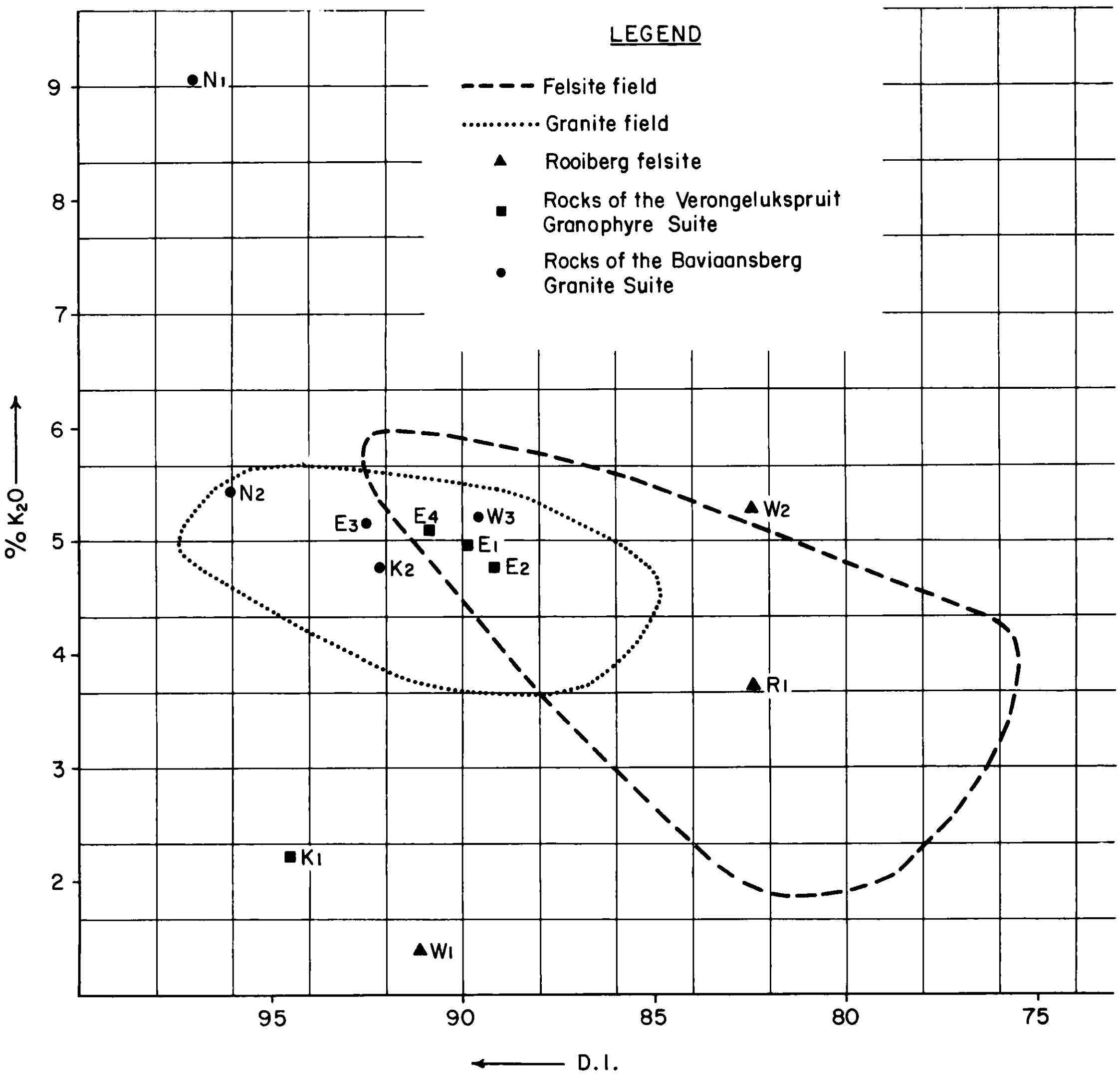

FIG 20- Variation diagram of K_2O vs. D.I. for Rooiberg felsite and granitic rocks from the Warmbaths area (adapted from Rhodes 1974, p. 96). D.I. - differentiation index. The felsite and granite fields were drawn to include 87,5% of the analyses plotted by Rhodes

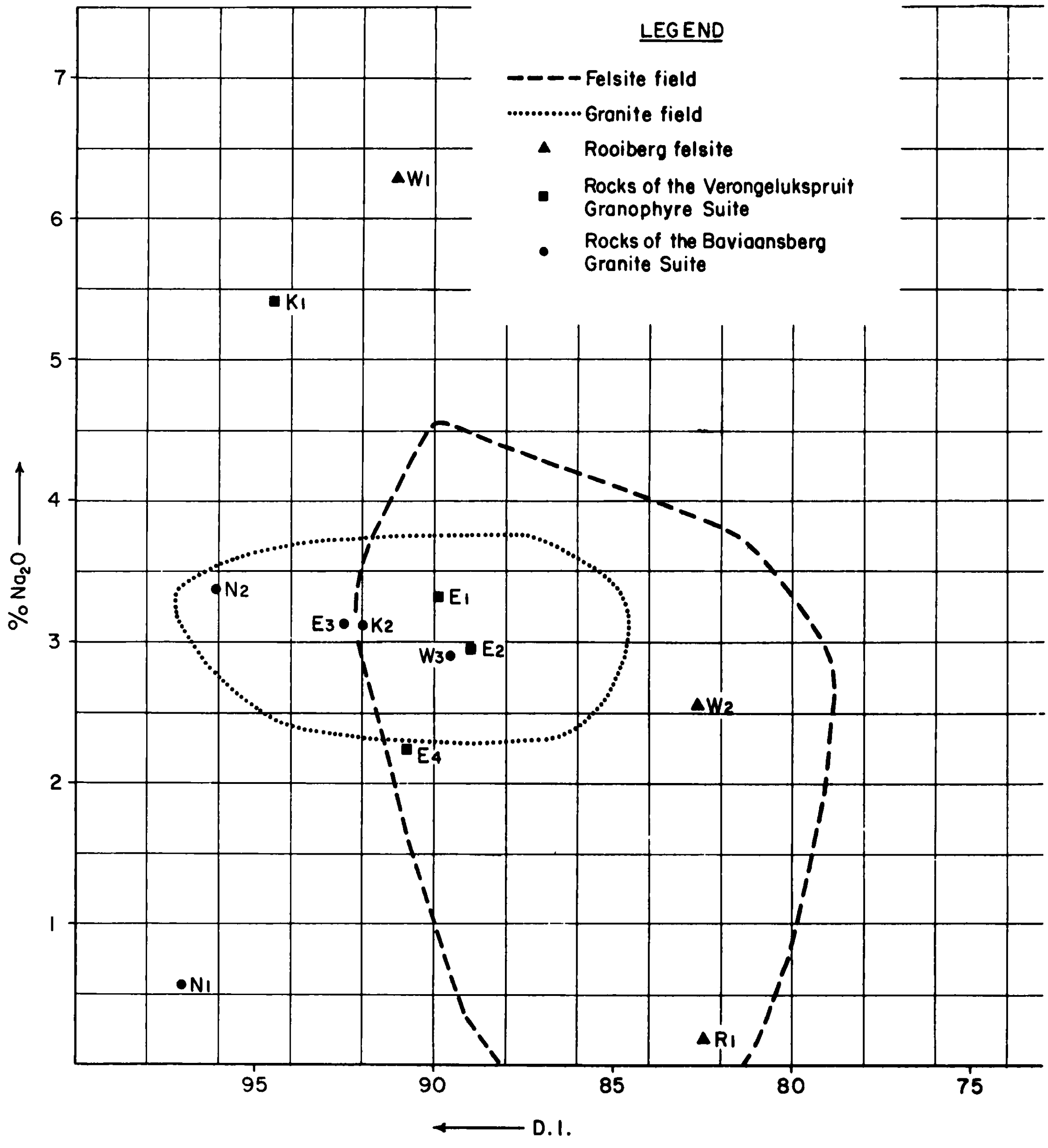

FIG.21.- Variation diagram of Na_2O vs. D.I. for Rooiberg felsite and granitic rocks from the Warmbaths area (adapted from Rhodes 1974, p.96). D.I.- differentiation index. The felsite and granite fields were drawn to include 87,5 % of the analyses plotted by Rhodes

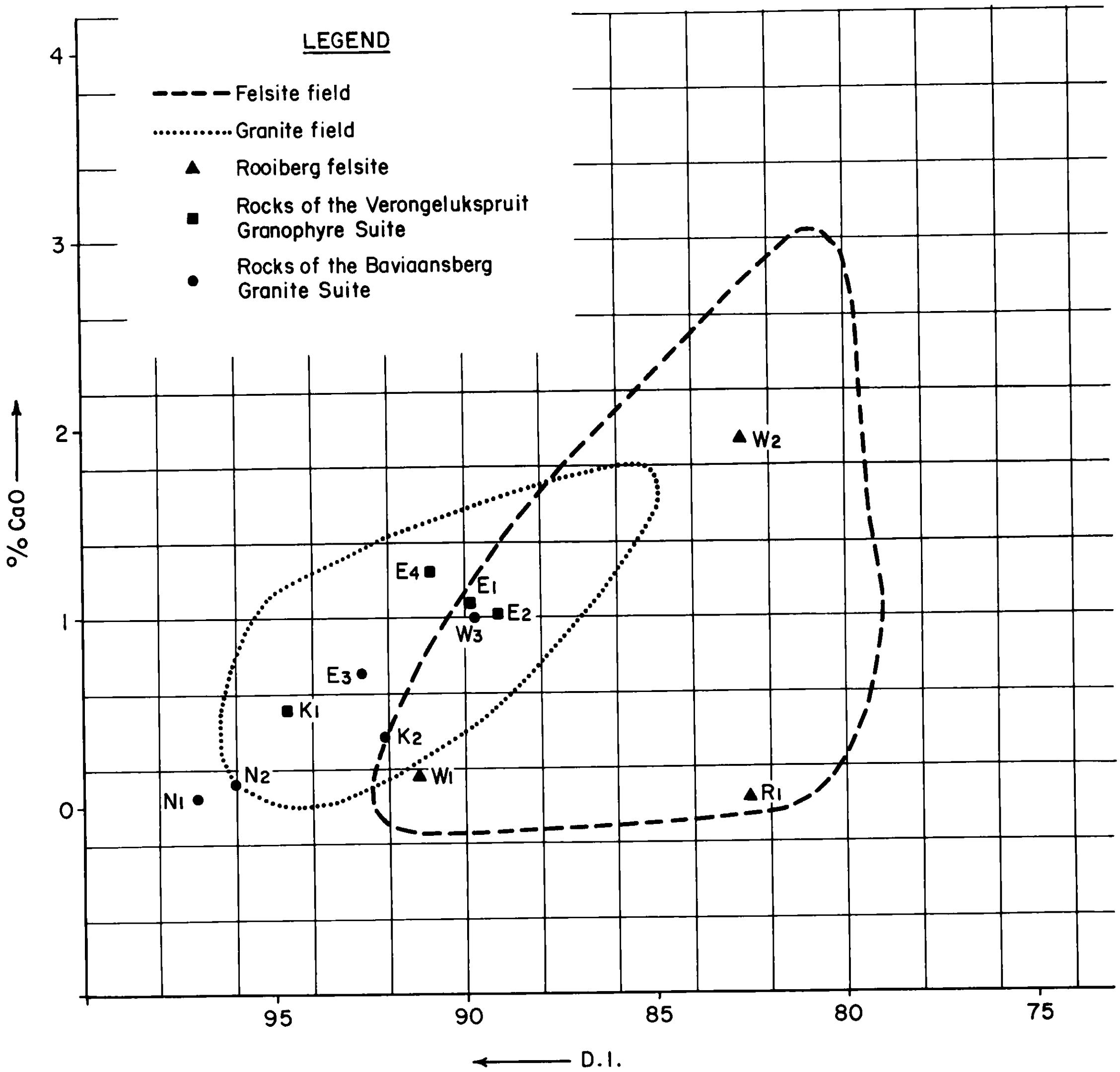

FIG. 22.- Variation diagram of CaO vs D.I. for Rooiberg felsite and granitic rocks from the Warmbaths area (adapted from Rhodes 1974, p.95). D.I.- differentiation index. The felsite and granite fields were drawn to include 87,5 % of the analyses plotted by Rhodes

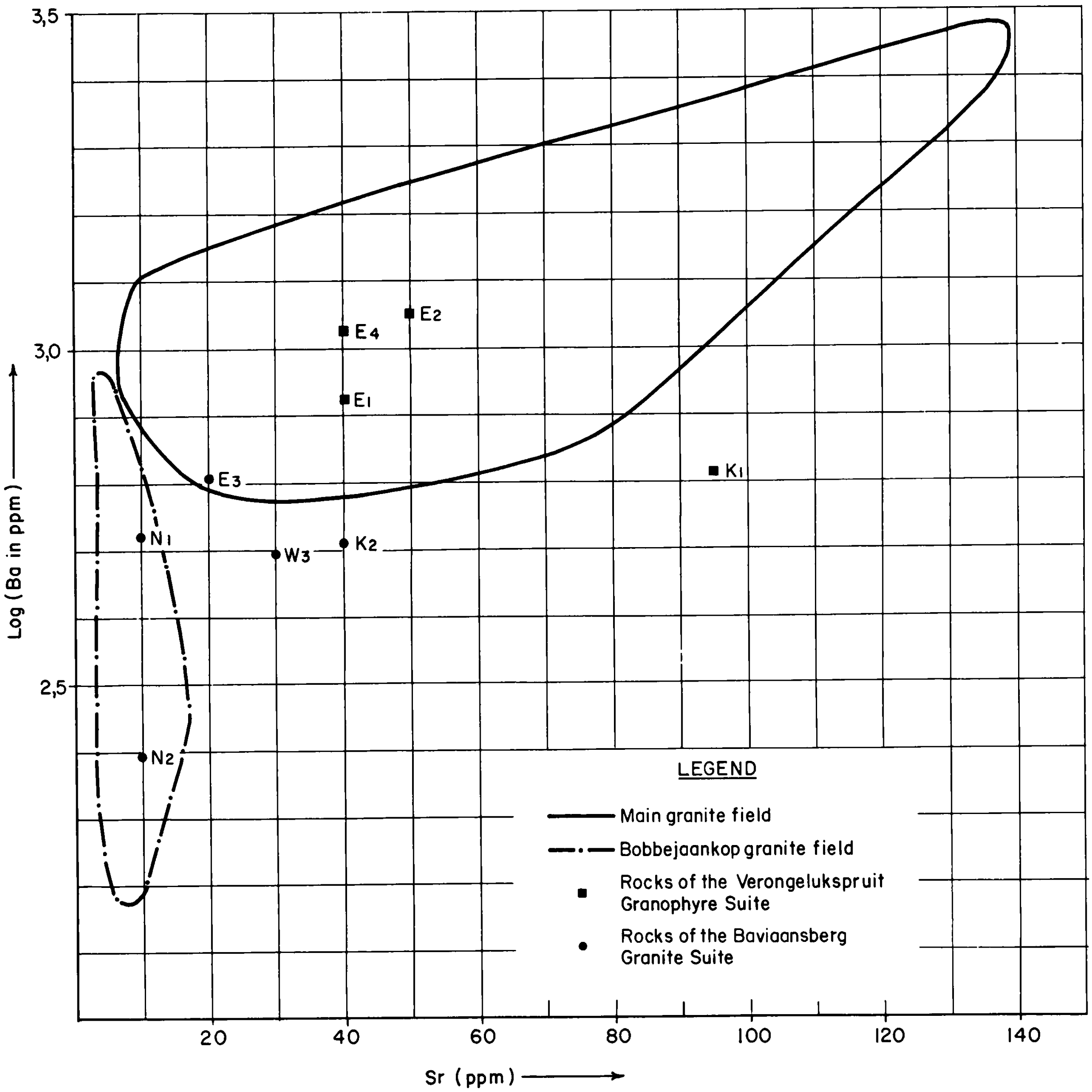

FIG.23.- Graph of Log Ba vs. Sr for Main granite and Bobbejaankop granite as well as for granitic rocks from the Warmbaths area (after De Bruiyn and Rhodes 1975 p.92)

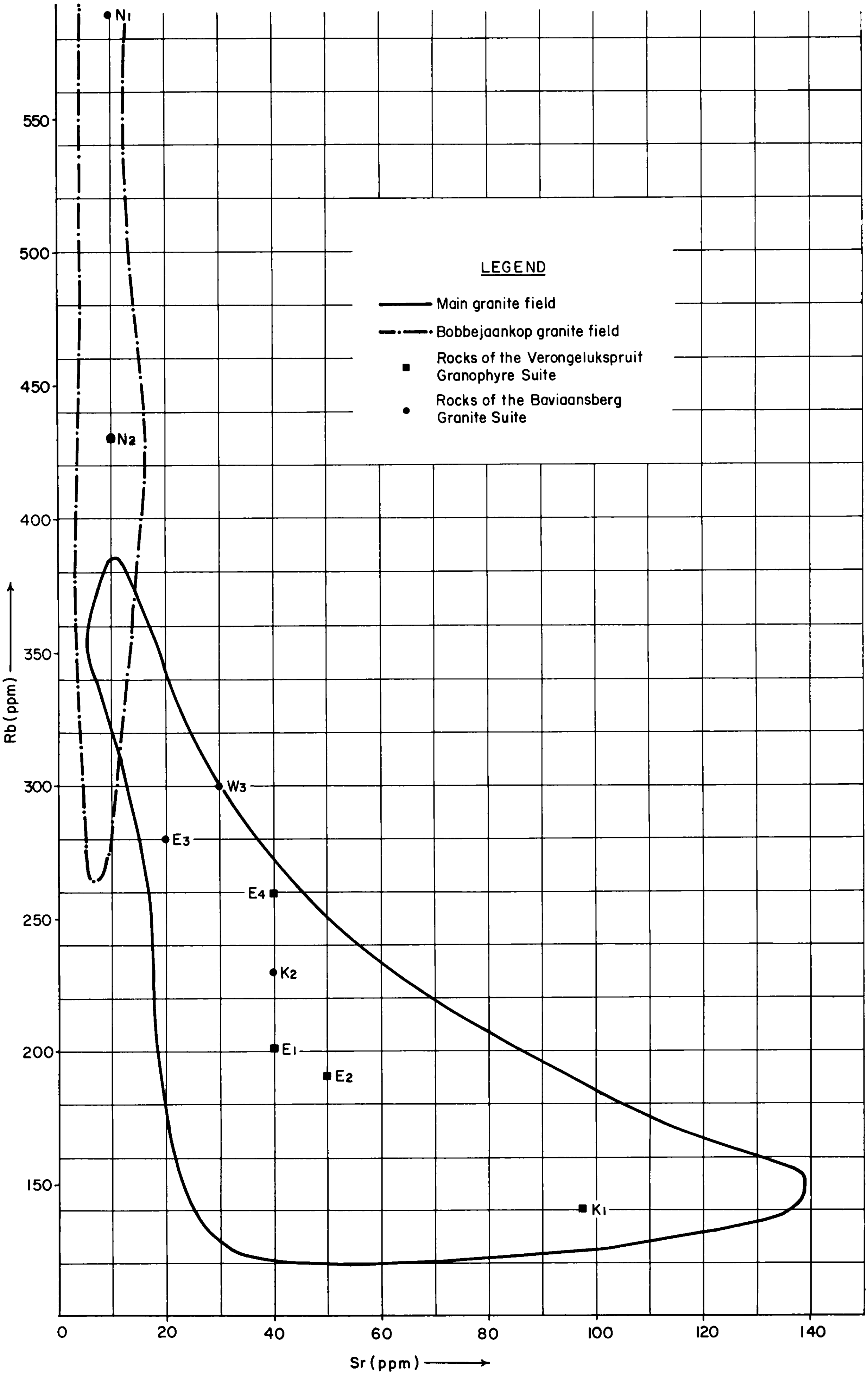

FIG. 24.– Graph of Rb vs. Sr for Main granite, Bobbejaankop granite and granitic rocks from the Warmbaths area (after De Bruiyn and Rhodes 1975 p. 94)

(b) the chilling of the rocks of the Baviaansberg granite suite against those of the Verongelukspruit granophyre suite and the Rooiberg felsite and the consequent formation of the Baviaansberg contact granite.

(c) the development of a zone of contact pegmatite within the Baviaansberg contact granite.

(d) the chemical characteristics which indicate that the Verongelukspruit granophyre is more closely related to the Baviaansberg granite and other granitic rocks of the Bushveld Complex than to the Rooiberg felsite.

(e) the presence of dykes, sheets and veins of aplite granite in the Baviaansberg granite.

Accordingly the following series of events are considered to present a feasible explanation for the observed relationships:-

(a) After extrusion of the Rooiberg felsite, and probably also after the emplacement of the basic rocks of the Bushveld Complex, granite porphyry – representing the first phase of granitic intrusion – intruded as a sheet-like body below Rooiberg felsite. The micro- to cryptocrystalline nature of the granite porphyry does not necessarily indicate a shallow depth of intrusion but may also depend on the volume of the intruding magma (Carmichael et. al. 1974 p. 5).

(b) After consolidation of the granite porphyry, the main phase of granitic intrusion as represented by the rocks of the Baviaansberg granite suite took place.

(c) Chilling of the Baviaansberg granite resulted in the formation of the Baviaansberg contact granite as a thin zone along the contact with Rooiberg felsite and the Verongelukspruit rock suite. This contact granite formed a fairly impervious roof or margin around the semicrystallized mush of the main facies of the Baviaansberg suite. During the ensuing stages of crystallization of the latter, residual fluids were forced outwards and upwards and were eventually trapped below the solid roof of contact granite, where they concentrated along the solid/mush interface. The fluids eventually crystallized in this position to form the contact pegmatite.

(d) The intrusion of the Baviaansberg granite caused partial metamorphic recrystallization of the granite porphyry and the formation of the Verongelukspruit granophyre as described earlier.

(e) During the final stages of crystallization of the Baviaansberg granite auto-injection of residual magma along fractures and joints in the Baviaansberg granite resulted in the formation of the aplite facies of the Baviaansberg granite suite.

7.4.2 CORRELATION WITH GRANITIC ROCKS FROM OTHER PARTS OF THE BUSHVELD COMPLEX

During the course of this investigation initial attempts to correlate the granitic rocks of the Warmbaths area with those of the Zaaiplaats area proved unsuccessful. These attempts were mainly based on a comparison of the observations in the Warmbaths area with the descriptions of the Zaaiplaats area in the literature. The author subsequently paid several visits to Zaaiplaats in order to obtain a first-hand knowledge of that area. When De Waal (1972, p. 143) questioned the long established subdivision and classification of the granitic rocks at Zaaiplaats and published a revised classification, it was decided to pursue this line of thought in an attempt to find a feasible correlation of the granitic rocks in the two areas.

Subsequently a number of thin sections from Zaaiplaats, originally used by Strauss and kept by the Geological Survey for reference purposes, were compared with those of the granitic rocks from the Warmbaths area. These studies led to the correlation as set out in Table 13.

TABLE 13

SUGGESTED CORRELATION OF THE GRANITIC ROCKS OF THE WARMBATHS AREA WITH THOSE OF THE ZAAIPLAATS AREA

KYNASTON (1908)	STRAUSS (1954)	DE WAAL (1972)	PRESENT INVESTIGATION
Zone of red granophyre	Granophyric granite (Main granite) Granophyre (Main granite) Granite porphyry (Main granite)	Granophyric granulite (Main Suite) Granophyre (Main Suite) Porphyritic granophyre (Main Suite) Granite porphyry (Main Suite)	Granophyre } Verongelukspruit Granophyre Suite Granite porphyry } —Intrusive Contact—
Zone of pegmatite and zone of medium-grained granulitic granite Zone of coarse, massive granite	Dykes, veins and sheets of Lease granite Lease micro-granite and pegmatite Contact micro-granite, (Main granite) Bobbejaankop granite Coarse-grained grey leococratic and coarse-grained grey mesotype granite (Main granite)	Aplite and pegmatite Bobbejaankop granite and granulite of the Main Suite	Veins and dykes of aplitic granite } Aplite Facies Fine- to medium-grained granite with pegmatite } Contact Facies Coarse, even-grained and porphyritic granite } Main Facies (Aplite Facies, Contact Facies and Main Facies) } Baviaansberg granite suite
Zone of fine granites, aplites and diorites	Foothills Granite	Foothills Granite	Not developed

7.5 CONCLUSION

The investigation of the granitic rocks of the Warmbaths area indicates a two-fold subdivision for the granitic rocks and two separate events of granite intrusion. The characteristics of the older granitic unit (Verongelukspruit granophyre suite) indicate that it owes its present character to metamorphic recrystallization which is ascribed to the intrusion of the younger granitic unit viz. the Baviaansberg granite suite. De Waal (1972, p. 143) found similar relationships for the granitic rocks of the Zaaiplaats area, but considered the mafic rocks of the Bushveld Complex to have been the major cause of metamorphism of his so-called Main Suite. Due to the absence of mafic rocks in the investigated area, a similar origin, although not excluded, seems unlikely for the rocks of the Verongelukspruit granophyre suite.

An attempt to correlate the granitic rocks of the investigated area with those from Zaaiplaats led to a revised subdivision of the granitic rocks at Zaaiplaats which is not in line with the views of previous workers. However, careful consideration of the described contact relationships between the younger Bobbejaankop granite and the older Main granite (Strauss, 1954, p. 36) reveals a degree of uncertainty concerning the exact relationships between the Bobbejaankop granite and the coarse-grained varieties of the Main granite, whereas less doubt seems to exist about the intrusive relationship between the Bobbejaankop granite and the medium-grained and granophyric varieties of the Main granite.

When seen in the light of these observations, the correlation as given in Table 13 becomes more acceptable and a revision of the subdivision for the granites at Zaaiplaats more justifiable. Such a revision, however, falls outside the scope of this investigation.

8. THE WATERBERG SYSTEM

The Waterberg System is represented in the area by a small section of the lower-most Swaershoek Stage, which has been preserved south of the Boschpoort fault on the farms Droogekloof 471 KR, Gorcum 435 KR, and Zwartkloof 470 KR (see Folder 1). The Waterberg beds have been overturned and dip southwards at an average dip of 40 to 45 degrees and are overlain along a normal contact by Rooiberg felsite. The maximum thickness preserved is ± 400m on Droogekloof 471 KR from where it decreases rapidly in both directions along strike. The middle and upper portions of the succession consist mainly of sandstone while in the lower portion, conglomerate and siltstone layers or lenses are developed.

The sandstone is as a rule medium- to coarse-grained, poorly- to well-bedded and light-brown, whitish-grey or purple in colour. Pebbles are common and occur either in washes, lenses and thin layers or as pebbles within the sandstone. The sandstone often shows extensive development of cross-bedding.

To the south, that is, towards the base of the succession, thin layers of siltstone are developed on at least two different horizons. The lower-most siltstone is in contact with Rooiberg felsite. The contact is well exposed in the valley formed by the Droëkloofspruit on Droogekloof 471 KR. This siltstone may be followed for a short distance in both directions along strike and to the east it reappears at the basal contact, immediately west of the eastern boundary of Droogekloof 471 KR.

The basal siltstone is separated from a conglomerate higher-up in the succession by brownish pebble-sandstone. In the valley of the Droëkloofspruit the conglomerate attains a thickness of 15 metres and forms a prominent cliff on the western side of the valley Conglomerate crops out intermittently near the base of the succession along the entire development of the Waterberg rocks. It usually contains well-rounded pebbles which vary considerably in size and which are felsite, quartzite, chert and banded ironstone.

A short distance above the conglomerate another thin layer of siltstone occurs which again may be followed for some distance along strike from the valley on Droogekloof 471 KR. The siltstone is dark purple in colour and is composed of a very fine-grained groundmass containing occasional and isolated grains of quartz which are distinguishable in hand specimen.

That the rocks of the Waterberg System were subjected to considerable movement is perhaps best illustrated by the siltstone layers in which the effects of folding and fracturing is well-preserved. At first, indications of shearing along the contact between the basal siltstone and the overlying Rooiberg felsite caused doubt about the overturned nature of the Waterberg beds. However, sections made from orientated samples of the siltstone clearly displayed overturned cross-bedding, which proved the overturned nature of the succession. The slight shearing at the contact is therefore interpreted as being the result of differential movement during folding and tilting of the Waterberg beds.

9. THE KAROO SYSTEM

Outcrops of rocks belonging to the Karoo System are found in the extreme south of the investigated area in the vicinity and just north of the road from Warmbaths to Mabula The outcrops occur sporadically in an area usually covered by thick soil (see Folder 1)

9.1 ROCKS OF THE ECCA SERIES

Approximately one kilometre west of the eastern boundary of Rietspruit 527 KQ a fine-grained, yellowish-brown sandstone and grit have been exposed in a quarry immediately north of the Warmbaths-Mabula road Approximately 300-400 metres north of this quarry a coarse, white grit crops out in a small and isolated occurrence A few hundred metres westwards from the aforementioned quarry, the same yellowish-brown sandstone and grit again occur in a quarry which is situated immediately south of the tarred road At this locality the sandstone and grit are resting directly on top of highly weathered Bushveld granite. The contact as exposed here is irregular and the sediments are dipping towards the south-south-east at a fairly low angle

9.2 BUSHVELD SANDSTONE

Outcrops of a cream- to red-coloured fine-grained and often quartzitic sandstone occur on Droogekloof 471 KR, Zwartkloof 470 KR and Roodepoort 476 KR. This sandstone is correlatable with the sandstone which forms Buyskop to the north-east of Warmbaths and is therefore considered to be Bushveld Sandstone – the correlate of the Cave Sandstone of the main Karoo basin It consists of quartz and feldspar, usually well-rounded, well-sorted and with a poor to moderate sphericity The grain size distribution of the rock is bimodal with modes of 0,125 mm and 0,25 mm The grains are cemented by a fine-grained quartzitic matrix.

9.3 BUSHVELD AMYGDALOID

Basaltic lavas crop out on Roodepoort 467 KR in the bed of the Platriver and have been exposed in a quarry immediately south of the Warmbaths-Mabula road further westwards on Klippan 490 KR Material from water-boreholes, however, proved that the lava occupies at least the area westwards up to the eastern part of Droogekloof 471 KR

The Bushveld Amygdaloid is a brownish-purple or chocolate-coloured rock which generally contains numerous amygdales of zeolites. The groundmass consists mainly of laths of plagioclase and subhedral clinopyroxene, in places subophitically intergrown with large amounts of magnetite and hematite.

10. POST-WATERBERG INTRUSIVES

Diabase dykes of post-Waterberg age, ranging in thickness between 2,5 and 8 metres, are developed and display two dominant directions, i.e. ENE-WSW and NE-SW On Elandsfontein 401 KR a sill-like intrusion of diabase occurs almost at the contact between Verongelukspruit granophyre and Baviaansberg granite.

Generally the diabase consists of uralitized clino- and orthophyroxene, plagioclase, chlorite, and opaque minerals The texture is ophitic to subophitic and the feldspars have usually been subjected to considerable sericitization and saussuritization Granophyric varieties with small amounts of quartz have also been found

11. RECENT DEPOSITS

The low-lying parts of the area are generally covered by soil, sand or grit, which locally attain considerable thicknesses, in particular in the area south of the southern felsite-range. These deposits are mainly derived from granite and the surrounding felsite ranges. Alluvium is developed along the streambeds of the major streams. Gravels along the banks of the Sand River and its tributaries consist mainly of rounded felsite pebbles.

Scree consisting of rounded to subangular boulders of felsite and, in addition, banded ironstone and chert, especially south of the southern felsite-range is, distributed along the slopes of the hill-ranges. Alluvial fans occur mainly along the foothills of the Hoekberge and south of the southern felsite-range.

Large ferricrete patches are developed on felsite in places but more frequently on granite.

12. STRUCTURAL GEOLOGY

The investigation of the area has led to interesting new results concerning the structural relationship between the Bushveld granite, the Rooiberg felsite and the Waterberg System. In the area three phases of deformation may be recognised. The deformative periods are:

(i) a pre- and early-Waterberg phase
(ii) a post- and possibly syn-Waterberg phase
(iii) a post-Karoo phase

12.1 THE PRE- AND EARLY-WATERBERG PERIOD OF DEFORMATION

Structures which originated during this period of deformation are mainly preserved in the area north of the Boschpoort fault where other or subsequent periods of deformation seem to have had little or no effect. They are:-

(i) two anticlinal structures and an accompanying synclinal structure, i.e. the Loubad and Zwartkloof anticlines and the Nylstroom syncline
(ii) a number of small faults developed in the Rooiberg felsite
(iii) an E-W striking fault and two NE-SW striking faults which apparently displace both the Bushveld granite, the Rooiberg felsite and the Waterberg System.

12.1.1 The Loubad and Zwartkloof Anticlines and the Nylstroom Syncline

The granite in the core of the Loubad anticline is surrounded by felsite, which forms the nose and the northern limb of the anticline. The felsite is overlain by Waterberg beds with more or less the same dip and strike in the lower portions as the tuffaceous intercalation in the felsite. The southern limb of the anticline is formed by an E-W striking branch-fault of the Crocodile Bridge fault-zone.

On Zwartkloof 470 KR in the Zwartkloof anticline the various formations display more or less the same relationships as in the Loubad anticline. The southern limb is cut off by the Boschpoort fault. A small dome-like structure of Bushveld granite is developed on the extension of the anticlinal axis near the eastern boundary of Zwartkloof 470 KR (see Folder 1).

Between the two anticlines, i.e. from Newburg 437 KR to Rhenosterpoort 402 KR, Rooiberg felsite forms the western rim of the Nylstroom syncline which falls largely in the area east of the present one. Dips measured in the felsite indicate that the Lower Waterberg beds and felsite almost form a conformable sequence. This relationship is enhanced by a conspicuous parallelism between the granite-felsite contact, the felsite-Waterberg contact and the intercalations in the felsite. Furthermore, the granite cores of the anticlines show very little or no effects of shearing.

12.1.2 Small Faults developed in the Rooiberg Felsite

On Middelfontein 391 KR and Rietpoort 390 KR along the northern limb of the Loubad anticline relative displacements of intercalations in the felsite indicate small faults intersecting the felsite but not the Waterberg beds. Similar minor faults are developed along the western rim of the Nylstroom syncline and further south in the Zwartkloof anticline.

12.1.3 The E-W Striking Fault and the NE-SW Striking Faults

The fault striking through the southern limb of the Loubad anticline has been followed from the western boundary of the investigated area through Bushveld granite along the southern limb of the Loubad anticline into the basal Waterberg beds on Rietpoort 390 KR. In the granite the fault is traced by quartz veins and mylonitic zones in places. Further to the east the position of the fault is inferred by displacement of the felsite, a linear contact between Bushveld granite and felsite and between the latter two formations and the Waterberg beds. Further east the fault grades into a flexure in the basal Waterberg beds (Dr. H. Jansen, pers. comm.).

On Beechwood 398 KR and Middelfontein 391 KR as well as on Zandrivier 397 KR, two NE-SW striking faults probably represent branch-faults of the above-mentioned fault.. The down-throw is on the north-west and according to De Vries (1969, Folder 1) these faults have also displaced the basal Waterberg beds.

12.1.4 Conclusions

The main structural features described in the previous text may be summarised as follows:-

(i) a marked parallelism between the felsite-Waterberg, the felsite-granite contacts and the intercalations in the felsite

(ii) dips of the same magnitude in the felsite and the basal Waterberg beds with a slight deviation in the nose of the Loubad anticline

(iii) the relative absence of shearing in the core of the anticlines in contrast with intensive faulting and shearing in the belt south of the Zwartkloof anticline.

These features indicate that the anticlines were formed in their embryonic stages by magmatic updoming of residual, still mobile phases of the Bushveld granite. The formation of the embryonic Nylstroom syncline may be attributed to concomittant magmatic withdrawal, viz. subsidence.

These processes led to adjustment of the resistant felsite cover and to the formation of small faults which intersect the felsite at numerous localities. Moreover; the quartz porphyry in the basal Waterberg beds is probably a manifestation of the still mobile phase of the acid Bushveld magma.

However, it is clear that after solidification of the Bushveld granite it must have reacted to stresses by faulting as illustrated by the fault intersecting the southern limb of the Loubad anticline. Fault-scarps were formed along the fault-line, as indicated by the coarse clastic sediments on the down-throw side. Old scree fans are probably represented by the so-called felsite-breccia (Jansen, 1969, p. 5). That the fault was active during early-Waterberg times is shown by local intraformational folding and chaotic sedimentation in the adjoining basal Waterberg beds on Rhenosterpoort 402 KR and by the distribution of the conglomeratic beds in the entire succession to the south.

12.2 THE POST- AND POSSIBLE SYN-WATERBERG PERIOD OF DEFORMATION

Deformation during this period was mainly confined to a narrow belt in the southern part of the area. The following structures are developed:-

(i) the Boschpoort fault

(ii) the Droogekloof Thrust

(iii) folding and tilting in the adjoining formations.

12.2.1 The Boschpoort Fault

This fault strikes from Cyferfontein 434 KR south-eastward to Zwartkloof 470 KR where it apparently disappears under the Droogekloof Thrust. The fault-plane dips steeply southwards. Being a normal fault with a down-throw to the south it has brought the Waterberg beds (Swaershoek Stage) into contact with the Bushveld granite. According to the above-mentioned relationships the fault was active between deposition of the basal Waterberg beds (Swaershoek Stage) and the period of thrusting.

12.2.2 The Droogekloof Thrust

The Droogekloof Thrust can be followed from Cyferfontein 434 KR in a south-easterly direction to west of Warmbaths. Due to poor exposures in the eastern part of Roodepoort 467 KR and further to the east, the continuation of the thrust to the east could not be proved. In general, the irregular or sinuous course of the fault-line indicates that the fault-plane dips to the south at a relatively low angle. Borehole data from the Zwartkloof fluorspar mine, in fact, suggest a dip of approximately 30 degrees to the south. However, local field-evidence points to even lower dips varying between 5 to 15 degrees south. The overthrust mass consists of rocks of the Transvaal System and Bushveld granite and the overridden mass of Bushveld granite, Rooiberg felsite and Waterberg beds.

12.2.3 Folding and Tilting in the adjoining Formations

Intensive folding accompanied by dynamometamorphic effects have been observed in the rocks of the Transvaal System along the Droogekloof Thrust.

Intensive minor folding is developed in the tuff along the eastern rim of the dome-like structure on Zwartkloof 470 KR. The entire fault-block between the Droogekloof Thrust and the Boschpoort fault consisting of Bushveld granite, felsite and Waterberg beds has been overturned.

12.2.4 Conclusions

Nowhere in the present area could the post-Waterberg age of the Droogekloof Thrust be established with certainty. However, there remains little doubt that the Thrust forms part of a regional pattern of upthrusting and overthrusting which includes the Gatkop overthrust and the upthrusts east of Thabazimbi. Hence, the Droogekloof Thrust is most likely of post-Waterberg age. The Boschpoort fault is apparently older than the Droogekloof Thrust. As the displaced Waterberg beds only belong to the Swaershoek stage, the age of the Boschpoort fault is limited to syn-Waterberg and post-Waterberg. The intensive folding of the Transvaal rocks, and the tuff intercalated in the felsite are the result of the same stresses which caused over-thrusting.

The overturning and folding of the block between the Boschpoort fault and the Droogekloof Thrust is probably due to the combined effect of the two faults. Pringle (1975, p. 9) reached a similar conclusion and further suggested that the Boschpoort fault and the Droogekloof Thrust fault may be contemporaneous.

12.3 POST-KAROO DEFORMATION

This period of deformation is represented by a E-W striking fault along the northern boundary of the Karoo beds. In the present area its existence has been established only at one locality, i.e. by a fault-breccia on Droogekloof 471 KR. Considering the extensive soil-covering and the fact that according to Kynaston (1909, p. 36) the Bushveld amygdaloid directly overlies Bushveld granite, the existence of the fault still remains doubtful.

13. SUMMARY AND CONCLUSIONS

To summarize, attention is again drawn to the following observations and conclusions:-

(i) The presence of a persistent zone of pyroclastic rocks and of quartzite xenoliths in the Rooiberg felsite, permits subdivision of the felsite into two major units.

(ii) This twofold subdivision seems to be applicable for the Rooiberg felsite over a considerable part of Central Transvaal and especially so for the so-called "Waterberg display" (Hall, 1932, p. 243) of the Rooiberg felsite.

(iii) Two different phases of granitic rocks exist in the investigated area viz.:

(a) the Baviaansberg granite suite
(b) the Verongelukspruit granophyre suite

(iv) The Verongelukspruit granophyre suite owes its present character to metamorphic recrystallization which is considered to be the result of the intrusive activity of the Baviaansberg granite suite.

(v) The chemistry of the granitic rocks indicates a close relationship between the two granitic phases and the older Verongelukspruit granophyre suite may therefore be considered as representing an earlier phase of granitic intrusion.

(vi) The granitic rocks of the Warmbaths area have much in common with the granites of the Zaaiplaats area.

(vii) A correlation with the granitic rocks of the Zaaiplaats area however, calls for a reconsideration of the established subdivision and views on the origin and mode of emplacement of the granites at Zaaiplaats.

14. ACKNOWLEDGEMENTS

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