THE TECTONIC DEVELOPMENT OF THE NAMAQUA MOBILE BELT AND ITS FORELAND IN PARTS OF THE NORTHERN CAPE

by

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ABSTRACT

The Namaqua Mobile Belt extends from the south-western coast of Southern Africa through northern Namaqualand and adjacent parts of South West Africa to the south-western margin of the Kaapvaal Craton near Prieska. Its Precambrian tectonic development is characterised by several successive periods of deformation and metamorphism, the last of which - the Namaqua tectogenesis - occurred between c. 0,9 and 1,25 Ga B.P.

The northern boundary of the mobile belt is the Namaqua front which, at different places along its length, appears as a metamorphic transition, as an oblique-slip fault, and as an interface between areas yielding radiometric ages of 2,5 - 2,9 Ga and 0,9 - 1,25 Ga respectively.

The foreland of the belt in the area under consideration is formed by the south-western marginal part of the Kaapvaal Craton and by the Kheis tectonic domain; the former comprises granitoids and metamorphites generally older than c. 2,5 Ga (the Skalkseput Granite, the Draghoender Granite and the Swartkop sequence), as well as supracrustal cover-rocks ranging in age between c. 2,5 and 1,8 Ga (the Seekoebaard Formation, the Transvaal Supergroup and the Matsap Formation). The area of the latter is underlain by a sequence of metasediments and metavolcanics (the Kheis Group), which has been deformed and metamorphosed prior to the deposition of the Seekoebaard Formation (probably prior to the intrusion of the Draghoender Granite c. 2,9 Ga B.P.).

Rock units within the Namaqua Mobile Belt (in the Namaqualand Metamorphic Complex) are represented by metasediments and metavolcanics of the Hartebeest Pan Formation (probably Kheis correlate), by the outliers of the Kaaien quartzite (the Kheis Group *sensu stricto*), and by the intrusive rocks. The majority of the intrusives are granitoids, which were emplaced during the Namaqua tectogenesis.

The structural framework of the Namaqua, Kheis and Kaapvaal domains indicates that similar sequences of tectonic phases causing similarly oriented structures can be recognised in all the three major subdivisions: the earliest recognisable structure is the regional foliation s_1 in the Kheis, in the Namaqualand Metamorphic Complex and in the Swartkop sequence of the Kaapvaal Craton. It was isoclinally folded during the second period of

deformation (F_2) and both sets of early structures, which are older than c. 2,5 Ga were refolded during two phases of post-Matsap diastrophism (F_3 and F_4 respectively). The former of the two is responsible for a general north-northeasterly axial plunge of structures in the Kaapvaal domain, and for the north-easterly trend of some structures in the Kheis and Namaqua domains. The latter phase (F_4) resulted in a general north-westerly alignment of structural elements in the Namaqua domain and in the adjoining parts of its foreland (i.e. in parts of the Kheis and Kaapvaal domains). It was terminated by a period of granitic intrusions, the last of which occurred c. 0,9 Ga B.P.

Related to the F_4 fabric is the Doringberg fault and other major oblique-slip fractures, which constitute a north-westerly trending tectonic zone some 300 km long (the Doringberg lineament) and situated in the foreland of the Namaqua Mobile Belt. The westernmost of these fractures separate the Namaqualand Metamorphic Complex from the Kheis Group.

The regional metamorphism in the Namaqua Mobile Belt is of low pressure/high temperature type; it probably followed after an earlier period of progressive metamorphism in the Kheis Group, in the Swartkop sequence and in the Hartebeest Pan Formation. This earlier metamorphism is related to the earliest period of deformation of these supracrustal rocks. Retrogressive metamorphism, which occurred in the area along the Namaqua front, was probably related to the late movements during the Namaqua tectogenesis.

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Annexure 1 : Geological Map of the
Marydale-Buchuberg Area,
Northern Cape

1. INTRODUCTION

1.1. General

The area bounded by longitudes 21°45'E and 22°30'E, and by latitudes 29°00'S and 29°30'S (Annex. 1) represents one of the typical examples of a complex Precambrian terrain. It extends from the tectonic domain of the stable crustal block of the Kaapvaal Craton in the east across a series of major fractures in the zone of the Doringberg lineament into the region of reconstituted and reactivated supracrustal rocks and intrusives of the Namaqualand Metamorphic Complex in the west. The investigation of this area lasted for a period of three and a half years between 1970 and 1974, and was financed by a grant from Falconbridge Explorations Ltd.

Geographically the area is situated in the upper part of the Orange River basin between Upington and Prieska, and falls in the geomorphologic province of the Cape Middle Veld (King, 1967), characterised by the presence of pre-Karoo surfaces (nearly all the Karoo sediments have been removed), and by the landforms of the late-Tertiary (post-African) cycle. The area also belongs to the Little Namaqua-Bushmanland Plain (Wellington, 1955), a subunit of the Cape Middle Veld in the northern Cape near the southern limit of the Kalahari Sandveld.

1.2. Previous Work

Earliest observations on the geology of the area under consideration were published between 1812 and 1870, and most of these are related to mineral occurrences whereas only a few recorded other interesting geological features (cf. Hatch and Corstorphine, 1905). Systematic geological work began in 1872, when G.W. Stow mapped the country north of the Orange River and gave lithological descriptions of some of the main units in an area of more than 10 000 km^2 (Stow, 1874). He also firstly proposed stratigraphic terms such as Kheis ("Micaceous and schistose rocks of Kheis"), Campbell Rand ("Siliceous and crystalline limestones of Campbell Randt"), Griqua Town ("Griquatown Jasper with Magnetite") and Matsap ("Quartzite of Matsap and Langeberg").

In 1899 and during the following ten years, when geologists of the Geological Commission of Cape of Good Hope mapped the country between Upington and Prieska, Stow's ideas and basic principles were mostly upheld. In detailed and thorough descriptions which were given by A.L. Du Toit, A.W. Rogers and E.H.L. Schwarz, the Kheis Group was subdivided into Marydale, Kaaien and Wilgenhout Drift "Beds", granites and gneisses in the western part of the area were distinguished, the Zoetlief and Pniel Formations of volcanic rocks and sediments were defined, the Black Reef quartzites and flagstones underlying the Campbell Rand dolomite were placed in the succession at the base of the Transvaal Supergroup, and the Ongeluk Volcanics as well as the mixtite occurring in the same sequence were first recognised.

After 1910 the country between Upington and Prieska was studied less systematically, but some of the problems were discussed in greater detail. Interest has been paid namely to the crocidolite asbestos deposits in the region and much notable information gathered. The knowledge of stratigraphy and structure of the lower part of the Transvaal Supergroup in the northern Cape improved considerably, the results of investigation contributed towards the explanation of the origin of crocidolite asbestos, banded iron-formation, and other characteristic minerals and rock types in the Asbestos Hills Iron Formation, and the area became one of the classic regions for the study of Precambrian banded iron-formations. Among the most important publications of this thematic group are those by Hall (1918, 1930), Peacock (1928), Wagner (1928), Du Toit (1945), Cilliers (1961), Hanekom (1966), Fockema (1967), and N.J. Beukes (1973).

Other important data are the radiometric age determinations, first obtained on specimens of pegmatite from Gordonia (Holmes, 1934) and later also on samples of other minerals and rocks from the Upington-Prieska area (Holmes and Cahen, 1957; Nicolaysen, 1962; Nicolaysen and Burger, 1965; Burger and Coertze, 1973; Burger and Nicolaysen, 1973). The data indicate that vast regions of Namaqualand and the northern Cape were subjected to plutonism and migmatisation some 1,0 Ga B.P., and that a much older intrusive cycle affected the pre-Transvaal sequences c. 2,5 - 2,9 Ga B.P. In more recent years several papers have been published which deal either with the geochronology of the African continent as a whole (Clifford, 1966, 1967, 1968, 1970 and 1972) or discuss the radiometric data obtained on specimens from various Precambrian rock-units (Oosthuyzen and Burger, 1964; Burger, Hugo and Strelow, 1965; Van Niekerk and Burger, 1964, 1967 and 1969; and others).

Results of detailed investigations carried out in the neighbouring Keimoes area between the years 1943 and 1954 are of similar significance, because interest has been paid there to the metamorphic rocks hitherto correlated with the Kheis Group, and to the associated intrusive rocks which lie in the direct northwestern continuation of the Kheis stratotype. The lithology and chemical composition of supracrustal rocks in the Namaqualand Metamorphic Complex around Keimoes and Kakamas have been characterised, the general stratigraphy and structure has been unravelled and charnockitic adamellite porphyries were described by Poldervaart (1966), by Poldervaart and Von Backström (1949) and by Von Backström (1961, 1964, 1967).

The tectonically most complicated part of the area was visited by Truter and De Villiers in 1947, who briefly described rocks on the farm Seekoebaard south of the Buchuberg Dam and pointed out that the metasediments and metavolcanics occurring on this farm belong to a single formation of pre-Transvaal age which should be correlated with the "Zoetlief" sequence in the T'Kuip Hills some 60 km south-east of Prieska (op.cit., 1948, pp. 146-148).

During 1957-59 some 1300 km^2 of the area between the Eselberge and Asbestos Hills were mapped by Leube (1964) who gave a description of all the major units including the post-Transvaal diabase sills and dikes. On his map of a scale of 1 : 74 376 Leube showed mostly the Transvaal Supergroup and the Matsap Formation, and partly also the Seekoebaard Formation. Older units were not mapped in greater detail until 1963, when Drewers compiled a map of a scale of 1 : 50 000 of the country on the western bank of the Orange River between the latitudes 29°00'S and 29°30'S for the Geological Survey. Also in the year 1963, septarian nodules in the Lower Griquatown group have been described and their origin was discussed by Von Backström.

In 1965 M.C. Du Toit presented a study of the Koras Formation, which occurs mostly on the western bank of the Orange River north of the 29°00' parallel. This author divided the Koras sequence into two parts separated by an erosional break, and confirmed Rogers' earlier observation that the basal part of the formation overlies the Kheis Group unconformably. He tentatively correlated the lower part of the Koras succession with the "Zoetlief" or Sinclair Formation depending on the age of the underlying granite-gneiss. The upper part of the Koras was correlated either with the Matsap or Auborus Formations, based on the presence of Transvaal Supergroup rocks among the clastic material. Subsequent radiometric dating carried out by Van Niekerk and Burger (1967) on apatite and zircon from the upper Koras quartz porphyry revealed, however, that at least the upper part of the sequence with an age of 1 085 Ma cannot be correlated with any of the other Precambrian formations in the region.

Two latest major contributions to the geological knowledge of the northern Cape are represented by the papers read at the Congress of the Geological Society of South Africa in Bloemfontein, 1973, and by the explanation accompanying the most recent edition of the Geological Map of South Africa (Van Eeden, 1972). These will be referred to in the appropriate parts of the following text.

1.3. Purpose of the present study

A motivation of the present study is contained in facts and findings of the previous work, among which the radiometric results are of particular significance. These results, obtained on various rocks and minerals of the Kaapvaal Craton, and on granitoids and pegmatites of the Namaqualand Metamorphic Complex, point to a marked difference between the two major units, and to the existence of a zone of c. 1,0 Ga old plutonism and reactivation. This zone, here termed the *Namaqua Mobile Belt*, extends from the west coast of South Africa across northern Namaqualand and Bushmanland to the western margin of the Kaaien Hills and Karoo boundary near Prieska (Fig. 1).

The relationship between the Namaqua Mobile Belt and the Kaapvaal Craton, the type of transition from the mobile belt into its foreland, a comparison of the tectonic development in the belt and in its foreland, and a reappraisal of the Precambrian tectonic development of the area under consideration were the main objectives of the present study, although several other problems such as the stratigraphy of the supracrustal sequences and the succession of plutonic and metamorphic events were also tackled.

1.4. Methods

Aerial photographs were used for regional mapping, fracture trace analysis and structural analysis. The geological map (Annex. 1), which was originally drawn at a scale of 1 : 50 000, combines the results of both photointerpretation and the data gathered in the field. These were recorded on the aerial photographs of a scale of 1 : 30 000, which cover greater part of the area north of the 29°21'S parallel, or on the 1 : 50 000 topographic sheets in the remaining part of the area, where the only aerial photographs available were those of a scale of 1 : 70 000.

The preliminary study of the aerial photographs revealed a great complexity of fold structures in the Kaaien Hills (see section 2.2.3.2.) and led to the recognition of major structural subdivisions of the area. This major grouping into the three tectonic domains was also confirmed during a study of the ERTS imagery as soon as it became available early in 1973. Aerial photographs and the ERTS imagery also provided information on major fractures in the zone of the Doringberg lineament (Fig. 40) and on macroscopic structures elsewhere (Fig. 9).

Field work, during which most of the structural data and other information were gathered, was followed by laboratory investigations involving a detailed structural analysis, a petrological analysis, and also a certain amount of chemical work.

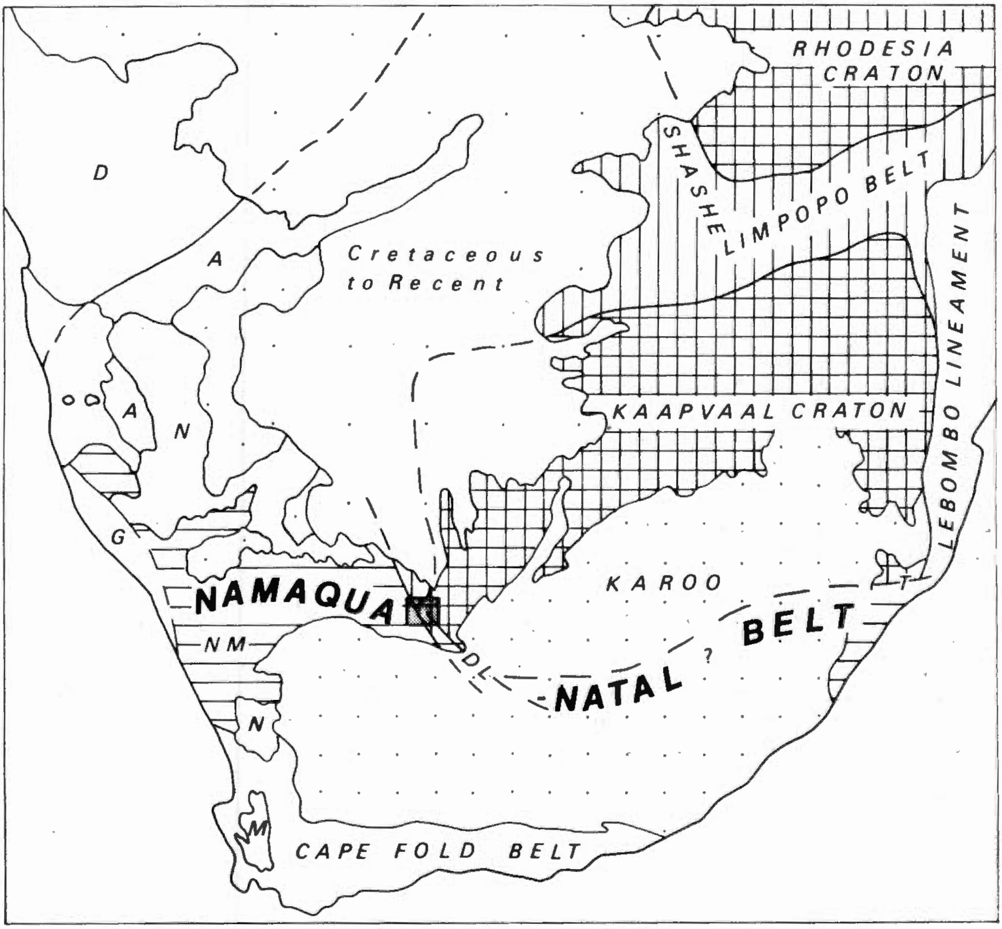

Fig. 1. Principal geological elements of Southern Africa. Abbreviations are: M - Malmesbury Group; G - Gariep Group; N - Nama Group; D - Damara Group; A - pre-Damara (Abbabis, Marienhof, Dordabis and Sinclair sequences); NM - Namaqualand Metamorphic Complex; DL - Doringberg lineament; T - Tugela fault. The area under consideration is shaded.

1.5. Acknowledgements

The project was initiated by the late Professor John de Villiers, who also obtained the financial support and guided the work until his sudden and unexpected death on November 11th, 1973. His supervision is gratefully acknowledged. The author is also indebted to Falconbridge Explorations Ltd. for the funds made available, and to Mr. C.M.H. Jennings of the same company for his interest in the work, his visits to the area and for helpful cooperation.

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The Director of the Geological Survey of South Africa approved the chemical analysis of sixteen rock specimens and the analytical work was carried out at the Department of Geochemistry of the University of Cape Town.

Thanks are also due to the members of the Precambrian Research Unit and of the Department of Geology, University of Cape Town, for the stimulating discussions and constructive criticism, to the farmers of the area - among whom Mr. B.F. Fourie of Seekoebaardsnek and Mr. J. de Villiers of Putsonderwater were particularly helpful - for their friendliness and hospitality, and finally to my wife Vlasta for her support throughout the course of study.

2. DESCRIPTION

2.1. Lithological units

2.1.1. Introduction

The great variety of rock types, found in the area under consideration can be grouped into three major divisions according to their tectonic setting. These will be described under the following headings:

(i) The Kaapvaal Craton

(ii) The Kheis Group

(iii) The Namaqualand Metamorphic Complex

Reasons for the adoption of this major grouping will become obvious during the course of the lithological description and also later, when the structural framework of the area has been described in section 2.2.

2.1.2. The Kaapvaal Craton

2.1.2.1. General

The Kaapvaal Craton, as first defined by Pretorius (1964) represents a fundamental segment of the earth crust. It comprises granitoids and metamorphites generally older than 2,5 Ga as well as supracrustal cover-rocks ranging in age between c. 2,3 and 1,8 Ga. The craton is bounded by major tectonic lines (Fig. 1).

In the area under consideration both facets of the craton are present; the older facet comprises the Swartkop sequence, the Draghoender Granite and the Skalkseput Granite. The younger facet is represented by the supracrustal cover of the Seekoebaard Formation, the Transvaal Supergroup, and the Matsap Formation, and by various igneous rocks intrusive into these three sequences.

Boundaries of the craton are distinct in the north-west (the Eselberge fault) and partly also in the south-west (the Brulpan fault). Part of the south-western boundary is an old intrusive contact between the Draghoender Granite and the Marydale Formation of the Kheis Group.

2.1.2.2. The Swartkop Sequence

This sequence of supracrustal rocks is exposed on Swartkop, a prominent hill rising about 80 m above the surrounding plain on the farm Greeffsput, some 13 km north of Marydale. The main outcrop is approximately 250 m wide and about 2 km long, striking northerly to north-northwesterly. A smaller outcrop of the same sequence is situated some 1 km south-west of Swartkop and xenoliths of similar lithology are found in the surrounding Draghoender Granite on the farms Greeffsput and Swartkopspan, but they are too small to be shown on the map.

Because of its position within the area of the Kaapvaal Craton the Swartkop sequence is described here. The reason why on the geological map (Annex. 1) this unit is correlated with the Kheis Group will be given in section 3.1.3.

Most frequent in the sequence are strongly foliated schistose rocks consisting of quartz, sericite, chlorite, actinolite, epidote, tremolite, magnetite, sphene and calcite. They carry very little plagioclase and sometimes display a relict amygdaloidal structure. The amygdales, filled with quartz, epidote and chlorite are flattened and sheared parallel to the foliation. On the western slope of Swartkop the schist is interbedded with a few thin marble layers (up to a few metres thick), and with occasional arkosic quartzite. Three intercalations of magnetite quartzite, one at the top of the hill and the other two on the eastern slope probably belong to one layer repeated by folding.

The magnetite quartzite from the layer at the top of the hill (V 2023[1]) is a dark grey rock in which light grey siliceous bands alternate with brown and red weathered ferruginous bands. The thickness of the bands in hand specimen varies between 1 and 5 mm. The banding is compositional, each of the "bands" being formed by alternating ferruginous and siliceous layers; the former are usually less than 0,7 mm thick and the latter less than 0,4 mm. Apart from quartz and magnetite (± hematite and limonite) the most typical mineral of the quartzite is a colourless, non-pleochroic amphibole, constituting between 5 and 10 per cent of the rock. Its habitus and optical properties such as the interference colours, elongation and extinction angle ($Z:c<23^{\circ}$) suggest that it is most probably a low-temperature hornblende.

Intrusive rocks younger than the Swartkop sequence are represented by serpentinite, which forms a small body within the sequence at the eastern slope of the Swartkop hill, and by numerous thin "offshoots" of granitoids which sometimes cut also serpentinite. The granitoids mostly resemble the Draghoender Granite but some of them carry blue opalescent quartz and thus differ from the typical Draghoender Granite.

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[1] Hand specimen; localities of all the samples which were collected and investigated during the present study are plotted on 1 : 50 000 topographic sheets. These, together with the field note-books, are kept at the PRU, Dept. of Geology, Univ. Cape Town.

It should be noted that the sequence is located in a zone of intense faulting and that at least some of the lithological boundaries were affected by tectonic movement and shearing; the faults and associated minor shear zones belong to the Vaalbult fault (section 2.2.5.) and strike north-northwesterly.

2.1.2.3. The Draghoender Granite

2.1.2.3.1. Introduction

Intrusive rocks in the area between the main outcrop of the Kheis Group in the west, the Seekoebaard Formation in the north and the Skalksput Granite in the east comprise a variety of rock types, most of which are of a granite composition and carry only a little muscovite. Three distinct groups of granitoids can be recognised:

(i) muscovite-biotite and biotite granite of "normal type";

(ii) biotite-muscovite granite and adamellite of the "leucocratic type";

(iii) intrusive rocks characterised by the presence of megacrysts of blue opalescent quartz.

Mafic rocks, xenoliths and outliers occurring within the Draghoender Granite will also be described here. The description of numerous diabase dykes and of dolerite is given in section 2.1.2.8.

Contacts of the Draghoender Granite with the other units are either tectonic or intrusive. Tectonic contacts include parts of the Brulpan fault (section 2.2.5.) and most of the boundaries between the Draghoender Granite and the Seekoebaard Formation; intrusive are parts of the contact separating the Draghoender Granite and the Skalksput Granite. Intrusions of the granitoids of the Draghoender type are also found in the Swartkop sequence and in the Kheis Group north-west as well as south and south-east of Marydale (the Marydale Granite). Granitic veins carrying the blue megacrysts of quartz cut also the Seekoebaard and Campbell Rand Formations on the farms Blouputs and Khaboom.

2.1.2.3.2. Muscovite-biotite and biotite granite of "normal type"

The most common type within the group of the Draghoender Granite is a white-grey biotite granite, usually medium-grained and, when studied in a hand specimen or in thin section, without a distinct dimensional preferred orientation of minerals (V 2583). On a mesoscopic scale (m - 10 m) the granite is less homogeneous and displays a mineral banding (cm - m zones rich in felsic and mafic minerals respectively). A gneissose structure occurs less frequently (e.g. on farm Swartkopspan, some 2,5 - 3 km west-northwest of the farmhouse).

Frequent are examples of a cataclastic deformation of the granite (e.g. specimen V 2031 from the Greeffsput-Swartkopspan boundary) and of the alteration of cataclasites in the zones striking north-westerly and west-northwesterly (e.g. pink and red granite from the locality some 1,7 km north-west of the Draghoender railway station).

The common biotite granite also carries a small amount of muscovite (Table 1) and with the increase in the muscovite and plagioclase content it passes into a white-grey or almost white biotite-muscovite granite and adamellite of the leucocratic facies.

The intrusions of the Draghoender Granite into the Kheis Group can be studied at three sections in the vicinity of Marydale. Two of these sections are some 0,5 - 1 km and 4 km south-east of Marydale, the third is situated some 2,5 km north-west of the village. The section described by Rogers and Du Toit (1908, p. 34) as being situated some 3,2 km south-east of Marydale is not well exposed at present.

In each of the three sections two principal parts can be recognised:

i) the north-eastern part, where the Draghoender Granite predominates and carries only small xenoliths of quartzite, amphibolite and hornblende schist, the size of which varies from several to a few tens of metres. One of the bigger xenoliths of this type was described by Rogers and Du Toit (op.cit., p. 45) and occurs in the Marydale River between the Draghoender and Marydale.

ii) the south-western part, where the Marydale amphibolite shows signs of contact metamorphism in the vicinity of the granite up to 20 - 25 m away from the contact line. In the same zone granite veins of cm thickness and lens-shaped bodies up to 1 - 2 m wide follow the foliation planes of the Kheis metamorphites. The granitoids are often greenish-grey, chlorite-bearing, sometimes with thin quartz-epidote veinlets. The same minor quartz and quartz-epidote veinlets occur in the Marydale amphibolite indicating that later shearing affected the contact zone.

On Swartkop some 13 - 15,5 km north of Marydale the schistose rocks of the Swartkop Sequence are penetrated by numerous granitic veins along the foliation planes. Numerous granite veins also cut the serpentinite body on the eastern side of the hill. The contact with the major body of Draghoender Granite is, however, concealed under the scree and rubble of the magnetite quartzite. Granite veins on Swartkop are of variable nature and, apart from the muscovite-biotite and biotite type, leucocratic granitoids are also present. Occasionally megacrysts of blue opalescent quartz have been found in the granitoids intruding the serpentinite.

Specimen no.	2691	4388	2797	2850	2031	2507	2538	2583	2542	4425	2237	2437	4424	481
Locality	Marydale Commonage		Brulpan		Greeffsput	Swartkopspan	Draghoender			Witvlei	Springputs	Witvlei	Kameelboom	Bo-Seekoebaard
Rock unit	Marydale Granite				Draghoender Granite						Skalkseput Granite			Hardeberg Granodiorite
Rock type	Muscovite - biotite adamellite	Muscovite - biotite granite	Hornblende-biotite granodiorite	Biotite - hornblende granite	Muscovite-biotite granite				Biotite - muscovite adamellite	Muscovite - biotite granite	Biotite-muscovite granite		Muscovite granite	Biotite Granodiorite
Quartz	28,3	49,2	35,2	44,9	31,8	39,5	39,2	30,1	46,2	46,1	31,6	39,6	47,6	31,0
Plagioclase	28,3	13,3	23,1	9,7	21,6	15,1	3,8	22,2	23,3	9,1	21,6	24,3	15,9	33,0
K-feldspar	28,2	21,6	5,0	20,6	38,6	35,6	52,0	35,6	22,2	26,8	43,0	30,9	29,6	5,9
Amphibole	-	-	8,4	11,4	-	-	-	-	-	-	-	-	-	-
Biotite	8,1	7,5	28,0	8,1	3,7	6,0	4,7	7,3	0,8	6,8	0,6	1,1	-	1,4
Chlorite	+	2,5	-	+	0,2	+	-	+	+	2,4	+	0.3	2,0	12,2
Muscovite	2,8	2,0	-	-	2,3	1,2	0,3	1,1	6,3	4,5	2,2	3,6	4,3	0,5
Sericite	+	+	+	+	+	+	+	+	+	+	+	+	+	2,9
Epidote	3,0	3,0	-	3,6	0,6	1,5	-	3,3	+	2,8	0,6	-	-	4,9
Calcite	1,3	0,7	-	-	-	-	-	-	1,2	+	-	-	-	0,9
Sphene	+	0,2	+	1,6	0,3	+	+	-	-	1,3	-	-	0,5	0,6
Leucoxene	+	+	+	+	+	+	+	-	-	+	-	-	+	0,1
Zircone	-	-	-	-	0,4	0,1	+	+	-	+	+	+	-	-
Apatite	+	+	+	+	0,2	0,3	+	+	-	+	+	+	+	-
Magnetite	-	+	+	-	+	+	-	-	-	+	+	-	+	5,0
Ilmenite	-	+	+	-	+	+	-	-	-	+	+	-	+	0,4
Limonite	-	+	+	-	0,1	+	+	-	+	+	+	-	+	1,2
Total	100,0	100,0	99,7	99,9	99,8	99,3	100,0	99,6	100,0	99,8	99,6	99,8	99,9	100,0
Points counted	1929	1493	1570	2039	2011	1468	2150	2445	1627	1558	1908	1736	1702	1777
Length measured (mm)	643,0	497,6	523,3	679,6	670,3	489,3	716,6	815,0	542,3	519,3	636,0	578,6	567,3	592,3

Table 1. Modal analyses of the Marydale, Draghoender and Skalkseput Granites and of the Hardeberg Granodiorite

Explanation: + = traces.

It is notable that zircon from a specimen described as granitised volcanic breccia yielded a radiometric age of 2,9 Ga. (Kent 1971, p. 12).

Granitoids occurring in the gneisses of the Kheis Group (farms Brulpan, Brulpoort and Marydale Commonage), comprise granitic and granodioritic types (Marydale Granite in Table 1.) which differ only slightly from the typical Draghoender Granite; they are usually characterised by a higher plagioclase content and by the presence of hornblende in some specimens

2.1.2.3.3. Biotite-muscovite granite and adamellite

The granite and adamellite of the leucocratic facies is coarser-grained than the common type described above and sometimes resembles the Skalkseput Granite. On the map it is shown only in the western part of the Draghoender outcrop, but smaller leucocratic bodies of mesoscopic size (m - 10 m) are present elsewhere. They occur in the Marydale River near the Draghoender B farmhouse, in the road cuttings along the Upington-Prieska road, some 2,5 km north-east of the Stuurmansput farmhouse, and at some exposures on the farm Greefsput and Swartkopspan, some 8 - 15 km north-northeast of Marydale.

The leucocratic facies is often unevenly-grained and displays an indistinct mesoscopic banding (V 2542) as well as signs of cataclastic deformation.

The main mineral constituents of the leucocratic facies are the same as in the common type of the Draghoender Granite but muscovite is much more abundant here than biotite (cf. V 2542 in Table 1).

2.1.2.3.4. Roosterpoort porphyry and other younger intrusive rocks

The only member of this kindred which is shown on the map occurs on the farm Roosterpoort, some 4,1 km west-southwest of Swartkop; it is a light grey and grey rock with megacrysts of blue opalescent quartz (less than 4 mm in size) and with pink and pinkish white-grey phenocrysts of feldspar (less than 7 mm in size) scattered in a fine-grained groundmass. The porphyry, which displays an indistinct foliation (310/52 NW[1]), carries biotite-rich mafic nodules (xenoliths?) which are usually only a few centimetres long (the maximum recorded size of the nodules was 20 cm).

The modal composition shown in Table 2 indicates that the Roosterpoort intrusive can be classified either as an adamellite porphyry when feldspars of both phenocrysts and groundmass are considered, or as a granite porphyry when only the feldspar content

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[1] where not specified, the two figures indicate azimuth of dip (from the north, clockwise) and the amount of dip respectively.

Phenocrysts		35,6 %
Quartz		9,2 %
Plagioclase An$_{<30}$		15,4 %
Microcline		11,0 %
Groundmass		64,4 %
Quartz		39,0 %
Feldspar		8,3 %
Microcline	4,5 %	
Plagioclase An$_{<25}$	1,5 %	
Unidentified	2,3 %	
Diopside		1,0 %
Biotite		10,7 %
Chlorite		0,5 %
Sericite		2,4 %
Calcite		1,3 %
Sphene		0,5 %
Leucoxene		0,2 %
Opaque minerals		0,5 %
Total		100,0 %
Points counted		1626
Length of line measured (mm)		542

Table 2. Modal composition of the Roosterpoort porphyry (V 3001).

in the groundmass is taken into consideration.

The porphyry is considerably less affected by the cataclastic deformation than the other types described in the group of the Draghoender Granite. Most of the feldspar phenocrysts are unaffected and only quartz megacrysts show strain shadows and granulation. Minute fractures in the groundmass are filled with calcite.

In the northern part of the farm Blouputs (near the Khaboom boundary) a light grey muscovite-biotite granodiorite intrudes both the metavolcanics of the Seekoebaard Formation and limestone of the Campbell Rand Formation; this intrusion is too small to be shown on the map. The granodiorite is fine- to medium-grained, cataclastic (strained quartz and mica) and carries variable amounts of carbonate either in aggregates scattered throughout the rock or in minor fracture-fillings. Among the other minerals colourless garnet and some tourmaline are mentioned in the description given by Rogers and Du Toit (1908, p.40); they have not been found during the present investigation.

Other rock-types which belong to the same kindred include pinkish white-grey pegmatite, aplite, and vein quartz of blueish-grey colour. They form veins only a few cm thick which cut both the common type of the Draghoender Granite and the leucocratic facies. They can be seen at various places within the Draghoender Granite and particularly in cuttings along the Upington-Prieska road south-east of Marydale. It is notable that in some of these road cuttings all three major types of the Draghoender Granite group are present (e.g. some 2,5 km north-east of the Stuurmansput farmhouse).

2.1.2.3.5. Xenoliths and outliers

Under this heading supracrustal rocks are described which occur within the Draghoender Granite. They are of various size (from a few cm to a few tens of m) and seem to be confined mainly to the western part of the Draghoender outcrop (only the bigger of xenoliths and outliers are dealt with).

The two biggest remnants shown on the map on the farm Roosterpoort, some 0,7 km east-northeast of the Brulpan fault, consist of amphibolite in which intercalations of quartz porphyry occur. The amphibolite is either fine-grained homogeneous, ill-foliated, or medium-grained and banded, with alternating layers characterised by variable content and grain-size of feldspars. The porphyry is a pink felsitic rock (V 2985), generally fine-grained and carrying mega-crysts of blue opalescent quartz (less than 8 mm) and phenocrysts of feldspars (less than 6 mm). The quartz megacrysts are often formed by several quartz grains and some of the megacrysts have a fine-grained rim 0,1 - 0,2 mm thick, composed of quartz grains smaller than 0,1 mm. Almost all the megacrysts are strained and a few are granulated. Phenocrysts of feldspar are usually 1 - 2 mm long and have almost euhedral cores of oligoclase mantled with a thin microcline rim (less than 0,1 mm). Some of the phenocrysts are albitised and few consist of microcline only.

In a fine-grained groundmass quartz (less than 0,04 mm) is the main constituent, being accompanied by feldspars (both plagioclase and K-feldspar), green biotite (partly altered) and by very small grains of colourless clinopyroxene (less than 0,08 mm). Sphene and leucoxene are the most frequent accessories.

Xenoliths of hornblende schist and quartzite have been described from the Marydale River between Draghoender and Marydale, and they were correlated with the Marydale and Kaaien Formation respectively (Rogers and Du Toit, 1908). They are only up to 100 m long and less than 10 m wide. Similar xenoliths of hornblende schist and amphibolite are exposed in the road cuttings along the Upington-Prieska road south-east of Marydale.

A second area of frequent occurences of xenoliths is on the farm Greeffsput between the Swartkop Formation and the western boundary of the Skalkseput Granite. In this area the rock-types constituting the xenoliths can be either correlated with the Swartkop sequence directly (e.g. magnetite quartzite and chlorite-actinolite schist) or they have slightly different lithologies from the rock-types on Swartkop. The former are restricted to the southern continuation of the Swartkop exposures whereas the latter (amphibolite and greenschist) seem to be confined to the western side of the hornblendite body shown on the map (Annex. 1). Amphibolite which is similar to the hornblende-rich rocks of the latter group forms a 10 m layer in granite on the south-western boundary of Greeffsput, some 2,6 km south-east of Swartkop.

An outlier of volcanics and quartzite resembling the Seekoebaard and Black Reef Formations respectively is preserved on the Greeffsput - Poupan boundary some 5,5 km north-west of the Greeffsput farmhouse. On the north-western side of this 20 m wide outlier the granite is mylonitised in a zone more than 1 m thick and the south-eastern boundary is formed by some 2 m of white schistose quartzite.

2.1.2.3.6. Dynamically metamorphosed granitoids

In a number of places the granite has been sheared and silicified. The zones of shearing strike north-westerly and west-northwesterly and are mostly confined to the Draghoender outcrop south of the 29°20' parallel. Minor zones of shearing are also developed locally along the boundary with the Skalkseput Granite and the Seekoebaard Formation.

The most typical of the first type is a belt of sheared Draghoender Granite some 8 km long and 200 - 400 m wide, which is shown on the map (Annex. 1) between the south-eastern Irene boundary and Marydale. The granite in this zone is frequently banded, banding being caused by a small-scale alternation of the leucocratic facies with more mafic types. Shearing is not of the same intensity throughout the zone and fades out in both north-westerly and south-easterly directions. Numerous silicified zones and quartz veins less than 5 m wide are oriented parallel to the general trend of the zone (120 - 140°). Pegmatitic veins up to 1 - 2 m thick, minor amphibolite layers (altered intrusive dykes) and albitised and epidotised granitoids are also associated with the shear zone.

Shearing confined to the contact between the Draghoender and Skalkseput Granites is of much smaller extent, and sheared and silicified granitoids in a zone up to 10 - 20 m wide along the contact have been encountered on the farms Greeffsput and Swartkopspan only. Parts of the contact on Greeffsput are followed by a thin diabase dyke.

In the zone of the Vaalbult fault sheared granitoids are represented by a medium- to coarse-grained muscovite-biotite granodiorite which is often unevenly grained and carries streaky aggregates of strained quartz from a few mm to 2 cm long.

Shearing and recrystallisation of the granodiorite is often accompanied and followed by the emplacement of quartz veins, some of which carry small amounts of copper sulphides (e.g. some 5 km south-southeast of the farm Vaalbult).

Some 4 km south-southeast of the Vaalbult farmhouse, light grey cataclastic muscovite-biotite granodiorite overlies sheared members of the Seekoebaard sequence. The contact between the granite and sheared amygdaloidal lava is a flat-lying tectonic surface (a thrust fault), well exposed at the top of the hill. The granodiorite is intensely fractured, the fractures being closely spaced (2 - 20 mm) and filled with crushed quartz, heavily impregnated with limonite. The granodiorite between the fractures is cataclastic, but its original texture is still preserved.

2.1.2.3.7. Mafic rocks

Dark grey hornblendite, most frequently homogeneous and coarse-grained, occurs on the farm Greeffsput, where it forms a sheet or a dyke some 6 km long and up to 0,4 km wide. It is segmented by several faults of north-northwesterly strike and, at some places, bounded by 10 - 15 m of greenschist. The sheet extends from the farm Poupan, to the farm Swartkopspan. A specimen from the centre of the dyke (V 2013) is almost exclusively composed of pale green hornblende, which is occasionally chloritised and carries inclusions of magnetite and ilmenite. These two opaque minerals also occur frequently between the hornblende crystals. Relicts of early pyroxene are present.

A much smaller body of altered mafic rock is shown on the map some 3 km north-east of Marydale. The rock is greenish-grey to greenish dark grey in colour and either medium-grained (composed of coarse-grained aggregate of actinolite and chlorite) or fine-grained (V 2760; composed of chlorite and accessoric magnetite only). The optical properties of chlorite indicate that it is a magnesium-rich type (clinochlore). At the exposure the rock is cut by minor pegmatite veins and some of the numerous fractures strike west-northwesterly.

2.1.2.4. The Skalkseput Granite

2.1.2.4.1. Introduction

The Skalkseput Granite is exposed in the area bounded by the Draghoender Granite in the west, by the Seekoebaard Formation in the north and north-east, and by the Doringberg fault in the east. Its outcrops occur in the extreme north (farm Rooilaagte) and then they widen towards the south and south-east (farms Potdans, Poupan, eastern and north-eastern part of Greeffsput, Soutputs, Skalkseput, Kameelboom, Springputs, Uitvlug, Geelbeksdam and Witvlei). The rock group comprises light grey granitoids which almost always contain muscovite and are usually medium- to coarse-grained. Although it is lithologically more uniform than the Draghoender Granite, certain variability in mineral composition, grain-size and structure has been noticed. The most typical are muscovite and/or biotit-muscovite granites, which are frequently cataclastic.

The boundary between the Skalkseput and Draghoender Granite is often sheared in the north. South of the 29°25' parallel the contact is not affected by shearing and xenoliths of biotite granitoids resembling the Draghoender Granite occur in the Skalkseput

Granite. Two such inclusions are exposed in the road cuttings along the Upington-Prieska road, some 3,3 and 5 km south-east of the Uitvlug farmhouse respectively.

2.1.2.4.2. Biotite-muscovite granite and adamellite

Light grey biotite-muscovite granite occurs in the south-eastern part of the area. A specimen collected some 1,1 km south-west of the Springputs farmhouse is medium- to coarse-grained, and generally homogeneous (but with distinct grain-size variations on a small scale). It is composed of quartz, microcline, oligoclase/andesine, muscovite, biotite, chlorite, epidote and common accessories (V 2237). The granite is not foliated but it is partly affected by a protoclastic deformation.

In the northern part of the farm Witvlei the granite is unevenly grained, composed of large crystals of microcline-perthite, smaller oligoclase crystals, and quartz grains of variable size. All the main constituents are affected by a protoclastic deformation (V 2437) and biotite is partly or completely chloritised. At the exposure the granite is traversed by veins of smoky quartz several cm wide, and by veins of white barren quartz less than 2 m wide. Both types of quartz veins strike north-westerly or west-northwesterly.

In prospecting pits some 2,5 km north-east of the Skalkseput farmhouse the granite is cataclastic and, apart from muscovite, it also contains chlorite (most probably chloritised primary biotite). The locality was described in detail by Rogers and Du Toit (1908), who discussed the nature of the boundary between the granite and the volcanics of the Seekoebaard Formation exposed in the pits and who came to the conclusion that "the junctions are evidently fault planes, and the repetition of granite and lava bands due to faulting (op. cit., p. 73). This finding is supported by the present investigation.

Light grey adamellite is also exposed immediately south-west of the Seekoebaard lavas on the Skalkseput-Poupan boundary. The grain-size of this rock-type is variable, mineral composition simple.

Some 3,5 km north-west of the Poupan farmhouse light grey granite is sheared and carries thin irregular streaky aggregates of quartz, chlorite, sericite, and limonite (V 2053). Farther north, in the western part of Potdans, the granite carries small amounts of chloritised biotite.

The white leucocratic facies of the Skalkseput Granite (farm Soutputs) is characterised by somewhat coarser grain, by a high quartz content, and by the presence of pegmatite veins. Its boundaries with the "normal" Skalkseput Granite are transitional.

A pegmatite vein striking north-easterly is exposed in the northern part of Soutputs and the north-western part of Skalkseput. It is an unzoned homogeneous type composed mainly of salic minerals. Numerous quartz veins which strike north-easterly occur mostly in the south-eastern part of the area. Some of these veins also carry feldspar and/or muscovite. Only the six biggest of the quartz veins are shown on the map (in the western and north-western part of Springputs) and should be distinguished from the other quartz veins which are associated with the shear zones.

2.1.2.4.3. Kameelboom diorite

A dyke of dioritic rock is exposed some 0,9 - 1,4 km south-southeast of the Kameelboom farmhouse within the outcrop of the Skalkseput Granite. The diorite is greenish-grey, medium-grained and homogeneous. Feldspars in the diorite are stained (red or pink) and epidote fills some of the fractures seen at the outcrop. The diorite is composed of altered plagioclase and green hornblende. Apart from secondary products of alteration of these two minerals the rock carries relicts of early formed clinopyroxene (in central parts of some of the hornblende crystals), a small amount of biotite, and accessoric quartz. The texture of the diorite resembles the ophitic texture of diabase.

Similar hornblende diorite also occurs near the railway line some 7,2 km west-northwest of the Springputs farmhouse, where it forms a small dike which could not be shown on the map. This diorite is greenish-grey or even dark green, medium-grained, homogeneous, with altered feldspar (characteristic pink colour). Numerous minor irregular fractures are filled with quartz and chlorite. Thicker quartz veins (cm - dm thickness) strike northwesterly. The texture of the rock is cataclastic.

2.1.2.4.4. Xenoliths and outliers within the Skalkseput Granite

Apart from several small outliers of the Seekoebaard Formation in the north (farms Poupan and Potdans) minor occurences of various supracrustal rocks and of granitoids different from the Skalkseput Granite are usually confined to the area south of the 29°25' parallel.

Of the supracrustal rocks the most interesting is a light grey quartz-sericite schist with the intercalations of sericite quartzite, which resembles similar rocks of the Groblershoop Formation (Kheis Group). It is exposed some 2,5 km south-east of the Springputs farmhouse in a zone only a few metres wide and up to 50 m long. Similar rock-types, also resembling the metasediments of the Groblershoop Formation of the Kheis Group were found in much smaller occurrences some 8 and 9 km south-east of the Springputs farmhouse.

Different rock-types are exposed on the Springputs-Uitvlug boundary, some 2,5 km north-west of the Uitvlug railway station. One of the two main types is a greenish-grey andesite, the other is a biotite schist with lens-shaped aggregates of quartz, 1 - 10 cm long. The outcrop is some 20 - 30 m wide and several hundreds of metres long. The andesite displays only little signs of dimensional preferred orientation of the minerals (mainly in the groundmass), and carries euhedral phenocrysts of andesine less than 1 mm long. Only a few of the feldspar phenocrysts are slightly bigger (1 - 3 mm). Also present are aggregates of quartz (0,5 - 2 mm) and occasional phenocrysts of K-feldspar. The groundmass is fine- to very fine-grained, composed of feldspars, quartz and chloritised biotite, and of elongate aggregates of quartz, calcite and chlorite. The biotite schist (V 2241) is well foliated and fine-grained, grey and dark grey in hand specimen. It should be noticed that the boundaries between these supracrustal rocks and the granite are tectonic, and that the microscopic study has not revealed any evidence of the contact metamorphism of the sequence caused by the Skalkseput Granite.

Minor layers of well foliated amphibolite are present some 3 km north-west of the Uitvlug railway station. They are only a few metres wide and up to 30 m long, formed by a fine-grained hornblende-rich rock. These amphibolite layers are associated with a zone of shearing which strikes north-westerly.

Exogenous inclusions of granitoids mostly confined to the area along the south-western boundary of the Skalkseput Granite are best exposed in the road cuttings some 3,3 and 5 km southeast of the Uitvlug farmhouse; grey and light grey muscovite-biotite and biotite granite (and adamellite), which is medium-grained and partly gneissose, is intruded here by a white-grey biotite-muscovite and muscovite Skalkseput Granite. The Skalkseput Granite at both localities is medium- to coarse-grained, shows only a small grain-size variability and represents a dominant rock-type. The gneissose granitoids are relatively rich in biotite and sometimes carry Ca,Mg clinopyroxene (V 2445).

2.1.2.4.5. Dynamically metamorphosed granitoids

Shear zones are more frequent in the Skalkseput Granite than in the Draghoender Granite, and they are of three different types:

(i) Minor shear zones striking north-easterly and east-north-easterly; they are marked by quartz (± feldspar and muscovite) veins. These shear zones are found on the farms Springputs, Kameelboom and Soutputs only;

(ii) Silicified shear zones and quartz veins striking mostly north-northeasterly; these are restricted to the northern part of the outcrop;

(iii) Zones of shearing, silicification and partial recrystallisation of granite in the southern part of the Skalkseput Granite (Table 3).

The shear zones of the first type are of smaller extent and less numerous than the zones of the other two types. The deformation of the granite in these minor crush belts is mostly cataclastic. Quartz veins associated with these zones are briefly described on page 18.

Locality	Outcrop No.	Strike	Dip	Length	Width	Number of zones	Remarks
Marydale River	2267	320° 115°	66°NE 63°SW	several metres	1 m	5 - 10	
	2268	330°	70°NE		0,5 m	several	
Springputs	2272	160°	?	1,2 km	10-30m	one	silicification
	2263	105° 110°	83°SW 76°SW	2,2 km 1,4 km	20 m 5 m		
	2236	295°	79°NE	2,1 km	30 m		
	2240	295° 115°	75°NE 69°SW	1,7 km	20-30 m		
Uitvlug	2241	115°	59°SW	3,0 km	50 m		
Springputs	2243	295°	73°NE	2,2 km			silicification
Uitvlug	2456	135°	80°SW	5,2 km			

Table 3. Some characteristics of the shear zones striking north-westerly to west-north-westerly.

The second type of shear zones is characterised by more pronounced brittle deformation of granite and by the frequent occurrence of veins of cavernous quartz. Granite in these zones is sometimes foliated and penetrated by 1 - 5 cm wide veins of quartz and aplite. Biotite, where present, is chloritised (V 1952).

The most intense shearing occurs in the zones of the third type, which strike north-westerly and west-northwesterly (Table 3). Granite in these zones is cataclastic and passes into foliated types in which chlorite and chloritised biotite coat some of the foliation planes (V 2469). With the increase in intensity of deformation the rock-types become unevenly grained, with scattered feldspar porphyroblasts and coarse-grained pegmatitic nests and lenses generally oriented parallel to the shear foliation. Extreme types of sheared granite are represented by fine-grained mylonitic rocks and by intensely silicified rocks often passing into quartz veins.

2.1.2.5. The Seekoebaard Formation

2.1.2.5.1. Introduction

The name of this newly designated lithostratigraphic unit is derived from the name of the farm on the western side of the Orange River, some 8 - 13,5 km south of the Buchuberg Dam, where parts of the most extensive member of the unit are well exposed. The name is also used with regard to the priority of the name firstly introduced by Rogers and Schwarz in 1899 ("the Zeekoe Baard Amygdaloid"). The type locality of the unit includes all parts of its triangular-shaped outcrop shown on the map between the Matsap Formation, Draghoender and Skalkseput Granite, and the Transvaal sequence. Outcrops of the same unit are also found on the eastern side of the Doringberg fault between the farm Geelbeksdam and the southern boundary of the area investigated.

Volcanic members of the sequence were firstly mapped by Rogers and Schwarz (1899); the "Zeekoe Baard Amygdaloid" of these authors was interpreted originally as a post-Transvaal intrusive and Schwarz (1905) even suggested its correlation with the Bushveld Complex. This correlation, however, was discarded when Rogers and Du Toit (1908) were able to prove that the Seekoebaard volcanics underlie the sediments of the Transvaal Supergroup. Consequently the sequence was included in the Ventersdorp "System".

On the geological maps published in the years 1908-1910 by the Geological Commission of the Cape of Good Hope (Sheets Britstown, Griquatown and Marydale) the Ventersdorp "System" is shown in four sub-areas:

(i) In a triangular-shaped area between the Eselberge, the older granitoids and the Doringberg fault;

(ii) In narrow strips along the Doringberg fault between Geelbeksdam in the north-west and Uitspanberg in the south-east;

(iii) In the T'Kuip Hills north-east of the Doringberg fault;

(iv) Between the T'Kuip Hills and Douglas.

Of these four sub-areas the first and parts of the second fall in the area investigated.

The Ventersdorp "System" in sub-area (i) and (ii) was subdivided by Rogers and Du Toit into the Zoetlief and Pniel "Series".

According to the original description (op.cit., 1908, pp. 66-82) the Zoetlief is represented by a basal quartz porphyry, the northernmost occurrence of which was shown on the farm Geelbeksdam. All the remaining parts of the sequence in sub-area (i) were included in the Pniel. Layers of sediments exposed between the Waterval synform of the Black Reef and Campbell Rand Formations and the main Matsap synclinorium of the Eselberge were correlated with the Matsap (op.cit., 1908, pp. 79-82). It was pointed out later that these sediments were not infolded but interbedded in the succession of lava south-east of the Buchuberg Dam and, consequently, the possibility of their correlation with the Matsap was rejected (Truter and De Villiers, 1948, p. 147). More recently, the position of the sediments in the Seekoebaard sequence was discussed by Leube (1964) who subdivided them into two parts:

(i) lower, predominantly clastic, exposed north of the Waterval synform;

(ii) upper, predominantly volcanic, exposed south of the Waterval synform.

On the most recent edition of the Geological Map of the Republic of South Africa (1970, scale 1 : 1 000 000), the sequence is grouped with the Dominion Reef System.

In the course of the present investigation the Seekoebaard sequence has been subdivided into four members (Table 4 and Fig. 2) two of which are well represented in the area shown on the geological map (Annex 1.)

Seekoebaard Formation	Witvlei Conglomerate Member (less than 100 m)	
	Blinkfontein Volcanic Member (600 - 900 m)	Bucklegraf Carbonate Bed (0 - 20 m)
	Waterval Member (400 - 700 m)	Skalkseput Conglomerate Bed (0 - 2 m)
	Geelbeksdam Porphyry Member (less than 50 m)	

Table 4. Stratigraphic classification and nomenclature of the Seekoebaard Formation.

2.1.2.5.2. Lithostratigraphy

2.1.2.5.2.1. Geelbeksdam Porphyry Member

Quartz porphyry layers only occur on the farms Geelbeksdam and Witvlei east of the Doringberg fault. They are of very limited extent and their relationship to the andesitic and dacitic volcanics of the Blinkfontein Volcanic Member is obscured by faulting. They have been placed at the base of the Seekoebaard sequence because Rogers and Du Toit (1908, p. 67) described a locality near Uitspanberg (some 25 km south-east of the Geelbeksdam farmhouse) where an amygdaloidal lava (most probably the correlate of the Blinkfontein Volcanic Member) is developed between the porphyry and the overlying Black Reef Quartzite.

A rock collected some 300 m south-west of the Geelbeksdam - Witvlei - Klein Windpomp beacon is dark grey, fine-grained, evenly grained and homogeneous in hand specimen, but with an indistinct mineral banding (primary layering) visible at the exposure. In thin section (V 2163) the porphyry is intensely altered, chlorite-rich, and its texture differs from the ophitic texture of most of the andesitic lavas of the Blinkfontein Member. The porphyry probably belongs to a granodioritic (rhyodacitic) kindred. In another thin section from the same locality Leube (1964, p. 13) described albite and oligoclase phenocrysts and rounded (corroded?) quartz megacrysts occurring in the microcrystalline groundmass rich in chlorite and also containing sericite and magnetite.

2.1.2.5.2.2. Waterval Member

The best exposures of this predominantly clastic member can be found between the Waterval synform of the Griquatown Group and the main Matsap synclinorium of the Eselberge (northern part of the farm Waterval, parts of the farms Onderseekoebaard, Bo-Seekoebaard and Rooidam, and the area south of the Buchuberg Dam between the Waterval and Onderseekoebaard). A few outcrops not shown on the map occur in the area of the Blinkfontein Member south-west and west of the south-western end of the Eselberge.

The involved structure of the Waterval Member is characterised by repetition of individual layers, by a distinct foliation of some of the rock-types, and by imbricated faulting.

The rock-types of this sub-unit comprise conglomerate, sandstone, feldspathic sandstone (arkose), slate and phyllite, tuffaceous sediments, tuffs, tuffites and a few lava flows.

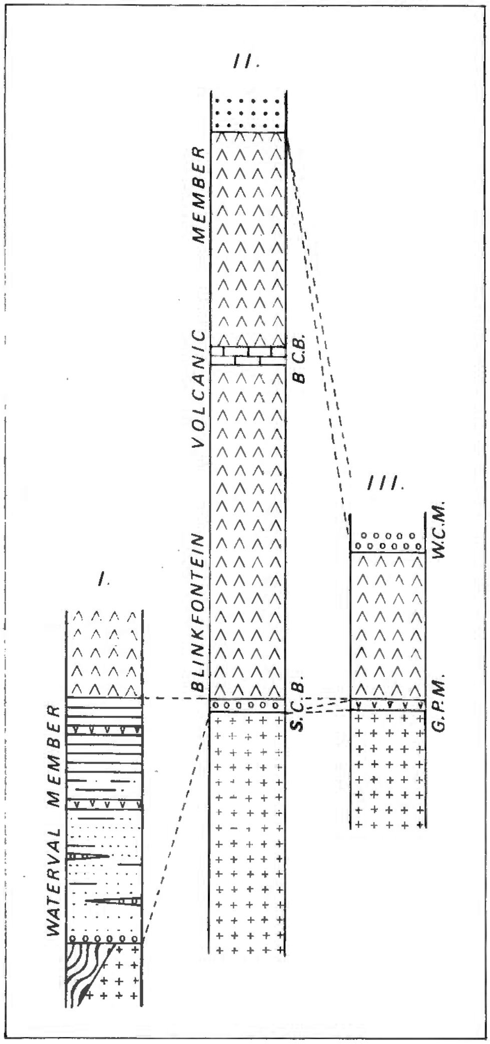

Fig. 2. Stratigraphy of the Seekoebaard Formation. I - north of the Waterval synform; II - south of the Waterval synform; III - east of the Doringberg fault. For explanation see text

Conglomerate

Coarse-grained clastics occur in the Waterval sequence on all farms north of the Waterval synform. They can be grouped into four distinct types, which represent different layers occurring at various parts of the sequence:

(i) coarse-grained type with pebbles and cobbles of dark ferruginous chert ("banded ironstone"); the matrix of this type is fine- to medium-grained, siliceous, and rich in hematite;

(ii) coarse-grained polymictic conglomerate with pebbles and cobbles of red ferruginous chert or jasper, quartz, white quartzite and dark ferruginous quartzite or chert ("banded ironstone"). Both angular and rounded pebbles and cobbles are present. Although the maximum size of the clastic material is 10-15 cm, most of the pebbles are less than 5 cm in diameter;

(iii) coarse-grained polymictic conglomerate with clastic material similar to that of types (i) and (ii), but with a subgraywacke matrix;

(iv) conglomerate with pebbles of amygdaloidal lava.

The order in which the conglomerates are listed corresponds in general to their pc tion in the succession; the first two types are the lowest and occur mostly in the north; the last one, interpreted by Leube (1964) as the stratigraphically highest, occurs in the southern part of the Waterval outcrop. Since the thickness of the conglomerates is not greater than 20-30 m, only some of the layers could be shown on the map (mostly the first two types).

Sandstone

Pure quartzarenite (Pei-Yuan Chen, 1968) is rare in the sequence and has been reported by Leube from one locality on the farm Onderseekoebaard "between the main road to Upington and the farmhouse close to the farm road" (op. cit., p. 11). It is a white, fine-grained rock.

More frequent is a feldspathic sandstone, which usually forms intercalations in the phyllite or, less frequently, is intercalated with the volcanics. One specimen (V 240) collected some 4 km north-west of the Waterval farmhouse, is a light grey alkalic arkose, which is fine- to medium-grained and flaggy. Almost all its feldspar is microcline. Another specimen (V 263) which comes from the exposures some 2,5 km east of the Waterval farmhouse is a plagioclase arkose; it is again fine- to medium-grained, but schistose, and indistinctly banded (minor variations in mineral composition).

Lithic sandstone is also found frequently, and it often carries variable amounts of volcanic and tuffaceous material; some of the rock-types of this group are true tuffarenites or volcanic arenites. Almost pure lithic sandstone is grey or even purplish grey in colour, fine-grained and homogeneous in hand specimen. Primary structure (bedding) is still preserved (cm - dm) and the clastic texture is only slightly affected by the brittle deformation which tends to divide the rock into distinct rhombic fragments.

The least tectonically affected litharenite is exposed in the prospecting pits some 1,75 km south-southwest of the Seekoebaardsnek farmhouse (V 750 A). This sandstone carries angular and subangular quartz fragments, the biggest of which are 0,6 - 1 mm in diameter and resemble poorly rounded quartz phenocrysts. Other bigger fragments are formed by a very fine-grained pelite (tuffite), by alkalic feldspar and plagioclase aggregates, by small chlorite aggregates and by grains of hematite and magnetite. The very fine-grained matrix of the sandstone is rich in graphitic substance and in streaky aggregates of very fine-grained sericite (± chlorite). When sheared, the sandstone retains its original coarser grains as porphyroclasts and the rest of the rock is converted into a very fine-grained mylonite, in which layers of sericite and chlorite develop parallel to the cleavage or crenulation foliation (e.g. specimen V 230 some 4 km north-west of the Waterval farmhouse).

Some 1,9 km north-east of the Bo-Seekoebaard farmhouse the porphyroclasts still display the variability of the original clastic material and comprise quartz grains, very fine-grained quartz aggregates, cherty clasts of pinkish colour and feldspar-rich fragments of acid and intermediate volcanic rocks. The texture of the rock is characterised by a distinct rhombic pattern of two intersecting conjugate shear fractures (V 948).

Slate and phyllite

The most common type of metapelite in the Waterval Member, which occurs almost as frequently as the arenites described above, is always fine- or very fine-grained with the lithological banding characteristically oblique to the foliation and fracture cleavage (*sensu* Whitten, 1966, p. 260). The foliation planes of the slate are often coated with minute flakes of sericite and chlorite. Most frequently the slate is light grey and does not carry a substantial amount of the tuffaceous material. Some of the primary lithological layers, however, are semipelitic and consist of abundant chlorite, less abundant sericite, accessory hematite and limonite grains, and also very small fragments of a very fine-grained pelite or tuffite (V 878).

The parallel structure of the semipelite becomes very distinct at places in the vicinity of the synforms of the overlying Transvaal sequence; as a result of this the lithological banding becomes almost obliterated and the rocks display the typical lepidoblastic or lepidogranoblastic texture of phyllite. Corresponding members of the Waterval sequence on the farms Khaboom and Kareelaagte are coarser-grained and can be classified as schists.

Tuffarenite

This is one of the most characteristic rock-types in the Waterval sequence, which occurs not only on both sides of the Orange River south of the Buchuberg Dam, but also west of the south-western end of the Eselberge. It is always greenish light grey or greenish-grey in colour, rather fine-grained and often finely banded. The grain size of the tuffarenite is more or less uniform, with the maximum diameter of the biggest clastic grains (quartz) usually not exceeding 0,5 mm. The quartz grains are subangular to subrounded and other fragments are angular to subangular. The minerals of the volcanic provenance are represented by abundant epidote, frequent chlorite and actinolite (V 3142 some 9 km south-east of the Ezelklaauw farmhouse). Some of the specimens also carry carbonate (calcite) - e.g. V 254 2,5 km north of the Waterval farmhouse. Opaque minerals (magnetite, ilmenite and hematite) are also relatively abundant.

Tuff, tuffite, epidotite

In various parts of the Waterval sequence the sediments become so rich in pyroclastic material that the rocks cannot be grouped with the tuffarenite any more and have to be described separately as tuff or tuffite. The texture of these rocks is also different from that of the arenites and tuffarenites (it is usually unevenly grained).

Pure pyroclastic rocks occur at various places of the Waterval outcrop and form layers of various thickness. These are not shown on the map mainly because of their small extent. The mineral composition of the tuffs is variable; clastic minerals are represented mainly by quartz and possibly by some of the feldspar grains; pyroclastic components include both lava fragments and individual minerals such as chlorite, actinolite, epidote, green hornblende, zoisite, leucoxene, feldspar and common opaque minerals (ilmenite and magnetite). Some very fine-grained parts of the tuffite layers are rich in graphitic substance. Quartz fragments sometimes resemble recrystallised vitric shards (e.g. V 804 A 1,5 km south of the Onderseekoebaard farmhouse). Many of the tuff specimens also contain a variable amount of calcite. Fine- and very fine-grained tuffitic rocks in the Waterval Member are characterised by a laminar or lenticular texture, and by the presence of fragments and aggregates of pyroclastic origin (V 224 from the slopes of the Eselberge some 4,5 km south-southwest of the Buchuberg Dam) which are sometimes up to 0,5 mm long and very thin. The matrix of the tuffitic rocks carries coarser quartz grains which, by their shape, resemble recrystallised vitric shards. Individual laminae or lenses in the matrix carry variable amounts of the opaque minerals, graphitic substance and chlorite.

The tuffitic rocks are often more intensely affected by the deformation than the other rock-types (e.g. phyllonite V 317 some 1,35 km north-east of the Waterval farmhouse) and some of the tuffitic layers are impregnated or completely replaced by hematite (V 353 some 5 km south-east of the Maraisdraai farmhouse).

A special type of tuffite is represented by epidotite, a fine- to very fine-grained rock of clastic texture, which occurs frequently in various parts of the volcaniclastic sequence of the Waterval Member. It is composed of minor fragments and clasts of various types of very fine-grained tuffitic rocks and semipelitic sediments, and also of epidote-rich clasts. The latter often constitute more than 50% of the rock (V 251 some 3 km north-northeast of the Waterval farmhouse). The matrix is very fine-grained, semipelitic or pelitic, and contains abundant carbonate.

Welded tuff, tufflava and lava

Welded tuff or ignimbrite is usually a medium- to coarse-grained rock, unevenly grained, composed of fragments of red jasper, fine-grained porphyry (felsite), epidotite and of clasts of unknown provenance, and heavily impregnated with hematite (limonite and/or graphite. Some of the fragments and clasts have epidote-rich outer rims or show other types of zonation, which may be interpreted as a result of "welding". The matrix is also unevenly grained, rich in quartz, epidote and chlorite, and often contains calcite (V 255 2,5 km north-northwest of the Waterval farmhouse). The welded tuffs are always massive in character and their parallel structure is indistinct. The layers of welded tuff in the Waterval Member are less than 10 m thick and seem to be more often associated with the sequence of tuffaceous sediments than with the tufflava layers or lava flows. In fact, the latter are only occasionally present in the area north of the Waterval synform.

Rock-types described here as tufflava are characterised by the presence of true pyroclasts and by the matrix of igneous appearance and origin. The pyroclasts are often very small (less than 5 mm) and have indistinct boundaries. They are more often monomineral clasts (epidote, quartz) rather than rock fragments (felsite, occasional tuffite). The texture of the matrix is diabasic or generally prophyritic, its composition andesitic (V 1006 some 4,4 km east-northeast of the Bo-Seekoebaard farmhouse).

Lava flows in the Waterval Member are represented by thin sheets of dacite and by flows of andesite. The volcanics are generally fine-grained and moderately or intensely altered, but display many primary features such as flow banding and pillow structures (the most typical pillow lava was found some 4 km south-west of the Onderseekoebaard farmhouse). Specimens can sometimes be found, in which a fine-grained homogeneous lava passes over a distance of a few centimetres into amygdaloidal upper part of a flow. More frequently such a transition takes place over a distance of a few tens of centimetres. Amygdales filled with quartz, chlorite, epidote, calcite and occasionally also with specularite are not more than 5 - 7 mm in diameter, the matrix between the amygdales is often actinolite-rich and altered (V 220 some 5,25 km south-southwest of the Buchuberg Dam).

Skalkseput Conglomerate Bed

A layer of coarse-grained conglomerate occurs below the base of the Blinkfontein Volcanic Member on the farm Skalkseput and on the boundary between the farms Vaalbult and Poupan. It differs from all the other Seekoebaard conglomerates in its lithology and in the constant stratigraphic position at the boundary between the Skalkseput or Draghoender Granite and the Blinkfontein sequence.

The best exposures of the conglomerate can be studied on the farm Skalkseput some 2,5 km north-east of the farmhouse and the same conglomerate is also partly exposed in the Marydale River some 3 km north-east of the Skalkseput homestead. The thickness of the conglomerate at all these localities varies between a few centimetres and approximately 2 m.

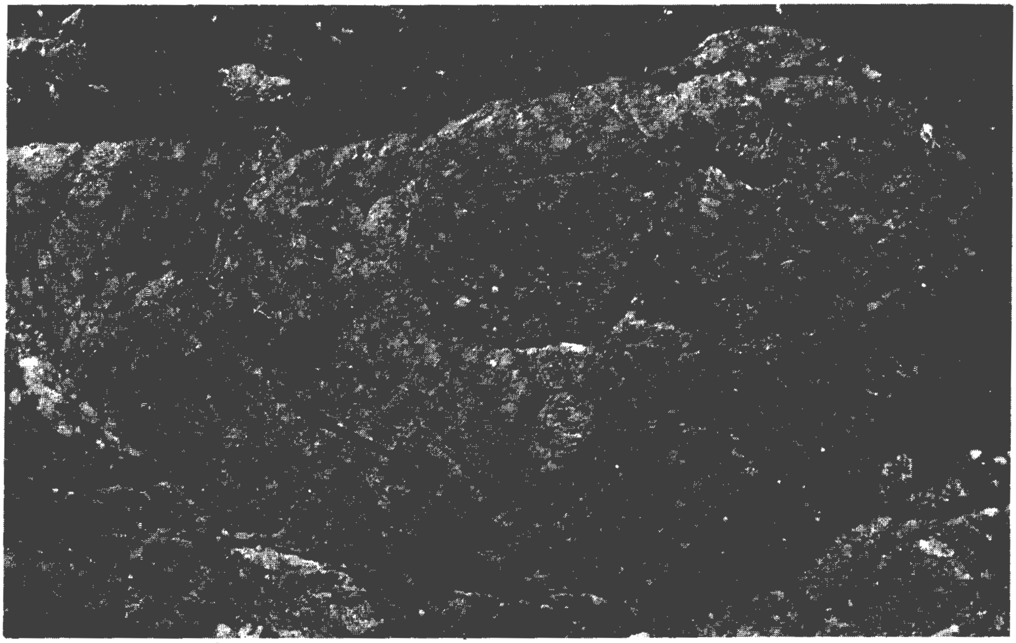

Plate 1. Skalkseput Conglomerate Bed. Marydale River, farm Kameelboom

Pebbles and cobbles in the conglomerate consist of quartz, biotite-muscovite granite and of leucocratic muscovite granite and matrix of the conglomerate is a subquartoze (subarkosic)sandstone. The maximum measured size of granite cobbles is 15 cm, quartz pebbles are usually smaller (less than 6 cm). The sphericity of smaller pebbles is high to moderate, whereas bigger pebbles and cobbles are characterised by moderate sphericity (0,4 - 0,7). Smaller pebbles are often rounded to sub-rounded, bigger pebbles and cobbles are rounded to well rounded. The percentage of the arenaceous matrix is variable, the distribution of the coarser clastic material uneven. (Plate 1)

The surface on which the conglomerate has been deposited was generally smooth and even. The conglomerate layer is followed paraconformably by the first flow of Blinkfontein lava.

2.1.2.5.2.3. Blinkfontein Volcanic Member

The best exposures of this sequence occur south of the Waterval synform on the farms Seekoebaard, Vaalbult, Bucklegraf, Rooilaagte, Poupan, Skalkseput and Kameelboom. Parts of the same sequence are present on the farms Blouputs, Kareelaagte and Khaboom, and the outliers of the Blinkfontein Volcanics occur also in the area of the Draghoender and Skalkseput Granite (see pp. 14-15 and 19).

The structure of this sequence is generally simple, characterised by gentle dips of the lava flows and other primary layers. In the vicinity of the Transvaal synforms, however, the Blinkfontein Member is intensely folded and often sheared. Another characteristic feature of the sequence is its cleavage which, at places, is more distinct than the primary layering.

The rock-types occurring in this sub-unit comprise both amygdaloidal and non-amygdaloidal lava, less frequently welded tuff and tuff, and occasionally also minor marble layers.

Volcanics

Dark green, blueish-green and greenish-grey andesite, quartz andesite and dacite predominate among the volcanics. They form numerous lava flows, which are well seen on the air photographs as dark grey and light grey multiple stripes; the width of the individual "stripes" (lava flows) is usually only a few metres. This primary layering caused by changes in the mineral composition of the lava is often recognisable in the field, but its scale is too small to allow more detailed sub-division of the volcanic pile on the map. Another primary feature regularly met with in the field is the alternation of amygdaloidal and non-amygdaloidal layers. Pillow structures and flow surface features can also be seen in the field and a good example occurs in the Marydale River some 3 km north-east of the Skalkseput farmhouse (Plates 2.1. and 2.2). At this particular outcrop some of the concentric layering of the lava can be explained as a surface expression of small spiracles - tubular openings or chimneys of cm - dm dimension, formed by explosive escape of gases from the lava, in which some lava may have been carried upwards to the surface to pile up around the narrow orifice (see example of the same feature given by Green and Short, 1971, Plates 147 A and B).

Plate 2.1. Pillow structure of the Seekoebaard lava. Marydale River, farm Kameelboom

Plate 2.2. Concentric layering in the Seekoebaard lava. Marydale River, farm Kameelboom

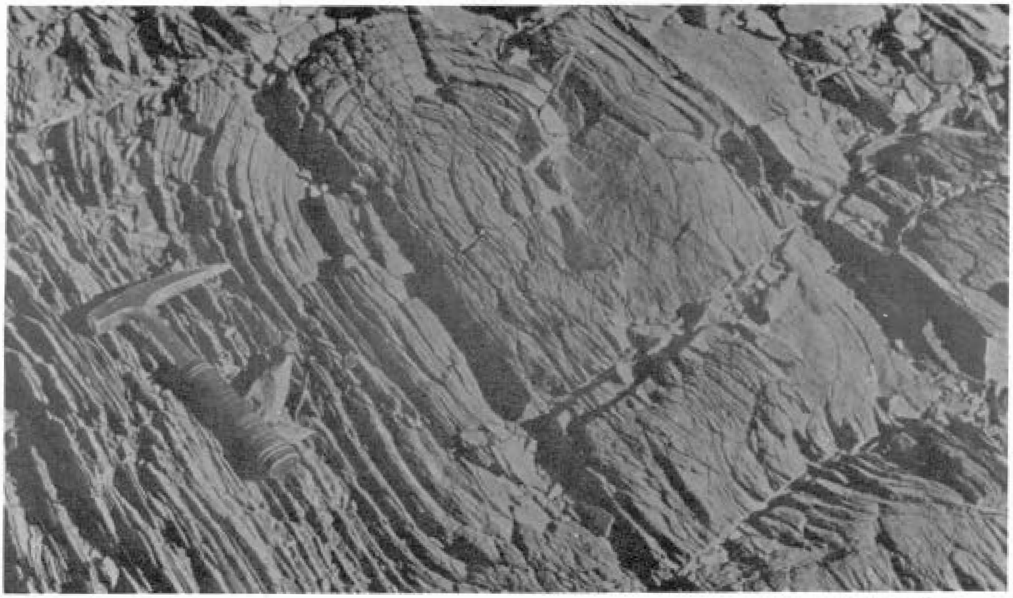

Plate 2.1.

Plate 2.2.

Mineral composition (Table 5) and other petrographic features of the lava indicate that most of the specimens studied have been subjected to alteration of variable intensity.

The layers of amygdaloidal lava intercalated in the non-amygdaloidal succession form impersistent beds which can be followed only over a limited distance (several metres to several tens of metres). The thickness of the layers is also variable (m to several metres). Amygdales in any particular layer are either scattered or closely spaced, their size varies between several mm and 10 - 20 mm, and the shape is more frequently round or oval than elongate or flattened. The amygdales are often filled with quartz or with an aggregate of quartz ± epidote ± chlorite ± calcite. Other material found in the amygdales is red jasper and specularite (V 309, some 3,2 km south-southeast of the Seekoebaard No 1 farmhouse). Some of the amygdales are filled with two types of quartz: milky quartz occurs in the centres and smoky quartz, where present, forms the outer rims (V 1833 some 1,2 km east of the Bucklegraf farmhouse). Other amygdales display zoning caused by concentration of either epidote or other minerals in distinct concentric layers. The matrix of the amygdaloidal types is fine- to very fine-grained, often rich in epidote.

Welded tuff and tuff

Heterofacial intercalations are very seldom found in the Blinkfontein volcanic sequence; they occur in the higher parts of the succession near the Bucklegraf Carbonate Bed and comprise both ignimbrite and pyroclastic rock (tuff). A specimen of ignimbrite (V 1876, 5,1 km east-southeast of the Bucklegraf farmhouse) is greenish dark grey in colour and composed of numerous small fragments and clasts, some of which are amygdaloidal. Matrix of the rock is fine-grained. In thin section the specimen is unevenly grained, consisting of three components: amygdaloidal lava, ignimbrite and tuffaceous material. The structure of the rock is chaotic.

Bucklegraf Carbonate Bed

Light grey and white crystalline carbonate forms an impersistent layer interbedded in the volcanics on the farms Seekoebaard No 1, Bucklegraf and Rooilaagte, and consisting of lens-shaped bodies less than 10 - 15 m thick. At some places the individual lenses are only a few metres long (e.g. the locality some 3,5 km south-east of the Seekoebaard No 1 farmhouse, where the carbonate layer is only about 2 m long and less than 0,5 m thick).

The carbonate layer is monomineralic, composed of calcite (Table 7) but accessory quartz is occasionally present (e.g. V 1846 some 1,8 km north-east of the Bucklegraf farmhouse). The calcite is unevenly grained and strained.

Specimen	246	272	305	425	822	1840	1930	1954
Locality	Seekoebaard No. 1			Bucklegraf	Onderseekoebaard	Bucklegraf	Skalkseput	Potdans
Plagioclase An$_{0-10}$	?Gm	-	?Gm	?	?	-	?	?
An$_{10-50}$	Ph,Gm	Ph,Gm	Ph,Gm	Ph,Gm	Ph,Gm	Ph,Gm	Ph,Gm	Ph,Gm
K-feldspar	Ph,Gm	Ph,Gm	Ph,Gm	Gm	Ph,Gm	Ph,Gm	Gm	Ph
Quartz	Gm	Gm	Mc,Gm	Gm	Mc,Gm	-	Gm	Gm
Clinopyroxene	-	-	Gm	-	-	-	Ph	-
Hornblende	-	-	Ph,Gm	Ph,Gm	-	-	Ph,Gm	Ph,Gm
Epidote	Gm	Gm	Gm	Mc,Gm	Mc,Gm	Mc,Gm	Mc,Gm	Mc,Gm
Chlorite	Gm	Gm	Gm	Gm	Gm	Gm	Gm	Gm
Zoisite	Gm	Gm	Gm	-	-	-	-	-
Clinozoisite	Gm	-	-	-	-	-	-	Gm
Actinolite Tremolite	Gm	-	Gm	Gm	-	-	Ph,Gm	Ph,Gm
Carbonate	Gm	Gm	Gm	Gm	Gm	Mc,Gm	-	-
Rutile, Sphene	-	Gm	Gm	Gm	Gm	Gm	Gm	-
Leucoxene	Gm	Gm	Gm	Gm	Gm	Gm	Gm	Gm
Opaque minerals	Gm	Gm	Gm	Gm	Gm	Gm	Gm	Gm
Rock type	Andesite	Quartz andesite			Dacite	Andesite	Dacite	Andesite

Table 5. Mineral assemblages of the non-amygdaloidal Seekoebaard lava

Explanation: Ph - phenocrysts, Gm - groundmass, Mc - megacrysts

2.1.2.5.2.4. Witvlei Conglomerate Member

A conglomerate entirely different from all the other coarse-grained clastics in the Seekoebaard sequence occurs at three localities in the vicinity of the Doringberg fault: south of the Black Reef synform on the farm Asbestos Hills, east of the Doringberg fault on the farm Geelbeksdam and immediately south of the investigated area on the farm Witvlei. Although all three occurrences are too small to be shown on the map, the conglomerate represents an important member of the lithological succession. It is coarse to very coarse-grained, and carries pebbles and cobbles of non-amygdaloidal and amygdaloidal andesitic lava, quartzite, semipelite, hard (silicified) pelite (tuffite?) and quartz. No granitoids are present among the clastic material. Occasionally the conglomerate carries boulders of lava up to 60 cm in diameter.

The pebbles, cobbles and boulders are rounded or well rounded, their sphericity is variable (0,3 - 0,9) and sorting is poor. The matrix of the conglomerate is a subquartose or lithic sandstone and constitutes less than 30 - 40 per cent of the rock (sometimes even less than 10%). The conglomerate is evidently immature or very immature.

2.1.2.5.3. Seekoebaard correlates on Blouputs and Khaboom

At two localities situated immediately east of the Brulpan fault on the farms Blouputs and Khaboom the Seekoebaard rocks are overlain by minor quartzite (sheared and schistose) and by a carbonate (Fig 3.) which can be correlated with the Black Reef and Campbell Rand Formations respectively. These two localities require special attention because Rogers and Du Toit (1908) correlated all the three rock-types with the "Marydale Beds" of the "Kheis Series" and this correlation was mainly based on the interpretation of the first geological map of the area (Rogers and Du Toit, 1910) and also on the assumption that the granitoid which intrudes both the carbonate and underlying sequence belongs to the older pre-Ventersdorp intrusives exposed farther south.

On the old geological map (Rogers and Du Toit, op. cit.) the two localities are not separated and the "Marydale Beds" are shown to underlie "Kaaien Beds" conformably. No tectonic line divides the two units and the outcrop is separated from the "Pniel Series" in the east by a large tract of "red sand". This picture contrasts with the present map in that the volcanics and overlying quartzite and carbonate are separated from the Kaaien Formation by the Brulpan fault, the Blouputs and Khaboom outcrops are divided into two parts by the sand dune of west-northwesterly trend, and the northern of the two outcrops passes towards the east into the type Seekoebaard Formation as it can be seen in the continuous exposures north of the sand dune.

Rock types occurring in the more extensive southern outcrop on the farm Blouputs comprise metavolcanics lithologically similar to the Blinkfontein Member, quartzite (sheared quartzite), biotite granodiorite and also limestone and dolomite. The metavolcanics - greenish-grey hornblende fels (*sensu* Winkler, 1967, p. 227) and amphibolite - are fine-grained, in some layers amygdaloidal, and interbedded with minor epidotite layers. The hornblende fels (V 3010) is a dark green massive rock lacking schistosity; it is rich in light green common hornblende and also carries completely altered feldspar, epidote, clinozoisite, quartz (often filling the amygdales), calcite and common opaque minerals. In the vicinity of the carbonate sequence which is completely surrounded by the exposures of the metavolcanics, the amphibolite and hornblende fels are sheared and interbedded with layers of greenish-grey mylonite. The mylonite is full of megacrysts of blue opalescent quartz (1 - 4 mm) and is characterised by a partly recrystallised fine- to very fine-grained matrix (V 3014). Biotite occurring in the matrix is most probably formed as a result of contact metamorphism caused by the biotite granodiorite exposed in an old prospecting pit nearby.

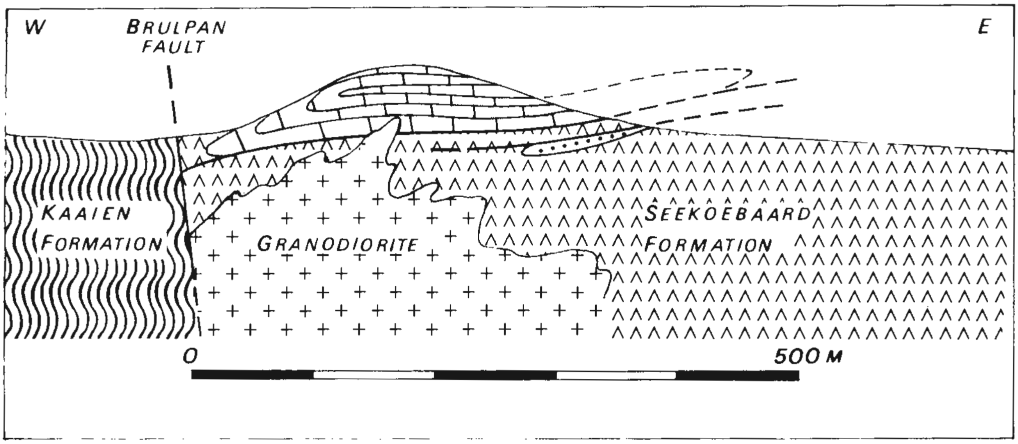

Fig. 3. Diagrammatic section showing the relationship of various rock units in the adjoining parts of Blouputs and Khaboom (an interpretation)

Explanation: Dots - sheared sandstone (Black Reef?); Brick-shaped pattern - Campbell Rand Formation

Quartzite and sheared quartzite occur on the south-eastern side of the outcrop of the carbonate sequence and form impersistent layers only a few metres long and up to 1 - 2 m thick. Their mode of occurrence resembles the imbricate structure typically developed in the Waterval synform of the Black Reef and Campbell Rand Formations.

Carbonate layers "remarkably like those of the Campbell Rand Group, though they cannot be more than 500 feet thick" (Rogers and Du Toit, 1908, p. 40) form an overturned or recumbent synformal structure overfolded towards the east-southeast. Their lithology is identical with that of the Campbell Rand carbonates, including the presence of characteristic chert layers from several mm to 30 mm thick. Their structure and metamorphic grade are also remarkably similar to the structure and very low-grade metamorphism of the typical Campbell Rand. The only difference from the typical Campbell Rand is in their high calcium content (Table 7). Recrystallisation of the carbonate, is largely due to the intrusion of the biotite granodiorite (V 3031 - Table 17); it should be noted that the radiometric data (Fig. 41) obtained from the Blouputs-Khaboom locality (Nicolaysen and Burger, 1965) suggest that the biotite granodiorite belongs most probably to the ±1,0 Ga age group.

The northern outcrop on the farm Khaboom comprises the overturned synform of the Campbell Rand and underlying metavolcanics. The intruding granodiorite is not present at the surface, but the mylonite occurring between the carbonate and the Seekoebaard metavolcanics is rich in feldspar porphyroblasts (mainly microcline), the biggest of which are up to 8 mm in diameter. Megacrysts of blue opalescent quartx are also frequent (V 3240).

2.1.2.5.4. Dynamically metamorphosed Seekoebaard rocks

Deformed, crushed and partly recrystallised rocks of the Seekoebaard Formation occur in zones of intense folding confined to the Transvaal synforms on the western side of the Doringberg fault and also to the area immediately south of the Matsap synclinorium. Less frequently the occurrences of such rock rock-types are associated with the faults.

Dynamically metamorphosed rocks (both sediments and volcanics) are present in various parts of the sequence. According to the degree of deformation they can be subdivided into strained, cataclastic and mylonitic types either with or without substantial recrystallisation. The effects of deformation are best seen in the amygdaloidal volcanics.

The least affected rocks are those in which the predeformational texture is still easily discernible, but in which individual minerals are either strained (undulatory extinction is quite common) or warped (e.g. feldspar phenocrysts). Only some of the amygdales are flattened, in particular those filled with chlorite (e.g. V 1860 2,2 km south-east of the Rooilaagte farmhouse).

The second stage of deformation in the amygdaloidal lava is characterised by the occasional occurrence of crushed zones, which are still discontinuous and usually less than 1 mm thick. All amygdales, including those filled with quartz, are flattened but the matrix still retains its predeformational texture (e.g. V 2005 in the north-western portion of the farm Poupan some 5 km north of Swartkop).

The third stage of deformation is represented by rocks in which the cataclastic (porphyroclastic) texture predominates (only small relicts of the predeformational texture are left) and the chlorite-filled amygdales are sheared out almost completely (V 1982 some 3,5 km north of the Skalkseput farmhouse). More severe crushing is characterised by rolled out bands and lenses of more competent material (V 1317 from the eastern bank of the Orange River on the farm Lelikstad).

The last stage of dynamic metamorphism is characterised by complete obliteration of predeformational features and by the development of streaky parallel textures (V 1875 0,5 km south of the old Blinkfontein homestead). The most typical example of mylonite is a rock from the hill some 5 km south-southeast of the

Vaalbult farmhouse (V 3089) which displays distinct porphyroclastic texture and parallel lenticular structure. The mylonite is developed in the zone of a reverse fault (a tectonic slide), along which a slice of Draghoender Granite was thrust over the amygdaloidal Blinkfontein lava.

Recrystallisation associated with the crushing and mylonitisation of the amygdaloidal lava involved the redistribution of epidote and calcite and preferred orientation of quartz and chlorite. Primary hornblende is at least partly destroyed and some of the feldspars are albitised.

2.1.2.6. The Transvaal Supergroup

2.1.2.6.1. Introduction

The sequence comprising common clastic and chemogenic sediments, as well as a characteristic thick succession of the banded iron-formation, layers of mixtite and volcanics, was first mapped in Griqualand West by Stow (1874). The following units were recognised: Siliceous and crystalline limestones of Campbell Randt (present Campbell Rand Formation), Griquatown Jaspers with Magnetite (mostly present Lower Griquatown group), Amygdaloidal and associated rocks of Pniel, Wetberg etc. (present Seekoebaard and Middle Griquatown sequences), Ferruginous breccia of Blink Klip, Irregularly bedded Jaspery rock near the Matsap Hills and Red Jaspers of the Rooy Kopjes (the last three probably representing parts of the present Lower and Upper Griquatown groups).

Later, the presence of the Black Reef Quartzite at the base of the sequence, was noted (Rogers and Schwarz, 1899) and the Ongeluk Volcanics or "Middle Griquatown Stage" was defined (Rogers, 1905). Thus, in the early years of this century, the succession was subdivided from bottom to top as follows:

(i) Black Reef Series

(ii) Campbell Rand Series

(iii) Griquatown Series

Apart from detailed descriptions of the Transvaal sequence south of the 29° parallel published by Rogers and Schwarz (1899), Rogers (1905) and Rogers and Du Toit (1908), several other papers deal with parts of the area under consideration and will be referred to in the appropriate sections of the following text. Two of these works, which should be mentioned here, are the most comprehensive accounts of the Transvaal Supergroup in the Koegasbrug area, and were written by Cilliers (1961) and Leube (1964); both of them accept the above subdivision of the succession into the "Series" and also propose a more detailed subdivision into "Stages" and "Substages".

The subdivision and nomenclature of the Transvaal Supergroup in the Koegasbrug area as proposed here (Fig. 4) is based on all the relevant data of previous work supplemented by the results of the present investigation. It complies with the South African Code of Stratigraphic Terminology and Nomenclature (1971) but, because of the complicated structure of some parts of the Transvaal sequence, the thicknesses quoted in the following text are mostly based on indirect data (data from previous work, thicknesses computed from the map and sections and, to a smaller extent, on direct measurements in the field).

2.1.2.6.2. Black Reef Formation

This basal unit of the Transvaal sequence occurs in the synformal relicts west of the Doringberg fault, in the Waterval synform on both sides of the Orange River, and in a major antiformal structure immediately east of the Doringberg fault on the farms Geelbeksdam, Witvlei, Windpomp and Klein Windpomp. It transgresses over the Blinkfontein Volcanic Member of the Seekoebaard Formation and, in the north, it also overlies the Waterval Member of the Seekoebaard sequence. The unconformity between the two formations is distinct on a regional scale, but often obscured in detail by faulting and intense folding, which led to the development of recumbent and imbricate structures. It is rather a disconformity than true angular unconformity.

The upper limit of the formation is defined by the disappearance from the sequence of the last pelite (shale and slate). This takes place over a very short distance (less than a few metres) and the boundary between the Black Reef and Campbell Rand Formations is thus distinct and mappable.

The rock-types occurring in the Black Reef succession comprise quartzose and subquartzose sandstone (orthoquartzite and feldspathic sandstone), conglomeratic sandstone and conglomerate, grit, siltstone and shale with a number of impersistent carbonate layers towards the top.

It should be noted that Leube (1964) proposed a subdivision of the Black Reef into three "sub-stages":

(i) Lower - limestone, dolomite, quartzite, siltstone, shale and basic lava; banded ironstone;

(ii) Middle - quartzite and intercalated shale;

(iii) Upper - "lower transition shale"

It is suggested, however, that the first two "sub-stages" should be grouped together under the name "Potdans Quartzite Member" because the limestone, dolomite, basic lava and banded ironstone are not interbedded with but infolded in the sequence of quartzarenite, siltstone and shale.

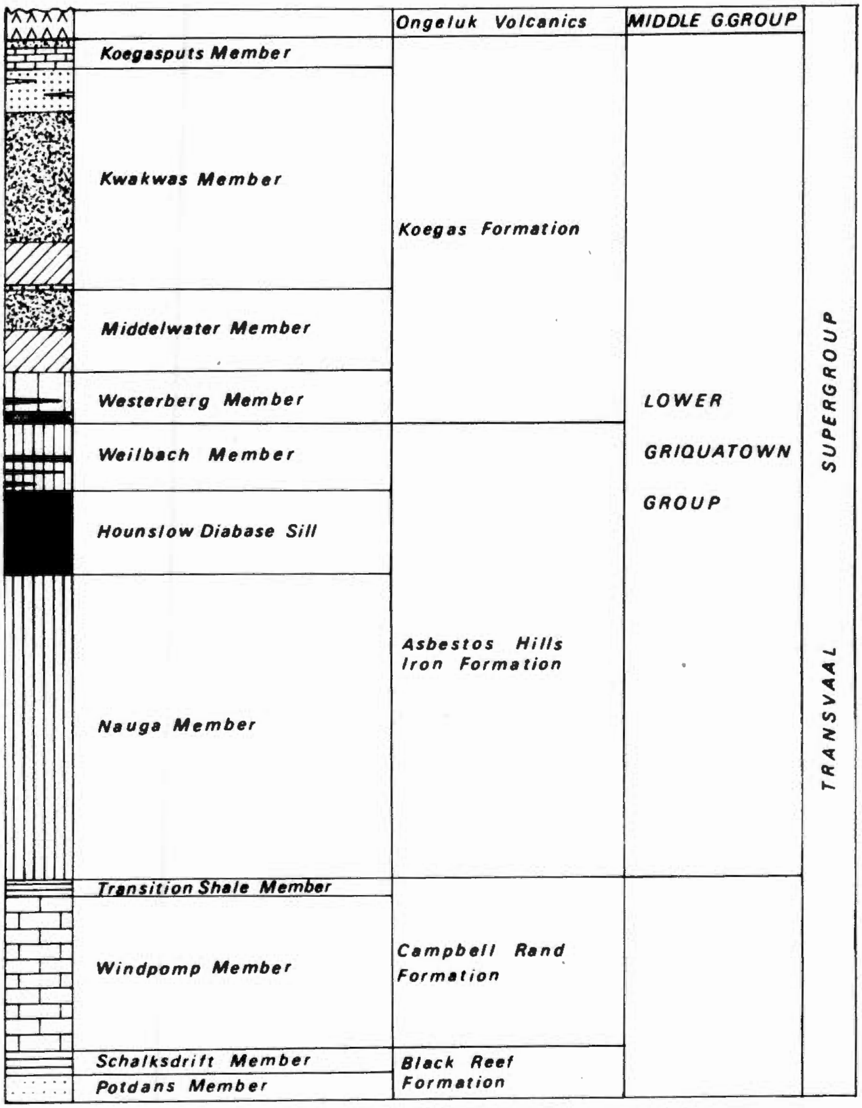

Fig. 4 Stratigraphy and nomenclature of the Transvaal Supergroup in the Koegasbrug area

Note: Grasgat Member is not shown in the stratigraphic column

2.1.2.6.2.1.1. Potdans Quartzite Member

Some 70 - 100 m of quartzarenite with occasional layers of siltstone, grit, conglomeratic sandstone and conglomerate constitute a characteristic lithological unit different from both the underlying and overlying strata. The most frequent rock-type in this succession is pure quartzarenite, interbedded with layers of feldspathic and lithic quartzarenite. Its colour is usually white or light grey, less frequently grey. Grey and dark grey quartzarenite occurs only occasionally (e.g. in a quarry on the southern side of the Draghoender - Westerberg Road). The quartzarenite is usually thinly bedded or laminated; massive types, however, are also present (mainly on the western bank of the Orange River). Lithological banding (colour and grain-size variations), ripple-marks and cross-bedding are common, but graded bedding is less frequent. Other sedimentological features of the arenites are summarised in Table 6.

Conglomeratic sandstone and conglomerate occur in the basal part of the unit. They are monomict with quartz being the main component of pebbles, detrital grains and arenaceous matrix. Pebbles are of various size (usually not more than 20 mm), discoidal, and their sphericity decreases with increasing size. Roundness varies between 0,4 and 1,0. Some of the pebbles are fractured, fractures being filled with crush quartz (V 1002 - Bo-Seekoebaard).

2.1.2.6.2.2. Schalksdrift Member

This member comprising some 50-60 m of slate, shale and minor carbonate, constitutes a distinct mappable unit; the succession, however, grades into both the underlying Potdans Quartzite Member and overlying Windpomp Member. The lower limit of the unit is marked by the disappearance of quartzarenite; the upper limit coincides with the top of the last pelite layer.

The most common rock-type in this succession is thinly bedded light grey, very fine-grained slate. When weathered it is usually soft, shaly and either white or red and brown stained. The slate is well exposed in the Transvaal synforms on the western side of the Doringberg fault and also on the farm Geelbeksdam and Windpomp east of the fault. In the involved area on the eastern bank of the Orange River (some 4,2 km south-west of the Bo-Seekoebaard farmhouse) the slate is greenish light-grey, finely laminated and parted along the planes of fracture cleavage.

2.1.2.6.3. Campbell Rand Formation

This succession, overlying the Schalksdrift Member conformably, starts with some 300-400 m of calcitic dolomite and dolomitic limestone (Windpomp Member) which has some 20 - 50 m of slate and shale at the top (Transition Shale Member). Its upper limit is also conformable, marked by the occurrence of the first layers of

Specimen no.			250	278	300	1877
Locality			Seekoebaard No. 2		Seekoebaard No. 1	Rooilaagte
Rock type			Pure quartz-arenite	Lithic quartz-arenite	Feldspathic quartzarenite	Lithic quartz-arenite
Detrital grains	Q	Percentage	>65		<90	>80
		Particle size in mm (minimum - most common - maximum)	0,1 - 0,5 - 1,5	0,05 - 0,2 - 0,9	0,1 - 0,5 - 2	0,1 - 0,8 - 1,5
		Sphericity	variable (grains affected by deformation)	0,3 - 0,6	0,4 - 0,9	0,4 - 0,9
		Roundness	0,25 - 0,7	variable (grains affected by cataclasis)	0,5 - 0,9	0,3 - 0,8
	F	Percentage	1 - 3	1 - 2	1 - 2	< 2
		Particle size in mm	0,1 - 0,5	< 0,5	< 0,4	< 0,5
		Sphericity	0,4 - 0,9	0,5 - 0,9	variable	variable
		Roundness	0,15- 0,4	0,2 - 0,6	0,1 - 0,5	0,15- 0,4
		Tourmaline	present	-	present	-
		Zircon	present	present	present	-
		Hematite, limonite	present	present	present	-
	R	Clastic fragments and grains of various supracrustal rocks	-	5 - 7 % fine- and very fine-grained sediments	-	< 5 % fine- and very fine-grained sediments
Matrix		Sericite	1 - 2 %	1 - 2 %	2 - 3 %	present
		Carbonate	-	-	-	2 - 3 %
Crush quartz		Percentage	c. 30 %	-	< 5 %	< 10 %
		Remarks	Fine- to very fine-grained. No lattice preferred orientation		Crush quartz developed around the bigger detrital quartz grains	

Table 6 Some lithological characteristics of the Potdans Quartzite Member

Specimen no.		1846	1639	2418	3012	4430	4431	1102	1480
Locality		Bucklegraf	321 Hay 16.10	Middelwater	Blouputs	Westerberg		Groot Witberg	Paardevlei
Rock unit		Seekoebaard Formation	Campbell Rand Formation		Campbell Rand Formation	Koegas Formation			
Rock type		Calcitic marble	Calcitic dolomite	Dolomitic sandstone	Limestone	Calcitic dolomite	Impure dolomitic limestone		Impure magnesian limestone
Gasometric results	Carbonate %	97,83	81,23	24,26	74,44	98,90	83,06	86,22	77,3
	Insolubles %	2,17	18,77	75,74	25,56	1,10	16,94	13,78	22,7
AAS results	Ca (%)	29,5	13,0	5,0	23,0	16,8	16,2	13,3	23,0
	Mg (%)	0,05	7,8	2,4	0,07	9,3	7,0	7,3	1,4
	Sr (ppm)	495	192	60	240	250	395	89	232

Table 7 Chemical composition of some carbonate bearing rocks of the Seekoebaard and Transvaal sequences

Samples are referred to on the following pages:
32 (V 1846), 34 (V 3012), 43 (V 1639 and 2418),
52 - 53 (V 4430 and 4431) and 56 (V 1102 and 1480)

the banded iron-formation. The Campbell Rand sequence is best exposed on the eastern side of the Doringberg fault (farms Windpomp and Klein Windpomp in particular). It also occurs in the Transvaal synforms on the western side of the fault and in small outcrops on the farms Blouputs and Khaboom in the west (see page 35). Only at one place in the central part of the Weilbach anticline does a thin upthrust tectonic slice of the Campbell Rand carbonate occur in the area of younger members of the Transvaal sequence.

2.1.2.6.3.1. Windpomp Dolomite Member

This unit, corresponding to the "Dolomite Stage" of Leube (1964), comprises mostly calcitic dolomite (Table 7, classification after Carozzi, 1960, p. 264) and dolomitic limestone, occasional layers of detrital sediments (arenite, siltstone) and minor slate. Rock types containing more than 90 per cent of either calcite or dolomite are not frequent. The carbonate rocks in the Windpomp sequence are usually light grey or grey, fine-grained, and occasionally oolitic. When weathered, they have a typical brown and dark brown colour, and display karstic superficial features (mostly rough surfaces, less frequently clints and grikes).

The two main types of carbonate rocks are also characterised by the presence of numerous layers of light grey chert. These layers are from a few mm to 300 mm thick and are sometimes ferruginous (e.g. farms Waterval and Nauga). They seem to occur at certain levels within the sequence where they are almost regularly (rythmically) interbedded with carbonate. The chert layers are always the most contorted members of the succession, which is intensely folded on cm - m scale.

There are numerous examples of impure carbonate rocks containing a variable amount of clastic quartz, and occasional layers of detrital sediments. One such layer is present in the south-western portion of the farm Middelwater and it is formed by light grey laminated sediment (V 2418 - Table 7) composed of detrital grains of quartz, alkalic feldspar and of less than 35 per cent carbonate. The carbonate is brownish stained, the matrix of the sediment is fine-grained, semipelitic. Low roundness of the clastic material and the presence of alkalic feldspars may possibly indicate a tuffaceous origin of at least part of the clastic material.

Towards the top of the succession the carbonate is interbedded with minor and impersistent layers of slate lithologically identical with the overlying member.

2.1.2.6.3.2. Transition Shale Member

Light grey and yellowish light grey (sometimes grey and grey-green) shale and slate forms a layer from a few metres to some

50 m thick, separating the Campbell Rand carbonates and the banded iron-formation. It is a very fine-grained pelite which is usually thinly laminated and carries limonitised pyrite concretions from a few mm to 30 mm in diameter (V 2420 - farm Middelwater). The limonitic concretions often display concentric structure.

In the Transvaal synforms west of the Doringberg fault and in the zone of the fault itself the transition shale is either very thin or absent. Elsewhere the zone between the Windpomp and Nauga Members has uniform lithological gradation and is usually 20 m thick (Table 8).

Unit	Thickness (m)	Lithology
Nauga Member (lowermost part)		Banded iron-formation
	20-30	Banded iron-formation with frequent layers of silicified shale up to 1 m thick
Transition Shale Member	15-20	White laminated shale, sometimes pinkish or red stained, with 1-2 cm layers rich in limonitic concretions (2 - 30 mm)
Windpomp Member (uppermost part	5	Siliceous and iron-banded carbonate with intercalations of silicified slate
		Dolomitic limestone and calcitic dolomite with occasional impersistent layers of pelite, and with frequent cherty layers (<5 cm)

Table 8 Lithology and thickness of transitional strata between the Windpomp and Nauga Member (farm Middelwater)

It should be noted that south-east of the Asbestos Hills (outside the investigated area) the thickness of the Transition Shale Member increases considerably and that on Buisvlei, some 23 km north-west of Prieska, it is more than 130 m thick (Hanekom, 1966).

2.1.2.6.4. Asbestos Hills Iron Formation

A sequence of some 650 - 900 m of banded iron-formation divided by a thick diabase sill into the thicker lower (Nauga Member) and thinner upper part (Weilbach Member) is the most characteristic of the Lower Griquatown group. It occurs in the Waterval synform in the north, then in the hills on the north-eastern bank of the Orange River between Bo-Seekoebaard and Koegasbrug, and finally in the Asbestos Hills south-east of Westerberg, and south-east of the investigated area between the Asbestos Hills and Prieska. It is not only known for its typical banded nature and high magnetite content, but also for the economically important layers of crocidolite asbestos interbedded in the succession.

A typical feature of the Asbestos Hills Iron Formation is its micro-, meso-, and also macrobanding, which can be used for a more detailed subdivision of the sequence. In the tectonically involved area along the Orange River, however, the individual macrobands do not constitute mappable units.

The lower limit of the banded iron-formation has been described above (page 44); the upper limit is marked by a distinct change in mineralogy and lithology of the sediments from the magnetite-rich banded iron-formation (Weilbach Member) into the minnesotaite and riebeckite slate (Westerberg Member). Although this upper limit is transitional it can still be recognised in the field and shown on the map as a single line. The marked mineralogical and lithological change is the main reason why the Westerberg Member was separated from the banded iron-formation and included in the Koegas Formation (see also Hanekom, 1966).

A comparison of the chemical composition of the Asbestos Hills Iron Formation and of some other Precambrian iron-formations in Table 9 points to characteristic features of these banded ferruginous cherty sediments: the high silica and iron content, and the very low content of aluminium.

2.1.2.6.4.1. Nauga Member

The lower banded iron-formation is between 400 and 800 m thick and overlies the Transition Shale Member conformably. At places close to the Doringberg fault the boundary between the Windpomp and Nauga Member is tectonic, marked by a zone of brecciation and by the absence of the transition shale (e.g. some 4 km south-west of the Bo-Seekoebaard farmhouse).

The succession starts with 20 - 80 m of highly ferruginous rocks; the colour of magnetite- (± hematite-) rich layers is dark grey or black, whereas siliceous layers are represented by white chert and red jasper. Mesobanding in this sub-unit is fine, individual bands being usually less than 10 mm thick.

Following in the succession are some 120 m of Lower Asbestos Zone (up to ten seams of crocidolite asbestos, separated by layers of the banded iron-formation). This part of the succession has been opened up by prospecting trenches at many places, in particular on the farm Nauga.

	1	2	3	4	5	6	7	8	9
SiO_2	41,47	41,56	39,85	55,1	46,12	47,9	48,35	49,48	46,86
TiO_2	0,18	0,07	0,105	0,12	0,04	0,05	0,01	0,01	0,05
Al_2O_3	3,87	1,45	1,22	0,10	0,86	0,9	0,48	0,68	0,43
Fe_2O_3	20,87	24,77	20,18	13,3	19,47	31,7	45,98	16,34	24,68
FeO	20,03	14,84	21,49	13,79	19,26	14,6	2,33	24,19	17,19
MnO	0,23	0,20	0,25	0,18	0,66	0,3	0,025	0,65	–
MgO	2,37	3,[illegible]0	3,93	2,50	2,88	1,8	0,32	2,95	2,58
CaO	2,36	3,73	2,01	3,1	1,79	1,45	0,1	0,1	1,49
Na_2O	1,33	0,82	0,89	0,33	0,05	0,2	0,33	0,03	0,16
K_2O	1,03	0,175	0,07	0,25	0,14	0,32	0,01	0,07	0,10
H_2O^+	0,73	0,55	0,56	0,21[1]	1,68[1]	0,47	2,0	5,2	0,57[1]
H_2O^-	0,005	–	0,27			0,1	0,04	0,38	
CO_2	5,29	7,29	8,28	7,80	6,79	n.d.	0,03	0,22	5,81
P_2O_5	0,29	0,18	0,23	0,01	0,07	0,1	0,04	0,08	0,25
C	n.d.	n.d.	n.d.	–	0,20	n.d.	0,08	0,15	–
S	–	–	0,025	n.d.	n.d.	n.d.	0,13	0,05	n.d.
Cl	0,13	0,185	0,13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
F	–	–	–	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Minus O = Cl,F	0,027	0,04	0,04	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total Fe	29,92	28,87	30,82	20,02	28,59	33,52	33,97	30,23	30,60
Total oxides	99,31	98,985	98,555	96,79	100,01	99,89	100,138	100,51	100,17
si	85,25	97,34	92,82	188,80	121,06	115,78	153,02	130,20	120,92
al	4,67	2,00	1,66	0,21	1,32	1,28	0,89	1,04	0,63
fm	86,14	86,54	91,21	86,76	93,28	94,01	97,74	98,48	94,67
c	5,19	9,36	5,02	11,39	5,04	3,76	0,34	0,28	4,12
alk	4,00	2,10	2,11	1,64	0,36	0,95	1,03	0,20	0,58
mg	0,17	0,31	0,24	0,24	0,20	0,17	0,19	0,18	0,21
k	0,33	0,12	0,04	0,33	0,65	0,51	0,01	0,58	0,29

n.d. = not determined

[1] = loss on ignition

Table 9 Chemical composition of some Precambrian ferruginous cherty sediments

I - Banded iron-formation between 10 and 783 m below the lowermost asbestos reef in the Westerberg Member; borehole W 2, Westerberg, Northern Cape (after Hanekom, 1966, Table 32, mean of the analyses iv - vii);

II - Banded iron-formation between 60 and 145 m above the Campbell Rand Formation; borehole DM 124, Warrendale Mine, Northern Cape (after Hanekom, 1966, Table 32, mean of the analyses viii and ix);

III - Banded iron-formation between 23 and 217 m above the Campbell Rand Formation; borehole DW 19A, Pomfret, Northern Cape (after Hanekom, 1966, mean of the analyses x and xi, Table 32);

IV - Drill core from the Lower Griquatown banded magnetic chert at Heuningvlei, Northern Cape (after Genis, 1961, Table 8, G7M);

V - Bivabik iron-formation, Minnesota, average composition (after Lepp, 1966, p. 248);

VI - Algoma type, mainly oxide facies, magnetite-quartz iron-formation, Timagami Lake area, Ontario; average of four analyses of some 17 m of section sampled systematically (after Douglas, 1970, p. 173);

VII - Superior type, oxide facies, hematite-magnetite-quartz iron-formation, Knob Lake iron ranges, Quebec and Labrador; average of six analyses of some 112 m of section sampled systematically (after Douglas, 1970, p. 173);

VIII - Superior type, silicate-carbonate-chert facies, Knob Lake iron ranges, Quebec and Labrador; analysis of some 17 m of section sampled systematically (after Douglas, 1970, p. 173);

IX - Drill core from Dales Gorge Member banded iron-formation at Wittenoom, Western Australia (after Trendall, 1968).

Above the Lower Asbestos Zone the iron content in the succession gradually decreases and bedding becomes more pronounced towards the top. Layers of chert and jasper are yellow, red and brown, and the thickness of this part of the succession is some 400 - 500 m.

The Intermediate Asbestos Zone which, in other parts of the Transvaal outcrop outside the investigated area, is up to 43 m thick and occurs approximately 130 m below the top of the Nauga Member, does not form a continuous layer in the Koegasberg area (only a few lenses of crocidolite asbestos represent this zone).

The remaining part of the Nauga Member is characterised by lower magnetite (± hematite) content, by frequent thick mesobanding (3 - 4 cm), by generally lighter colour, and by the presence of yellow and brown jaspery bands.

Mesobanding is the most typical macroscopic feature of the banded iron-formation. Some bands are very persistent while others pinch out over a short distance. It has been suggested by Fockema (1967) that the "pinch and swell" structures were produced during compaction of the rocks and that the surface of deposition was not necessarily undulating at the time of sedimentation.

Another interesting sedimentary feature is the occurence of chert breccia layers which can be found in both the lower and upper part of the banded iron-formation (in both the Nauga and Weilbach Members). Four different types of these breccias have been recognised by Fockema (op. cit.) in the Kuruman area farther north:

(i) both rounded and angular chert fragments are present; some of them are contorted, but the breccia itself is not deformed;

(ii) both rounded and angular chert and banded iron-formation fragments are present; the fragments pass laterally into unbroken layers;

(iii) ditto "i", associated with gravity folds;

(iv) ditto "i", with ferruginous matrix and occurring on one stratigraphic level.

Types i-iii are also present in the Koegasbrug area.

Microbanding in the iron-formation is caused by the alternation of thin laminae of different mineral composition; there are the following types of laminae in the sediments of the Asbestos Hills Iron Formation:

(i) siliceous (cherty), composed of microcrystalline quartz and, much less frequently, of chalcedonic quartz;

	I	II
SiO_2	46,20	49,35
Al_2O_3	16,63	11,26
Fe_2O_3	0,63	3,01
FeO	9,22	9,93
MgO	5,00	6,97
MnO	0,14	0,21
CaO	5,49	9,57
Na_2O	0,55	3,70
K_2O	3,00	2,41
H_2O+	1,29	1,27
H_2O-	0,11	0,10
CO_2	1,68	1,13
TiO_2	0,30	0,58
P_2O_5	0,05	0,14
Cl	0,19	0,27
F	0,00	0,02
Minus O = Cl, F	0,04	0,07
Total	100,44	99,85
si	94,5	114,5
al	20,1	15,5
fm	63,0	49,0
c	12,1	23,5
alk	5,0	12,0
mg	0,73	0,49
k	0,78	0,30
p	0,0	0,1
ti	0,5	1,0
co_2	4,7	3,6
h+	9,0	10,0
cl	0,7	1,1
f	0,0	0,2

Table 10 Chemical composition and Niggli values of the Hounslow diabase (I) and of the Marker Sill (II) (After Hanekom, 1966)

(ii) carbonate, composed of calcite, dolomite and/or siderite;

(iii) ferruginous, composed of magnetite, hematite and ferristilpnomelane;

(iv) stilpnomelane (more frequently ferri- than ferrostilpnomelane);

(v) riebeckite and crocidolite;

(vi) minnesotaite.

Of the types described above the first three are the most frequent.

2.1.2.6.4.2. Hounslow Diabase Sill

The diabase sill which separates the Nauga and Weilbach Members can be followed continuously from Middelwater in the south-east to Klein Witberg in the north-west. The sill is up to 150-200 m thick (usually 100-120 m) and it thins out towards the noth-west. In the northern part of Klein Witberg this diabase is only a few metres thick. One to three minor sills of the same diabase are intruded in the lower part of the Weilbach Member. In the large antiform south of Westerberg the major diabase sill transgresses into the Weilbach Member and joins with one or two of the minor sills; on the limbs of the same structure, however, the major and minor sills become separated again.

The Hounslow Diabase Sill transgresses the bedding also on a regional scale (e.g. farms Nauga and Middelwater), the angle between its contact planes and bedding of the iron-formation being very small. On a regional scale the sill is always conform to the macrobanding of sediments. The intrusive nature of the sill is documented by chilling of its marginal parts, by thermal effects upon the neighbouring rocks and on asbestos in particular, and possibly also by its homogeneous and evenly grained nature.

Light greenish-grey and greenish-grey diabase, more frequently medium- than fine-grained, non-foliated and irregularly jointed is the most frequent rock-type in the sill. It has typical ophitic or subophitic intergrowths of plagioclase and clinopyroxene, but both these minerals are altered, feldspars being heavily saussuritised. The alteration seen under the microscope is strong even in the specimens which are macroscopically absolutely fresh, and it affects also other minerals such as hornblende, sphene etc.

Chemical analyses of diabase from two different sills in the Westerberg Mine (Hanekom, 1966) are shown in Table 10.

2.1.2.6.4.3. Weilbach Member

Some 100-150 m of the upper banded iron-formation constitute this unit, the lower limit of which is mostly defined by the contact with the main diabase sill. and the upper limit by a distinct mineralogical and lithological change. This change is marked not only by the first appearance of minnesotaite and riebeckite slate layers of the Westerberg Member, but also by the sharp difference in the mode of occurence of magnetite in the two sub-units; while in the Weilbach Member magnetite forms micro- and mesobands throughout the succession, in the Westerberg Member it is confined to the asbestos-bearing horizons only (it is either absent or minor in other parts of the Westerberg Member).

The Weilbach Member comprises rock-types generally lighter in colour and lower in iron content in comparison with the Nauga Member. Microbanding has the same character as in the latter member but mesobanding is more often thin than thick. Weathered equivalents of fresh rock-types are commonly brown or dark brown.

Interbedded in the succession are bands rich in riebeckite and crocidolite. These have blue colour and are less affected by weathering than the ferruginous layers. They were referred to as "potential crocidolite" (Hall, 1930), as "mass fibre crocidolite" (Du Toit, 1945), and as "blue bands" (Leube, 1964). Blue bands are less than 1,5 m thick and contain very little magnetite.

One of the blue bands, which is called Blue Bank, occurs almost at the top of the Weilbach Member and can be found not only in the Koegas area, but also on the farms Pypwater 321, Leelykstaat and 314 Hay 15.11.

A layer of greenish-grey cross-fibre asbestos much lower in ferric iron than crocidolite also occurs in the Weilbach sequence and has been described by Cilliers (1961) under the name of prieskaite.

One to three minor diabase sills already mentioned above (p. 49) are from a few metres to c. 20 m thick and not very persistent along the strike. They are intruded in the Weilbach Member between Pypwater and Westerberg. The thickest of these sills occurs also on the farms Hounslow and 314 Hay 15.11 in the north-west, and on Nauga, De Duinen and Middelwater in the south-east.

2.1.2.6.5. Koegas Formation

This sequence, overlying the banded iron-formation conformably, comprises minnesotaite slate, riebeckite slate, quartz-chlorite fels (*sensu* Winkler, 1967, p. 227), layers of semipelite, arenite and carbonate, and, at the top, a characteristic layer of mixtite. It differs from the underlying jaspilite in its remarkably low content of magnetite, and in the clastic origin of most of its members. Usually it can be subdivided into eight mappable units (Fig. 4 on p. 39) which, towards the north-west, pass laterally into an undifferentiated sequence of siliceous rocks hitherto known as the "Jasper Zone". Jaspers are best exposed on the 314 Hay 15.11 and on Klein Witberg, and will be described separately (section 2.1.2.6.5.4.). An important feature of the Koegas Formation is the increase in silica content towards its top, and the enrichment in iron-content in the uppermost parts of the Kwakwas Member.

The maximum thickness of this newly designated unit is some 1100 m, but it usually varies between 600 and 800 m.

2.1.2.6.5.1. Westerberg Member

The lowermost member of the Koegas Formation is up to 100 m thick and well characterised by its predominant rock-type (minnesotaite slate). Also characteristic is an almost complete absence of magnetite-rich layers (confined to the asbestos seams only), and the ochrous colour of the weathered parts.

The lower boundary of the Westerberg Member is transitional, the transition zone being thin (less than 1 m) and marked by a distinct mineralogical and lithological change described above (p. 50). The difference between the minnesotaite slate and the banded iron-formation is also expressed in their different chemical composition (Table 11 - Fe_2O_3 and H_2O^+ in particular).

The uppermost 7 - 8 m of the underlying Weilbach Member comprise two less important asbestos reefs (Second and Third Outer Reefs in the Westerberg area) and the top of the banded iron-formation sequence is formed by 1,5 m of hard riebeckite slate ("Blue Bank"). First 27 m of the Westerberg Member above the "Blue Bank" are known as the Westerberg Asbestos Zone, which is being mined at present in the Westerberg syncline. The asbestos reefs are (from bottom upwards): Outer, Intermediate, Bottom Visser, Visser, Lower Main, Main and Inner. The diabase sill, which occurs up to 13 m

	Minnesotaite slate		Banded iron-formation				
SiO_2	44,20	39,63	37,66	43,07	43,54	43,30	36,00
Al_2O_3	0,14	0,19	0,00	8,08	1,32	5,93	0,17
Fe_2O_3	3,00	6,51	15,97	14,31	21,93	23,78	23,48
FeO	33,82	32,49	28,10	20,20	19,66	17,24	23,04
MgO	2,83	2,80	3,10	2,45	2,36	2,10	2,60
MnO	0,18	0,36	0,79	0,40	0,13	0,06	0,33
CaO	2,22	2,81	3,48	2,43	2,29	1,24	2,76
Na_2O	0,93	1,83	0,70	0,63	0,97	2,15	1,57
K_2O	0,47	0,45	0,52	1,22	1,08	0,51	1,31
H_2O+	3,42	3,19	3,07	0,66	0,71	0,76	0,80
H_2O-	0,05	0,04	0,02	0,00	0,02	0,00	0,00
CO_2	7,80	8,82	5,67	6,10	5,35	2,22	7,50
TiO_2	0,18	0,18	0,20	0,18	0,18	0,18	0,19
P_2O_5	0,18	0,28	0,23	0,35	0,27	0,18	0,37
Cl	0,07	0,15	0,16	0,15	0,15	0,16	0,06
F	0,00	0,00	0,00	0,00	0,00	0,00	0,00
S	0,05	0,00	0,00	0,00	0,00	0,00	0,00
Minus O = Cl, S	0,04	0,03	0,04	0,03	0,03	0,04	0,01
Total oxides	99,50	99,70	99,63	100,20	99,93	99,77	100,17
Total Fe	28,39	29,80	33,01	25,71	30,62	30,03	34,33

Table 11 Comparison between the chemical composition of minnesotaite slate (Koegas Formation) and ferruginous rocks of the Asbestos Hills Iron Formation, Westerberg, Northern Cape (data from Hanekom, 1966)

above the Inner Reef is some 7 m thick and is generally referred to as the Hanging Wall Sill or as the Marker Sill (Hanekom, 1966). The chemical composition of this rock is shown in Table 10. Another minor diabase sill follows the boundary between the Westerberg and Middelwater Members in the eastern part of the farm De Duinen.

The most typical rock in the Westerberg succession is the minnesotaite slate, which is grey or dark grey, fine- to very fine-grained and finely banded (usually 1 - 5 mm). When fresh, the slate is relatively hard. Minnesotaite-rich bands also carry riebeckite and stilpnomelane, which sometimes tend to be concentrated in thin laminae. Disseminated pyrite is a common accessory in various parts of the succession. Thin layers of calcite dolomite and impure dolomitic limestone were found on the southern bank of the Orange River; their ochrous weathering and a relatively low content of calcium and magnesium (Table 7) indicates possible presence of ferriferous carbonate.

2.1.2.6.5.2. Middelwater Member

Towards the top of the Weilbach succession riebeckite becomes more important and bands composed exclusively of this mineral become thicker (up to a few centimetres). Finally, the succession passes into the riebeckite slate of the lower part of the Middelwater Member. The boundary is transitional, but distinct, and in outcrops the weathered riebeckite slate differs from ochrous products of weathering of the minnesotaite slate in its red and red-brown colour.

The Middelwater Member comprises riebeckite slate and quartz-chlorite fels and, as defined here, it is almost identical with the Middelwater Substage of Hanekom (1966). The only departure from the previous subdivision is the inclusion of the so-called "Jasper Zone and associated Upper Asbestos Zone" (formerly part of Hanekom's Middelwater Substage) in the overlying Kwakwas Member. The main reason for this is the disconfomity between the quartz-chlorite fels and overlying conglomerate of the "Jasper Zone" and the gradual transition of the latter upwards into the riebeckite slate of the Kwakwas Member (see section 2.1.2.6.5.3.).

The maximum thickness of the Middelwater Member, according to Leube (1964), is some 200 m in the south, decreasing to some 160 m in the north. Hanekom (1966) estimated that the riebeckite slate and quartz-chlorite fels of the Middelwater "Substage" are up to 266 m thick. Even this figure, however, seems to be slightly lower than the actual maximum thickness (some 300 m), which can be deduced from the width of the outcrop and from the sections (Fig. 13).

Riebeckite Slate

The lithologically uniform succession of the lower riebeckite slate is up to 200 m thick and comprises blueish dark grey, well bedded and foliated rocks, in which the lithological banding and fracture cleavage usually intersect at an obtuse angle. In thin section the slate is fine-grained, with the riebeckite crystals oriented parallel to the fracture cleavage (V 1747, Koegasputs). Riebeckite is occasionally accompanied by accessory minnesotaite, abundant stilpnomelane, and chlorite, and fairly plentiful quartz and feldspar; hematite, limonite and siderite are accessories. Hanekom (1966) reported that riebeckite is accompanied by a second amphibole which displays almost the same pleochroism, but has a positive elongation and an extinction angle of 28° (probably eckermannite).

Riebeckite-rich layers are usually hard and resistent to weathering, as are the less than 1 m thick silicified cherty layers which occur near the base of the sequence.

Thin intraformational conglomerate forms impersistent layers less than 1 m thick and have a limited lateral extent. It is occasionally present in the eastern part of the farm Middel Koegas, and south of the Middelwater farmhouse outside the investigated area.

Quartz-chlorite fels

A succession of greenish light grey metasediments, which have been called either mudstone (Cilliers, 1961) or shale (Leube, 1964), overlies the riebeckite slate conformably and comprises fine- and very fine-grained metapelitic and semipelitic types composed mainly of quartz, chlorite, and of less frequent carbonate. Present name of these rock types is used in the sense suggested by Winkler (1967, p. 227).

Although macroscopically uniform and massive, the rock is often finely banded, due to alternations of thin laminae of various mineral compositions. Cross-lamination and examples of minor oscillatory ripple-marks can also be seen in places. Thin diabase sills are present on the farms De Duinen, Nauga and Westerberg.

2.1.2.6.5.3. Kwakwas Member

Up to 650 m of riebeckite slate, quartz-chlorite fels, semipelite, minor arenite, carbonate and quartzite constitute this newly designated unit, which is separated from the underlying Middelwater Member by a disconformity. The lowermost unit in the Kwakwas sequence is a conglomerate or breccia layer, from a few cm to 3 m thick, composed of siliceous pebbles and fragments cemented by a siliceous matrix, and characterised by its pitted, weathered surface. This basal layer is followed by some 10 m of light brown chert or jasper with several slaty intercalations, and with minor asbestos seams at the top (the Upper Asbestos Zone). Finally, the asbestos-bearing zone is overlain by the upper riebeckite slate, which is up to 100 m thick.

The upper riebeckite slate is blueish dark grey or black, and macroscopically structureless, but with a distinct micro-banding caused by grain-size and mineral composition variations. Mesobanding is seen in places. The uppermost part of the riebeckite slate succession passes into poorly bedded brown pelite and semipelite. This layer is sometimes siliceous, banded, and up to 5 m thick (e.g. farm Hakschin). It also displays slump structures and other features of synsedimentary deformation (e.g. farm Kwakwas).

Overlying the upper riebeckite slate are some 400 m of characteristic greenish rocks comprising homogeneous, non-stratified quartz-chlorite fels, finely laminated transitional types between quartz-chlorite fels and semipelite and, finally, intercalations of semipelite and argillite of red-brown colour. Cross lamination and oscillatory ripple-marks are found at various parts of the succession (e.g. specimen V 1501, farm Kwakwas).

Typical quartz-chlorite fels from the Lelykstaat-Grasgat boundary (specimen V 1284) is greenish-grey, fine-grained homogeneous and banded, only in some layers. It is composed of quartz, alkalic feldspar, oligoclase, abundant chlorite, frequent stilpnomelane and sericite. Calcite, dolomite, sphene, leucoxene, tourmaline, magnetite, hematite and limonite are accessory.

Rocks representing the transition from quartz-chlorite fels to common semipelite and argillite are banded, mostly composed of salic minerals and unevenly grained (bigger clastic grains in a fine-grained matrix).

Red-brown semipelite and argillite first occur in 1 - 10 m thick layers in the upper part of the succession of quartz-chlorite fels, these intercalations are present throughout the area between Grasgat in the north-west and Bultfontein, Bonfoi and Swaartpan in the east. In thin section semipelite and argillite are fine- to very fine-grained, heavily impregnated with hematite and limonite, and finely laminated (laminae less than 0,5 mm thick). The top of the upper quartz-chlorite fels is formed by a 15-50 m layer of poorly bedded red-brown semipelite.

The upper part of the Kwakwas Member (the third mappable unit in the Kwakwas sequence) starts with layers of dark brown semipelite, which is non-stratified, silicified in places, and sometimes ferruginous. It is up to 30 m thick and passes upwards into another layer of semipelite interbedded with cm - 10 cm bands of light grey, brown and red chert and quartzite. Arenaceous bands are also present. This layer is up to 25 - 30 m thick and well characterised by the presence of pseudoconglomerates (Figs. 11A, 11B, and 14) Further upwards in the succession (following 20 - 30 m) semipelite is intercalated with minor layers of impure carbonate (ochrous weathering, maximum thickness 50 cm), and with two bands of fine-grained calcareous sandstone up to 3 m thick; the weathered bedding surfaces of this sandstone have a characteristic metallic lustre.

The remaining few metres just below the Koegasputs Member are siliceous, jaspery and poorly bedded.

2.1.2.6.5.4. Jasper, slate, semipelite

The succession of the Koegas Formation described above is easily mapped south of latitude 29°10'. In the north, on farms Lelykstaat, Klein Witberg, Rooidam and, to some extent also on the farm Middelkop, the sequence of sediments between the banded iron-formation and the Koegasputs Mixtite Member becomes thinner, lithologically less variable and jaspery or ferruginous.

The transition between the two different Koegas lithofacies takes place in the southern part of the farm Klein Witberg, where the Westerberg Member becomes rather thin (up to only a few tens of metres), and where the other layers in the Koegas sequence are much more siliceous than in the south and south-east. In adjoining parts of Klein Witberg and Lelykstaat dark brown, yellow-brown and red jasper follows immediately above the banded iron-formation and, towards the top, it passes into a succession of siliceous slate with jasper and semipelite intercalations. The boundary between the jasper and banded iron-formation is defined by a distinct change from highly magnetic ferruginous rocks (the Weilbach Member) to almost non-magnetic siliceous and jaspery layers of the Koegas Formation.

Jaspers and similar siliceous rocks are also occasionally found south of latitude 29°10', where they sometimes occur at the base of the riebeckite slate of the Middelwater Member. They can be interpreted as a stratigraphic tongue or as a lentil of the main jasper succession and never become thicker than some 50 m (e.g. Westerberg).

2.1.2.6.5.5. Koegasputs Mixtite Member

The uppermost member of the Lower Griquatown group comprises limestone, magnesian limestone (V 1480 - Table 7) siliceous limestone, impure dolomitic limestone (V 1102 - Table 7), chert and mixtite. It occurs immediately below the base of the Ongeluk Volcanics in the Abramsdam, Paarde Vlei and Leelyksdam synforms. The thickness of the member is less than 65 m, and both its lower and upper limits are always distinct.

Limestones in the lower part of the member are light grey and often slightly brownish on weathered surfaces. Occasionally, limestone is intercalated with minor chert layers but more frequently the carbonate is siliceous and hard (e.g. Leelyksdam synform). At places the carbonate is rich in dolomite - e.g. specimen from Paarde Vlei, containing 54,1 per cent Ca,Mg $(CO_3)_2$ (Young, 1906). Columnar stromatolites up to 25 cm in diameter occur on the farm Kwakwas some 3 m below the top of the carbonate layer (Leube, 1964).

The thickness of the limestone varies between some 10-20 m and 50 m. The rock is usually overlain directly by mixtite but at some places in the Leelyksdam synform the two rock types are separated by less than 1 m of siliceous (jaspery) pelite and semipelite or by poorly bedded jasper (V 1468 - Kwakwas). Leube (op.cit.) reported that limestone layers are also intercalated in mixtite over a distance of several tens of metres on farm Swaartpan.

The mixtite, overlying the carbonate disconformably, is a poorly sorted, non-stratified or poorly bedded sediment containing clasts which are sometimes striated (glacial striation). It forms a layer up to 15 m thick (usually only up to 3 - 5 m), and comprises both coarser- and finer-grained types. No apparent regularity exists in distribution of these two varieties.

In both types of mixtite the coarser clastic material (pebbles, cobbles, and occasional boulders) is formed by harder rock types; chert, jasper, banded iron-formation, quartzite, sandstone, less frequent semipelite and occasional carbonate. The clasts are of variable size (from 0,5 to 15 cm in diameter) and of greatly variable shape. Where the ratio between the clasts and matrix is high, the pebbles and cobbles are mostly sub-rounded or rounded. In the matrix-rich layers of the finer-grained type of mixtite clasts tend to be angular or sub-angular. No visible preferred orientation of the coarser-grained clastic material was observed in the field, and the compositional, textural and structural variability is greater across the strata than along the strike.

The matrix of the mixtite is poorly sorted and of variable grain-size. Most frequently it is a fine- or medium-grained feldspathic and lithic sandstone, composed of abundant quartz and feldspar grains, of rock-fragments, and of less frequent chlorite, sericite, calcite and accessory opaque minerals. Although its colour is usually greenish light grey, yellow, brown and red stained types are also sometimes found.

Heterofacial intercalations in mixtite are represented by cm-dm layers of lithic sandstone and semipelite. Leube (1964) also reported two layers of lava which, on the farm Kwakwas, divide the mixtite horizon into three layers.

2.1.2.6.6. Ongeluk Volcanics

This sequence of andesitic volcanics, which overlies the Koegas Formation conformably, is exposed in three separate synforms; in the Abramsdam synform (Middelkop, Zwart Veld and Swaartpan), Paarde Vlei synform, and in the Leelyksdam synform. It comprises both amygdaloidal and non-amygdaloidal lava, tuff-lava, ash-flow tuff, tuff, and occasional tuffite. Minor layers of red jasper are also present. The maximum thickness in the area under consideration (600 - 700 m) represents only a portion of the thickness of the entire Ongeluk sequence.

Best exposures of the Ongeluk succession were found in the Paarde Vlei and Leelyksdam synforms; they indicate that the first several metres of the succession are usually composed of fine- or medium-grained lava, which is more often non-amygdaloidal than amygdaloidal. Near the base of the volcanic succession the lava is intercalated with an impersistent layer of poorly bedded bright red, red-brown or dark red jasper, which is only a few metres thick (The Grasgat Member). Above the jasper the succession becomes rather variable (a borehole drilled near the farm house Nuwevlei intersected alternating dm - m layers of lava, tuff-lava and coarse-grained pyroclastic rocks), and this lithological variability is rather common throughout the area. True igneous rocks have lesser extent than hitherto reported in the literature.

Both porphyritic and non-porphyritic types of lava were found, the former are represented by andesites with feldspar phenocrysts and microcrystalline mesostasis (V 1074 A - Poljaspoort), and by types with diabasic texture (V 1188 - Klein Witberg). Alteration of the volcanics is evidenced by the presence of ubiquitous epidote. Epidote, often associated with quartz, also fills minor and mesoscopic fractures up to several cm thick.

Since the lava exposures are usually covered by talus, primary structures are found only in a few places (e.g. pillows north-east of the old Koegasputs farmhouse).

2.1.2.7. The Matsap Formation

2.1.2.7.1. Introduction

Quartzites, grits, sandstones and conglomerates forming hilly ridges west of the Matsap Pan in the Hay District some 96 km north of Prieska were first described by Stow (1874) under the name of "Quartzite of Matsap and Langeberg". The same rock-types exposed in the Eselberge, a south-western continuation of Langeberg, were given the name Matsap Series and briefly described by Rogers and Schwarz in 1899. The first detailed characteristics of the Matsap Formation in its type area were presented by Rogers and Du Toit (1908, pp. 89-92). The Matsap sequence (then System) was subdivided into three parts;

(i)	Lower Matsap beds:	conglomerates and shale bands in quartzite and grit. Thickness more than 914 m (3000 feet);
(ii)	Middle Matsap beds:	basal conglomerate, altered lava, breccia, tuff, quartzite and grit. Thickness more than 1219 m (4000 feet);
(iii)	Upper Matsap beds:	purplish quartzite and grit, no shale. Thickness several thousand feet.

The structure of the Matsap Formation in the Eselberge was described as fairly complicated and repetition of certain layers explained by faulting and folding. The position of the Matsap Formation above the "Griqua Town Series" as well as its lithology were the main reasons for its correlation with the Waterberg sandstones of the Transvaal.

Detailed descriptions of the Matsap Formation were later given by Truter et al. (1938) and by Leube (1964). The classification and subdivision adopted by these authors is based on Rogers' results obtained from the mapping of the type area in the Langeberg hills.

UPPER MATSAP	Quartzose sandstone, subquartzose sandstone and lithic graywacke, all carrying scattered pebbles of quartz, banded iron-formation and red jasper. Frequent pebble "washes" along bedding planes. Conglomerate layers. Occasional layers of hematite-rich banded sandstone. No volcanics, no pelite.	4 000 - 5 000 feet 1 219 - 1 524 m
MIDDLE MATSAP	Andesitic lava, breccia, tuff and tuffarenite, minor sandstone, grit and conglomerate with rounded lava boulders and with clastic material from pre-Matsap formations.	2 000 - 4 000 feet 610 - 1 219 m
LOWER MATSAP	False-bedded pinkish to brownish coarse-grained sandstone; dark greenish-grey shale and dolomitic limestone up to 100 feet (some 33 m) thick; aluminous shale and basal conglomerate, both locally replaced by manganese ores.	3 000 feet 914 m
TYPE AREAS	Olifantshoek area (Geological Map, Sheet No. 173 Langeberg Eselberge	
REFERENCES	Rogers and Du Toit (1909) Truter et al. (1938) Du Toit (1939) Leube (1964) Haughton (1969)	
Note: for explanation see section 3.1.7.		

Table 12 Stratigraphy of the Matsap sequence (A compilation based on previous work)

2.1.2.7.2. Lithology

Of the three Matsap type areas (Table 12) the Eselberge and the southernmost part of the Langeberg fall in the area under consideration. The Matsap sequence in this area (Upper Matsap in Table 12) is intensely folded and, in the Eselberge, also intensely faulted. It is for this reason that the thickness estimate of some 1200 - 1500 m is unreliable.

The Matsap Formation overlies the Transvaal and Seekoebaard sequences unconformably. This unconformable relationship is well marked north of the Orange River whereas south of the river, and in the south-western part of Eselberge in particular, the boundary between the Matsap and Seekoebaard sequences is tectonic. A major zone of faulting and shearing separates the Matsap synclinorium of the Eselberge from the metamorphosed and structurally complex Kheis Group in the north-west.

Of the two Matsap sub-units shown on the map, quartzose sandstone, sub-quartzose sandstone and conglomerate (M_1) occupy the lower parts of the succession and occur in the synclinorial closures of Bo-Seekoebaard, Poljaspoort and Spitsrand. These rock-types occur also in parts of the Eselberge, where their presence is largely due to the intense folding and imbricate structure of the synclinorium. Such tectonic slices of quartzose and sub-quartzose sandstone are usually too small to be shown on the map.

The upper part of the succession consists of lithic sandstone, lithic greywacke and conglomerate (M_2), which occur in the Eselberge and in the northern part of the area.

The rock types in the lower unit are characterised by a prevailing light grey colour, by their high maturity, and by the quartzose and subquartzose composition. Conglomeratic layers in this sequence carry the same clastic material as the conglomerates occurring higher up in the succession (M_2), but have a better sorted matrix. Although quartz pebbles usually predominate over the other rock-types, at some places abundant volcanic material and red jasper from the Ongeluk Volcanics is present (e.g. V 944 some 2,6 km north-east of the Bo-Seekoebaard farmhouse). The maximum size of pebbles is 3 cm, their sphericity and roundness ranges from 0,4 to 1,0 and from 0,7 to 1,0 respectively

Quartzose sandstone (pure or lithic quartzarenite according to classification of Pei-Yuan Chen (1968) is light grey or slightly purplish in colour, medium-grained, and more often non-stratified than distinctly bedded. It is composed of 90 - 96 per cent quartz, half to two thirds of which occurs in grains bigger than 0,5 mm (maximum size some 1,5 mm). Rims of peripheral growth quartz are very common and 0,1 - 0,2 mm thick (e.g. V 905 - Lapberg). Rocks slightly lower in quartz contain also sericite (e.g. V 910 - some 2,6 km north-northwest of the Spitsrand farmhouse) and feldspar (V 918 - some 600 m north-west of the Spitsrand farmhouse). Rock fragments in the three above specimens are 0,1 - 2 mm in diameter and of very variable size; they are more frequently rounded than sub-rounded, and their sphericity is often higher than 0,4. Fragments include fine-grained carbonate rocks, calcareous sandstone, fine-grained semipelite and very fine-grained pelite, fine-grained quartz-feldspar aggregates (volcanic material), medium- and coarse-grained quartz-feldspar aggregates (probably intrusives), quartz aggregates with sutured grain boundaries and cataclasite. Most of the clasts are probably derived from the Transvaal sequence.

Bigger quartz pebbles, as well as rounded jasper and banded iron-formation pebbles are occasionally present in the lithic quartzarenite of Hardeberg (V 475), and in the easternmost part of the area. These pebbles are up to 3 cm in diameter.

Most characteristic rock-types of the Matsap Formation occur in the upper part of the succession, and comprise lithic sandstone with layers of subquartzose sandstone and lithic greywacke (Pettijohn, 1957, p. 291). They have a purple colour and carry various coarser clastic material in form of scattered pebbles,thin pebble "washes" and conglomeratic layers. Most of this coarser material originates from the underlying Transvaal sequence and comprises subangular to rounded pebbles of banded iron-formation, rounded and well rounded red jasper, and also chert, semipelite and carbonate. The size of pebbles in the conglomerates is variable, usually 6 - 8 cm; the maximum size recorded was 25 cm. In the pebble "washes" the pebbles are generally smaller (2 - 4 cm in diameter) and often display an imbricate structure.

Typical lithic greywacke or litharenite is represented by specimen V 514 from the Daskop-Seekoebaardsnek-Soutputs beacon. It is purplish light grey in colour, medium-grained, non-stratified, and carries abundant rock-fragments as well as clastic feldspars. Quartz is a major component (70 - 75 per cent of the litharenite). Sphericity and roundness of the clastic material are variable and sorting is poor. Among the heavy minerals tourmaline and hematite are the most common.

In some layers of the lithic sandstone hematite becomes so abundant that it constitutes some 55 - 60 per cent of a particular lamina. One such example is specimen V 570 (1,85 km south-east of the Daskop farmhouse), in which 1 - 25 mm thick hematite-rich layers alternate with 1 - 12 mm thick quartz-rich layers. While the hematite content varies between 1 - 2, 2 - 3, 10 - 20, 40 - 50 and 55 - 60 per cent in individual laminae, quartz forms 85, 80, 65 - 75, 50 - 55 and 30 per cent of these laminae respectively. The heavy mineral concentration increases with the increased percentage of hematite; rock-fragments, feldspar and sericite do not show any relation to the above systematic changes in modal composition.

All the Matsap rocks mentioned so far include types which are either undeformed or only partly cataclastic (less than 10 per cent crush matrix). In the Eselberge, however, there is ample evidence of more intense cataclasis associated with certain periods of deformation (see section 2.2.2.4.). Cataclasis and recrystallisation locally led to the development of thin dm - m layers of white secondary tectonic quartzite (e.g. farms Welgevonde and Waterford immediately north of the area under consideration).

2.1.2.8. Intrusives of various ages

2.1.2.8.1. Hardeberg Granodiorite

This granitoid occurs at the foothill of the Hardeberg some 5,5 km north-east of the Bo-Seekoebaard farmhouse. It is light grey and grey in colour, medium- to coarse-grained, and generally homogeneous. In thin section the granodiorite has a cataclastic texture and its individual minerals are slightly unevenly distributed. It also displays lattice-preferred orientation of groups of quartz grains. Feldspars are affected by an intense alteration which almost completely obliterates the polysynthetic twinning of plagioclasse. Quartz-feldspar symplectite is also present. Intensely chloritised biotite is accompanied by some epidote, and by accessory sphene, leucoxene, magnetite and limonite.

The marginal parts of the Hardeberg Granodiorite are sheared, gneissose, and rich in epidote. In thin section these rocks sometimes display a blastomylonitic texture characterised by lens-shaped quartz-feldspar aggregates, 2 - 3 mm long, separated by a fine-grained mylonitic matrix (V 480). Preferred orientation is somewhat less distinct in thin section than in hand specimen.

Although the contact zone between the granodiorite and neighbouring Matsap rocks is covered by sand and scree, the mode of occurrence and type of tectonic involvement of the granodiorite points to a possible post-Matsap age.

2.1.2.8.2. Mafic and ultramafic dykes, sills and sheets

Two different groups of these rocks are shown on the map (Annex. 1):

(i) gabbro, diabase, amphibolite;

(ii) dolerite.

Among the rock-types of the first group diabase is the most common and occurs in all the major lithological units described above. It forms both dykes and sills, the latter being confined mostly to the Transvaal sequence. Diabase sheets and amphibolite layers, characterised by a moderate to steep dip and by discordant relationship to the neighbouring rock units, were emplaced along some of the faulted lithological boundaries (e.g. in the Kheis Group).

Most of the diabase dykes are concentrated in three swarms, one of which comprises smaller and generally shorter bodies striking north-westerly; this swarm occurs in the Draghoender Granite and partly also in the Skalkseput Granite. The other two swarms appear on either side of the Doringberg fault and comprise dykes of considerable length and of slightly changeable strike (north-westerly in the south, north-northwesterly to northerly in the north). A few diabase dykes in the Koegasbrug area have an almost east-west strike.

Diabase dykes in the swarms differ in the intensity of their recrystallisation. In the eastern two swarms the alteration is often weak and does not obliterate the primary diabase texture. Minerals such as chlorite, epidote, clay minerals, calcite, serpentine, chrysotile and talc are developed. In the westernmost swarm at least some of the rock types display a metamorphic texture and contain large amounts of hornblende which partly or almost completely replaces pyroxene (e.g. V 2990 - farm Roosterpoort).

Apart from the swarms a few solitary diabase bodies occur in the Groblershoop Formation, in the Draghoender and Skalkseput Granites, and also in the Matsap Formation. The first group is represented by several dykes and sheets exposed north of the Eselberge and these diabase bodies exhibit effects of intense shearing and recrystallisation (diabasic texture almost obliterated - V 60, 3,5 km north-west of the Buchuberg Dam). It should be noted that these dykes differ from the few amphibolite dykes which also cut the Groblershoop Formation, but which are foliated parallel to the regional foliation in the Kheis sequence; an example is a dyke, some 5 m thick, exposed 1,5 km south of the village of Buchuberg (V 154 north of the area shown on the geological map in Annex. 1)

The second group comprises north-easterly striking dykes (usually N 20°E) on the farms Greeffsput, Soutputs, Springputs and Witvlei.

Diabase dykes, sills and sheets in the Matsap Formation are confined to the area north of the Orange River. Although only the two biggest bodies are shown on the map (Annex 1), several others can be found at various places in both the well exposed and sand covered parts. Diabase is moderately to intensely altered, sometimes rich in epidote, chlorite and calcite (V 495 some 5,7 north-east of the Seekoebaardsnek farmhouse).

Several thicker diabase sheets are intruded in the Waterval Member of the Seekoebaard Formation south of the Buchuberg Dam. They comprise rocks which are remarkably fresh and hard in hand specimen, but intensely altered when examined in thin section. The main constituents of the diabase are augite and saussuritised plagioclase, whereas hornblende, biotite, chlorite, accessory quartz, ilmenite, sphene and leucoxene are less important. The diabase, most probably of post-Matsap age, is affected by a cataclastic deformation (V 204, 1,75 km south of the Buchuberg Dam). An isolated diabase outcrop some 6 km south-east of the Ezelklaauw farmhouse (V 3253) possibly belongs to the same group of intrusive diabase.

Mafic dykes which occur in the north-wester part of the farm Skalkseput, are coarser-grained and much less altered than the common diabase described above. Their main constituents, plagioclase An_{60-65} and augite, are accompanied by green hornblende, some olivine and accessory biotite. Common opaque minerals (ilmenite, magnetite) are also present. It is obvious that this rock type described as hornblende-augite picrite by Rogers and Du Toit (1908, p. 44) represents rather a gabbro or an olivine gabbro.

Orthoamphibolite which has also been grouped with the mafic dykes and sills occurs along some lithological boundaries (quartzite vs. quartz-sericite schist) and in minor shear zones in the Kheis Group. The former type is represented by a medium-grained amphibolite on the farm Allenrust (V 3337). The Khaboom amphibolite forms sheets which strike parallel to the regional foliation in the Kheis Group and display a typical metamorphic texture (granonematoblastic) with sieve texture of some feldspars. The rock consists of a medium-grained, hornblende-rich "matrix", in which streaky aggregates and porphyroblasts of plagioclase up to several mm long are present (V 3277-8 some 1,7 km south-east of the Khaboom farmhouse).

The Allenrust sheet, which is lithologically similar to the Khaboom amphibolite, has been affected by later shearing resulting in retrograde metamorphism.

Dolerite dykes and *picrite* sheets occur mostly in the western part of the area on the farm Putsonderwater west of the Kaaien Hills, north-west of Draghoender and on the farm Keukendraai. They strike north-easterly or north-northwesterly and are only a few metres thick. For this reason only the thickest and most important bodies are shown (i.e. one of the Draghoender dykes and the sheets on the farm Keukendraai). All these occurrences were briefly described by Rogers and Du Toit (1908); the Keukendraai sheets were grouped with picrites of post-Kheis age.

On the accompanying map the Keukendraai picrite (abundant olivine, small amount of plagioclase) has been grouped with dolerite mainly because of its absolutely fresh, unaltered nature, which indicates that the rock has not undergone the pre-Karoo alteration which is typical for the common post-Matsap diabase dykes.

2.1.2.8.3. Kimberlite

Kimberlite pipes are confined to the area north of the Orange River. One of the pipes cuts through the silicified limestone of the Koegasputs Mixtite Member on the farm Kwakwas, the other two occur in the Ongeluk Volcanics on the farm Groot Witberg. One of the latter pipes has been located during the present investigation. All the pipes are only a few metres in diameter, and are deeply weathered.

2.1.3. The Kheis Group

2.1.3.1. General

The name of the Kheis Group is derived from a place on the Orange River, some 90 km south-east of Upington. Kheis (or 'Kheis) is a Hottentot word for a drinking place of animals in the Orange River. It was first used by Stow (1874) for the quartzite, quartz-sericite schist and mica schist exposed at the type locality, and between Kheis and Langeberg; on Stow's map the unit appears as the "Micaceous and schistose rocks of 'Kheis". Similar rock-types which occur in the area south and south-south-east of Kheis were later mapped by Rogers and Schwarz (1899), and grouped together with Stow's 'Kheis under the name "'Kheis Series". In 1907 work in the Hay and Gordonia Districts proved that the Kheis rocks extend far north of the Orange River (Rogers, 1907, pp. 15-22), and in the same year a sequence of sheared sediments and lavas of the Wilgenhout Drift Series was first described (op. cit., pp. 35-42). In 1908 further work in the area south of the Orange River showed that the "'Kheis Series" is underlain by a succession of basic lavas, and new names "Kaaien Beds" and "Marydale Beds" were proposed for the two units. These two were then included in a new stratigraphic unit - the Kheis Series (Rogers and Du Toit, 1908, pp. 8-15). In 1909 the Wilgenhout Drift Series was examined in greater detail, and it was found to overlie the Kaaien Beds conformably. Consequently, the Wilgenhout Drift sequence was included in the Kheis Series and given the rank of "Beds".

The subdivision and nomenclature of the Kheis Group as proposed by Rogers and Du Toit was retained by later workers; the only changes adopted since concerned the usage of the terms "System" and "Series" instead of the older "Series" and "Beds" respectively.

Although the original descriptions of Rogers and Du Toit are detailed and comprehensive, a revision of the Kheis stratigraphy and an adequate definition and description of the sequence in terms of present standards of stratigraphic classification are needed. First steps taken in this respect are (a) a redefinition of the type area and (b) a revision of the Kheis stratigraphy in the newly-designated type area.

The type area of the Kheis Group has never been defined accurately. Nearest to an acceptable definition is probably the map showing the distribution of the Kheis sequence in parts of the northern Cape between the 21°meridian in the west, the Karoo boundary in the south, and the boundary of the younger sequences in the north and north-east (Rogers, 1910, Plate X). Both the map and the original descriptions indicate, however, that in the western part of the area the Kheis occurs only in isolated outcrops within the granitoids and gneisses of the Namaqualand

Metamorphic Complex. It is also known that west of the Kaaien Hills the exposures are often poor and scarce. It should be noted that the most important parts of the original descriptions by Rogers and Du Toit deal mainly with the area of the Kaaien Hills and the country east of it. The newly designated type area of the Kheis (Fig. 5) therefore includes these parts only. This means that the proposed new western boundary of the type area corresponds to the western boundary of the main outcrop of the Kaaien Formation (western slope of the Kaaien Hills). It is also suggested here that the Orange River valley between Buchuberg and Straussburg should be taken as the approximate new northern boundary of the type area.

The classification and nomenclature of the Kheis Group as proposed here (Table 13) is based partly on the author's own knowledge of the newly designated type area, and partly on the published data of previous work. In accordance with the South African Code of Stratigraphic Terminology and Nomenclature (1971) the Kheis can be given a rank of Group, and individual parts of the sequence a rank of Formation or Member. One major and several minor changes are proposed, the former being the introduction of a new lithostratigraphic unit with the rank of formation (the Groblershoop Formation), and the latter expresses the need for more detailed subdivision of the existing formations into individual members.

2.1.3.2. The Marydale Formation

2.1.3.2.1. Introduction

The name was given to the unit by Rogers and Du Toit (1908, p. 10) after the village of Marydale, which is built in part on the amphibolites and hornblende schists of this sequence. In their first descriptions Rogers and Du Toit (op. cit., p. 19) defined five sub-areas where the Marydale was found:

(i) the farm Blouputs some 24 km north of Marydale;

(ii) the Brulpan - Marydale - Stuurmansput belt;

(iii) Swartkop some 14 km north of Marydale;

(iv) several localities between the Doringberg fault in the north-east and the outcrop of the Kaaien Formation in the south-west;

(v) the Vaalberg - Groot Modderfontein - Soetvlei belt.

In 1909 metamorphosed supracrustal rocks occurring in the Namaqualand Metamorphic Complex west of the main ridge of the Kaaien Hills were "placed in the Marydale Group on account of their resemblance in petrological character to rocks included in that group" (Rogers and Du Toit, 1909, p. 17). These, however, are not dealt with here because they fall outside the type area of the Kheis; their description is given in section 2.1.4.

According to the original description the Marydale comprises a considerable variety of metasediments (quartzite, meta-arkose, slate, marble), and metavolcanics of different composition. However, the lithological variability becomes less apparent when each of the five originally defined sub-areas is examined separately. In fact, two types of sequence can be recognised in these sub-areas, which differ, to some extent and can therefore be given the rank of member. The *Groot Modderfontein Member*, possibly the older of the two, occurs in sub-areas (iii) and (v). The other, the *Stuurmansput Member*, is confined to sub-areas (ii) and probably (iv). The sequence in the remaining sub-area cannot be correlated with the Marydale (pp. 34-36).

2.1.3.2.2. The Groot Modderfontein Member

This member is exposed outside the area under consideration, and occurs over a distance of some 70 km between Witfontein in the north-west and Soetvlei in the south-east (Fig. 5). The outcrops in this belt are often limited and far apart, particularly between Groot Modderfontein and Soetvlei. The maximum width of the belt does not exceed some 10 km. The sequence as originally described starts with "a considerable thickness of arkose with some grits and phyllites, which is followed by sheared igneous rocks, for the most part probably of volcanic origin, varying in composition from acid to ultrabasic" (Rogers and Du Toit, 1908, p. 19). The amygdaloidal structure of the metavolcanics is well preserved at places.

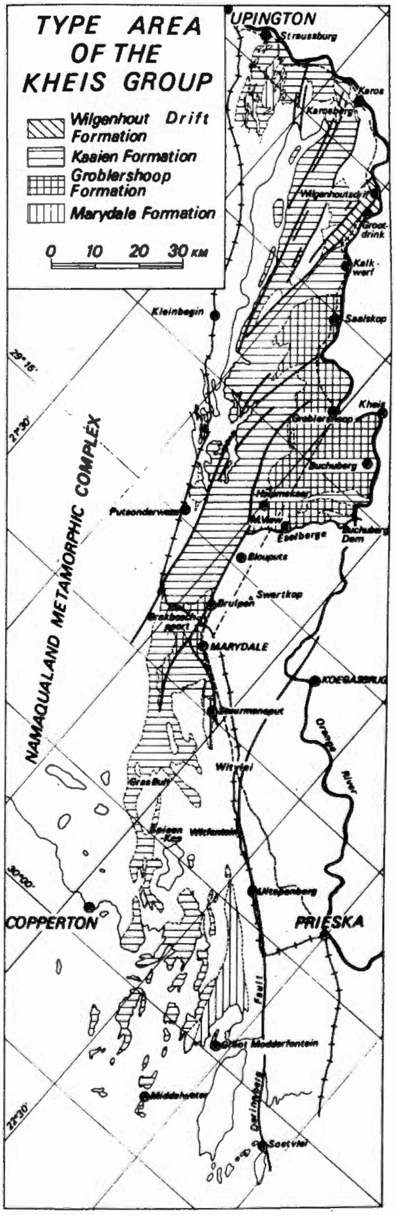

Fig. 5

The most characteristic rock type which is intercalated with the metavolcanics, is a magnetite quartzite. The quartzite forms one to three layers, totalling 200 - 250 m, and occurs at various places in the belt. Almost everywhere in the belt the quartzite is accompanied by a very thin layer of marble.

Both the metavolcanics and the magnetite quartzite are intruded by a variety of ultrabasic igneous rocks, most of which are altered. Later intrusives represented by granite and pegmatite veins are numerous between Groot Modderfontein and Uitspanberg. On Soetvlei only one place has been found where granite is in contact with the metavolcanics, but the boundary is most probably tectonic. No granite was found cutting the magnetite quartzite.

2.1.3.2.3. The Stuurmansput Member

The main outcrop of the Marydale Formation in the area under consideration is some 30 km long, stretching from the farm Brulpan in the north-west to Stuurmansput in the south-east. Between Brulpan and Stuurmansput the outcrop is 150 - 400 m wide and follows the south-western contact of the Draghoender Granite. Xenoliths of rocks which are correlated on lithological grounds with the Marydale Formation *sensu stricto* are present in the Draghoender Granite only a few tens of metres east of the main Kheis outcrop. Layers of the Marydale amphibolite are also present on the farm Irene, 7 - 10 km south and south-east of Marydale, and on the neighbouring farm Rooidam, some 6 - 9 km south of Marydale.

The most frequent rock-types in the Stuurmansput Member are metavolcanics represented mainly by amphibolite and hornblende schist. Interbedded with the metavolcanics are a few thin layers of porphyry, minor marble lenses less than 1 m thick, light grey leucogneiss and leptite, grey or dark grey arkosic metaquartzite, and also thin layers of cherty magnetite quartzite.

The sequence is often intruded by a variety of mafic rocks, some of which are altered. Minor pegmatite veins are also present, but no intrusive rocks which might be older than the sequence have been found.

2.1.3.2.3.1. Metavolcanics

The least metamorphosed rocks of this group are amphibolites and hornblende schists occurring north-west of Marydale. They consist of green hornblende, actinolite, a small amount of plagioclase, quartz, some microcline, and accesory magnetite and sphene. Epidote, chlorite and calcite are found both in the matrix and in minor veinlets. The most interesting are amphibolite bands with relict amygdaloidal texture, amygdales being usually composed of quartz.

South-east of Marydale and on the eastern part of the farm Stuurmansput the amphibolite is usually fine-grained, contains quartz and displays the amygdaloidal texture only in places.

Stratigraphic unit			Lithology	Maximum estimated thickness
Kheis Group	Wilgenhout Drift Formation		phyllite, schist, sheared tuff, quartzite with hematite-rich layers, dolomite, calcareous argillite, green diabasic lava, conglomerate porphyry	2 000 m
	Kaaien Formation		quartzite, minor quartz-sericite schist	1 000 - 2 000 m
	Groblershoop Formation	Helpmekaar Member	quartz-sericite schist, minor quartzite, magnetite-rich bands	150 - 200 m
			quartz-sericite schist, mica schist, minor quartzite	1 500 m
		Mountain View Member	quartz-sericite schist, epidote-chlorite schist, tremolite-actinolite schist	200 - 300 m
	Marydale Formation	Stuurmansput Member	amphibolite, hornblende schist, minor leptite, leucogneiss and granulite, occasional felsitic porphyry	500 - 1 000 m
		Groot Modderfontein Member	sheared metavolcanics with intercalations of magnetite quartzite. Arkose, grit, phyllite	1 000 m

Table 13 Subdivision and nomenclature of the Kheis Group

A typical representative of this group is a dark green amphibolite (V 2586) which is well foliated and displays a distinct mineral lineation on foliation planes. Clusters and aggregates of quartz grains up to 3 mm in size occur in a hornblende-rich matrix, the texture of which is inequigranular, granoblastic. In some cases quartz-feldspar bands separate those rich in hornblende, the former sometimes displaying a "granulitic" texture with quartz grains elongated parallel to the mineral banding (specimen 6705 from the A. Poldervaart collection).

In the western part of the farm Stuurmansput and on the farms Irene and Rooidam the difference in grain-size between hornblende-rich and quartz-feldspar-rich bands becomes less distinct; the amphibolite is usually coarser-grained and on Stuurmansput carries clinopyroxene and/or large porphyroblasts of pale red garnet. The most common size of the porphyroblasts is 5 mm, the maximum recorded size is 25 mm. The garnet porphyroblasts are poikiloblastic ("sieve" structure) and carry minute quartz>hornblende> plagioclase inclusions. The inclusions are remarkably scarce in the marginal zone of porphyroblasts which, in some cases, is up to 0,5 mm wide (V 2605).

Mineral composition of various types of the Marydale metavolcanics (Table 14) and their chemical composition (Fig. 6) will be briefly discussed in section 3.1.2.

2.1.3.2.3. Heterofacial intercalations

Rock-types other than amphibolite and hornblende schist are scarce in the sequence. They occur south-east of Marydale and also on the farm Stuurmansput[1]; the former locality is described in detail by Rogers and Du Toit (1908, pp. 34 - 36) and thin layers of "marble", "felsite" (porphyry), "grey slates" (sheared metavolcanics), "quartzite" and "mica schist" (probably an infold of the Groblershoop Formation) are reported.

On the farm Stuurmansput the intercalations in the amphibolite and hornblende schist consist of leucogneiss and impure quartzite, both of which occur between the farmhouse and the north-western farm boundary. The intercalations are very thin (a few decimetres only) and discontinuous.

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[1] The original farm Stuurmansput has been divided into several parts, some of which were given new names (e.g. Irene, Happy Valley etc.). The present farm Stuurmansput is in the north-eastern portion of the original farm Stuurman's Put mentioned many times in reports by Rogers and Du Toit.

Specimen no.	2586	2605	4349	4350	4352	4370	4372	4373	4374	4375	4376	4377	4378
Locality	Stuurmansput												Marydale
Rock unit	Stuurmansput Member (Marydale Formation)												
Rock type	Quartz amphibolite	Garnet amphibolite	Plagioclase - actinolite fels	Garnet-biotite leucogneiss	Hornblende gneiss	Quartz amphibolite							
Amphibole	57,4	64,4	28,2	+	17,6	65,9	49,1	54,9	42,9	62,5	58,2	70,4	78,9
Quartz	20,8	13,8	37,5	43,4	42,9	21,8	32,9	32,0	36,8	16,0	22,0	17,2	11,0
Plagioclase	20,6	12,3	23,2	17,9	16,7	8,9	14,6	7,9	14,0	9,3	13,2	3,8	0,8
K-feldspar	+	+	6,2	29,7	10,9	1,3	0,5	2,0	2,1	0,5	2,4	1,5	+
Biotite	-	-	0,5	2,7	0,3	-	-	-	-	-	-	-	-
Muscovite	-	-	-	0,8	0,5	-	-	-	-	-	-	-	-
Sphene	+	+	-	-	0,9	0,2	0,1	+	-	1,8	1,7	1,0	-
Leucoxene	-	-	-	-	1,3	+	+	-	-	+	+	+	-
Magnetite, titanite	+	0,3	3,8	3,3	1,8	1,8	2,8	3,0	3,9	+	2,3	1,4	3,6
Hematite, limonite	-	+	-	+	+	-	-	-	-	-	-	-	-
Zircon	-	-	-	+	-	-	-	+	+	-	-	-	-
Apatite	+	+	+	+	-	-	-	-	+	-	+	+	-
Epidote	+	-	-	-	7,1	-	+	-	-	+	+	+	5,6
Chlorite	+	-	0,6	-	-	-	-	-	-	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	-	+	-	9,8	-	4,4	+
Garnet	-	7,3	-	1,8	-	-	-	-	-	-	-	+	-
Total	98,8	98,1	100,0	99,6	100,0	99,9	100,0	99,8	99,7	99,9	99,8	99,7	99,9
Points counted	1193	1873	1200	1432	1232	1691	1835	1845	2371	1723	1743	1459	1558
Length measured (mm)	397,6	624,3	400,0	477,3	410,6	563,6	611,6	615,0	790,3	574,3	581,0	486,3	519,1

Table 14 Modal analyses of some rock types of the Marydale Formation

A specimen of the leucogneiss (V 2628) consists of quartz, microcline and biotite, and its texture is granoblastic, inequigranular, characterized by polygonal grain boundaries. Megacrysts and aggregates several mm long are formed by quartz and feldspar, and occur in an evenly grained matrix, in which the grain size is usually less than 0,5 mm. Indistinct foliation is defined by a weak mineral banding (biotite). Another specimen (V 4350 in Table 14) is characterised by the presence of plagi[illegible]lase and garnet.

A specimen of the impure quartzite (No. 6711 in the A. Poldervaart's collection) consists mainly of quartz, but plagioclase, K-feldspar and biotite are abundant, muscovite and garnet occasional and common accessories are present. The texture of the quartzite is granoblastic, inequigranular (clusters and bigger quartz grains as well as plagioclase porphyroblasts).

2.1.3.3. The Groblershoop Formation

2.1.3.3.1. General

The name of the unit is derived from a village on the southern bank of the Orange River some 88 km south-east of Upington. The type locality is in the north-eastern part of Sheet 2821 DD (Groblershoop) and along the Orange River between Buchuberg and Saalskop (Fig. 5).

The unit comprises quartz-sericite schist, mica schist and minor quartzite, a succession previously included in the "Kaaien Beds" as first defined by Rogers and Du Toit (1908). In the stratigraphic sequence of the Kheis Group the Groblershoop Formation occurs above the Marydale Formation and below the Kaaien Formation (below the main quartzite sequence).

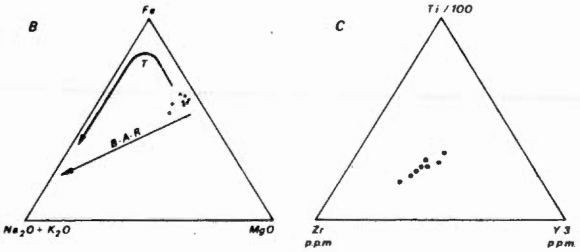
The Groblershoop Formation is extensively developed in the north-eastern and central parts of the Kheis outcrop (Fig. 5) and its thickness there exceeds 1000 m. Its great extent is also due to the repetition of individual layers by folding. In the south-east (south of 29°15' parallel) the thickness of the Groblershoop Formation decreases rapidly, and the quartzites of the Kaaien Formation are often separated by only a few metres of metapelite from amphibolite of the Marydale Formation.

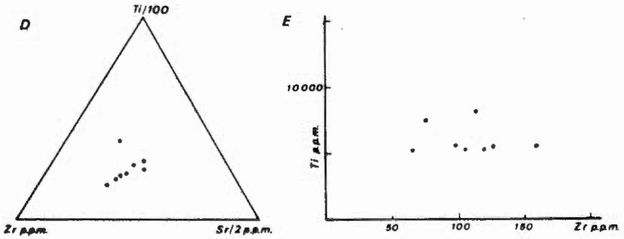
The stratotype of the unit is the sequence of quartz-sericite schist, mica schist and minor quartzite on both sides of the Orange River between Buchuberg and Saalskop. In the south-east the unit is bounded by a tectonic zone, which runs on the north-western side of the Eselberge, and separates the Kheis Group from the Matsap Formation. In the west the extent of the Groblershoop Formation is bounded by the western slope of the Kaaien Hills. East of the Kaaien Hills the unit is confined to the lower ground and, away from the Orange River, it is poorly exposed. In the Kaaien Hills the unit occurs in poor exposures in the central parts of

Specimen no.	4370	4372	4373	4374	4375	4376	4377	4378
SiO_2	56,28	55,32	57,70	62,43	52,64	52,73	50,71	48,44
TiO_2	0,95	0,93	0,88	0,89	0,90	0,94	1,27	1,39
Al_2O_3	13,80	14,88	15,44	13,84	13,84	14,89	13,66	14,00
Cr_2O_3	0,02	0,03	0,03	0,02	0,03	0,03	0,02	0,04
Fe_2O_3	4,01	4,55	4,05	3,72	5,44	4,49	4,54	5,05
FeO	6,88	6,29	5,90	5,17	6,14	7,04	9,59	10,15
MnO	0,18	0,19	0,17	0,14	0,23	0,19	0,24	0,25
MgO	5,04	4,79	3,67	3,43	5,33	5,34	6,62	6,39
CaO	8,98	11,23	9,98	8,43	12,69	11,75	11,10	10,56
Na_2O	1,94	0,63	0,72	1,31	0,55	0,53	0,78	0,73
K_2O	0,40	0,34	0,21	0,16	0,34	0,11	0,26	0,29
P_2O_5	0,11	0,14	0,22	0,11	0,17	0,16	0,11	0,14
L. O. I.	0,337	0,463	0,252	0,262	0,980	0,338	0,438	1,401
H_2O^-	0,243	0,039	0,033	0,024	0,022	0,010	0,038	0,043
Total	99,53	99,822	99,849	100,463	99,302	98,548	99,376	98,874
Nb (p.p.m.)	3,1	3,9	4,5	5,7	n.d.	2,0	n.d.	6,1
Zr (p.p.m.)	101	116	124	169	65	98	76	112
Y (p.p.m.)	23	24	23	23	22	24	27	26
Rb (p.p.m.)	4,9	3,2	3,0	3,1	13	n.d.	4,5	2,2
Sr (p.p.m.)	159	150	154	182	132	241	86	195

n.d. = not detected

The ferrous iron in the samples was determined by a standard wet chemical technique and the ferric iron calculated from the total Fe present by difference





A - analytical results (samples 4370 - 4378 correspond to the same numbers in Table 14)

B - Fe - $Na_2O + K_2O$ - MgO diagram (B - A - R = basalt - andesite - rhyolite association; T = tholeiitic flood basalts); crystallisation trends (thick lines) after Hyndman (1972, p. 80)

C - Ti/100 - Zr - Y.3 diagram (cf. Pearce and Cann, 1973, Fig. 3)

D - Ti/100 - Zr - Sr/2 diagram (cf. Pearce and Cann, op. cit., Fig. 4)

E - Ti - Zr diagram

Fig. 6

Chemical composition of eight samples of the Marydale amphibolites broad domal structures. There are a few places east of the main ridge of the Kaaien Hills where the Groblershoop rocks are overlain by Kaaien quartzite; the most prominent among these synformal relicts is the quartzite of Luisdraai se Berge some 17 km south-east of Groblershoop.

Quartz-sericite schist and schistose quartzite also occur on Marydale Commonage in the triangular area bounded by the Brulpan fault in the west, by the outcrop of the Marydale Formation in the north-east, and by several minor faults in the south.

The unit can be subdivided into three lithologically different sub-units, two of which can be given a rank of member.

2.1.3.3.2. The Mountain View Member

This unit occupies a strip 6,1 km long and up to 1,2 km wide between the Maraisdraai farmhouse in the north-east and the Mountain View farm boundary about 1 km south-west of the farmhouse in the south-west (part of the sequence is hidden under Karoo and superficial deposits) and may represent a transition zone between the metavolcanics of the underlying Marydale Formation and the metasediments of the Groblershoop Formation. Rock types found in this sequence are epidote-chlorite schist (V 400), calcite-epidote-quartz-chlorite schist (V 403), and tremolite-actinolite schist interbedded with quartz-sericite schist. The first three rock-types, described by Rogers and Du Toit (1908, p. 40) as "hornblendic rock" or "hornblende schist", probably represent sheared and retrograded metavolcanics.

In the eastern part of the Kaaien Hills (farms Stillerus and Boesmanshoek) correlates of the Groblershoop Formation are interbedded with greenish grey hornblende schist (V 3460) in which the matrix is fine-grained and quartz-rich, the hornblende forms porphyroblasts which are sometimes almost euhedral and often more than 5 mm long (maximum length recorded was 9 mm). The hornblende is green, remarkably tabular and the structure of its poikiloblastic inclusions indicate that the porphyroblasts are mostly post-kinematic (Plate 8.2.)

On Marydale Commonage the boundary between the Marydale Formation and the quartz-sericite schist of the Groblershoop Formation is more distinct than farther in the north and only a few metres of the sequence may belong to the Mountain View Member. The boundary is apparently sheared and occupied by numerous quartz veins.

2.1.3.3.3. The main Groblershoop sequence

The main part of the Groblershoop Formation above the Mountain View Member is most probably some 1000 m thick and comprises rock-types which, apart from quartz, sericite and muscovite, also carry variable quantities of feldspar, garnet and biotite. The texture of these rocks is lepidogranoblastic and granoblastic. Some relict sedimentary structures, however, are still present (e.g. cross-bedding at some places in the Orange River valley

Specimen no.	400	403	3460	186B	3314	374	3208	3621	2736	3054	2912
Locality	Mountain View		Stillerus	Buchuberg	Keukendraai	Buchuberg	Helpmekaar	Koegrabie	Marydale	Blouputs	Brulpoort
Rock unit	Groblershoop Formation							Groblershoop (?) migmatites			Kaaien Formation
	Mountain View Member						Helpmekaar Member				
Rock type	Epidote-chlorite schist	Calcite-epidote-chlorite-quartz schist	Hornblende schist	Garnet-quartz-muscovite schist	Garnet mica schist	Sericite quartzite	Magnetite quartzite	Biotite-muscovite gneiss	Biotite gneiss	Muscovite - quartz schist	Felspathic sericite quartzite
Quartz	26,5	37,0	40,3	37,0	38,6	86,8	81,5	34,6	43,6	73,2	80,0
Plagioclase	3,0	6,2	5,5	4,2	2,1	+	0,6	22,1	8,4	4,9	2,4
K-feldspar	+	+	-	-	-	-	-	?	36,6	8,5	7,2
Biotite	11,0	-	4,7	2,6	+	-	-	14,6	10,6	-	-
Muscovite	-	-	7,3	48,9	51,6	13,1	7,6	22,2	-	12,1	8,7
Garnet	-	-	-	4,4	3,4	-	-	-	-	-	-
Amphibole	+	-	30,6	1,1	1,8	-	-	-	-	-	-
Chlorite	34,0	31,4	+	+	1,2	-	+	+	-	-	-
Epidote	21,7	22,0	9,5	-	-	-	-	5,5	-	-	-
Sphene	+	3,1	+	-	-	-	+	-	0,3	-	-
Calcite	-	+	-	-	-	-	-	-	-	-	-
Apatite	-	-	+	-	+	-	-	-	+	-	-
Zircon	-	-	+	+	+	-	+	-	+	-	-
Magnetite	3,8	+	1,8	1,7	0,4	+	10,3	0,8	0,2	0,1	-
Hematite, limonite	+	+	+	+	0,6	+	+	+	+	1,1	1,7
Total	100,0	99,7	99,7	99,9	99,7	99,9	100,0	99,8	99,7	99,9	100,0
Points counted	1194	1487	1739	1843	1969	1523	1575	1897	1838	1563	1588
Length measured (mm)	398,0	495,6	579,6	614,3	656,3	507,6	525,0	632,3	612,6	521,0	529,3

Tab. 15 Modal analyses of some rock types of the Groblershoop and Kaaien Formations

3 - 10 km north-west of the Buchuberg Dam).

The boundaries of this sequence with the underlying Mountain View Member and with the overlying Helpmekaar Member are transitional. The boundary stratotype for the lower limit is on the farm Mountain View, and for the upper limit in the western part of the farm Helpmekaar. The reference-stratotype for the upper limit is in the area of the Luisdraai se Berge.

2.1.3.3.4. The Helpmekaar Member

This member is confined to the areas in the vicinity of the base of the main quartzite sequence (close to the eastern margin of the Kaaien Hills) and its thickness is probably 100 - 200 m. The most characteristic feature of this member is the predominance of quartz-sericite schist and minor quartzite, and the presence of magnetite-rich layers. These are from a few mm to several cm thick and occur in two horizons which are not widely separated. Magnetite-rich bands however occur also in the lowest layers of the Kaaien Formation on Luisdraai se Berge. A marked characteristic of the magnetite-rich bands is that they resemble clastic metasediments which differ from the cherty ferruginous layers encountered in the Marydale Formation.

The boundary with the Kaaien Formation is generally distinct especially at places where the Groblershoop Formation has been migmatised (e.g. Brakboschpoort). The upper limit of the Groblershoop Formation should therefore be defined by the top of the last metapelite layer (top of the last schistose layer under the main quartzite sequence).

2.1.3.3.5. Possible correlates of the Groblershoop Formation

West of the main outcrop of the Groblershoop Formation mica schist, quartz-sericite schist and minor quartzite occur in the depressions of the Kaaien Hills. They are usually poorly exposed and, towards the south, they grade into gneisses, augen gneisses and migmatites, the latter two being particulartly frequent on the farms Brakbos, Brakboschpoort, Rooidam and Irene, and on the south-western part of Marydale Commonage and Stuurmansput.

The northernmost occurrence of rock types of this group is situated some 4 - 6 km north-east from the Koegrabie railway-station close to the eastern margin of the Namaqualand Metamorphic Complex. Quartz-sericite schist and mica schist in this occurrence pass into a biotite-muscovite gneiss which is well exposed on the northern margin of a large pan some 4,5 km east-north-east of Koegrabie. The gneiss is medium- to coarse-grained, rich in quartz and feldspar, (Table 15) and displays indistinct mineral banding (biotite-rich bands are 1 - 12 mm thick). No dimensional preferred orientation of minerals can be seen in thin section (V 3621) and even muscovite and biotite are oriented randomly. Of the two micas biotite is the bigger, often forming porphyroblasts up to 10 mm long. It is largely chloritised, chlorite pseudomorphs being accompanied by numerous small epidote grains. Quartz-epidote veinlets of various orientation and thickness are seen in outcrop.

Another locality where the affinity of the migmatised rocks with the Groblershoop Formation can be documented is situated some 3,5 - 2,7 km west-northwest from the Blouputs farmhouse. Here the schistose rocks underlying the Kaaien Formation become coarser downwards in the succession and are often homogeneous in detail (in hand specimen). On a larger scale, however, the amount of leucosome is very variable and the mineral banding is distinct. The sequence is penetrated by numerous aplitic veins emplaced along the foliation planes and interbedded with minor quartzite layers less than 2 m thick. The mineral composition of the schistose rocks is generally simple (V 3054 in Table 15) and the texture is granolepidoblastic or lepidogranoblastic.

At some places south of the 29°15' parallel the gneisses display boulder weathering and their parallel texture (mineral banding) becomes indistinct. A representative specimen of gneiss collected some 2 km south-east of the Brulpoort farmhouse (V 2703) is light-grey, medium-grained, and rich in feldspar. It consists of quartz, abundant andesine An_{35}, microcline, biotite as well as some garnet and common accessories (zircon, magnetite, apatite, etc.). Biotite and some of the feldspar grains are altered to chlorite and epidote, possibly as a result of movements along the Brulpan fault.

Some 4 km west of Marydale (at the foot of the southern slope of Twaalfponderkop) the gneiss is fine-grained, stromatic, with transitions to ophtalmic types (V 2687). Lens-shaped quartz and quartz-feldspar augen, and large feldspar porphyroblasts up to 30 mm long are abundant in a banded matrix which is composed mainly of quartz, microcline, and oligoclase-andesine. The texture of the substrate is inequigranular, granoblastic.

Metatect-rich biotite migmatite from the south-eastern corner of the Marydale Commonage (V 2736) is light grey in colour, medium-grained and displays an indistinct mineral banding. In hand specimen the banded structure passes frequently into ophtalmic structure (augen and lenses of microcline aggregates several centimetres long and up to 15 mm thick). The migmatite is rich in K-feldspar (microcline) which, at places, constitutes more than 30 per cent of the rock (Table 15). The texture of the migmatite is inequigranular, granoblastic with grain boundaries being more often lobate than polygonal or sutured.

2.1.3.3.6. Orthoamphibolite

Amphibolite intercalated in the augen gneisses and migmatites of the southern part of the area and in the schistose rocks of the Groblershoop Formation of the northern part of the area, forms discontinuous bodies from a few metres to a few decametres thick;

it is always situated in the proximity of the boundary between the Groblershoop and Kaaien Formation, and follows the strike of the regional foliation. It has been found in the northwestern portion of the farm Brulpan, on the farms Geelbospan and Khaboom, and at a few other localities in the Kaaien Hills (e.g. farms Koegrabie and Voorentoe Oos).

The Brulpan amphibolite is greenish dark grey, of dense appearance, fine-grained, poorly-foliated, and contains hornblende crystals usually 0,4 - 0,5 mm long (maximum length 2 - 2,5 mm). It displays dimensional preferred orientation in hornblende-rich layers which alternate with layers rich in plagioclase. The latter are fine- to very fine-grained, with polygonal grain boundaries (the granoblastic texture is almost equigranular) and also contain quartz and common accessories (apatite, rutile).

A layer of amphibolite which can be traced almost continuously from the farm Geelbospan to the farm Khaboom and which seems to occur again near the boundary between the Groblershoop and Kaaien Formations, differs from the type described above in the occurrence of sphene-rich bands (V 3071), and in a somewhat coarser grain-size of plagioclase -rich streaky lenses. Farther to the north-west, in the western part of the farm Khaboom, amphibolite occurring in the same structural position sometimes displays a relict texture of the original intrusive rock (V 3228). It is greenish light grey or light green, medium-grained, and well foliated. Hornblende, which is the most abundant mineral (more than 50 per cent) does not display a distinct dimensional preferred orientation and plagioclase is coarser than in the types described above. The mineral composition of the amphibolite indicates that the original intrusive rock was of dioritic or quartz dioritic composition. In another specimen from the same layer (V 3229) the relict igneous texture is indistinct, but the amphibolite contains a relatively large amount of sphene.

Amphibolites from Koegrabie (V 3636) and Voorentoe Oos (V 3655) are also similar to the rocks described above.

2.1.3.4. The Kaaien Formation

2.1.3.4.1. General

This unit was given its name after the Kaaienbult or Kaaien Hills in the eastern part of the Kenhardt District and in the north-western part of the Prieska District. It is exposed almost continously for a distance of some 240 km from Straussburg in the north-west (some 5 km east of Upington) to the farm Middelwater in the south-east (Fig. 5). West of the main outcrop (west of the Kaaien Hills) the quartzite occurrences are of much smaller extent, forming isolated outliers in the granitoids and gneisses of the Namaqualand Metamorphic Complex. East of the Kaaien Hills, in the area of the Groblershoop Formation, thicker Kaaien quartzite is present in places (e.g. Luisdraai se Berge).

It was proposed above (p. 72) that the quartz-sericite schist, mica schist and minor quartzite should be separated from the main quartzite sequence and called the Groblershoop Formation. Consequently, the Kaaien Formation as defined here, includes only the main quartzite sequence above the Groblershoop Formation and below the Wilgenhout Drift Formation.

The unit stratotype of the Kaaien Formation is the succession in the Kaaien Hills between the Karosberg in the north-west (25 - 30 km east-northeast of Upington) and the Boesmansberg in the south-east (some 38 km south-west of Prieska). Since the structure of the sequence is complex, the unit stratotype is best defined by several type localities, some of which, after a thorough examination in future, may be designated as component-stratotypes. In the area investigated two of such localities are present: (i) the quartzite hills along the Putsonderwater - Buchuberg road between the farms Middelka and Kareelaagte and, (ii) the Brakboschpoort Hills with good outcrops along the Marydale - Kenhardt road, some 10 - 15 km west-northwest of Marydale.

2.1.3.4.2. Lithology

The maximum thickness of the Kaaien Formation is probably between 1000 and 2000 m in the north-west, and less than 1000 m in the south-east. At some places in the south-east and north-west (outside the area under consideration) the quartzite is not more than 100 - 200 m thick.

The lithology of the unit is generally uniform, but variable in detail. Variations are found in colour, grain size, mineral composition and structure of the quartzite as well as in the manner with which the individual layers alternate.

The most frequent colour of the quartzite is light grey, less frequently white or grey, and occasionally dark grey. Usually the light grey types are banded, with bands being of grey and dark grey colour and from a few mm to a few tens of mm thick. At some places the banding may possibly be a secondary feature since it was not found in parts of the sequence where relict sedimentary structures are present. It is this banding that is isoclinally folded as documented by some exposures in the Kaaien Hills (e.g. some 9 km north-east of Putsonderwater).

It is notable that in the Brakboschpoort Hills, where the quartzites have been studied in detail, the colour changes with increasing distance from the Namaqualand Metamorphic Complex. The quartzites in the south-west (in the vicinity of granitoids and gneisses) are more frequently grey and even blue-grey in colour, than the quartzite in the north-east, farther away from the boundary.

The grain-size of the quartzite is usually fine to very fine at some places. Very fine-grained types which have a massive ("glassy") appearance, are often darker in colour. Medium-grained types frequently carry feldspar. The only coarse-grained quartzite with elongated quartz pebbles has been reported from the Kalkwerf synform some 55 km south-east of Upington (Du Toit, 1965). Another coarse-grained metasediment, which has previously been correlated with the Kaaien Formation (unpublished reports of the Geological Survey - J. de Villiers, pers. comm.), occurs on the farm Neeldale (Eyerdop Pan Pr. Q. 1 - 10), some 15 km south-southwest of Marydale, and is most probably younger than Kheis. The layer is exposed in the area of the Namaqualand Metamorphic Complex west of the Kaaien Hills and its relation to the Kheis proper is not known. It is an oligomictic conglomerate composed of pebbles, cobbles and boulders of vein quartz and Kaaien? quartzite and of much less abundant cobbles and boulders of granite. One of these boulders yielded radiometric age of 2,9 Ga (Burger and Nicolaysen, 1973). All clasts in the conglomerate are well rounded or rounded, and their sphericity usually varies between c. 0,5 and 0,7. Some of the quartzite cobbles, however, are deformed and flattened (sphericity less than 0,2 - 0,4). The matrix of the conglomerate consists of metaarkose or of a quartz-sericite schist.

Quartz, muscovite and sericite are most common minerals of the Kaaien quartzite. The latter two frequently coat the foliation planes and are scarce in fine- and very fine-grained rock types. The amount of feldspar present in the quartzite is variable, usually not exceeding 10 - 20 per cent (e.g. V 2912 in Table 15). Feldspathic and arkosic quartzite layers are present at various places, more often in the lower part of the succession than near its top. The other minerals present in the quartzite are biotite, chlorite, epidote, magnetite, apatite and zircon. Although the mineral assemblages of the quartzite do not reflect the degree of regional metamorphism suffered by these rocks, the occurrence of some minerals, (e.g. phyllosilicates), as well as the texture of the rocks point to the intense recrystallisation which must have taken place in the Kaaien Formation at some places (e.g. in the Kaaien Hills and also in the outliers of quartzite in the Namaqualand Metamorphic Complex).

The Kaaien Formation has been intruded by mafic rocks which form sheets and sills generally parallel to the regional foliation, and by various granitoids belonging to the Namaqualand Metamorphic Complex. These are usually fine- or medium-grained and occur mostly on the western side of the Kaaien Hills. In the same area, a porphyry, associated with the above granitoids, is also intrusive into the quartzite (see section 2.1.4.3.6.).

2.1.3.5. The Wilgenhout Drift Formation

The type area of this unit is south-east of Upington (Fig. 5) and comprises three sub-areas: (1) the Karos antiform some 25 - 30 km east-southeast of Upington (Fig. 34); (2) the Kalkwerf synform some 50 km south-east of Upington and, (3) small isolated outcrops between the two previous sub-areas.

All members of the unit are intensely folded and often also sheared. They comprise basal porphyries, phyllite and schist, quartzite with hematite-rich layers, conglomerate, dolomite, calcareous argillite and green diabasic lavas with occasional amygdaloidal structures (Rogers, 1907). Some of the phyllite and schist layers are tuffaceous. Du Toit (1965) pointed out that many of the rocks resembling sheared lavas in the field are, in fact, very fine-grained sheared grits and argillaceous quartzites.

Although the Wilgenhout Drift Formation, which does not occur in the area under consideration, was always interpreted as being younger than the Kaaien Formation, the question of its stratigraphic position is still open to discussion. It should be remembered that even the geologists who first described the unit, were not sure of its exact correlation, and that they seriously considered the possibility of the Wilgenhout Drift and Marydale sequences being direct correlates (Rogers, 1910). The field relationships at the Karos "anticline" which, according to Rogers and Du Toit (1909) clearly show that the Wilgenhout Drift Formation overlies the Kaaien quartzite, are not convincing in the writer's opinion; in fact, the Karos structure is a complex antiform, in which the Wilgenhout Drift phyllite and schist occur *under* the Kaaien quartzite (Fig. 34). For this reason the present correlation of the Wilgenhout Drift Formation (Table 13) must be regarded as tentative and provisional, and the problem, of the proper stratigraphic position should be given priority in any future reappraisal of the Kheis stratigraphy.

2.1.4. The Namaqualand Metamorphic Complex

2.1.4.1. General

With the exception of isolated outcrops of Kaaien quartzite, the rock units on the western side of the Kaaien Hills differ from those of the Kheis Group and Kaapvaal Craton described in previous section, in their lithology and in the different degree of metamorphoses. They comprise both supracrustal sequences and intrusive rocks and belong to a province which has previously been referred to as the Namaqualand Granite-Gneiss Massif (Gevers et al, 1937). The new name of the province, used in the following text, underlines the metamorphic character of many of its various members, and the highly intricate structure of the entire region.

2.1.4.2. Supracrustal sequences

2.1.4.2.1. Introduction

Metamorphites in the NMC west of the Kaaien Hills can be subdivided into two lithostratigraphic units, both of which were previously correlated with the Kheis Group (Rogers and Du Toit, 1909). The first unit, comprising quartzite, quartz-sericite schist and some mica schist, corresponds to the Kaaien Formation of the Kheis Group and will be described under this name in the following text.

For the second unit, which has originally been correlated with the Marydale Formation (op. cit., p. 17), a new name is proposed and its lithology is briefly described.

2.1.4.2.2. Kaaien Formation

A quartzite identical to that of the Kaaien Hills forms outcrops partly or completely surrounded by the granitoids of the Namaqualand Metamorphic Complex which, at several places, clearly intrude the quartzite (e.g. the Brakbos Granite on the farms Sonderpan Oos and Middelka, and porphyry some 1,9 km north-north-west of the Sonderpan Station). These outcrops are aligned in a north-westerly direction (N40 °W) and occur between Putsonderwater, La Kock's Hoop and Boksputs. Small isolated quartzite layers are also found in the southern part of the area, where they are always confined to the outcrop of granitoids. No quartzite of the "Kaaien" type seems to be associated with the Hartebeest Pan Formation.

The lithology of the quartzite sequence is generally uniform, but variable in detail. The dominant rock-type is quartzite, characterised by a fine and very fine grain, by a light grey colour, and by an indistinct banding. Primary sedimentary structures such as cross bedding and graded bedding have not been found. In the hills on the farm La Kock's Hoop the quartzite is in places coarser and feldspathic.

The structure of the sequence is identical with that of the Kaaien Hills; axial plane folding is particularly well developed on Vaalberg (farms Koegrabie and Sonderpan Oos), where the quartzite is also intruded by two mafic sills emplaced along the planes of regional foliation.

2.1.4.2.3. Hartebeest Pan Formation

The supracrustal sequences in the eastern portion of the Namaqualand Metamorphic Complex (excluding the quartzite layers) were previously correlated with the Marydale Formation of the Kheis Group, the correlation being based on the assumption that the Kaaien Hills have the general structure of a syncline (Rogers and Du Toit, 1909). This assumption however, is invalidated by the data presented in section 2.2.3.; the structure of the Kaaien Hills is rather complex, typical of axial-plane folding (see section 2.2.3.) and the western part of the hills is separated from the Namaqualand Metamorphic Complex by the Brakbos fault and associated major fractures. The lithological difference between the metamorphites of the Namaqualand Metamorphic Complex and the Marydale Formation of the type area, and the lack of continuity of exposures from the Marydale stratotype into the Namaqualand Metamorphic Complex also seems to justify the introduction of a new name for the metamorphites west of the Kaaien Hills.

It is therefore proposed here to define the Hartebeest Pan Formation as a sequence of metasediments and metavolcanics, which belongs to the Namaqualand Metamorphic Complex and which is best exposed on the farm Hartebeest Pan. It continues beyond the limits of the area under consideration both in the north-west and south-east, and comprises various rock-types which can be grouped into three different lithological sub-units:

(i) Glen Connan Member, occupying the central part of the belt of metamorphites and comprising leptite, quartz-rich leptite, hornblende leptite, hornblende-biotite leptite, biotite leptite, biotite schist, sillimanite-biotite schist, leucogneiss andalusite-biotite schist, and amphibolite.

(ii) Dudley Member, incorporating the low-grade metamorphites in the north and north-east, and comprising phyllite, phyllonite, schist, felsite, porphyry, amphibolite and minor magnetite layers.

(iii) Grieff Member, exposed in the south-western part of the area and comprising sillimanite-biotite-garnet gneiss and migmatised gneiss, in which intercalations of sillimanite-biotite gneiss, hornblende-biotite gneiss and amphibolite occur.

The boundaries between the three sub-units are either tectonic (faults, shear zones) or the sub-units are separated by the intrusions of granitoids.

The most characteristic rock type in the Hartebeest Pan sequence is *leptite*, a fine-grained rock (grain size 0,05-0,5 mm), with occasional blastoporphyritic texture, and a variable quartz/feldspar ratio. Mafic minerals are usually represented by biotite and hornblende, the latter becoming sometimes so abundant, that the rock passes into hornblende schist or amphibolite. Where the original porphyritic texture is preserved, the rock corresponds to the Svecofennian leptite of central Sweden as defined by Sundius in 1923 (cf. Geijer, 1963). The entire sequence comprises several types of light-coloured quartzo-feldspathic metamorphite, some of which, however, show no clear evidence of a possible volcanic origin. It seems more appropriate, therefore, to use the name leptite as applied by Eskola (1914) on the rock-types of the Orijarvi zone. According to this definition leptite is a fine-grained or aphanitic metamorphite of Precambrian age, composed mostly of salic minerals.

The above definition is also in agreement with a proposal submitted by the "Granulite Group" (Mehnert, 1972), in which the term leptite is used for fine-grained granoblastic rocks irrespective of the character of their mafic minerals or of their metamorphic grade. Mineral composition and feldspar content in particular do not seem to be important criteria for the petrographic

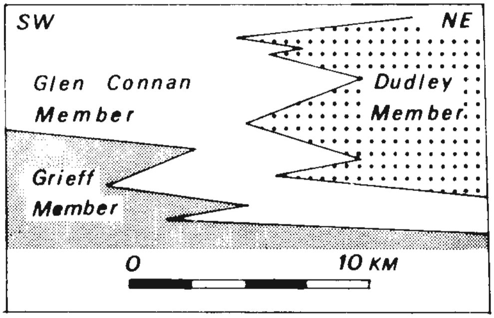


Fig. 7 Stratigraphic relationships within the Hartebeest Pan Formation (a stylised diagrammatic section)

classification of leptites. In the Hartebeest Pan leptites for example, the total amount of feldspar usually varies, even between the individual microbands; and the plagioclase/K-feldspar ratio is also rather variable.

Two types of micro- and mesobands, which differ in their content of mafic and salic minerals, occur throughout the Hartebeest Pan leptites. Sometimes bands of different mineral composition also have slightly different grain sizes (V 4178 - Brakboschpoort). The mineral composition of individual bands is variable as is the ratio between the number and thickness of the salic and mafic microbands. A gradual transition between the leptite s.s. and amphibolite is not uncommon, such transitions being particularly typical for the marginal parts of the heterofacial intercalations of either amphibolite in leptite or *vice versa.*

The mineral banding, often tightly folded on a microscopic scale, is cut by quartz-epidote veinlets; these are usually only a few mm thick and run oblique to the foliation (V 3429 - Putsonderwater). Some quartz veinlets and lenses are oriented parallel to the mineral banding.

Sometimes a dimensional preferred orientation is recognisable even in porphyritic leptites which is usually defined by the parallel orientation of larger grains of ribbon quartz. Neither the very fine-grained matrix (groundmass) nor the feldspar phenocrysts display any preferred orientation (V 3670 - Glen Connan).

The two main constituents of leptite, quartz and feldspar, are always present in the fine-grained matrix, which is often unevenly grained (alternating microbands of slightly different grain size). The texture of the microbands is granoblastic, and characterised by polygonal and interlobate grain boundaries. Ribbon quartz is present (e.g. V 3531 - Sonderpan Wes, V 3670 - Glen Connan) but lattice preferred orientation is indistinct or absent. With an increase in the metamorphic grade grain boundaries become straighter, the granoblastic texture is slightly coarser-grained, equigranular (V 3532 - Sonderpan Wes), and in the mineral assemblage K-feldspar becomes prominent (V 3532 in Table 16).

Specimen no.	3429	4178	3532	3666	4000	4344	3778	3468
Locality	Glen Connan	Brakboschpoort	Sonderpan Wes	Glen Connan	Hartbeespan	Rooiputs	Grieff	Putsonderwater
Rock unit	Glen Connan Member				Grieff Member			Glen Connan Member
Rock type	Leptite					Schist	Gneiss	Amphibolite
Quartz	70,0	62,6	64,0	69,6	56,0	53,4	42,4	5,6
Plagioclase	12,4	10,7	8,4	15,0	20,0	1,8	6,3	8,1
K-feldspar	1,8	4,1	9,1	1,7	7,1	18,8	26,4	1,2
Amphibole	-	-	-	10,7	-	-	-	76,9
Biotite	0,4	-	13,5	-	5,2	24,7	10,7	-
Chlorite	5,3	13,8	+	0,5	-	-	-	2,6
Muscovite	+	-	1,5	-	-	0,6	-	-
Sillimanite	-	-	-	-	2,8	+	1,5	-
Cordierite	-	-	-	-	2,2	+	0,8	-
Garnet	-	-	-	-	4,9	-	11,2	-
Clinozoisite	-	-	-	-	-	-	-	1,5
Epidote	8,7	8,6	+	0,2	-	-	-	2,6
Calcite	+	-	-	-	-	-	-	-
Sphene, leucoxene	+	+	+	+	-	-	+	0,5
Zircone	-	-	-	-	+	-	-	-
Apatite, rutile	-	-	-	-	-	+	+	-
Spinel	-	-	-	-	0,5	-	-	-
Magnetite, limonite	1,3	+	3,4	2,1	1,0	0,5	0,6	1,0
Total	100,0	99,8	99,9	99,8	99,7	99,8	99,9	100,0
Points counted	1400	1602	1680	1612	1371	1656	1708	1338
Length measured (mm)	466,6	534,0	560,0	537,3	457,0	352,0	569,3	446,0

Table 16 Modal analyses of the supracrustal rocks in the Namaqualand Metamorphic Complex

Plagioclase in the matrix of the non-porphyritic leptite is more frequently andesine An_{30-40} than oligoclase or albite-oligoclase. In the porphyritic types feldspars both in the matrix and phenocrysts are represented by oligoclase, albite-oligoclase and K-feldspar. The size of the feldspar phenocrysts is often 0,5 - 1,5 mm (e.g. V 3670 - Glen Connan).

With a decrease in the amount of quartz and an increase in the percentage of phyllosilicates leptite in the Hartebeest Pan Formation grades into schist. Changes in the mineral composition are reflected in the development of lepidogranoblastic texture and a distinct planar structure (schistosity). With an increase in feldspar content the rock types in the leptite series grade into leucogneiss. However, some specimens with more than 20 per cent feldspar, which retain their typical fine-grained texture, can still be classified as leptite (V 4000 - Hartebeest Pan). Both schist and leucogneiss are less frequent than the leptite s.s.

Amphibolite in the leptite series occurs mostly in the Dudley Member and to some extent also in the Glen Connan and Grieff Members. It is rather fine-grained, well foliated and finely banded (mineral banding is distinct on weathered surfaces). Apart from the microbands of salic minerals, leptite mesobands and thicker leptite intercalations occur in the amphibolite in parts of the farms Sonderpan Wes and Glen Connan. This sequence of alternating amphibolite and leptite is shown separately on the geological map.

In the least metamorphosed parts of the sequence, amphibolite sometimes contains epidote and zoisite (V 4111 - Middelput). Most frequently, however, it has a typical medium-grade mineral assemblage and at places it also contains biotite (V 3709 - Glen Connan). High-grade amphibolite and pyribolite have not been found in the area under consideration, but they occur in the same sequence farther west and north-west.

Biotite leptite and garnet leptite ("granulite") are the two most characteristic rock types of the Grieff Member and of the southern parts of the Glen Connan Member. They are fine-grained, finely banded, and display textural and structural similarity to the leptite described above. Their mineral assemblage, however, reflects high-grade metamorphism, and they are associated with gneisses and migmatised gneisses, in which they form layers varying in thickness from 1 to 100 m.

Sillimanite-biotite gneiss is one of the less extensive rock-types in the Grieff Member. It is a grey, well foliated rock, medium-grained and rich in biotite. The best example of this gneiss can be found in exposures some 3 km south of the Grieff farmhouse.

Various types of *gneiss, migmatised gneiss and migmatite* ("Migmatite" in Annex. 1) belong to the Grieff Member. Where exposed, they always occur between the granitoids and leptite. In the low- and medium-grade metamorphites of the Dudley and Glen Connan Members the gneiss is absent.

The gneiss, migmatised gneiss and migmatite are poorly exposed and can be studied properly only in specimens from bore holes and gravel pits and their presence is sometimes indicated only by abundant biotite and garnet in the surface cover. For this reason the true extent of the gneisses is not easily mappable and, consequently, the area of granitoids as shown on the existing geological maps seems to be greatly exaggerated, mainly at the expense of the gneiss.

The common garnet-biotite and sillimanite-biotite-garnet gneiss is medium- to coarse-grained, schistose and well foliated. It carries garnet porphyroblasts and glomeroblasts up to 25 mm in diameter, biotite-rich bands, and lens-shaped aggregates of biotite several centimetres long (V 3728 - Glen Connan). In the migmatised gneiss salic minerals are more distinctly separated, either in the form of rare leucosome bands, 1 mm - 20 mm thick, or, less frequently, in feldspar porphyroblasts a few mm across.

Migmatite (cf. Mehnert, 1968, p. 355) in the sense used here is a banded gneiss, in which leucosome and melanosome can be distinguished, the latter being always more abundant than the former.

Mylonite and phyllonite occur in a zone up to 500 m wide and some 9 km long on the farm Glen Connan, and also in a similar but smaller and poorly exposed shear zone some 4,6 km north-east of the Middelput farmhouse. They are of grey or dark grey colour, fine- to very fine-grained, well foliated, and often fissile. The mylonite zone on the farm Glen Connan is also characterised by the presence of numerous quartz veins and lenses of greatly variable size, oriented parallel to the foliation. The thickest of these veins are several metres wide and some of them are shown on the geological map. In this zone mylonite has most probably been derived from rocks of the leptite series.

In the Middelput occurrence the rock type is a phyllonite (quartz phyllite), with some intercalations of albite-epidote amphibolite (V 4111). In the same zone of phyllite and phyllonite thin intercalations of magnetite, 10-25 cm thick, occur in the western part of the farm Brakboschpoort (this western part is sometimes called Dudley).

2.1.4.3. Intrusive rocks

2.1.4.3.1. Elandslaagte Granite

This granitoid occurs in the south and south-east (Jacomyns Pan, Rok Optel, Geitjes Pan, Eyerdop Pan and parts of the Brakbosch Poort), and differs from all the other intrusive rocks of the Namaqualand Metamorphic Complex in always containing muscovite, which is often even more abundant than biotite, and having also a somewhat less homogeneous character. The biotite-muscovite granite is usually medium- to coarse-grained, with a few zones of gneissose structure resembling the melanosome-rich parts in the migmatite series. The granite is pegmatitic at places, with feldspar and muscovite crystals up to several cm long. The boundaries of this pegmatitic facies and of schlieren in the quartz-rich facies are transitional.

The Elandslaagte Granite is lithologically somewhat similar to the Skalkseput Granite of the Kaapvaal Craton. It should be noted, however, that the Elandslaagte Granite as well as some of the other intrusive rocks in the Namaqualand Metamorphic Complex are not well exposed and that over a wide area the outcrops are few and deeply weathered. The relation of the Elandslaagte Granite to the other granitoids is therefore not well established and more detailed work in this respect is needed.

2.1.4.3.2. Hartbeespan Granite

A coarse-grained porphyritic biotite granite (V 3461 in Table 17) occupies parts of the area between the outcrop of the Hartebeest Pan Formation and the western margin of the Kaaien Hills. Its best exposures are near the Hartbeespan Shed and also 3 km south-west of Putsonderwater. The most characteristic components of the granite are euhedral phenocrysts of K-feldspar which are up to several cetimetres long and often display a weak dimensional preferred orientation (most frequently in a west-northwesterly direction). This preferred orientation is usually accompanied by similar parallelism of the groundmass constituents, and by more or less distinct foliation.

Where it occurs in the vicinity of the Hartebeest Pan sequence, the Hartbeespan Granite seems to be confined to the area where medium- and high-grade metamorphites are found. It is separated by large bodies of the Sonderpan Granodiorite and Brakbos Granite from the low-grade metamorphites.

The Hartbeespan Granite passes into the Sonderpan Granodiorite through a decrease in the amount of K-felspar phenocrysts and their virtual disappearance; the transition is gradational, but the change is rapid.

Specimen no.	3461	3499	3545	3502	4366	3562	3583	3031
Locality	Putsonderwater	Sonderpan Wes		Sonderpan Oos	Brakbos	Eindgoed		Blouputs
Rock unit	Hartbeespan Granite	Sonderpan Granodiorite		Brakbos Granite		Eindgoed Granite		
Rock type	Biotite granite	Hornblende-biotite granodiorite		Muscovite granite	Biotite granite	Biotite granite		Biotite-muscovite granodiorite
Quartz	30,4	33,6	27,9	23,6	30,4	40,8	31,8	42,5
Plagioclase	20,4	36,4	37,3	32,3	27,0	18,8	18,3	29,2
K-feldspar	40,6	17,3	19,8	36,8	39,3	30,6	45,5	17,3
Amphibole	–	2,4	2,0	–	–	–	–	–
Biotite	8,6	8,9	11,1	+	2,1	+	2,5	3,6
Chlorite	–	+	+	–	0,3	2,9	1,8	+
Muscovite	+	–	+	7,1	0,1	+	–	5,6
Sericite	+	–	+	+	–	6,9	+	+
Epidote	+	–	+	–	0,6	+	+	–
Calcite	+	–	0,8	–	+	–	+	1,7
Sphene,leucoxene	+	–	+	–	+	+	+	+
Zircone, apatite	+	+	+	–	–	+	–	+
Magnetite,limonite	+	1,4	0,9	+	+	+	+	+
Total	100,0	100,0	99,8	99,8	99,8	100,0	99,9	99,9
Points counted	2303	2497	2564	4333	1563	1897	2094	1962
Length measured (mm)	767,6	832,3	854,6	1444,3	521,0	632,3	698,0	654,0

Table 17 Modal analyses of intrusives in the Namaqualand Metamorphic Complex and of the Blouputs Granodiorite

2.1.4.3.3. Sonderpan Granodiorite

Non-porphyritic coarse- and medium-grained hornblende-biotite granite and granodiorite is widespread in the area west of the Kaaien Hills, and where its outcrop is reasonably good, the rock is shown on the accompanying geological map under the name of Sonderpan Granodiorite. In parts of the area, however, where the outcrop is poor, and where various intrusives cannot be mapped separately, these igneous rocks are grouped under the heading "Undifferentiated granitoids in the area of poor outcrops". Large parts of such areas are occupied by the Sonderpan Granodiorite.

Two modal analyses of the Sonderpan Granodiorite (Table 17) show the characteristic presence of amphibole (common green hornblende) which is usually accompanied by relicts of an early formed clinopyroxene. The granodiorite is often cataclastic, various stages of cataclasis being definable even in one thin section (e.g. V 3496 - Sonderpan Oos).

Sometimes the granodiorite is unevenly grained, carries occasional microcline-perthite phenocrysts, 2 - 12 mm long, and contains dark, fine-grained biotite-rich segregations (xenoliths?), up to 25 mm long (V 3588 - Koegrabie).

2.1.4.3.4. Brakbos Granite

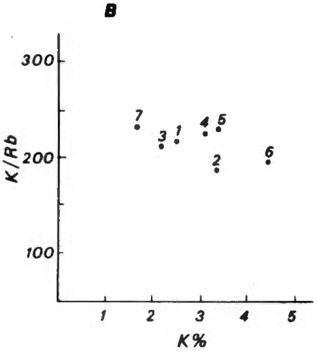
Light grey biotite granite, fine-grained and distinctly different from the types described above, is the most common intrusive rock in parts immediately west of the Kaaien Hills. It is also the only member of the granitoid suite which is found intrusive into the Kaaien quartzite. The mafic minerals in the Brakbos Granite are mostly represented by biotite or, in places, by hornblende. Muscovite is a major constituent in one specimen only, which comes from a small granite intrusion within the Kheis outcrop, 1,25 km north-west of the Unitjesberg.

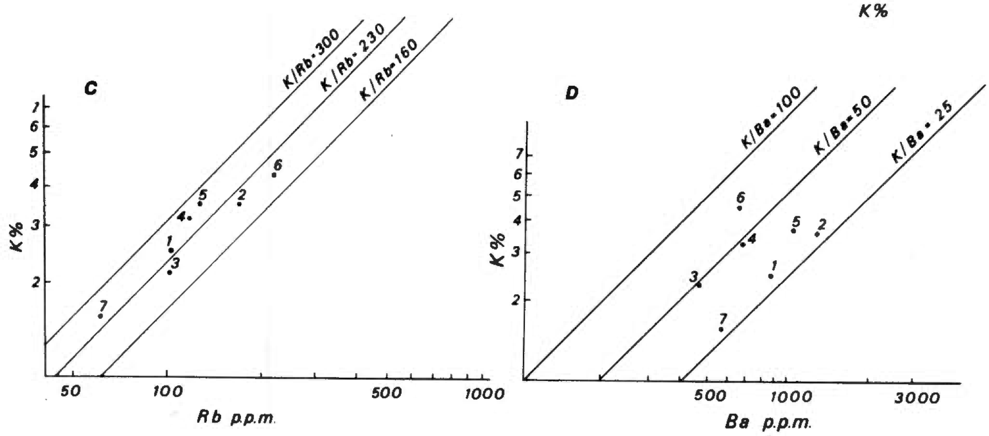
Brakbos Granite from the type locality (V 4366 in Table 17) is even-grained and does not display any sign of dimensional preferred orientation of constituent minerals. It is, however, slightly cataclastic and its biotite is partly chloritised. In the vicinity of the tectonic margin of the Kaaien Hills and also in the small intrusions within the outcrop of Kaaien Formation in the Namaqualand Metamorphic Complex, the Brakbos Granite is frequently cataclastic, displaying sometimes all stages of a transition from strained intrusive rock to a mylonite (e.g. V 3397 - Putsonderwater-Brierspan boundary). The cataclastic facies is indistinctly banded, the banding being caused by alternation of 1 mm - 5 mm thick zones of coarser, recrystallised salic minerals, which are segregated from the rest of the granite (V 3518 - Sonderpan Oos). The cataclastic granite is also somewhat richer in K-feldspar (microperthite) which forms grains from 2 to 10 times larger than grains of other minerals (V 3803 - Brierspan).

Specimen no.	2583	4425	4388	4424	4366	3562	481
SiO_2	73,14	71,00	70,62	77,91	73,88	74,92	69,15
TiO_2	0,16	0,35	0,36	0,10	0,08	0,16	1,07
Al_2O_3	14,24	14,53	14,18	12,59	14,44	13,31	11,42
Cr_2O_3	0,015	0,01	0,02	0,01	0,01	0,01	0,013
Fe_2O_3	0,92	0,96	0,94	0,38	0,23	0,46	3,47
FeO	0,56	1,27	1,80	0,26	0,50	0,94	2,76
MnO	0,02	0,03	0,05	0,01	0,02	0,04	0,12
MgO	0,31	0,62	1,29	0,33	0,15	0,20	1,34
CaO	1,43	1,67	2,57	0,52	1,27	1,10	3,46
Na_2O	5,21	4,24	3,51	4,48	4,42	3,29	1,78
K_2O	3,12	4,10	2,76	3,77	4,24	5,34	1,94
P_2O_5	0,08	0,12	0,07	0,05	0,02	0,05	0,16
L. O. I.	0,662	0,675	1,251	0,403	0,406	0,571	1,987
H_2O^-	0,38	0,024	0,010	0,013	0,062	0,047	0,81
Total	100,237	99,099	99,431	100,816	99,728	100,438	99,480
Nb (p.p.m.)	5,2	10,1	12	12	n.d.	8,1	14
Zr (p.p.m.)	163	286	139	64	72	120	271
Y (p.p.m.)	10,5	17	15	7	3,8	28	33
Rb (p.p.m.)	108	185	101	128	137	232	68
Sr (p.p.m.)	255	218	205	104	443	91	137
Ba (p.p.m.)	859	1104	486	689	1076	656	593

The ferrous iron in the samples was determined by a standard wet chemical technique and the ferric iron calculated from the total Fe present by difference

n.d. = not detected





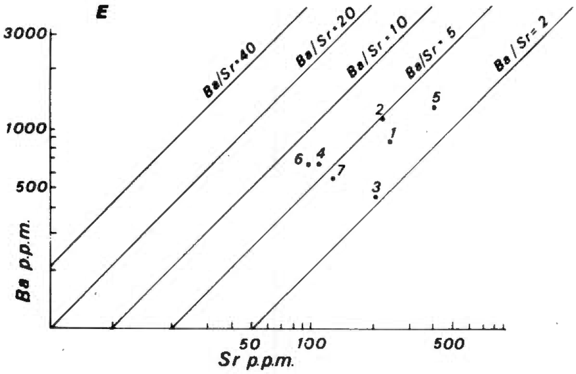


Fig. 8

Chemistry of the Draghoender, Marydale, Skalkseput, Brakbos, Eindgoed, and Hardeberg granitoids

A - Analytical results: Draghoender Granite (2583 ,4425) Marydale Granite (4388), Skalkseput Granite (4424 ~~and 4425~~), Brakbos Granite (4388), Eindgoed Granite (3562), and Hardeberg Granodiorite (481). Modal analyses of the DG, MG, SG, and HG are given in Table 1 (p. 11) and modal composition of the BG and EG is given in Table 17 (p. 89);

B - Abundance of K plotted against K/Rb ratio;

C - Abundance of K plotted against Rb;

D - Abundance of K plotted against Ba;

E - Abundance of Ba plotted against Sr.

Numbers 1 - 7 in B, C, D, and E correspond to the specimen numbers in A: 1 - 2583; 2 - 4425; 3 - 4388; 4 - 4424; 5 - 4366; 6 - 3562; 7 - 481

2.1.4.3.5. Eindgoed Granite

Fine-grained biotite granite of a conspicuous fleck structure (*sensu* Mehnert, 1968, p. 37) is present in the north-western part of the area, its best exposures being situated some 500 m east-north-east of the Eindgoed farmhouse near the Koegrabie-Boksputs road, and also in close vicinity of the Koegrabie homestead. The granite is light grey in colour, homogeneous on a large scale, but inhomogeneous in hand specimen.

Characteristic are "flecks": aggregates rich in mafic minerals and mantled by a halo rich in quartz and feldspar (Plate 3). The flecks are round and oval, several mm big (usually less than 10 mm, sometimes up to 20 mm), and seem to be randomly distributed in all parts of the outcrops. There are, however, slight variations in the number of flecks per square unit from place to place. Light grey halos surrounding the flecks are 1 - 5 mm wide and, in hand specimen, their inner boundary is more distinct than the outer one, which is rather gradational. The granite "groundmass" is evenly grained and does not display any sign of dimensional preferred orientation.

In thin section the granite is characterised by a typical hypidiomorphic texture, and by a lath-shaped habit of plagioclase crystals (albite-oligoclase and oligoclase). The size of plagioclase crystals is 0,5 - 2 mm, and their shape is almost euhedral. They are partly or completerly altered. The granite is affected by a weak cataclastic deformation, the salic minerals being strained (pressure shadows) and some of the feldspar crystals slightly bent.

In comparison with the "groundmass" the flecks are richer in biotite and also carry cordierite. Texture and grain size in the flecks are identical with texture and grain size of the "groundmass". Cordierite is largely altered, and in some flecks only a fine-grained aggregate of phyllosilicates (sericite and/or pinite) indicates the former presence of cordierite.

A genetic explanation of the fleck structure in the Eindgoed Granite may involve two possibilities:

(i) metamorphic differentiation of a previously homogeneous material (Loberg, 1963);

(ii) selective granitisation (Mehnert, 1968), at the closing stages of which fragments of resisters were carried and partially dissolved by the granitic magma during or slightly before its emplacement.

Since the petrography of the Eindgoed Granite and its field relations indicate an intrusive behaviour at the time of emplacement, and there is a variation in the mineral composition of a number of flecks studied, the latter possibility seems to be more

Plate 3 Fleck texture of the Eindgoed Granite Farm Koegrabie

acceptable. Similar stictolithic rock forms dm - m layers in a stromatite series in the western part of the Namaqualand Metamorphic Complex (e.g. some 11 km north of Kamieskroon in the cuttings of the National Road between Vanrhynsdorp and Springbok) and possibly represents an earlier stage in the development of the anatectic flecky granite (i.e. the flecks are confined to certain bands in migmatite).

2.1.4.3.6. Porphyry

Porphyry which occurs in the north-western part of the area between the Kaaien Hills and the northern part of the outcrop of the Hartebeest Pan Formation is mostly associated with the granitoids. It forms dykes and sills from a few tens of metres to several thousand metres long, and the largest of these bodies are several hundred metres wide. Most of the bodies strike northwesterly and west-northwesterly. The boundary between the porphyry and neighbouring rock types is usually obscured by superficial deposits and only some 2 km north of the Sonderpan Station where the porphyry is found within the outcrop of the Kaaien quartzite, can the intrusive relationships to the surrounding rock be proved.

The porphyry from various bodies has slightly different grain sizes and colours but it always carries feldspar phenocrysts and, frequently xenocrysts of blue opalescent quartz. The phenocrysts consist of andesine and/or microcline. in groundmass, however, the former is much less frequent than the latter. The groundmass is usually fine- to very fine-grained. Mafic minerals are represented by biotite, hornblende, less abundant clinopyroxene and occasional orthopyroxene. Apatite, allanite, zircon, sphene, magnetite and ilmenite are accessory. The most interesting feature of the rock is its cataclastic deformation, which is variable from place to place. Quartz xenocrysts, for example, show strain shadows, undulatory extinction and/or similar extinction irregularities, granulation (porphyroclasts) or even recrystallisation (in some of the xenocrysts aggregates of sutured quartz grains are developed). Pressure fringes of chlorite around magnetite and of very fine-grained quartz and feldspar around the feldspar phenocrysts are also found (V 3512 - Sonderpan Oos).

In its petrographic character and mode of occurrence the porphyry is similar to the charnockitic adamellite porphyry (Poldervaart, 1966) from the neighbouring Keimoes - Kakamas area, but it is either retrograded or has never reached the high-grade metamorphism typical of the latter rock.

2.1.4.3.7. Gabbro, hyperite[1], olivine hyperite[2]

Gabbroic rocks usually form small isolated bodies (plugs) confined mostly to the area underlain by granitoids. In one case only does the shape of the outcrop indicate a sheet-like from of the body (a dyke) which is more than 1 km long and, at places, up to 200 m wide (e.g. farm Titiespan). All these bodies fall within a zone broadly following the east-southeasterly regional trend; this zone or line of mafic plugs and sheets oversteps the eastern margin of the Namaqualand Metamorphic Complex and, consequently, a few mafic bodies also occur in the Kaaien Hills south of the 29°15' parallel.

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[1] & [2] The term hyperite as applied here underlines the presence of both opx and cpx (in contrast with gabbroic rocks, in which only cpx is present). Should the reccommendations submitted by the Subcommission on Systematics of Igneous Rocks be accepted, the term hyperite will be replaced by the newly proposed term gabbromorite.

The majority of the gabbroic rocks have a typical ophitic texture, are coarse-grained and relatively fresh. None of the mafic bodies has chilled margins, but some of them are affected by a weak cataclastic deformation or even foliated in their marginal parts (e.g. V 4239 - Brakboschpoort). The mineral composition of all the members of this group is similar: hypersthene, diallage, augite, brown hornblende, some brown biotite, labradorite (An_{60}) and common accessory minerals. Olivine is only present in some of the specimens.

The occurrences of gabbroic rocks in the Kaaien Hills differ from fresh, unaltered and virtually undeformed mafic intrusive in the Namaqualand Metamorphic Complex either in their tectonic involvement (Brakboschpoort) or in their association with the Marydale volcanics (Irene). The Brakboschpoort occurrence, described in detail by Rogers and Du Toit (1908, pp. 41-43) and situated some 2 km east-northeast of the Brakboschpoort farmhouse, is a typical olivine gabbro which forms a body, some 350 m long and up to 90 m wide. In the marginal parts (several cm to several metres) the gabbro is retrograded, actinolite-rich, and has the macroscopic appearance of a fine-grained amphibolite foliated parallel to the strike of the longer axis of the body (N15°W). The inner boundary of this retrograded margin is transitional but the outer boundary with the gneisses of the Kheis Group is sharp and distinct. The most unusual feature of the Brakboschpoort gabbro are cm-dm wide zones of sheared actinolite gabbro with grains and aggregates of quartz resembling amygdales (Rogers and Du Toit, op. cit.) These minor zones occur in various parts of the body and seem to be of secondary (retrogressive) nature. The marginal parts of the Brakboschpoort gabbro are intruded by thin veins of coarse muscovite granite with variable strikes.

The Irene gabbro is closely associated with the Marydale amphibolite, and has all the macroscopic features of an intrusive rock. It is slightly lighter in colour than the gabbros in the Namaqualand Metamorphic Complex, but is evenly grained and apparantly homogeneous in hand specimen. In thin section, however, it displays clear evidence of shearing and retrogressive alteration which seems to be more intense here than in the case of the Brakboschpoort gabbro. Its primary ophitic texture is largely destroyed and primary minerals such as hypersthene, diopside and labradorite are partly downgraded (e.g. amphibole rims around pyroxenes). Olivine is absent in this rock. In some parts irregularly shaped "islands" of primary minerals are separated by a fine- or veryfine-grained "crush" matrix; in other parts streaky relicts of the primary minerals alternate with microbands of mylonite (V 2644 - 1 km south-east of the Irene farmhouse).

2.1.4.3.8. Serpentinite

Two serpentinites occur in the Namaqualand Metamorphic Complex some 1,5 km north and 13,5 km south-west of Putsonderwater respectively. The first of the two occurrences is rather small, accompanied by several smaller serpentinite bodies only a few metres in length, and situated immediately north-west and south-east of the body shown on the map. The biggest of these serpentinites is partly exposed in a prospecting pit (thin veinlets of chrysotile asbestos). The second serpentinite, exposed on the farm Glen Connan, is located in a west-northwesterly trending fault zone.

2.1.4.3.9. Pegmatite

Pegmatites and associated rocks in the Namaqualand Metamorphic Complex are confined to the southern and south-western parts of the investigated area and comprise three different types:

(i) veins and lenses of blueish quartz ± feldspar (shown on the map);

(ii) unzoned homogeneous pegmatites composed of quartz and feldspar ± muscovite, biotite, tourmaline, magnetite, ilmenite and zircon (these pegmatites are usually too small to be shown on the map);

(iii) complex beryl-columbite-tantalite bearing pegmatite (mostly south-west and west of the area under consideration).

All these types occur in a west-northwesterly striking belt, in which the veins of the first group seem to be confined to the north-eastern part, and the complex pegmatites to its south-western part. The unzoned homogeneous pegmatites occur in both the central and south-western parts of the belt. The north-eastern margin of the belt runs in a west-northwesterly direction from the area immediately north of the Hartbeespan shed to the Grieff farmhouse, the south-western boundary of the belt occurs outside the area under consideration.

The belt, which is 30 - 60 km wide and more than 300 km long (Hugo, 1969) is known as the Namaqualand Pegmatite Belt (Ward, 1971) and extends from the south-western margin of the Kaapvaal Craton in the Prieska District to the southern parts of South West Africa and to western Namaqualand (Joubert, 1971).

It is interesting to note that the conclusions concerning the mode of emplacement of pegmatites and associated rocks as formulated by Hugo (1969) have been confirmed in the area investigated; the emplacement seems to have been controlled by fractures and joints in the intrusive rocks and by the foliation and schistosity in the reconstituted supracrustal rocks.

The mineral composition of pegmatitic bodies and the petrographic character of the host rocks also seem to be related. While the simplest quartz and quartz-felspar veins occur predominantly in the low- and medium-grade metamorphites, the complex pegmatites are confined to the area occupied by the high-grade metamorphites and granitoids. This may indicate a deep-seated environment for the pegmatite emplacement (more than 6 - 7 km), in which both pegmatite fluid and host attained approximately the same temperature (according to Hugo, op. cit., the temperature of the pegmatite fluid was more often 250-550°C than 550-700°C), and where the pressure gradient was shallow (Rivalenti and Sighinolfi, 1971).

The pegmatites and related rocks described here belong to the older pegmatitic phase of Hugo (op. cit.). The so-called biotite granodiorite pegmatite phase in which simple pegmatites are intimately associated with granodiorite and which yielded ages of 890-937 Ma (Hugo, 1965, p. 189) is most probably absent in the area under consideration.

2.2. Structural framework

2.2.1. Introduction

The supracrustal sequences and intrusive rocks described in the previous section constitute three major tectonic units, the development of which differed greatly, and the boundaries of which were activated at various times. All three units, the Kaapvaal domain, the Kheis domain and the Namaqua domain, are separated by contacts of varying nature; in their present form most of these contacts are eithter faulted or represent an abrupt change in metamorphic grade and/or in tectonic pattern.

The most important of the major boundaries is the zone of the Doringberg lineament (Plate 4 and Fig. 9), which separates the reconstituted and reactivated rocks of the Namaqualand Metamorphic Complex from practically unmetamorphosed sequences and granitoids of the Kaapvaal domain and from the Kheis domain. The lineament comprises various oblique-slip faults, some of which are first-order shears, and others represent lower-order fractures. It is oriented oblique to the regional trend in the Namaqualand Metamorphic Complex and cuts across the regional trend in the Kheis and Kaapvaal domains.

2.2.2. The Kaapvaal Domain

2.2.2.1. General

The Kaapvaal domain occupies the south-western marginal part of a major crustal segment known as the Kaapvaal Craton (Pretorius, 1964). The craton is composed of Precambrian rocks belonging to three assemblages:

(i) greenstone belts and associated intrusives (Anhaeusser et al., 1968);

(ii) continental-type basins formed in an epeirogenic environment on the craton (Pretorius, 1965); and

Plate 4 ERTS-1 image E 1053 - 07540, Band 7 (courtesy of NASA and of the C.S.I.R. - N.P.R.L.)

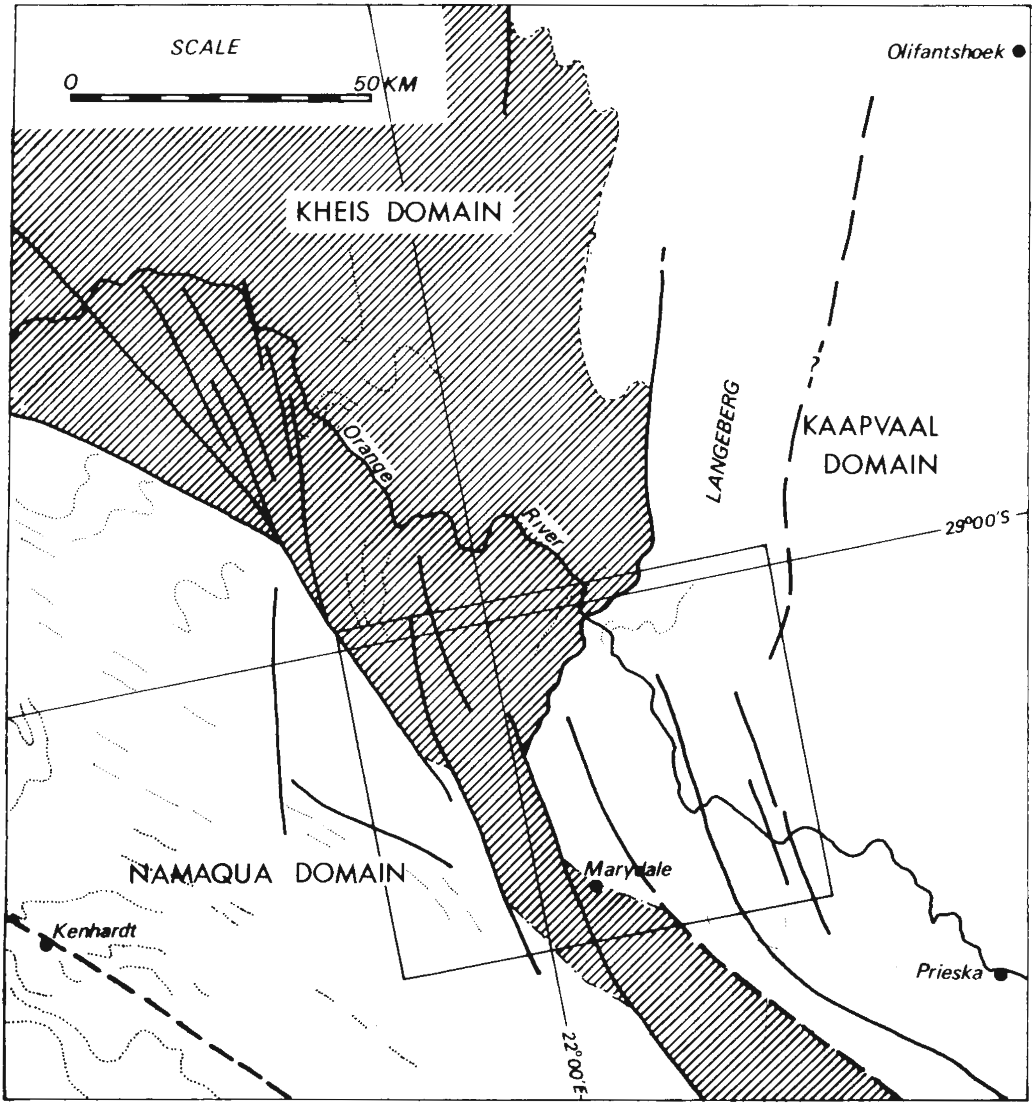


Fig. 9 Principal units, major fractures and aerial trends in the area along the Namaqua front (ERTS-1 image E 1053 - 07540, Band 7 - an interpretation)

(iii) igneous rocks and complexes, some differentiated and layered, mostly emplaced in an epeirogenic environment (Pretorius, op.cit.).

When applied to the area under consideration and combined with the available radiometric data (Burger and Coertze, 1973) this grouping may be expressed as follows:

(i) consolidated basement more than 2,5 Ga old;

(ii) practically unmetamorphosed supracrustal sequences c. 2,5 - 1,8 Ga old; and

(iii) younger intrusive rocks and dykes.

The boundaries of the craton are distinct on a regional scale (Fig. 1): in the north it is bounded by the Limpopo Mobile Belt, in the east the margin is defined by the line of the Lebombo structure, in the south and south-west the edge of the craton coincides with the front of the Namaqua-Natal Mobile Belt, and in the west the boundary can probably be placed between the Waterberg-Matsap synclinorium and the Kheis Group.

When concealed under younger sediments, the boundary can be located with the help of geophysical data: in the main Karoo basin, for example, its position is indicated by a sinuous line of gravity highs stretching from Britstown in the west to the Tugela fault in the east. It has been suggested recently that some other features occurring along this line (e.g. fissure zones and thermal springs) are also associated with a deep-seated zone of crustal weakness along the cratonic margin (Olivier, 1972).

In the area under consideration the cratonic boundaries are formed by the faulted contact between the Kheis and Matsap sequences in the north-west and by the south-western boundary of the Draghoender Granite in the south and south-west.

(i) The faulted contact between the Kheis and Matsap, which will be referred to as the Eselberge fault, is situated on the north-western side of the Matsap synclinorium and, where exposed, it is marked by a zone of shearing and silicification, which is at places well over 50 m wide. The best outcrops of the zone of shearing are confined to the vicinity of the Orange River, where the Kheis and Matsap exposures are practically continuous. On the south-eastern side of the zone the lithic sandstone of the Matsap Formation has a characteristic purplish colour and carries occasional pebbles of clastic material derived from the Transvaal Supergroup. On the north-western side of the zone a succession of light grey quartzite and quartz-sericite schist is exposed which displays features distinctly different from those of the Matsap:

(a) It is a sequence characterised by a penetrative pervasive foliation which is different from the fracture cleavage locally developed in the Matsap; the foliation in the Kheis is a true schistosity, and the foliation planes are coated with recrystallised phyllosilicates;

(b) Although primary sedimentary structures are present in the Kheis sequence, the Kheis rocks immediately north of the Matsap synclinorium have a metamorphic character and thus differ from the Matsap sediments which are unmetamorphosed;

(c) In contrast to the immature Matsap sediments the Kheis sequence is composed of types originally well sorted, the lithology of which indicates a completely different sedimentary environment from that of the Matsap.

The only difficulty in distinguishing between rock types of the two units may be experienced within the sheared zone where Matsap sediments are silicified and lose their purplish colour. In thin section, however, relicts of the original psammitic texture are preserved (V 4423 - 2,9 km north-west of the Buchuberg Dam). The change in primary lithology, metamorphic grade and structure over the zone of the Eselberge fault is so abrupt that the zone itself cannot be interpreted as a transition of any kind.

It should be noted that farther away from the Orange River, where the Eselberge fault is concealed under sand and other superficial deposits, the cataclastic deformation of the Matsap rocks is more intense along the north-western boundary of the synclinorium than elsewhere. Also interesting is fact that relicts of Dwyka follow the inferred outcrop of the fault, and that their thickness indicates a rough pre-Dwyka morphology in the zone of the Kheis/Matsap contact.

(ii) The south-western boundary of the Kaapvaal domain between the farms Khaboom and Brulpan follows one of the major fractures of the Doringberg lineament, the Brulpan fault. It is important to note that both in the north-west and south-east the fault leaves the boundary of the Draghoender Granite and fades out within the Kheis domain.

From Brulpan to Irene the contact between the Draghoender Granite and the Kheis Group is intrusive (see pp. 9 - 10), and the remaining part of the boundary on the farm Stuurmansput is again faulted.

Within the limits outlined above ("i" and "ii") the Kaapvaal domain comprises two subdomains:

(a) The granite basement older than c. 2,5 Ga;

(b) The Seekoebaard, Transvaal and Matsap sequences.

The structures of the two subdomains can be divided into three groups: first, structures older than 2,5 Ga, second, pre-Matsap structures younger than c. 2,5 Ga and, third, post-Matsap structures.

2.2.2.2. Structures older than 2,5 Ga

These structures are confined to the areas of the Swartkop Formation, Draghoender Granite and, to a lesser extent, to the area of the Skalkseput Granite, which represents a post-tectonic element in the pre-Seekoebaard facet of the Kaapvaal domain and marks the terminal phase of the consolidation of the pre-Witwatersrand basement in the northern and north-eastern Cape. The Skalkseput Granite is overlain unconformably by the Seekoebaard Formation (pp. 28 - 29) and thus, by its minimum radiometric age of 2,5 Ga (Burger and Coertze, 1973) sets a datum for major paleogeographical changes in the development of the Kaapvaal domain.

Planar structures of the Swartkop Formation are characterised by a persistent north-northwesterly strike and by a steep dip of both the lithological layering and foliation. Field evidence suggests that the foliation is axial planar to tight isoclinal folds of a decameter scale (e.g. repetition of magnetite quartzite layers) and that it developed prior to the intrusion of the Skalkseput Granite. Its maximum age may be even greater than 2,5 Ga because, in the author's opinion, the date of 2,9 Ga obtained on a granitic rock from Swartkop (Kent, 1971, p. 12) reflects the age of intrusive rocks cutting the planar structure in the Swartkop sequence.

The pre-Skalkseput age of the foliation in the Swartkop Formation can also be postulated on the basis of a striking difference between the structures of the Swartkop and Seekoebaard Formations: while the former is a metamorphosed sequence, tightly folded and well foliated (schistose) with almost vertical foliation planes, fold structures in the Seekoebaard Formation are open and gentle, with the lithological layering often almost horizontal, and with planar structures represented by two sets of fracture cleavage; the schistosity in the Seekoebaard Formation is only locally developed (in the zones close to the Transvaal synforms) and has a moderate to gentle northwesterly dip. On the farm Greeffsput, immediately north of Swartkop, outcrops of the two formations are separated by only a few metres of granite, but the difference in their structure is still distinct and considerable.

It should be noted that the Swartkop sequence is affected by shearing in zones parallel to the foliation; this shearing, which partly obliterated the relationships with the neighbouring granitic rocks, is of much younger age (post-Matsap) and is confined to the major fractures of the Vaalbult fault (one of the major fracture systems in the Doringberg lineament).

Earliest recognisable structures in the Draghoender Granite are represented by primary mineral banding, which can be clearly separated from the effects of post-Matsap reactivation of granite and its partial recrystallisation in zones trending west-northwest.

Mineral banding has been encountered in parts of the farms Swartkopspan, Draghoender, Irene, Uitvlug, and on the Marydale Commonage, and is characterised by a variable attitude. This variability seems to follow a general arcuate pattern in which the attitude of the primary banding changes systematically from an easterly strike in the north to south-southeast in the south.

The earliest structures in the Skalkseput Granite are represented by north-easterly striking bodies of leucocratic biotite-muscovite granite and adamellite on the farm Soutputs, and possibly also by north-easterly striking pegmatite in the north-western part of the farm Skalkseput. Both the leucocratic facies and pegmatite are affected by later shearing (pp. 20 - 21).

2.2.2.3. Pre-Matsap structures younger than c. 2,5 Ga

Evidence of deformation post-dating the intrusion of the Skalkseput Granite and pre-dating the deposition of the Matsap Formation comes mainly from the Transvaal and Seekoebaard sequences; older rocks do not show any significant structures which might correspond to this period of deformation. Although the exact reconstruction of this facet of the pre-Matsap tectonic pattern is difficult to establish (mainly due to the intensity of two periods of post-Matsap folding), some characteristic features are present which indicate that the deformation accompanied and immediately followed the deposition of the pre-Matsap supracrustal rocks.

The first set of planar structures in the Seekoebaard Formation comprises bedding and lava flows (s_0), both of which cut the earlier structures in the granitic basement at an obtuse angle. Although the contacts between the Seekoebaard sequence and the older basement are often faulted, the regional extent of the Seekoebaard Formation suggests that it transgressed over various parts of the basement. Primary structures in the southern part of the Seekoebaard outcrop have very gentle dips (Fig. 10 A) and, at places on the farm Skalkseput, they are practically horizontal.

The attitude of s_0-planes becomes progressively more variable towards the north and north-east and in the vicinity of the Transvaal synforms and the Matsap synclinorium s_0-structures are intensely deformed along north-northeasterly and north-westerly plunging axes (Fig. 10 D). These two linear sets however, represent the post-Matsap deformation and will be described later.

The pre-Transvaal deformation of the Seekoebaard sequence is demonstrated mainly by the unconformity between the Black Reef Formation and the underlying Blinkfontein Volcanic Member. Where unaffected by the post-Matsap deformation, the s_0-pattern suggests a morphology of randomly distributed small domes and basins several tens and hundreds of metres across; this pattern is fairly distinct on the aerial photographs in the southern part of the Seekoebaard outcrop. On the geological map, where only a few of these primary structures could be shown ("Aerial Trend" in Legend,

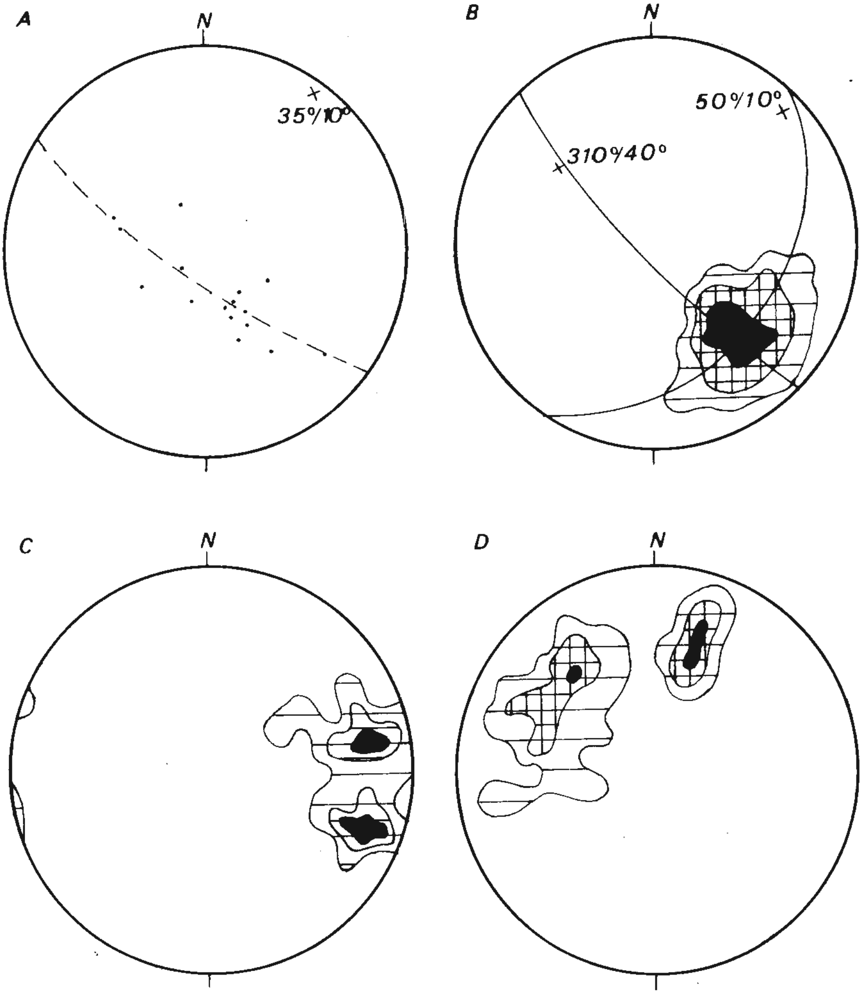


Fig. 10 Equal-area projection of structural elements in the Seekoebaard Formation.
Explanation: A - poles to primary structures (s_0); B - poles to schistosity planes (contours 2-5-10 %, 192 measurements); C - poles to cleavage planes (contours 2-5-10 %, 100 measurements; D - linear structural elements (contours 2-5-10 %, 71 readings)

Annex. 1.), the random distribution is indistinct and a north-northeasterly grain of the post-Matsap deformational pattern emerges as the dominant one.

A second set of pre-Matsap planar structures in the Seekoebaard Formation (Fig. 10 B) is represented by a moderately dipping foliation developed in zones close to the Transvaal synform south of the Waterval structure. The foliation is mostly defined by a preferred orientation of quartz and chlorite and has a persistent north-westerly dip. In the area north of the Waterval structure its attitude is less persistent, most probably due to the intense post-Matsap refolding.

In the Transvaal sequence which transgresses over various members of the underlying Seekoebaard succession, the earliest recognisable structure is again bedding (lithological layering, bedding fissility etc.), different types of which have been described in section 2.1.2.6. Pre-Matsap planar structures younger than bedding fissility are impersistent, usually overprinted by later deformation and not well definable.

Here attention will be paid to the set of structures comprising various penecontemporaneous folds, sedimentary boudinage structures (e.g. pseudoconglomerates), chert breccia layers and slumps of various size. These structures which developed during the initial stages of the Transvaal deformation, are confined to certain sub-units in the sequence, and even within the sub-units they tend to occur in some layers only. Their shape and orientation indicate that relative movement along bedding planes was involved, and that in the initial stages of deformation unconsolidated and partly consolidated sediments were affected. Also notable is the fact that the metamorphic grade in the Transvaal sequence is very low (e.g. riebeckite-stilpnomelane, stilpnomelane-chlorite and stilpnomelane-minnesotaite assemblages).

For descriptive purposes such structures can be classified according to their relative age regarding the deposition and lithification of the sediments. Three principal groups were recognised: first, synsedimentary structures (e.g. disrupted bedding, slump bedding, etc.), second, slump structures developed after deposition and before lithification of sediments and, third, structures developed after lithification.

The earliest structures in the Transvaal succession are represented by various types of slip or similar folds which are interpreted as slump structures; the best examples of such folds of cm-dm scale are found in the banded iron-formation (e.g. Fig. 11 C, D) and in the Windpomp Dolomite Member. Their axes plunge north-easterly at moderate and low angles in the N30 - 85°E sector (Fig. 12 D), most of them being concentrated between 40 and 60°. The slip folds are sometimes truncated at the top surface of the layer and laterally they pass into undeformed strata.

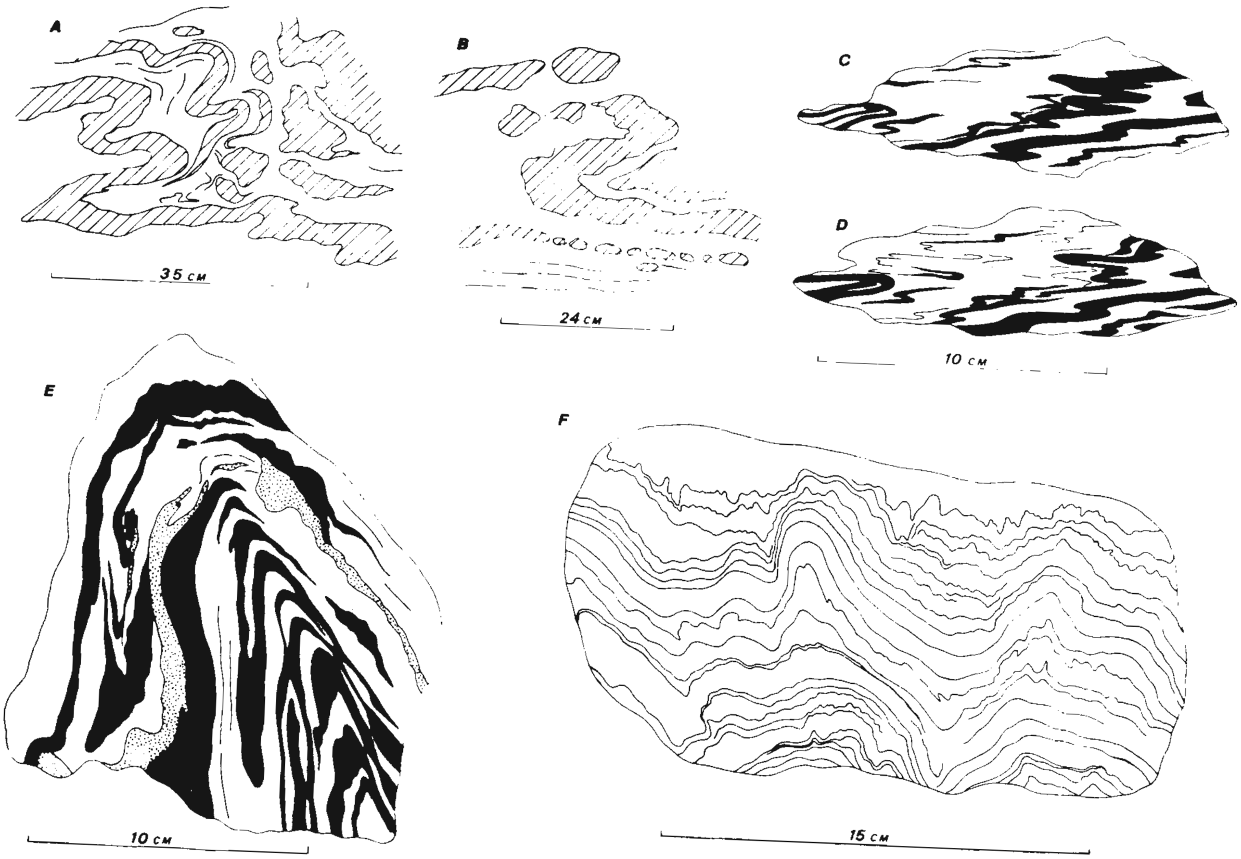

A
35 cm
B
24 cm
C
D
10 cm
E
10 cm
F
15 cm

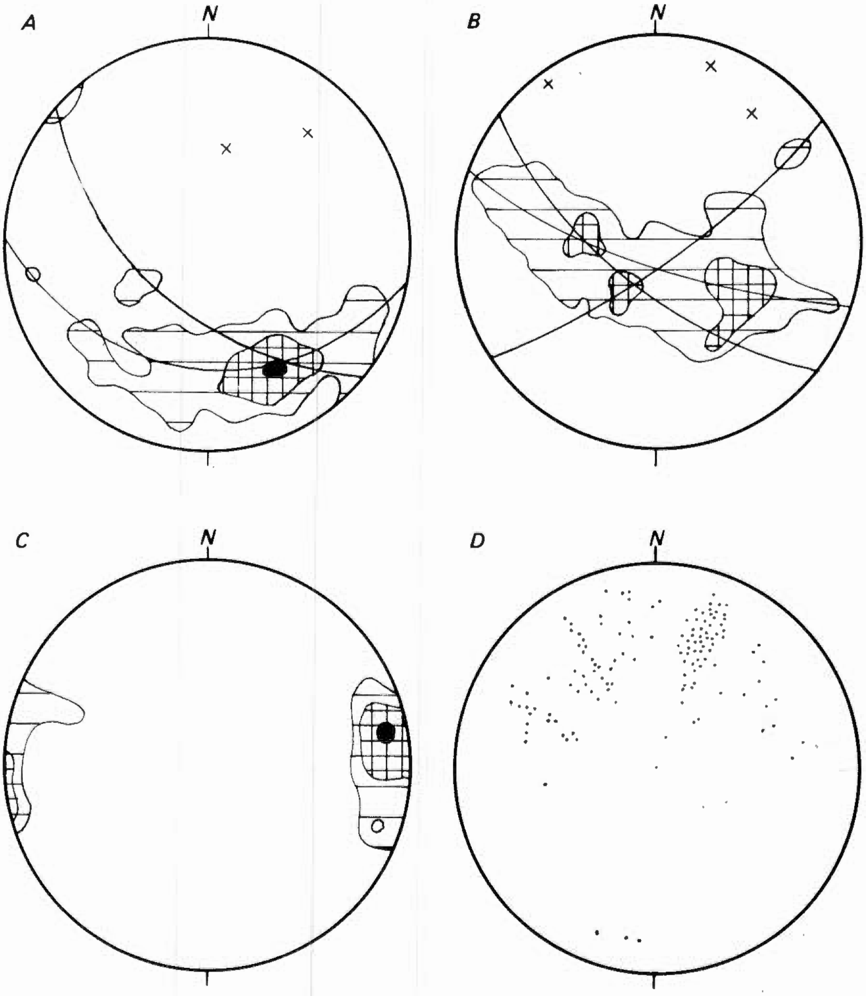
Fig. 11 Examples of gravity structures in the Transvaal Supergroup A,B - pseudoconglomerate (farm Grasgat); C,D - slump folds in the banded iron-formation (314 Hay 15.11); E - refolded slump folds in the banded iron-formation (314 Hay 15.11); F - an example of the disharmonic folding (a cobble of banded iron-formation in the terrace gravel, farm Onderseekoebaard)

Inferred décollement surfaces are often marked by secondary quartz layers a few mm thick or display signs of relative movement (slickensiding).

The earliest folds in the Transvaal Supergroup (in particular those confined to the banded iron-formation) tend to form a disharmonic pattern. An example of such disharmonic folding is shown in Fig. 11 F and displays all the characteristic features of slump structures: an abrupt change in profile in passing from one S-surface to another, a non-systematic change in the attitude of axial surface and, when studied in hand specimen, also a variation in fold axis orientation.

Disharmonic folding is also recognisable on a large scale: first, in the banded iron-formation, where the intensity of plication varies across the boundaries between mesobands, second, by the difference in fold profiles of antiforms such as those in the vicinity of Koegas and synforms such as Paarde Vlei and Leelyksdam (Fig. 13) no matter how intense the post-Matsap refolding was and, third, in the difference in tectonic involvement of the lower part of the succession (including the Westerberg Member) when compared with the relatively simple structure of the remaining upper part of the Transvaal sequence.

Another interesting feature illustrating the character of the earliest Transvaal deformation is the presence of pseudoconglomerate layers, two of which occur at the base and the uppermost part of the Kwakwas Member respectively (pp. 54 - 55). The second of the two "conglomerates" is particularly interesting, because its tectonic origin can be well demonstrated (Fig. 11 A,B). It is a dark grey or brownish-grey semipelite of quartzitic appearance, containing numerous oval nodules less than 40 mm in size, and boudins less than 7 cm long. The cherty material of both the nodules and boudins is very fine-grained (blank areas in Fig. 14). The nodules have thin limonite-rich outer rims (ruled areas in Fig. 14), and when they occur scattered in the plane of bedding foliation they resemble sedimentary clasts. Individual "pebbles" however, represent tectonically separated parts of


A
N
B
N
C
N
D
N

a competent layer which was segmented during slumping (Fig. 11 B). Folds of dm - m size which occur in the pseudoconglomerate layer and are closely related to the development of this sedimentary boudinage structure, plunge in various directions.

Among other types of sedimentary boudinage pinch-and-swell structures are the most conspicuous (Plate 5.1). Frequently, they occur in the banded iron formation, but many other layers show similar features (i.e. the tendency to loose their continuity and to be represented by a series of distinct lenticular units). The lenticular pinch-and-swell habit of some layers may reflect the existence of minor undulation in the depositional surface as well as a certain amount of subsequent differential movement of the plastic material in the layers due to the load of superincumbent strate (Cilliers, 1961). It is also possible that these structures were still being produced during lithification of the sediments (Fockema, 1967), but this is probably the last possible stage during the tectonic development of the Transvaal basin when such structures could form.

A similar spread in time can also be postulated for the origin of chert breccias, of which three types occur in the Koegas area (p. 48). The first type may represent late sedimentary of early slump structures, the second is clearly a product of slumping, and the third may have developed during the process of lithification or after it. None of the chert breccias however, can be compared with so-called flat-pebble conglomerates known to be developed mostly north of the area under consideration, and believed to have been formed by wave action.

The above structures, including the slump folds, seldom reach more than several metres in size. This fact, when compared with values for the maximum observed thickness of slump elsewhere (30, 65 and 200 m respectively) given by Roberts (1972), Helwig (1970) and Lewis (1971), may represent an important criterion concerning the development of the Transvaal basin in the northern Cape.

Fig. 12 Equal area projection of structural elements in the Transvaal Supergroup
Explanation: A - poles to the bedding (subarea 1, north of the Koegas syncline) - 158 measurements; crosses = π-axes $5^\circ/50^\circ$ and $40^\circ/30^\circ$; B - poles to the bedding and bedding foliation (subarea 2 - south of the Koegas syncline) - 253 measurements; crosses = π-axes $20^\circ/10^\circ$, $40^\circ/20^\circ$ and $325^\circ/10^\circ$; C - poles to the cleavage planes, prominent fractures and quartz veins (subareas 1 and 2) - 108 measurements.
A,B and C - contours 2-5-10 %.
D - linear structural elements (145 measurements).

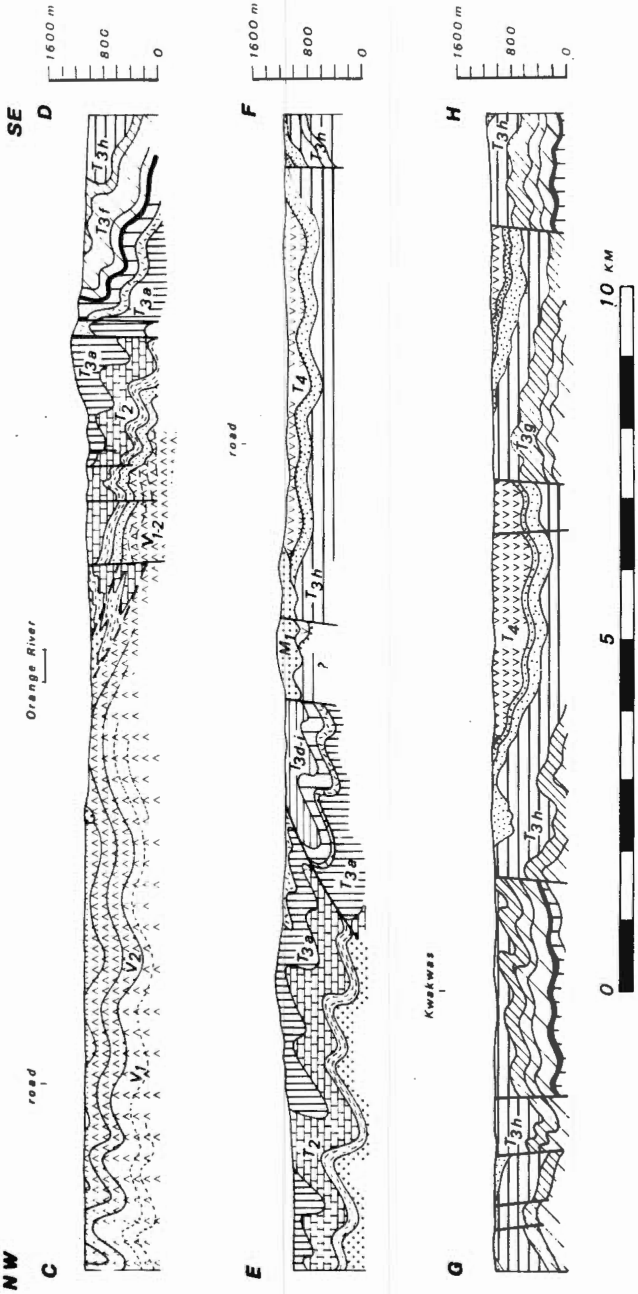

NW
SE
C
D
E
F
G
H
1600 m
800
0
Orange River
road
road
Kwakwas
T3h
T3f
T3a
T2
V1-2
V2
V1
T4
M1
T3d-i
T3g
?
0
5
10 KM

Fig. 13 Diagrammatic cross-sections through the Transvaal Supergroup. Formations shown in the sections are: 1 - the Seekoebaard; 2 - the Black Reef (stipples and dashed lines); 3 - the Campbell Rand (T_2); the Asbestos Hills Iron Formation ($T_{3}a,b,c,$); 4 - the Koegas Formation ($T_{3}d$-i); 5 - the Ongeluk Volcanics (T_4); 6 - the Matsap.
Note: symbols used in the sections correspond to those on the map (Annex. 1).
Section lines C-D, E-F and G-H are shown on the geological map (Annex. 1)

On a large scale (several tens or hundreds of metres), the pre-Matsap folds in the Transvaal sequence are gentle, wide and open (Fig, 15/1). Where unaffected by post-Matsap refolding, the axial surfaces strike north-easterly (e.g. Leelyksdam syncline) and are practically vertical. Doubly plunging major fold structures of this generation are common in the eastern part of the area (Paarde Vlei 151). They are probably related to the doubly plunging folds in the Kuruman area described by Fockema (1967), who expressed the opinion that the prominent north-trending monoclines and terrace folds and the nearly east-west trending apparent cross-folds in which they lie (causing the north-trending folds to be doubly plunging) were formed simultaneously.

In the zone along the Doringberg fault, however, some of the doubly plunging structures were formed as a result of two superposed phases of post-Matsap folding (e.g. the recumbent antiform on the eastern side of Koegas).

Last to be mentioned here is the regional unconformity at the base of the Matsap Formation; the Matsap strata rest on formations progressively older from south-east to north-west (Middle Griquatown group and Seekoebaard Formation respectively), and thus demonstrate the tectonic activity that terminated the period of the earliest deformation in the Transvaal basin of the northern Cape

2.2.2.4. Post-Matsap structures

2.2.2.4.1. First post-Matsap folding

The earliest post-Matsap structures are those with the original axial surfaces trending north-northeasterly (N20°E) and with flexural slip folds plunging in the same direction (Figs. 16 A, 17). While the axial trend of the folds is generally persistent, their plunge varies between 20°-70°. Minor and mesoscopic folds (*sensu* Dennis, 1967) are less common than the larger structures, which are clearly recognisable on aerial photographs (Fig. 18). All macroscopic folds (10-100 m) are overfolded towards the east-southeast, so that their axial surfaces have a consistent west-northwesterly dip. Related to this overfolding are local overthrusts, in which antiforms are always

Plate 5.1. Sedimentary boudinage structure of the banded iron-formation. Leelykstaat

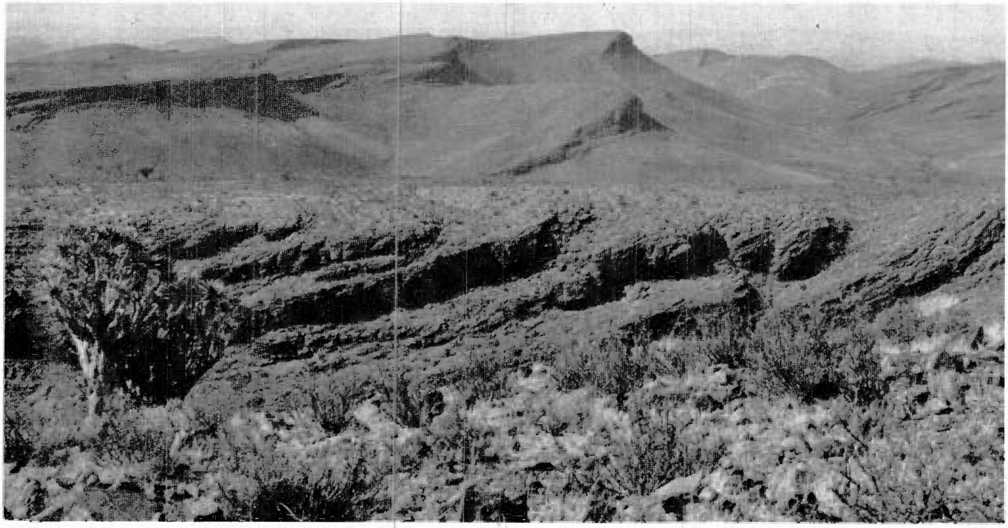


Plate 5.2. North-easterly plunging synclines of the Asbestos Hills Iron Formation. Hounslow

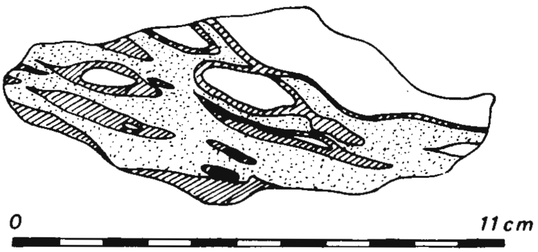


Fig. 14 A nodular rock (pseudoconglomerate) from the upper part of the Kwakwas Member (Transvaal Supergroup). Farm Grasgat. For explanation see pages 107 and 109

situated on the western upthrusted part of the fault plane (Fig. 15/III). Some of these overthrusts also developed in the marginal parts of the Matsap synclinorium and separate the Matsap Formation from neighbouring units (e.g. the Eselberge fault on the Kheis/Matsap boundary).

Planar structures in the Matsap Formation comprise bedding, bedding foliation, crenulation foliation, fracture cleavage and joints. Bedding foliation (bedding fissility) is parallel to the lithological layering and it is widely or closely spaced depending on the grain size of the sediments. Mineral growth with a preferred orientation of sericite and chlorite along the fissility planes can rarely be seen; the sediments are affected by neocrystallisation only in shear zones of only restricted extent (e.g. in the southwestern part of Soutputs and on some farms north of the 29°00' parallel). The width of such zones seldom exceeds 2 m and outside the shears Matsap sediments show no signs of recrystallisation.

The fissility is better pronounced in more intensely folded parts of the Matsap synclinorium; it is therefore likely that the bedding foliation developed as a result of flexural-slip folding during the earliest period of post-Matsap deformation.

Also probably related to the same deformation is the crenulation foliation in the conglomeratic layers and pebble washes which, contrary to the bedding foliation in the neighbouring lithic sandstone and lithic graywacke layers, display a planparallel structure obliquely crossing the original sedimentary s_0-surfaces. This obliquity is probably a result of different mechanical behaviour of the two rocks types. The dip of the crenulation foliation is also north-westerly (e.g. exposures on the eastern side of the Buchuberg Dam).

A third set of planar structures in the Matsap Formation comprises non-penetrative fracture surfaces, which have a specific geometric relationship to the earliest post-Matsap folds (they are of variable orientation but tend to intersect in a line parallel to the fold axes); these fracture surfaces are particularly distinct in the hinge areas of the earliest post-Matsap folds.

Fig. 15 Four stages of the development of macroscopic fold structures in the Transvaal sequence.
Explanation: I - pre-Matsap deformation; II - post-Matsap folding; III - post-Matsap overthrusting; IV - second post-Matsap (Namaqua) deformation with repetition of movement along existing thrust planes and with the development of lag faults

Last among the planar structures in the Matsap Formation are joints which, in terms of a geometrical classification, comprise the following groups:

(i) strike joints, also known as bc-joints or axial-trace fractures (Hancock, 1964);

(ii) dip joints (ac-joints), for which the name kathetal joints (*Kathetos* = Gr. perpendicular) has been introduced by Hancock (op. cit.);

(iii) oblique joints or joints (hkl) and (hk0);

(iv) lens belts, which represent gaping and infilled en echelon tension fractures within a shear zone. Such structures have been called pinnate tension joints, en echelon tension gashes or feather joints (Cloos, 1932). Hancock (1964) who introduced the name lens belts, used the term lens to describe the tension gash part of the structure, and belt to describe the shear zone;

(v) bedding joints or (ab-joints).

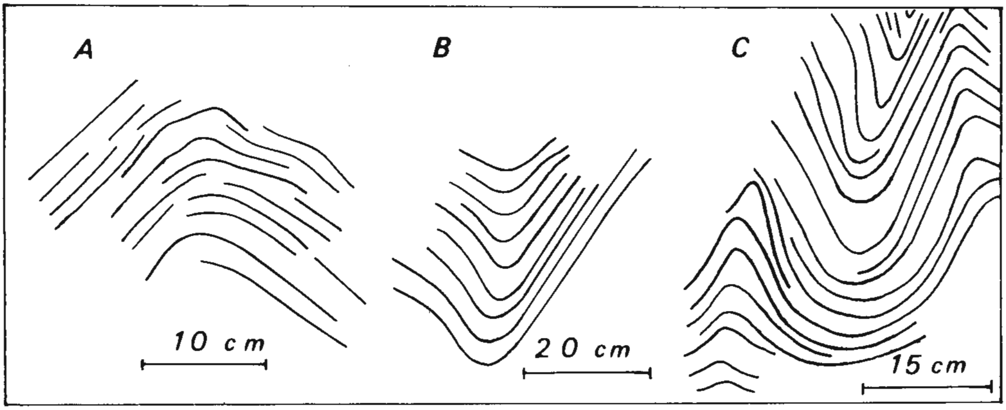


Fig. 16 Examples of fold profiles of the earliest post-Matsap structures. A - Matsap Formation, Maraisdraai (V 131); B - Campbell Rand Formation, Bo-Seekoebaard (V 968); C - Seekoebaard Formation, Waterval (V 257).

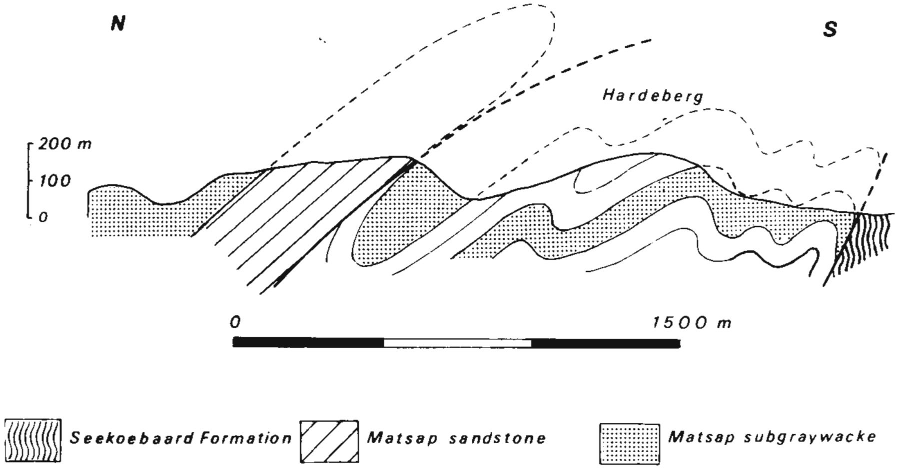


Fig. 17 Folding and faulting of the Matsap Formation on Hardeberg (farm Seekoebaardsnek).

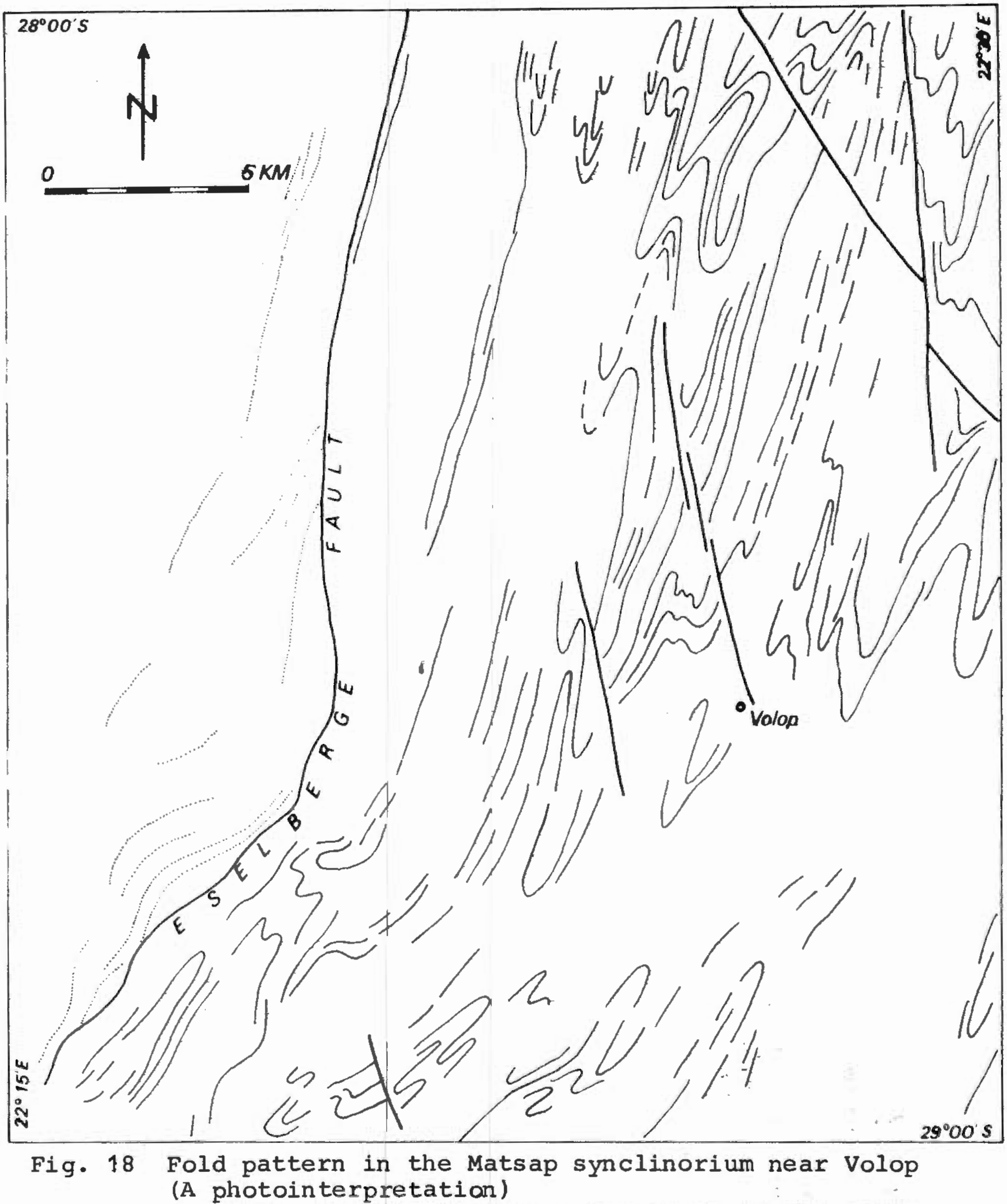


Fig. 18 Fold pattern in the Matsap synclinorium near Volop (A photointerpretation)
Explanation: dotted lines - foliation in the Kheis Group; light lines - bedding in the Matsap Formation; heavy lines - major fractures and faults

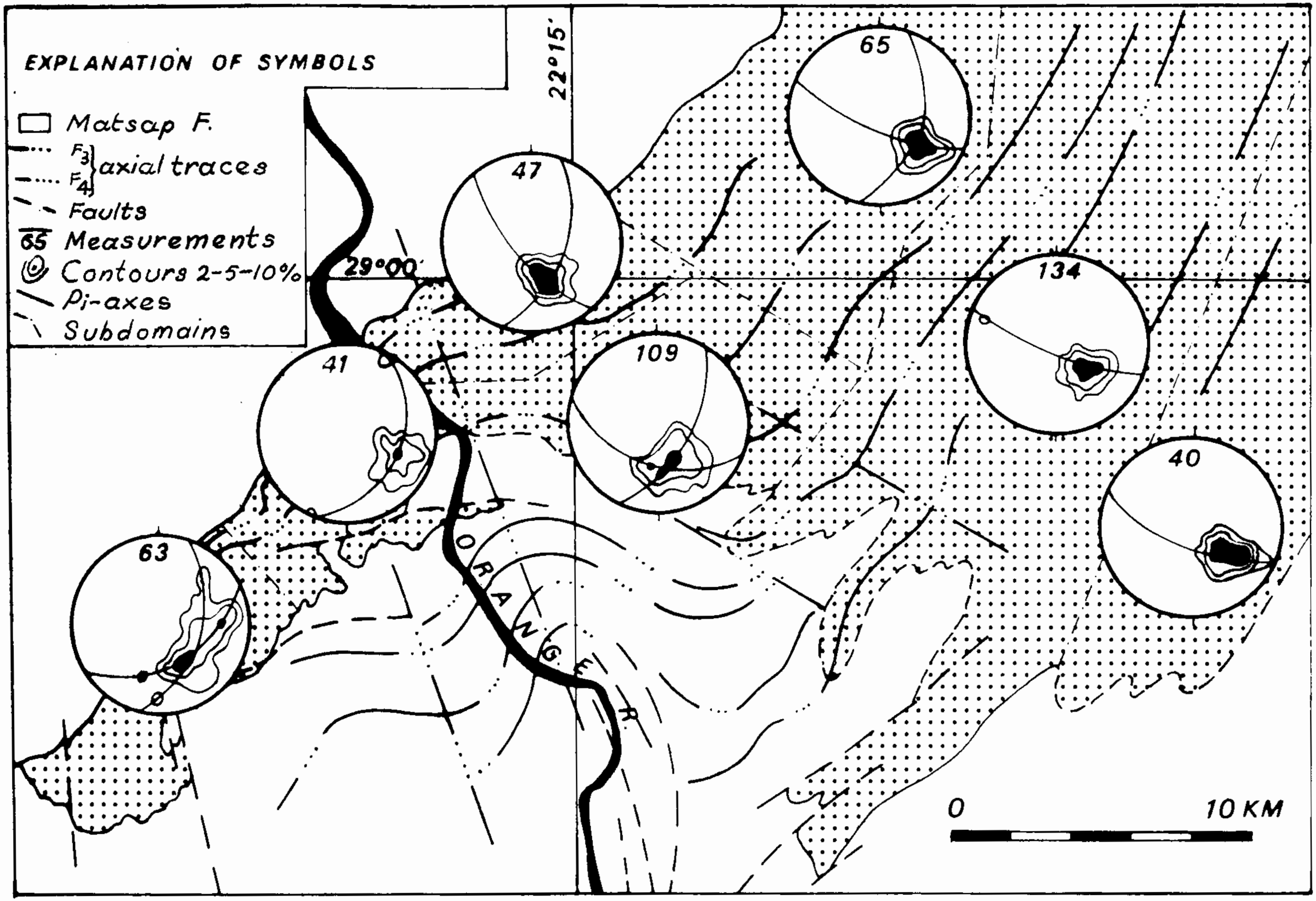


Fig. 19 Two sets of fold structures in the Matsap Formation.
(contoured are poles to bedding and bedding foliation)

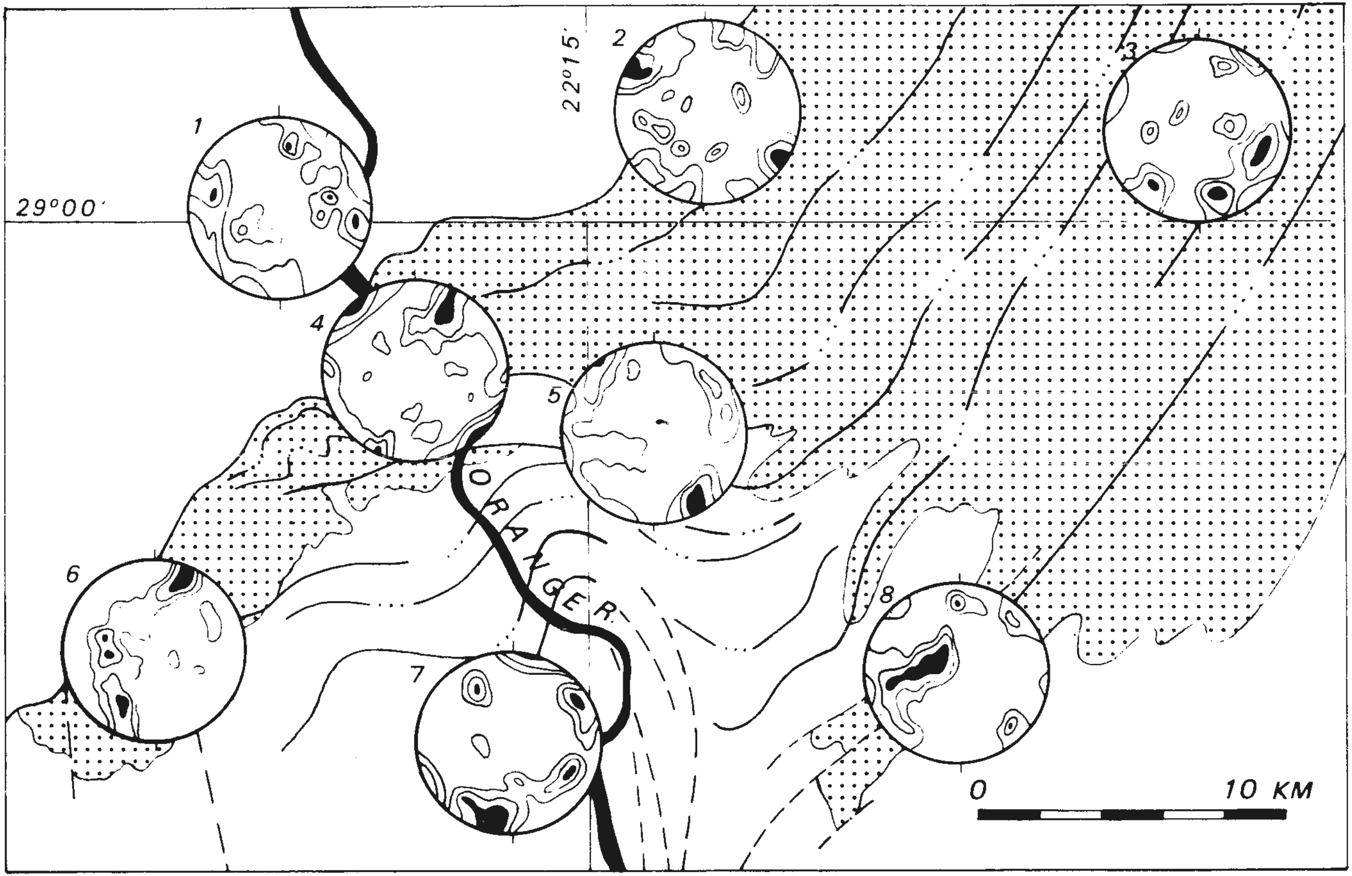


Fig. 20 Sets of joints in the Kheis Group (1), Black Reef Formation (7) and Matsap Formation (2 - 6 and 8)
(For explanation of symbols see Fig. 19; contours 2 - 5 - 10% of 120 measurements)

Diagrams in Fig. 20	Unit	Axial trend of the first post-Matsap folds	bc-joints	ac-joints	Oblique joints		Angle between the sets of oblique joints	
							Mean	Maximum
1	Kheis Group	45°- 50°	n.a.	n.a.	330°- 10°	75°-115°	105°	145°
2	Matsap Formation	30°	25°- 35°	110°-135°	330°	80°	110°	110°
3		20°	10°- 30°	100°-120°	310°-320°	65°- 80°	115°-120°	130°
4		40°- 50°	40°- 55°	130°-145°	340°-360°	90°-110°	110°	130°
5		80°	80°	170°	10°- 30°	130°-150°	120°	140°
6		50°- 60°	50°- 55°	140°-145°	345°-355°	110°-120°	125°	135°
7	Lower Griquatown group	30°	25°- 35°	115°-125°	320°-350°	70°-100°	110°	140°
8	Matsap Formation	40°- 50°	40°- 50°	130°-140°	340°-360°	90°-110°	110°	130°

Table 18 Azimuths of sets of joints shown in Fig. 20

By their origin the first four groups of joints are exokinetic (i.e. resulting from the regional strain), whereas bedding joints, which are the result of strain within the rock-unit itself, represent endokinetic structures. The strike and dip joints most probably fall into the category of structures related to the first post-Matsap compressive stresses (tension, release or extension fractures); oblique joints are, in fact, incipient shear fractures (Billings, 1972, p. 169). All the joints fall into the category of tectonic fractures (Nevskyi, 1973).

Joints of the first three groups form two distinct sets, both of which are symmetrically oriented about the first post-Matsap fold axes; the orientation relative to the original fold structures remained constant even during the refolding of the Matsap synclinorium at the time of the second post-Matsap event (Fig. 20 and Table 18), which is also responsible for moderate and gentle dips of the sets of joints in some areas (e.g. No. 6 in Fig. 20).

Structures of the first post-Matsap folding are also developed in the Transvaal and Seekoebaard sequences. They comprise both planar and linear elements, the latter being mostly represented by intersections of s-surfaces and, less commonly, by elongate clastic grains in sediments. On a meso- and macroscopic scale the post-Matsap structural linearity is characterised by folds of the north-northeasterly plunge (Plate 5.2.). Fold profiles of structures of this group sometimes display thickening of fold hinges as is commonly found in similar-type folding (Fig. 11 E, 15/II, III, and 16 B,C), and chevron folds frequently occur (e.g. in riebeckite slate in the Koegas Formation in the vicinity of Koegas).

While post-Matsap refolding was more intense in antiforms, the Transvaal synforms usually retained their pre-Matsap geometry and remained generally broad and open (e.g. Leelyksdam and Paarde Vlei synforms). The intensity of the first post-Matsap refolding dies out with increasing distance from the Matsap synclinorium; the structurally most involved areas are the synclinorial "roots" of the Transvaal sequence on the farms Onder- and Boven Seekoebaard and on Waterval where overfolding and overthrusting often resulted in development of complex imbricate structures. Fractures separating individual slices of the sequence formed in close connection with major folds of the first-post-Matsap generation (usually of tight or isoclinal type). Such fractures, broadly conformable with major geometric features of the fabric are accompanied by thinning and/or excision of members of the sequence affected by folding, and therefore belong to the category of tectonic slides (Fleuty, 1964). Major fractures are always situated on the northern and north-western side of the synclinorial "roots" and are accompanied by a number of minor faults occurring within the synforms; sometimes slices of the underlying Seekoebaard Formation have also been incorporated in this complex pattern (e.g. in the Waterval synform).

Two of the tectonic slides separating the Black Reef Formation from the underlying Blinkfontein Volcanic Member of the Seekoebaard Formation can be traced almost continuously from the farm Rooilaagte to Schalksdrift (321 Hay 16.10), and the same two tectonic lines also occur on the eastern side of the Doringberg fault on the farms Geelbeksdam and Windpomp. The slides can best be studied on Schalksdrift, and a particularly well exposed example can be viewed from the road on the opposite side of the Orange River some 4 km west from Westerberg. The tectonic slide is marked by a thin impersistent layer of brecciated carbonate (tectonic slice of the Campbell Rand Formation), which has a characteristic brown or ochrous colour on the weathered surfaces. This layer is between several centimetres and c. 15 m thick. More tectonic slices are sometimes wedged between sheared Seekoebaard lava and overlying Black Reef quartzarenite (e.g. thin layers of the Transvaal slate and quartzarenite), but the carbonate is always present and makes the tectonic contact very distinct. It resembles the so-called "Rauhwacke", a layer of tectonically brecciated dolomite which was described from the Swiss Alps (Heim, 1922). The two tectonic slides described above are practically horizontal at many places, most probably as a result of refolding during the second post-Matsap event; this refolding was accompanied by further tectonic movement along the existing thrust planes (Fig. 15/IV).

A tectonic slide carrying the Draghoender Granite over lava of the Seekoebaard Formation is shown on the geological map (Annex. 1) in the southern part of the farm Vaalbult. The thrust plane, separating the cataclastic muscovite-biotite granodiorite (pp. 15-16) in the west from the sheared lava (pp. 36-37) in the east, dips gently towards the west.

Several tectonic slides also separate competent and incompetent segments of the Matsap synclinorium in the vicinity of the Buchuberg Dam. They can clearly be seen on aerial photographs and their arcuate or sinuous traces indicate that the slides have been refolded during the second period of post-Matsap tectonic activity. As a consequence of this refolding some of the slides converge in the limbs of large-scale refolds and individual segments of the Matsap synclinorium thin out or are excised (e.g. in the Boegoeberge south-west of the Buchuberg Dam).

Finally, the north-northeasterly axial plunge of the first post-Matsap structures is also shown by the outcrop pattern of the Skalkseput and Draghoender Granites in the southern part of "Blinkfontein 10" ; the northern margins of these intrusive bodies are seen on the geological map (Annex. 1) as two triangular-shaped areas with their sharp edges pointing towards the north-northeast. The two "triangles" are bounded by faults on their north-western sides, and several shears and silicified zones run parallel to these faults within the granites.

Planar structures related to the first post-Matsap folding and occurring in the Transvaal and Seekoebaard sequences are impersistent and non-penetrative. They comprise a fracture cleavage which is axial-planar to open folds of 10 - 100 m scale (mainly in the Seekoebaard Formation) and sets of joints corresponding to those found in the Matsap Formation (p. 119). The fracture cleavage strikes slightly east of north (sub-maxima in Figs. 10C and 12C), and dips mostly to the west-northwest at angles between 60° and 90°. The planes of this cleavage are numerous in the vicinity of the Matsap synclinorium and also in the inferred south-western continuation of the Transvaal synforms on "Blinkfontein 10". The silicified shear zones and associated fracture cleavage which are restricted to the northern part of the Skalkseput Granite (p. 19) also strike north-northeasterly.

2.2.2.4.2. Second post-Matsap folding

Structures of this generation trend north-westerly, west-northwesterly and north-northwesterly, and are found in all units of the Kaapvaal Craton which were described in section 2.1.2. They comprise folds and other linear structures, various types of planar structures, and shear zones.

Macroscopic folds (*sensu* Dennis, 1967, p. 152) of the second post-Matsap generation are present in the Matsap synclinorium (Hardeberg, parts of the Eselberge, p. 152 and Annex. 1), and their shape is also indicated by the outcrop pattern of diabase sills north of the Waterval synform and by the sinuous trace of earlier major fractures such as the Eselberge fault. The most conspicuous among these large-scale structures are the major refolds of the Transvaal synforms and antiforms on both sides of the Orange River north of about the 29°15' parallel. In these refolds the axial surfaces of the first post-Matsap structures constitute a similar-fold pattern on a megascopic scale (Figs. 19 and 20) in which the axes of the second post-Matsap structures plunge again north-westerly. The plunge of megascopic folds seems to be steeper than that of the mesoscopic structures.

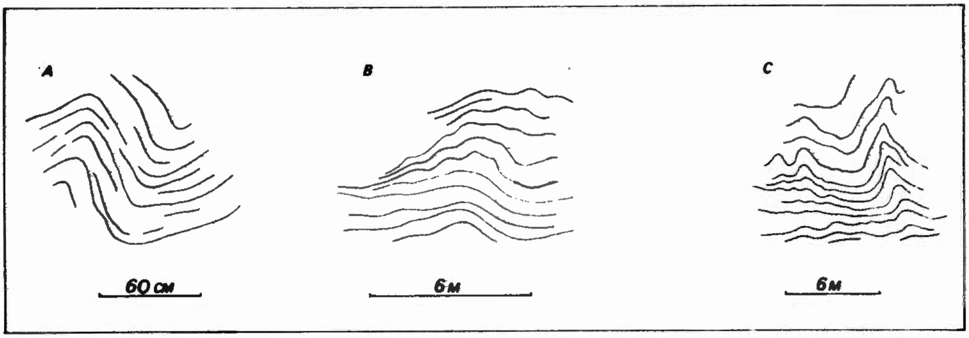


Fig. 21 Examples of fold profiles of the second post-Matsap structures
A - Matsap Formation, Maraisdraai (V 234 = 310°/33°NW)
B, C, - Westerberg Member, Deelfontein (V 1820 = 330°/14°- 45°NW)

Mesoscopic folds (*sensu* Dennis, 1967, p. 152) of the second post-Matsap generation are of the flexural-slip type, their profiles being characterised by a constant thickness of layers throughout the structure, and by medium- (30°- 45°) or high-angle (more than 45°) fold closures (e.g. Figs. 21 A-C). The plunge of all these folds is north-westerly (Figs. 10D and 12D) and two to three maxima are usually present when the linear data are plotted on a stereographic projection. The axial surfaces of the folds are usually nearly vertical or steeply inclined to the south-west. Their trend is perpendicular or almost perpendicular to that of the two earlier sets of structures occurring in the Seekoebaard, Transvaal and Matsap sequences. The second post-Matsap folds are confined to the area along the Orange River and to the Eselberge. They fade out towards the north-east and have not been encountered beyond the line linking the names "Daskop 302" and "Folmink 331" on the geological map.

The actual size of the second post-Matsap folds of mesoscopic scale depends on the spacing of s-surfaces in the foliated sequences and, consequently, the folds in the Seekoebaard phyllite and Transvaal slate are therefore of smaller amplitude than those in the banded iron-formation or in the Matsap sandstone and subgreywacke. This is in agreement with the results of experimental flexural-slip folding of foliated model materials (Weiss, 1969).

The smallest structural elements of this generation are the kink bands which occur mostly in phyllite of the Waterval Member of the Seekoebaard Formation and, much less frequently, in some incompetent layers of the Matsap Formation. Planar structures deflected by the kinks comprise schistosity in phyllite and fracture cleavage in the Matsap subgreywacke. Since both types of planar structures dip north-westerly, the kink bands have either

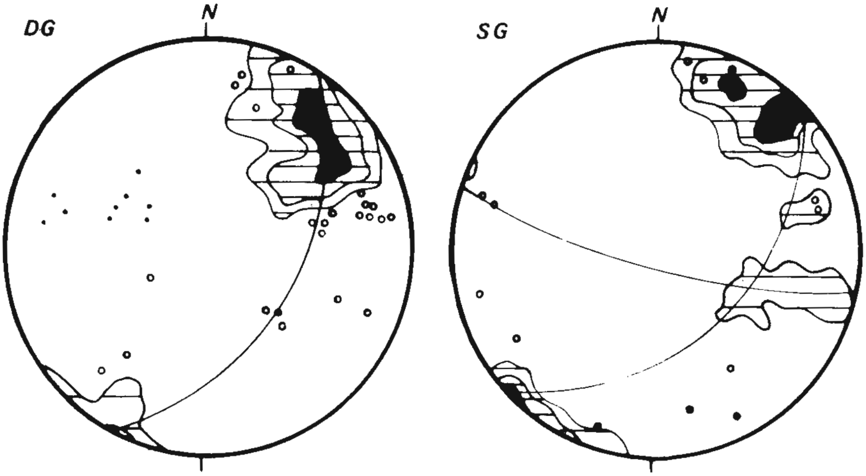


Fig. 22 Equal - area projection of structural elements in the Draghoender Granite (DG) and in the Skalkseput Granite (SG)
Contours 2 - 5 - 10% (62 and 60 measurements respectively) represent poles to fracture cleavage planes, circles correspond to individual fractures and to various minor dykes (not shown on the map) Dots indicate plunge of linear structures.
For explanation see text.

north-easterly or north-westerly axial plunges. North-westerly plunges vary between 315°/39° and 0°/58°, the north-easterly ones between 20°/41° and 50°/27°. The kink bands are synthetic (discrete kink bands *sensu* Dewey, 1965), less than 10 mm wide, and most of them terminate by a decrease in fold amplitude. The length of the kink bands sometimes exceeds 1 m. In some places two sets of kink bands are developed which have only slightly different orientation, but which differ greatly in their width (e.g. 1 - 2 mm and 5 - 10 mm respectively in the Waterval phyllite, V 223). Where developed the kink bands in the Matsap subgreywacke are only represented by one distinct set of kinds.

The fracture cleavage in the Seekoebaard Formation is the most conspicuous among the planar structures of the second post-Matsap folding. It strikes slightly west of north (sub-maxima in Figs. 10C and 12C), and occurs in zones of limited width (several metres to several tens of metres). These zones seem to be associated with the major north-northwesterly striking faults and occur most frequently in the vicinity of the Orange River. The best examples of this can be seen along the Marydale - Koegas road in the vicinity of the Orange River where the north-northwesterly striking cleavage together with the earlier set of fracture cleavage planes (p. 121) almost obliterate the primary layering in the Seekoebaard lava and give a characteristic rugged appearance to the outcrops.

Related to the major refolds of the second post-Matsap generation are steep slickensided fractures in the Matsap Formation, which have a north-westerly and north-northwesterly strike, and which occur in the Orange River valley north of the Buchuberg Dam. Slickensides on these planes are either subhorizontal or dip gently towards the north-west. Some of the tectonic slides of the first post-Matsap generation described above are also slickensided (pp. 120 - 121), but since these striae are oriented parallel to the strike of the thrust planes, their origin can be related to the flexure-slip movement which affected the pre-existing tectonic surfaces during the second post-Matsap deformation.

Other prominent fracture zones of the second post-Matsap generation are defined by the diabase dykes. They occur both in the granitoids and supracrustal sequences, most of them being concentrated in three swarms two of which occur on either side of the Doringberg fault (pp. 62 - 63). The dykes are younger than the first post-Matsap folding, but still somewhat older than the Doringberg fault.

Major fractures are also situated along the contacts between the Seekoebaard Formation and the Skalkseput and Draghoender Granites. Although frequently concealed under superficial deposits, such tectonic boundaries appear as remarkably straight lines on the aerial photographs. Their strike is 315° - 320° in the northwest, changing to 345° in the vicinity of the Orange River, where they run almost parallel to the diabase dykes.

Shears and silicified zones of north-westerly and west-northwesterly strike are present in both the Skalkseput and Draghoender Granites. In the Skalkseput Granite they are confined mostly to the southern part of the outcrop (farms Draghoender, Springputs and Uitvlug) and in many of them shearing is associated with silicification. It is notable that the magnitude of these zones decreases towards the north-northeast (Table 3). In the Draghoender Granite the largest of the shear zones is some 8 km long and 200 - 400 m wide; it is shown on the geological map (Annex. 1) and briefly described on p. 15. A lack of blastomylonitic textures in the granitoids indicates that the dynamic metamorphism resulting from the tectonic movement in these zones was of low intensity.

Planar structures developed in the shear zones strike west-northwesterly or north-westerly (Fig. 22) and comprise fracture cleavage, as well as individual fractures of various strike;

some of these fractures are filled with diabase dykes. Linear elements (i.e. rodding and slickensiding of a corresponding orientation (Fig. 22) are associated with the planar structures in the Draghoender Granite. In the Skalkseput Granite a second set of fracture cleavage is present, which is poorly defined on the equal-area projection (Fig. 22) and belongs to the set of the first post-Matsap structures (p. 121).

2.2.3. The Kheis Domain

2.2.3.1. General

The structure of the Kheis domain is characterised by four superposed sets of folds (F_1, F_2, F_3 and F_4): the earliest of these is accompanied by a persistent axial-planar structure (the regional foliation) and is folded by isoclinal folds of the second set. The two sets of folds, which deform the regional foliation correspond in their morphology and regional trend to the first and second post-Matsap structures of the Kaapvaal domain. Planar structures associated with these two later sets of folds are very limited in extent.

The prevailing type of interference pattern differs in various parts of the Kheis tectonic domain. For example, in the Kaaien Hills features of typical axial-plane folding[1] are much more distinct than in the area east of the hills or east of the Brulpan fault in the vicinity of Marydale. The trend and plunge of linear elements is also different in each of the three different parts of the area mentioned above. Consequently, the Kheis domain can be subdivided into three parts, i.e. into the Kaaien, the Groblershoop and the Marydale subdomains (Fig. 23).

Although the relative ages of the four sets of superposed structures have been established, their true age will always be difficult to define. Since all four sets are developed in one lithological unit (i.e. in the Kheis Group) the criteria used for chronological differentiation of individual tectonic episodes, such as those applied in the Kaapvaal domain (i.e. unconformities intrusive contacts etc.), are not available. For this reason the four sets of structures in the Kheis domain will be labelled in the way frequently accepted for the description of complex structural patterns, and the individual sets will be given symbols F_1, F_2, F_3 and F_4 respectively.

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[1] The term axial-plane folding is used here to describe the deformation of the axial planes of F_2 recumbent folds during the two post-Matsap tectonic episodes.

2.2.3.2. The earliest sets of structures (F_1 and F_2)

Isoclinal folds of various size together with the dominant regional foliation, which is axial planar to some of these folds represent the most characteristic structural elements of this group. Both types of structural elements are present in all the three Kheis subdomains; their distinctiveness, however, differs in various parts of the Kheis outcrop depending on the attitude of the fold structures relative to the exposed surface (Fig. 26) or on the lithology of the foliated rock type.

Linear structural elements of the first two generations comprise various types of lineations (intersections of S-surfaces, mineral lineation, mullions and rodding) and folds of two basically different profiles: the first type of these folds (F_1) is characterised by sharp hinges, while hinge zones of the second folds (F_2) are smooth and round. The latter type is more frequently developed than the former, and examples are present both on the mesoscopic and macroscopic scale.

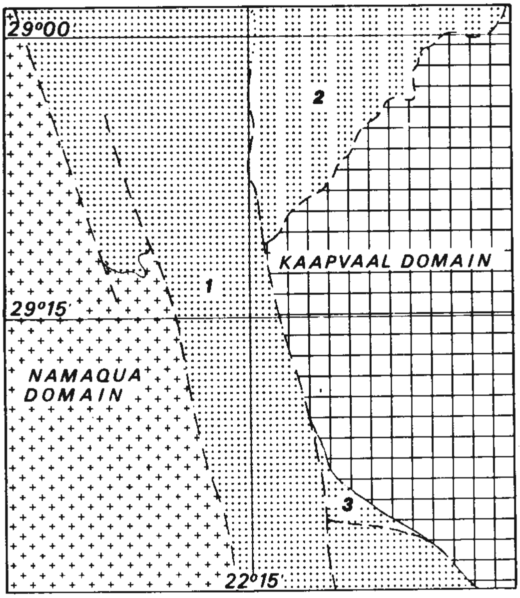

Fig. 23 Three subdomains in the Kheis tectonic domain
1 - Kaaien subdomain;
2 - Groblershoop subdomain;
3 - Marydale subdomain

Mesoscopic folds with smooth round hinges are best developed in the Kaaien subdomain. They have various directions of plunge depending on the degree of their involvement in the two subsequent tectonic episodes; most frequently, however, they plunge south-westerly (Figs. 27 A and 28 A). The attitude of their axial planes (s_2) is more variable and dips are more often gentle in the Kaaien Hills than in the two other subdomains, where the s_2 planes dip either north-westerly (Groblershoop subdomain) or are nearly vertical (Marydale subdomain). Fold profiles of the F_2 folds are tight (Figs. 24 and 25 and Plate 6), and although slip folds (similar folds) are predominant in this category, in some more competent layers the F_2 folds are also of flexural-slip type (parallel folds).

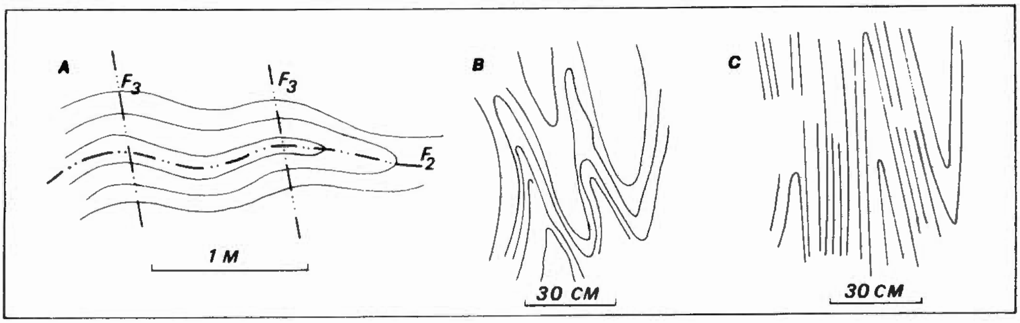

Fig. 24 Examples of fold profiles of the F_2 structures in the Kheis Group
A - Groblershoop subdomain, Welgevonde (V 531);
B - Marydale subdomain, Irene (V 2649);
C - Marydale subdomain, Marydale (V 2733)

Mesoscopic folds with round hinges (Plates 7.1. and 7.2.) are not the earliest tectonic structures occurring in the Kheis domain. In some places in the Kaaien subdomain they refold earlier isoclinal folds with sharp hinges (F_1), the axes of which trend parallel, oblique or at right angles to the F_2 axial trend (Fig. 26). These mesoscopic folds with sharp hinges are very seldom seen in the field (e.g. in the southern part of the Kaaien Hills), most probably because only a few of them have such an attitude relative to the exposed surface, that would make their hinge zones distinctly recognisable. The F_2 folds have not been found in the eastern part of the Groblershoop subdomain, where the primary sedimentary structures such as cross-bedding are preserved (e.g. in the Orange River Valley).

The relationship between the two types of mesoscopic folds (Fig. 26) suggests that the earlier structures with sharp hinges developed in a separate period of deformation which preceded the second tectonic episode. For that reason the folds with sharp hinges are classified here as F_1 structures.

It is noteworthy that in Namaqualand small isoclinal folds with sharp hinges, classified by Joubert (1971) as F_1 structures, are also refolded by tight isoclinal folds with round hinges. The F_2 folds in Namaqualand are related to the regional foliation in a similar way as are the mesoscopic folds with round hinges (F_2) to the regional foliation in the Kheis domain.

As in Namaqualand (Joubert, 1971, p. 104-106), the small F_1 folds with sharp hinges are practically the only evidence of pre-F_2 deformation in the Kheis domain, any early lineation (l_1) has been obliterated during the second episode of deformation, and s_1 planar elements can be distinguished from the s_2 foliation in the hinge zones of F_2 folds only. Along the long limbs of F_2 folds s_1 and s_2 are essentially parallel. The restricted occurrence of mesoscopic F_1 folds in the southern part of the Kaaien subdomain may indicate that the earliest deformation D_1 was less intense in the north, and that the F_1 structures probably open out and disappear in a northerly direction, as was tentatively suggested by Joubert (1971, p. 106).

Apart from the mesoscopic fold structures, which occur in various parts of the Kheis domain, several macroscopic folds can be seen in the field and on aerial photographs. They are always tight isoclinal structures with round hinges and with their limbs parallel to the regional foliation. Best examples of these folds were found at the following localities:

Plate 6 Tight F_2 fold in the quartzite of the Groblershoop Formation, Marydale (detail of the Fig. 24 C)

(i) Voorentoe Oos, a hill some 2 km east-southeast of the farmhouse. Kaaien subdomain;

(ii) The village of Buchuberg, outcrops between the Buchuberg-Noltesville and Buchuberg-Buchuberg Dam roads. Groblershoop subdomain;

(iii) Grootberg, some 3 km south of the Voorentoe Wes farmhouse. Kaaien subdomain;

(iv) Dabep, exposures 0-2 km east-northeast of the homestead. Groblershoop subdomain;

(v) Stillerus, some 9 km west-southwest of the farmhouse. Kaaien subdomain;

(vi) Geelbospan, some 2 km south-east of the farmhouse. Kaaien subdomain;

(vii) Roosterpoort (between the farms Blouputs and Brulpan), Fig. 33 C. Kaaien subdomain.

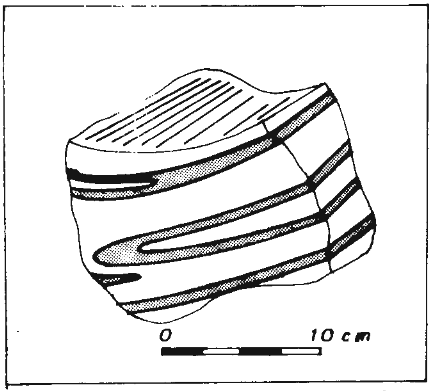

Fig. 25 An example of tight F_2 folds in the Kaaien quartzite (Kaaien subdomain, Brulpan, V 2815)

Note weak refolding of F_2 structures

Macroscopic folds of the F_2 generation also occur in other parts of the Kheis domain; in some places their presence can be deduced from characteristic structural patterns revealed by a detailed geological map (Fig. 33 B and 33 D), in others they can be seen in deep valleys (e.g. Grootberg, Voorentoe Wes), or on the sides of hills (e.g. some 7,5 km north-west of the Blouputs farmhouse - dip symbol with value "49" on the geological map.

When examined in detail, the structural pattern of the macroscopic F_2 folds indicates that the repetition of lithological layers in the Kheis domain was brought about mainly by the isoclinal folding during the second episode of deformation. There exists practically no evidence which would point to the direct relationship between such a repetition and the F_1 structures.

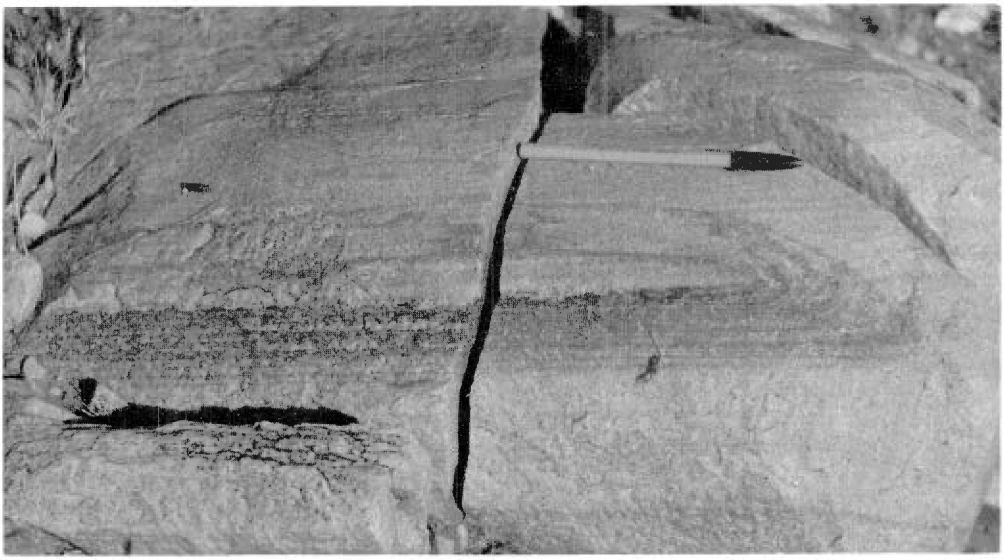

Plate 7.1. Regional foliation s_1 folded by the mesoscopic F_2 folds in the Kaaien Formation.
Farm Middelka

Plate 7.2. Mesoscopic F_2 folds in the Kaaien Formation.
Farm Middelka

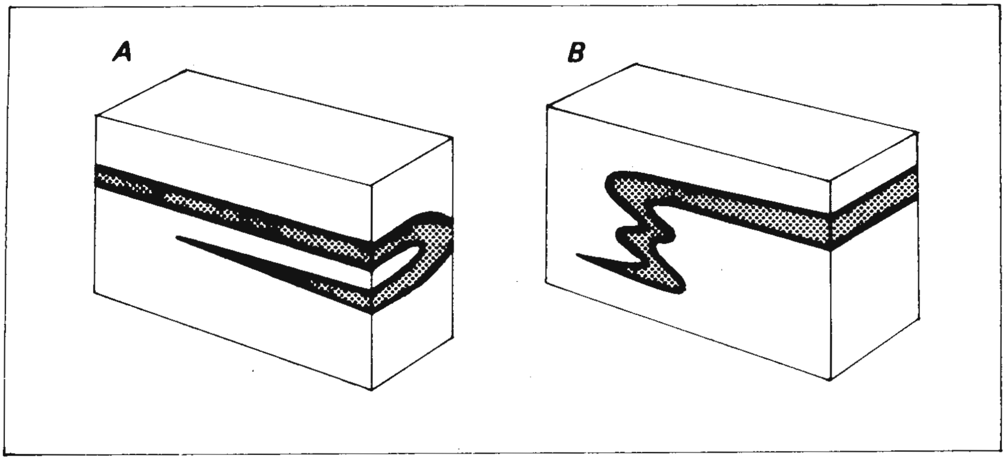

Fig 26 Relationship between the two earliest sets of folds in the Kheis domain (F_1 folds shaded).
A - F_1 and F_2 axial trends intersecting at right angle;
B - F_1 and F_2 coaxial

Among the linear structural elements of mesoscopic scale that originated during the second episode of deformation, mineral lineation, mullions and rodding are the most distinct. Strong mineral lineation is seen in the less competent layers in the Kaaien and Groblershoop subdomains, and also in the Marydale amphibolites of the Marydale subdomain. In the Kaaien quartzite, where the mineral lineation is not so well developed, mullion structures are the most characteristic (e.g. the southern part of the Kaaien subdomain, the Marydale subdomain). They comprise both foliation and fold mullions (Whitten, 1966, p. 315), the former being more abundant than the latter.

Rodding is usually confined to layers of mica schist and quartz-sericite schist in the Groblershoop subdomain, and the rods are often formed by quartz or quartzite. A good example of rodding is exposed in the quartz-sericite schist some 1,9 km northwest of the Keukendraai farmhouse; elongate spindle-shaped lumps of quartz are of various size, often 5 - 10 cm long, but usually less than 1 cm thick. The rods sometimes resemble clasts or pebbles, but their tectonic origin is quite obvious, and it has been also recognised by previous workers (Rogers and Du Toit, 1908, p. 57).

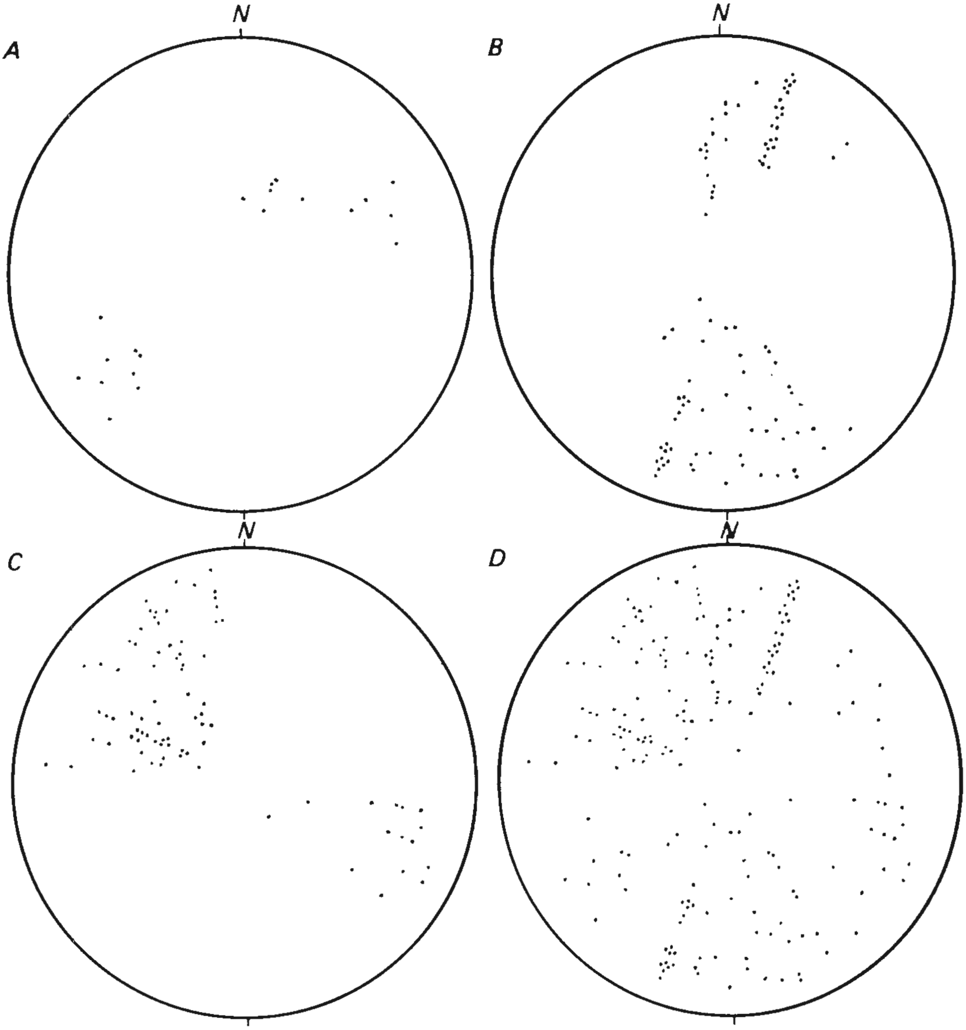

Fig. 27 Equal-area projection of the linear structural elements (including the mesoscopic folds) in the Kaaien subdomain

A - F_2, l_2,
B - F_3, l_3,
C - F_4, l_4,
D - combined projection of A,B, and C
(195 readings)

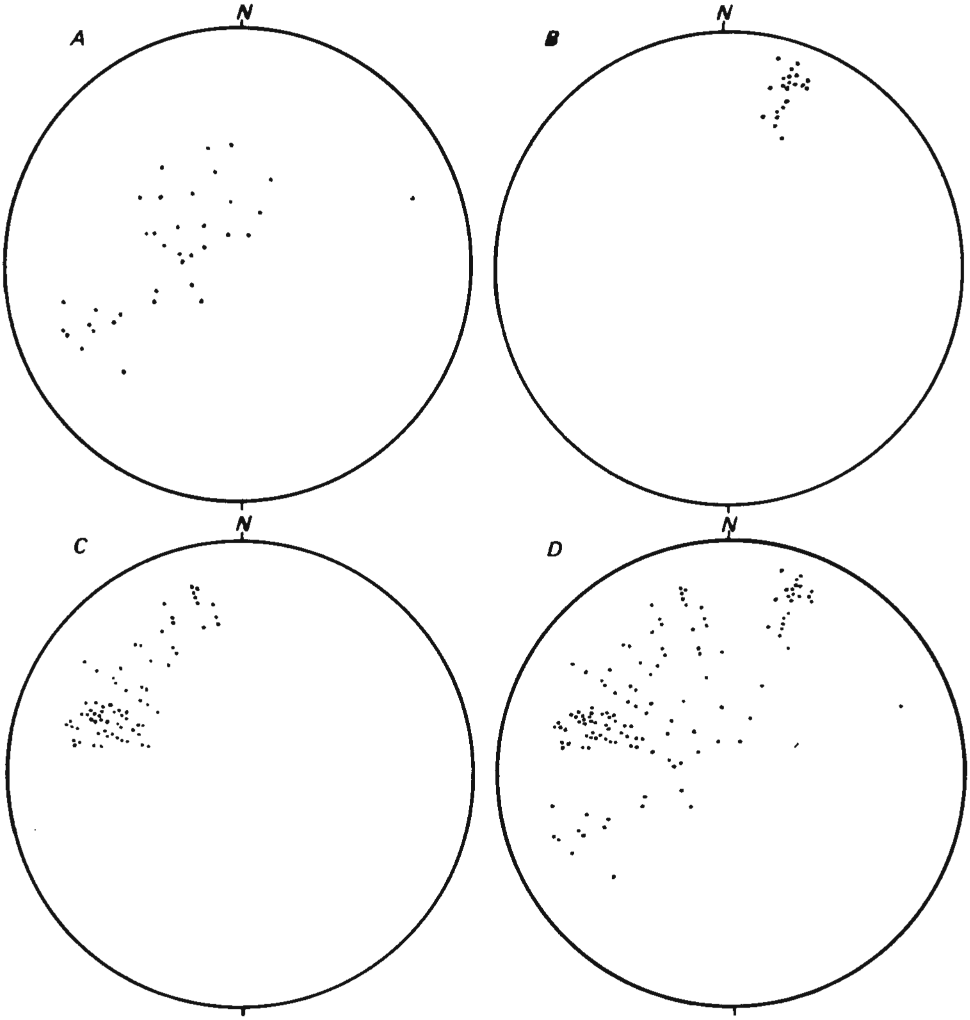

Fig. 28 Equal-area projection of the linear structural elements (including the mesoscopic folds) in the Groblershoop subdomain

A - F_2, l_2,
B - F_3, l_3,
C - F_4, l_4,
D - combined projection of A, B, and C
(130 readings)

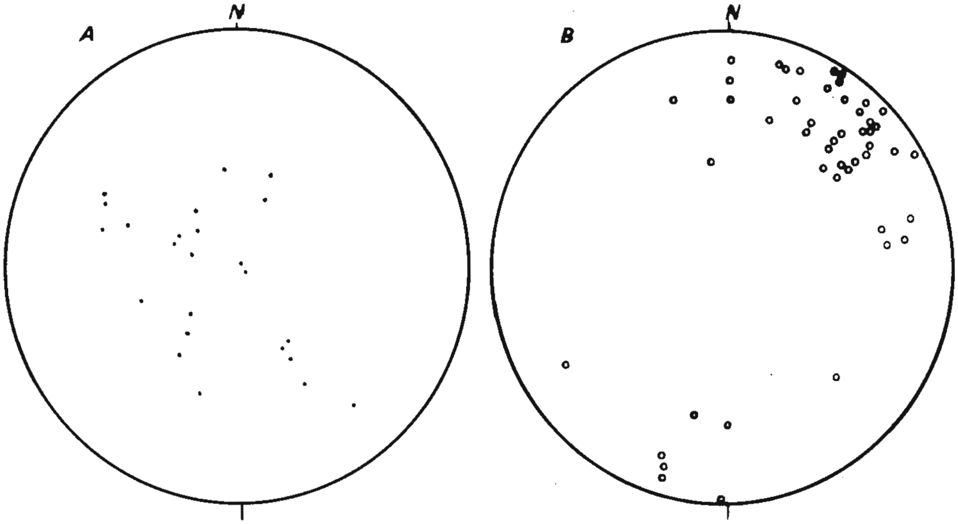

Fig. 29 Equal-area projection of 24 linear (A) and 48 planar (B) structural elements in the Marydale subdomain

The dominant regional foliation (s_1) is the most distinct among the planar structures. It is particularly well developed in schistose rocks of the Groblershoop subdomain, in amphibolites and schistose rocks of the Marydale subdomain, and it can also be seen in less competent layers of the Kaaien subdomain. The foliation is defined by dimensional preferred orientation of mica flakes (the lepidoblastic schistosity of Harker, 1939), and of hornblende crystals (the nematoblastic schistosity of Harker, op. cit.). As has been mentioned above, the foliation is oriented parallel to the limbs of F_2 folds but, in the fold hinges of F_2 structures this foliation is folded. Also folded by the F_2 folds is the lithological banding which, at many places, may be parallel to the primary layering. It should be noted, however, that in some quartzite layers (in the Groblershoop subdomain in particular) transposition structures did not develop, and primary layering represented by cross-bedding is preserved (e.g. Dabep 304, exposures in road cuttings on the northern bank of the Orange River).

The attitude of the regional foliation is more or less uniform in the Groblershoop and Marydale subdomains, where it strikes north-easterly (Fig. 31) and west-northwesterly to north-westerly (Fig. 29). In the Kaaien subdomain its attitude is much more variable (Fig. 30), the resultant picture being in agreement with

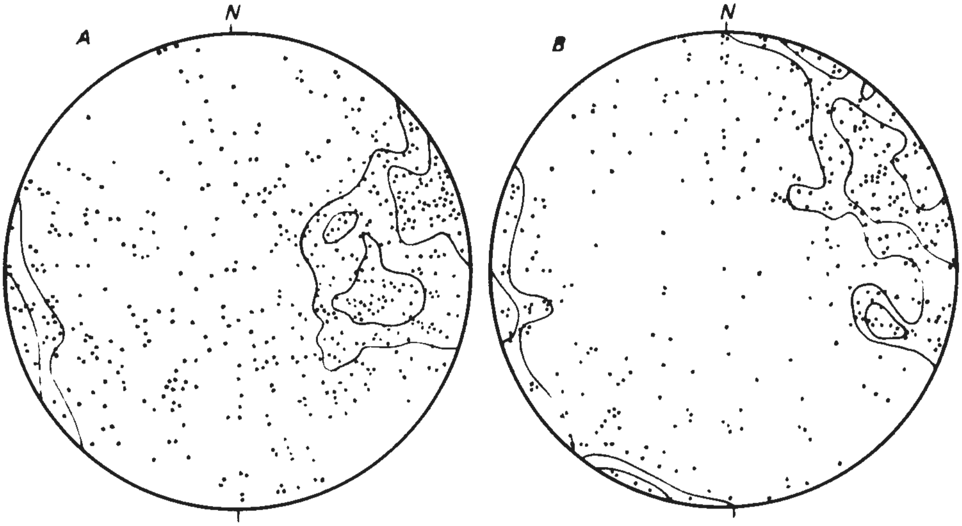

Fig. 30 Equal-area projection of the planar structual elements in the Kaaien subdomain of the Kheis domain

A - 550 poles to foliation (north of the farms Brulpan and Brulpoort)

B - 359 poles to foliation (Brulpan, Brulpoort, and area to the south)

Contours 2% and 3%

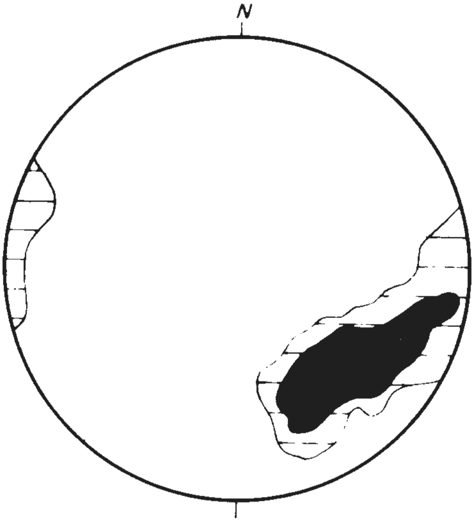

Fig. 31

Equal-area projection of planar structural elements in the Groblershoop subdomain of the Kheis domain

(204 poles to foliation planes)

Contours : 2% and 5%

Note : 120 poles are concentrated within the area + 5%

the pattern of the axial plane folding (p. 125) well developed in the Kaaien Hills.

Planar structures related to the F_2 folds comprise both axial-plane foliation (s_2) and crenulation foliation (strain-slip cleavage). They are generally impersistent and occur mainly in the incompetent layers of the Groblershoop subdomain, or in mica schist and quartz-sericite schist layers in the Kaaien subdomain. Very little or no mineral recrystallisation took place along these planes, which differ markedly from the s_1 schistosity.

Thin amphibolite layers (metamorphosed mafic sills) were emplaced along the s_1-s_2 planes. They occur at various places in the Kaaien subdomain (e.g. Sonderpan, Khaboom, Voorentoe), and also in the Groblershoop subdomain (Boegoeberg). The majority of these layers follow lithological boundaries, and some of them have been affected by later shearing (see also pp. 63 - 64).

2.2.3.3. The third episode of deformation (F_3)

It has been shown in the previous section that, during the second episode of deformation in which the Kheis sequence was isoclinally folded, the earlier planar structures such as primary lithological layering s_0, schistosity s_1, and axial-plane foliation s_2 were, on a regional scale, aligned more or less parallel to the F_2 axial planes or, in the case of the crenulation foliation s_2, parallel to the F_2 axial traces. Later, during the third episode of deformation, both lithological layering and regional foliation were refolded and the superposition of pre-existing structures by F_3 folds resulted in the development of a characteristic interference pattern of the $F_2 \wedge F_3$ type. This pattern is well seen on the aerial photographs and on the geological map and represents one of the typical features of the D_3 deformation.

Folds of the F_3 generation are best developed on the mesoscopic scale. They comprise various flexural slip types, two examples of which are shown in Fig. 36. The axes of these folds plunge north-northeasterly and, less often, south-southwesterly, and their axial planes dip at moderate or high angles towards the west-northwest. The predominant north-northeasterly plunge of F_3 folds is more distinct in the Groblershoop subdomain (Fig. 28B), possibly due to the greater distance of the subdomain from the Namaqua front. In the Kaaien subdomain the plunge of F_3 structures varies (Fig. 27B), this variability being either due to the variable attitude of earlier planar structures or, more likely, the double plunge was brought about by later refolding of the F_3 structures about F_4 fold axes which plunge west-northwesterly and north-westerly. A similar double plunge of the F_3 structures also exists in the Marydale subdomain, but the picture there is less distinct (Fig. 29A).

The change in the spatial relationship between the F_3 and earlier structures (which, among other criteria, defines the

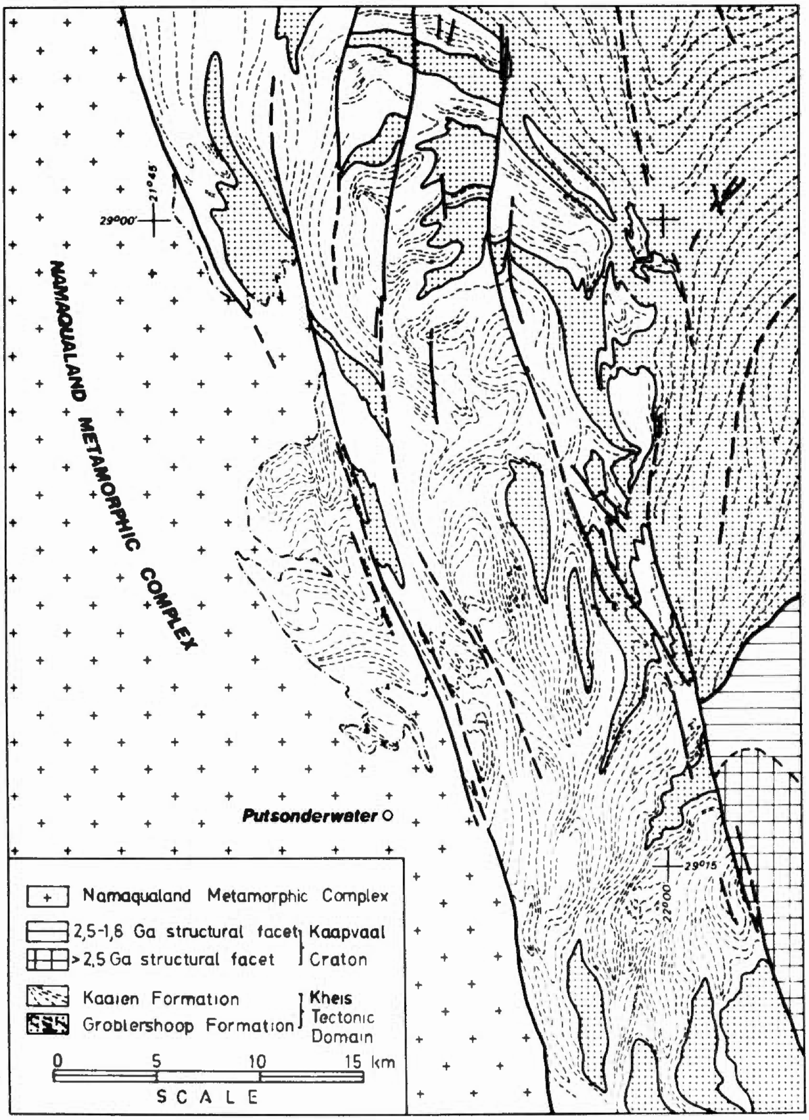

Fig. 32 An example of axial-plane folding in part of the Kaaien Hills (dashed lines represent traces of regional foliation s_1)

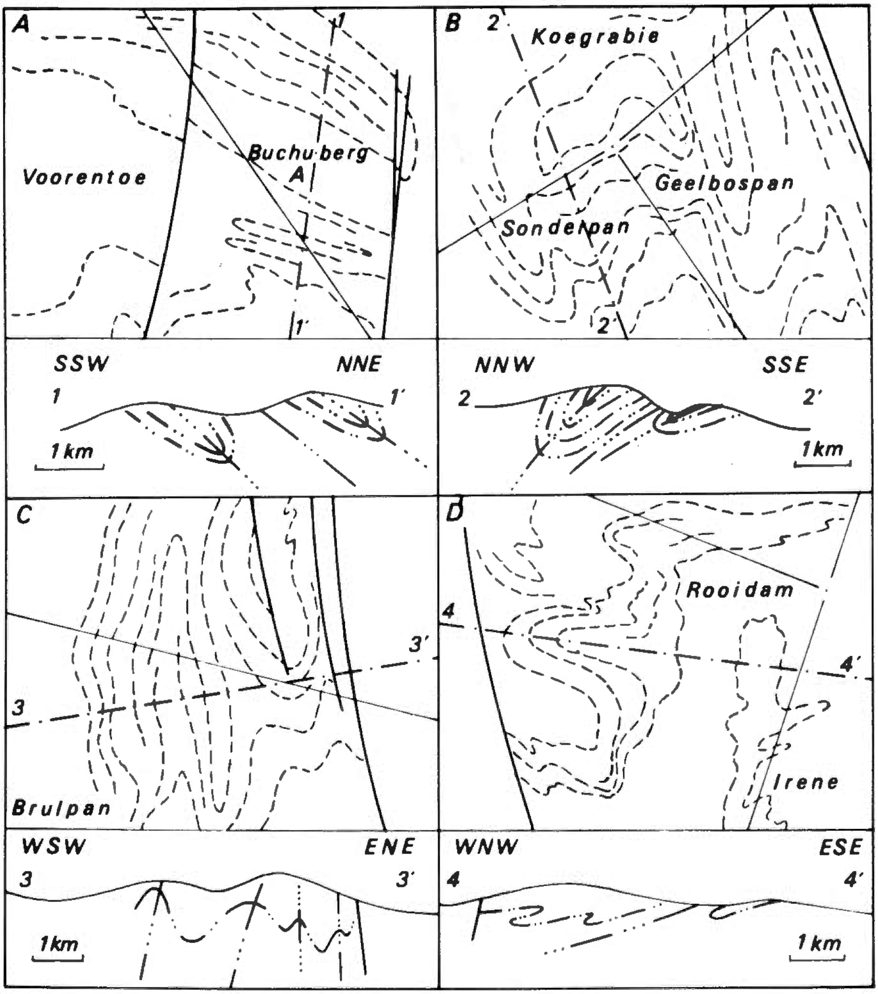

Fig. 33 Simplified diagrammatic maps and stylised sections of $F_2 \wedge F_3 \wedge F_4$ patterns in four parts of the Kaaien subdomain
Aerial photographs (Job, Strip, Number): A - 431/22/1602; B - 431/25/2291; C - 431/29/2385; D - 524 E/10/513
Explanation: thick lines - faults; thin dashed lines - s_1-planes (regional foliation).
Dot-and-dashed lines in sections 1 - 4 represent the axial planes of F_2 (..), F_3 (...) and F_4 (....) structures

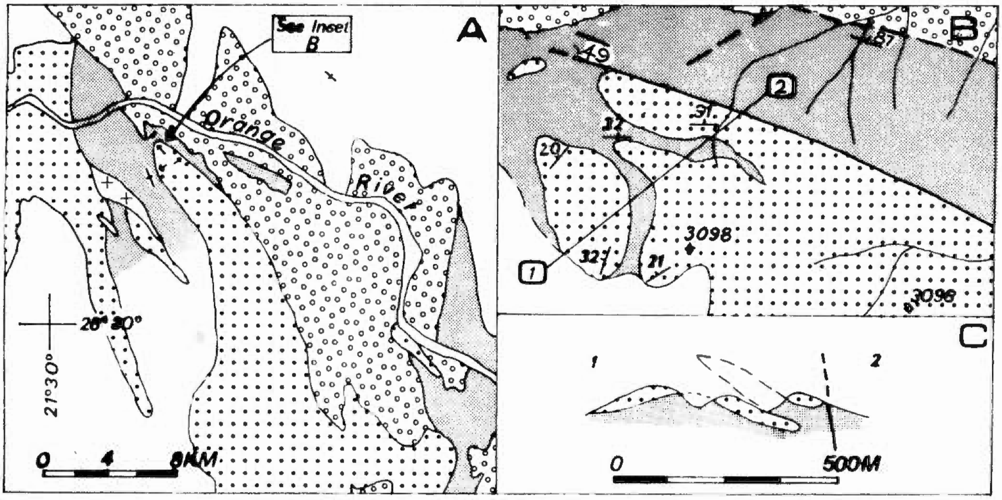

Fig. 34 Axial-plane folding of the Kheis Group on KAROS 42 some 30 km east-northeast of Upington
Explanation: A - Map of the area along the Orange River showing the Karos structure as a simple anticline with the Kaaien Formation (stippled) in the core, and the Wilgenhout Drift Formation (shaded) on flanks (after Rogers and Du Toit, 1909). The Koras Formation (circles) overlies the Kheis Group unconformably; areas of the Kalahari Beds and superficial deposits are left blank;
B - Detail of the "anticlinal" closure;
C - Sketch section across the Karos structure.
For further explanation see the text.

difference between the superposed fold patterns in the three Kheis subdomains) also seems to be responsible for the systematic changes in the morphology of mesoscopic F_3 folds. In the Groblershoop subdomain, for example, where the angle between F_2 and F_3 axial trends is smaller than in the other two subdomains (ca. 40°) and where the two sets of folds have practically constant orientation (axial trends N60°E and N20°E respectively), the F_3 folds are more frequently asymmetrical, often of a type shown in Fig. 36A. Contrary to this, the profiles of the mesoscopic F_3 folds are generally symmetrical in the Kaaien subdomain (e.g. Fig. 36B).

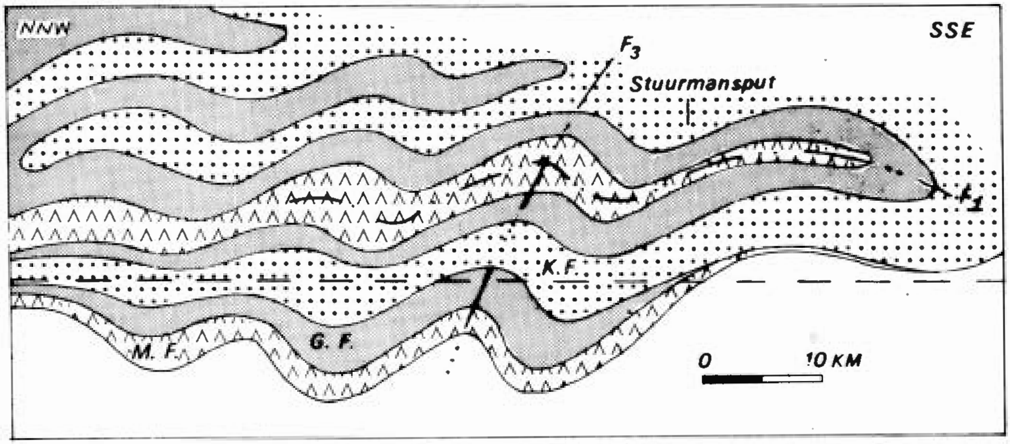

Fig. 35 Axial-plane folding ($F_2 \wedge F_3$) in the Kaaien Hills - a stylised diagrammatic section
Note: vertical scale grossly exaggerated
Abbreviations are: M.F. - Marydale Formation; G.F. - Groblershoop Formation; K.F. - Kaaien Formation
Dashed line marks present-day surface

Asymmetrical fold profiles are also typical for some of the macroscopic F_3 structures; such folds, the shape of which indicates an east-southeasterly vergence[1], are developed in the southeastern part of the Groblershoop subdomain (e.g. the south-western termination of the ridge of Luisdraai se Berge). In the remaining two subdomains where most of the macroscopic F_3 structures were later refolded during the last major episode of deformation (D_4), the east-southeasterly vergence is no longer easily recognisable and in the southern part of the Kheis outcrop the F_3 structure trend becomes much less pronounced. It is either almost completely overprinted by the F_4 set of structures (the Namaqua trend) or, in the vicinity of the Namaqua front, the $F_2 \wedge F_3$ interference structures become re-aligned in a new direction (Fig. 32).

The $F_2 \wedge F_3$ interference pattern, particularly well developed in the Kaaien subdomain, is best defined in antiforms, the inner parts of which are occupied by the basal members of the Kheis sequence (i.e. by the Groblershoop and Marydale formations). In the

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[1] The direction of overturning or of inclination of a fold. Also the direction in which a geologic structure or family of structures is facing.

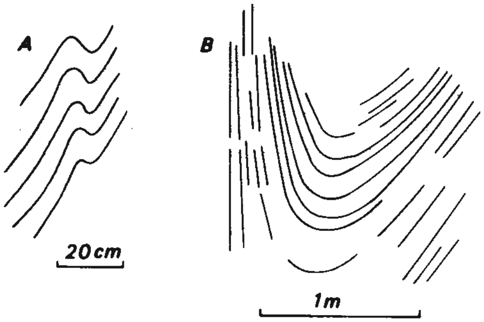

Fig. 36 Two examples of F_3 folds in the Kheis domain. A - Groblershoop subdomain (V 374); B - Kaaien subdomain (V 2979)

synformal parts of the $F_2 \wedge F_3$ interference structures only the Kaaien Formation is exposed. In the northern portion of the Kaaien subdomain the cores of the $F_2 \wedge F_3$ antiforms are formed by quartz-sericite schist, mica schist and minor quartzite (Groblershoop Formation *sensu stricto*), whereas the inner parts of the same antiforms south of the 29°15'S parallel are occupied by biotite gneiss and augen gneiss ("Kh" on the geological map). In the extreme south these inner parts of large $F_2 \wedge F_3$ antiforms are also composed of the Marydale Formation (e.g. Brakboschpoort, Rooidam and Irene). Because the degree of weathering is rather high in the case of the Groblershoop metasediments, the inner parts of large-scale $F_2 \wedge F_3$ antiforms usually form valleys. One of the best examples of such morphological depression is the Brakboschpoort valley, which is completely surrounded by hills of the Kaaien quartzite. It should be remembered, however, that the present shape of the Brakboschpoort antiform and similar structures is a result of a combination of both the $F_2 \wedge F_3$ and $F_3 \wedge F_4$ patterns, and that probably not many of the F_3 antiforms were originally doubly plunging.

In comparison to similar interference patterns developed in Namaqualand and described by Joubert (1971), the domes and basins in the Kaaien Hills are smaller, averaging 6 - 10 km in wavelength, and only a few of them are truly periclinal (the closest to a periclinal structure is probably the Brakboschpoort antiform). The suggested formation of $F_2 \wedge F_3$ interference structures in the Kaaien Hills is schematically shown in Fig. 35.

The recognition of complex interference patterns in the Kaaien Hills and elsewhere is one of the prerequisites for a stratigraphic classification of the Kheis Group in the Marydale - Upington area. A good example is the structure of Karos, a re-interpretation of which (Fig. 34) may lead to an important change of the present views on the relationship between the Kaaien and Wilgenhout Drift Formations (p. 81).

Lineations originating during the F_3 folding are usually poorly developed. As in Namaqualand (Joubert, 1971) the F_3 lineations in the Kheis domain are mostly represented by intersections of s_3 surfaces with the regional foliation s_1; they have different orientations in zones of strong refoliation in the Groblershoop subdomain and in gently to moderately dipping refoliation planes of the tectonic slides in the Kaaien subdomain. Mineral lineation related to the F_3 folding is negligible.

Planar structures developed during the F_3 folding are present in the zones of refoliation and shearing which are often marked by silicification, or followed by diabase sills. The most distinct of these zones occur in the south-eastern part of the Groblershoop subdomain and run parallel to the Eselberge fault. In fact, even the tectonic boundary between the Kheis and Matsap (the Eselberge fault itself) originated during F_3 folding and bears many signs of F_3 refoliation in the Kheis.

2.2.3.4. The fourth episode of deformation (F_4)

The complex tectonic pattern resulting from three superposed sets of structures is overprinted by a generation of F_4 structural elements which occur in all three subdomains of the Kheis domain. The F_4 structures again comprise both mesoscopic and macroscopic folds, lineations and planar structural elements, with west-northwesterly, north-westerly and north-northwesterly orientation. It is also important to note that the abundance and prominence of F_4 structures increases towards the south-west i.e. towards the Namaqua front.

Mesoscopic folds of the F_4 generation are of flexural-slip type (flexure folds *sensu stricto*) and of variable wavelength. Their amplitude, however, is often small, and the shape is frequently asymmetrical (Fig. 37). Asymmetrical folds are particularly well developed in the Marydale subdomain (in the south-eastern vicinity of Marydale). The mesoscopic F_4 folds are also characterised by interlimb angles of more than 30°. They plunge west-northwesterly, north-westerly and north-northwesterly and the two to three maxima recognisable in stereographic projection are due to the presence of conjugate linear sets (conjugate mesoscopic folds and crenulations). The most distinct of these maxima in the Groblershoop subdomain (Fig. 28C) is between 280° and 295°. In the Kaaien subdomain (Fig. 27C) the same maximum is subdued and the most distinct is the maximum at ± 350°. Axial surfaces of the F_4 folds are planar, usually near vertical or steeply inclined to the south-west. Their trend is perpendicular or almost perpendicular to that of the F_3 structures.

Macroscopic structures of the F_4 generation comprise various types of folds and interference patterns which are always well identifiable on aerial photographs. These structures are best developed in the Kaaien subdomain but some of them are also present in the Groblershoop and Marydale subdomains. Trend, plunge, morphology and, to some extent also the symmetry of the macroscopic F_4 fold structures, correspond to the same attributes of mesoscopic F_4 folds described above. The type of interference pattern of the axial-plane folding in the Kaaien Hills (Fig. 32)

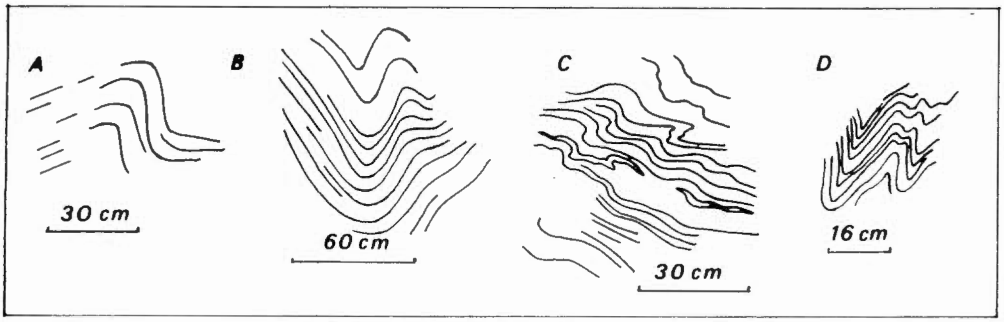

Fig. 37 Examples of fold profiles of F_4 structures in the Kheis domain
A - Groblershoop subdomain (V 50); B, C - Marydale subdomain (V 2713 and V 2675); D - Kaaien subdomain (V 2838)

indicates that the macroscopic F_4 folds are not only responsible for the double plunge of at least some of the $F_2 \wedge F_3$ antiforms and synforms, but they also cause the deformation of F_3 axial surfaces and crumpling of the boundaries between the Groblershoop and Kaaien Formations in some of the interference structures. All the three different expressions of F_4 refolding can be identified in Fig. 32.

While F_4 refolds are quite common in the Kaaien subdomain, they are apparently restricted to the boundaries of the Marydale Formation in the Marydale subdomain. Macroscopic F_4 folds are also scarce in the Groblershoop subdomain, where only the structure of the Boegoeberge indicates that the Kheis Group north of the Eselberge Fault has been subjected to large-scale deformation during the Namaqua tectogenesis. The Boegoeberge refold which is evident on aerial photographs and shown on the map, bears all the characteristic signs of a F_4 structure: layering (pseudo-bedding) is of constant thickness throughout the fold, the angle of closure is moderate to high, the axial surface vertical, and the plunge north-westerly.

In the Kaaien subdomain the attitude of pre- F_4 planar structures is generally steeper than similar s-planes in the Groblershoop subdomain. The strike of earlier planar structures in the vicinity of the Namaqua front (in the Kaaien subdomain) is also characteristically different from the regional trend of the foliation deeper in the Namaqua foreland (in the Groblershoop subdomain) the foliation planes in the Kaaien subdomain are more often aligned parallel to the F_4 Namaqua trend than the foliation planes in the Groblershoop subdomain (Figs. 30 and 31).

It is obvious that the steep dip of the s_1-s_2 foliation occurs mostly in zones between the individual $F_3 \wedge F_4$ synforms and antiforms (e.g. on the farm Geelbospan near the boundary with Stillerus, and in parts of Karee Boom 7), and that in the western part of the Kaaien subdomain the zones of steep foliation run parallel to the north-northwesterly striking major fractures (e.g. farms Geelbospan and Middelka). In some of these zones the plunge of l_2 lineations is also very steep; in the Marydale subdomain, for example l_2 is practically vertical at a few places south-east of the village.

Confined to the zones of steep foliation are also minor shear zones (usually less than a few metres wide) which have the same strike direction as the major fractures (faults), but show a lower intensity of cataclastic deformation than the faults. Apart from cataclastic deformation, movement in these shear zones also resulted in metamorphic downgrading of the mineral assemblages involved (e.g. the shear zone exposed at the pump station c. 1 km south-west of Marydale).

F_4-linear structural elements other than folds are represented by minor crenulations of the regional foliation, which are best developed in schistose rocks of the Groblershoop subdomain and, less frequently, by the intersection of s_4 planes and earlier planar surfaces in the zones of steep dip of regional foliation. In the structural diagrams (Figs. 27 - 29) these lineations are grouped together with other linear structural elements such as mesoscopic folds. They seem to be abundant in ductile rock types such as schist and amphibolite, and also in those interference structures in which the doubly plunging $F_2 \wedge F_3$ synforms and antiforms are not well developed (i.e. in the Groblershoop subdomain).

2.2.4. The Namaqua Domain

2.2.4.1. General

West of the Kaaien Hills, in the Namaqualand Metamorphic Complex, the structural pattern is characterised by a persistent north-westerly trend and by the dominant role played by the granitoids and other intrusives. Linearity is not only expressed in the predominant west-northwesterly and north-westerly strike of the foliation, but also in the similar orientation of metamorphic zones and areas in which the intensity of deformation seems to be homogeneous. The occurrences of individual rock types such as pegmatites, gabbroids, porphyries and, to some extent, different types of granitoids are also arranged parallel to this zoning. From south-west to north-east the zones of different lithologies are as follows:

(i) Zone of pegmatite occurences;

(ii) Zone of coarse-grained granitoids and of occasional mafic plugs (structures are generally broader in this zone);

(iii) Zone of both coarse- and fine-grained granitoids and of occasional mafic plugs (structures are generally tighter in this zone);

(iv) Zone of porphyry occurrences and of occasional outliers of the Kaaien Formation (the most frequent rock type in this zone is a fine-grained granitoid, i.e. Brakbos and Eindgoed Granites).

The last of these zones is separated from the main outcrop of the Kaaien Formation by the faults of the Doringberg lineament. Supracrustal rocks of the Hartebeest Pan Formation occur mostly in zones (ii) and (iii).

2.2.4.2. The earliest sets of structures (F_1 and F_2)

The supracrustal rocks of the Hartebeest Pan Formation display a foliation which is defined by dimensional preferred orientation of minerals and expressed in a corresponding fissility. The distinctiveness of this planar structure varies from place to place depending on the content of phyllosilicates, and on the nature of a particular rock type. The foliation is generally not distinct in leucogneiss and in granulitic biotite leptite and garnet leptite; in other types of leptite, however, it is distinct, and it becomes very distinct in schist and gneiss. Microscopic evidence from the two latter rock types suggests that this foliation represents a transposition structure (s_1); apart from the common examples of mineral banding, which represents an advanced stage of metamorphic recrystallisation and of transposition of primary lithological layering s_o, less advanced stages of elongation, attenuation and flattening of primary (F_1) folds can also be recognised (e.g. V 3679, 3688 and others).

It should be noted that no primary (F_1) folds of mesoscopic or macroscopic scale have been found and that mesoscopic isoclinal folds which are present at various parts in the Hartebeest Pan Formation fold s_1 and therefore belong to the second generation (F_2) of the earlier structures. However, isoclinal F_2 folds of cm and dm size are seldom seen in the field because of poor outcrops west of the Kaaien Hills. F_2 mesoscopic folds are best seen in the zones of the steep dip of foliation and it was actually in these zones where most F_2 structures were identified.

Even where F_2 fold hinges cannot be identified directly, intense folding of the s_1 planes is documented by the presence of a strong lineation l_2; good examples of such structures are the irregular mullions of amphibolite found 2,5 km north-east of the Glen Connan farmhouse (V 3679). Similar mullions and also boudinage structures are confined to layers of leptite and schist, whereas such structures are scarce in the gneiss and migmatite.

The relationship between microscopic primary (F_1) folds, the schistosity s_1 and mesoscopic isoclinal folds and other F_2

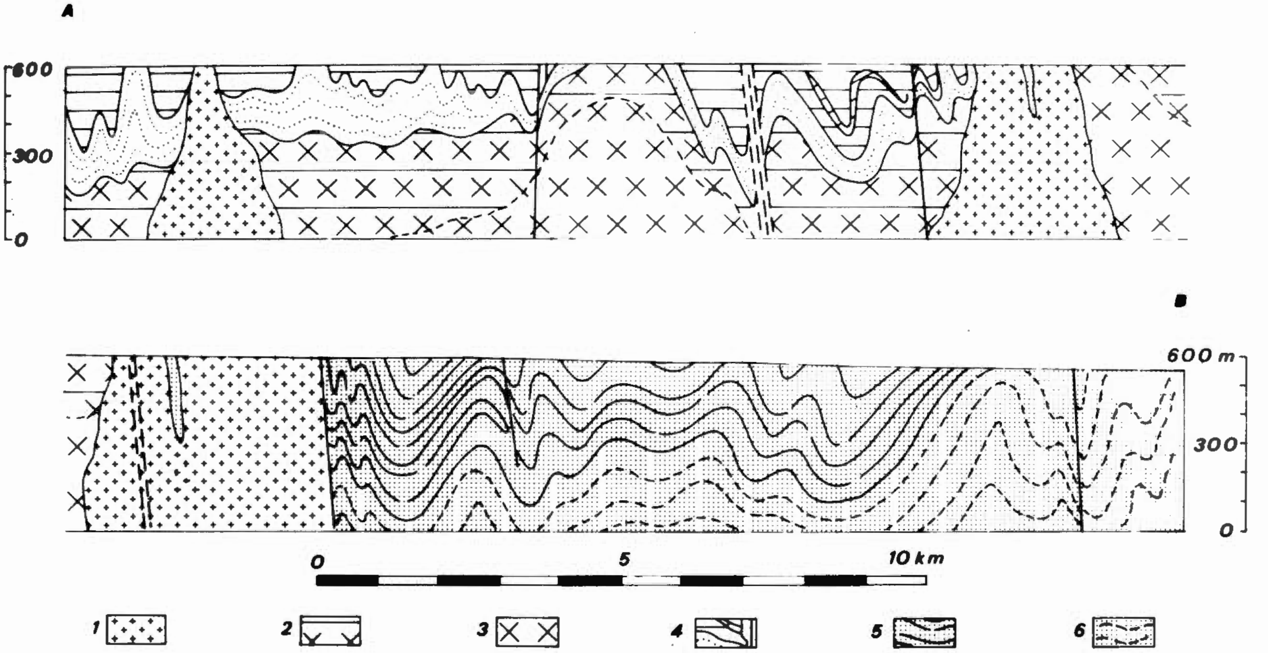

Fig. 38 Diagrammatic section through the Namaqua domain and parts of the Kheis Group
Explanation of symbols: 1 - Brakbos Granite; 2 - Sonderpan Granodiorite; 3 - Hartbeespan Granite; 4 - Hartebeest Pan Formation; 5 - Kaaien Formation; 6 - Groblershoop Formation.
Section line A - B is shown on the geological map (Annex. 1)

structures in the Namaqualand Metamorphic Complex seems to be very similar to the relationship between F_1 folds, the regional foliation (s_2) and the F_2 fold structures in the Kheis domain, described in Section 2.2.3.2. (pp. 126 - 136). However, the poor outcrop in the area west of the Kaaien Hills and resulting paucity of structural data obtainable from the Namaqualand domain underline that such a correlation should be approached with great care.

2.2.4.3. The dome and basin structures

Subsequent to the earlier periods of deformation (F_1 and F_2) the pseudo-bedding and corresponding foliation of the Hartebeest Pan rocks were folded, and a characteristic interference pattern developed. This pattern of domes and basins, aligned and elongated in a west-northwesterly and north-westerly direction, is only well defined between 29°15'S and 29°22'S; in parts of the area where the Hartebeest Pan Formation is relatively thin or where it is absent the structural grain is remarkably linear and the domes and basins cannot be identified. Basins occupied by the supracrustal rocks of the Hartebeest Pan sequence are less than 3 km wide and up to 13 km long, and their north-eastern limb is usually faulted (Annex. 1 and Fig. 38). On the south-western side the basins often pass gradually into antiforms, the inner parts of which are occupied by the Hartbeespan Granite and Sonderpan Granodiorite. It is notable that in many places the granitic and granodioritic "core" is mantled by a zone of gneiss and migmatite, and that the inner parts of the basins are occupied by leptite, leucogneiss, amphibolite and schist of the Glen Connan Member.

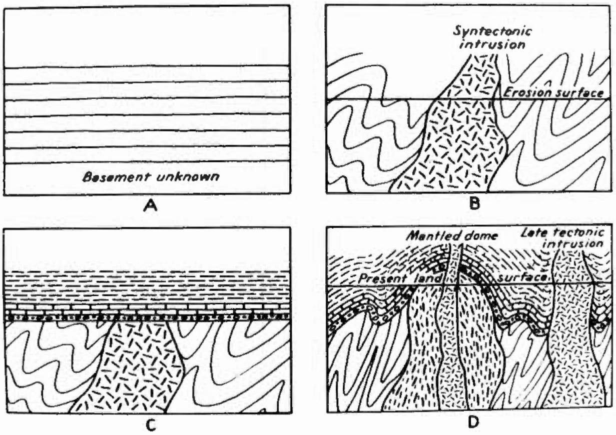

Fig. 39

Origin of mantled gneiss domes

A - First sedimentation;
B - First orogeny;
C - Second Sedimentation;
D - Second orogeny;

(After Eskola, 1949). Reproduced from Billings (1972, p.347)

The dip of foliation is frequently steeper on the limbs than in the central parts of the interference structures. At places the geometry of the interference pattern may resemble that of the mantled gneiss domes (Fig. 39), described by Eskola (1949) as a typical feature of areas of polyphase deformation and metamorphism but the difference between such domes and the fabric in the Namaqua domain is quite obvious: the anticlinal structure and presence of the second supracrustal sequence (Fig. 39) contrast with the complex structure of the Hartebeest Pan Formation and with the lack of evidence for a simple younging of the Hartebeest Pan supracrustals away from the granite domes.

There is a marked difference between the north-eastern and south-western limits of the Hartebeest Pan Formation; in the north-east the boundary between the supracrustal rocks and granitoids is fairly distinct and follows the north-westerly regional trend, whereas isolated layers of gneiss and other metamorphites which occur south of the 29°22'S parallel make the definition of the corresponding boundary in the south difficult. The north-eastern boundary of the Hartebeest Pan Formation also represents an important line beyond which no quartzite of the Kaaien Formation occurs.

The zones of steep foliation on the limbs of large interference structures are often followed by layers of mylonitic rocks; these comprise protomylonitic and mylonitic types (Spry, 1969) where the original supracrustal rock was involved, and protocataclastic and cataclastic rocks, where shearing affected the granitoids. Examples of mylonite and phyllonite were described on page 87, cataclastic granitoids occur practically everywhere.

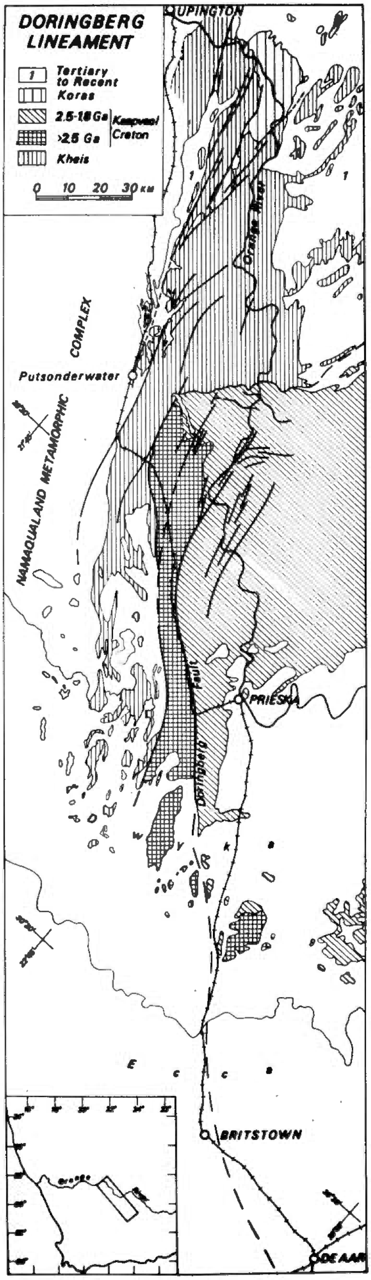

Fig. 40

2.2.5. Faults

The most distinct among the major fractures are those which constitute the zone of the Doringberg lineament (Fig. 40): the Doringberg fault itself, the De Duinen, Vaalbult and Brulpan faults (Vajner, 1972), and the Brakbos fault which follows the western margin of the Kaaien Hills for some distance, and the Sonderpan fault in the Namaqualand Metamorphic Complex. Almost all these faults seem to be arranged *en echelon*, and cause right-lateral (dextral) displacement. The amount of this displacement can be measured for the Doringberg and De Duinen faults, where the distance between reference lines (i.e. between the displaced parts of the Transvaal beds) on either side of the fracture is 9,5 and 3,5 km respectively. Although no clear reference lines can be defined for the other faults, the size of the faults and the offset of structures on both sides of these major fractures indicate that the total displacement in the zone between the Sonderpan and De Duinen faults could amount to more than 50 km.

All faults mentioned above strike north-northwesterly or almost northerly, all of them are very steep or vertical, and some of them are marked by mineral occurrences (mainly copper - e.g. the Vaalbult fault, but also lead and silver - e.g. the Doringberg fault). It should be noted that the Doringberg fault is still seismically active (Krige and Maree, 1951).

Complementary to the major fractures in the zone of the Doringberg lineament are shorter and less important faults on the boundary between the Seekoebaard Formation and the older granitoids (p. 124), the west-northwesterly and north-westerly striking faults in the Namaqualand Metamorphic Complex (pp. 147-148), the west-northwesterly and north-westerly striking shears and silicified zones in the pre-Seekoebaard granitoids (pp. 15 and 19-21), the swarms of diabase dykes (pp. 62-63 and 124), and steep slickensided fractures in the Matsap Formation (p. 124).

Finally, the dynamic metamorphism produced by faulting in the zone of the Doringberg lineament is generally of a very low grade and its exact nature depends on the ductility of the rock types involved. In the Kaaien Formation, for example, the Brakbosch fault is marked by an extremely narrow zone of tectonic crush breccia often less than 30-40 cm wide (e.g. farms Sonderpan Oos, Geelbospan). The quartzite on both sides of the fracture zone is cataclastic, but practically unaffected in hand specimen. The Doringberg fault, on the other hand, is followed by a wide zone of shearing (the zone is several metres wide and poorly exposed), and by zones of intense NNW striking cleavage (in the volcanics of the Seekoebaard Formation (pp. 123-124). The Brulpan fault, is marked by a silicified zone several metres wide where it traverses the outcrop of the Kaaien quartzite (e.g. exposures at the Marydale-Putsonderwater road some 4 km northwest of Marydale).

Major fractures other than faults and associated structures in the zone of the Doringberg lineament are the Eselberge fault (pp. 100-101) and the reverse faults and tectonic slides (pp. 119-121).

3. DISCUSSION AND INTERPRETATIONS

3.1. Stratigraphy

3.1.1. Introduction

The stratigraphic classification and nomenclature of the sequences of supracrustal rocks, and of intrusives described in section 2.1., is based on the South African Code of Stratigraphic Terminology and Nomenclature (1971), which summarises earlier recommendations published by the IUGS. In accordance with these recommendations, the newly established and re-defined subdivisions in the area under consideration represent formal lithostratigraphic units; the only exception to this (the Lower and Middle Griquatown groups) will be discussed in section 3.1.6.

3.1.2. The Kheis Group

3.1.2.1. Lithostratigraphy

The Kheis was given the rank of an autonomous lithostratigraphic unit during the first period of systematic investigation of the northern Cape, and all results of subsequent work support this classification (see pp. 65-66). The Kheis stratigraphy (Table 13) is reasonably well defined, although much more detailed work remains to be done in parts of the Kheis stratotype outside the area under consideration (e.g. the Groot Modderfontein Member and the Wilgenhout Drift Formation).

One problem which will have to be investigated in future is the question of the floor on which the Kheis was deposited, because there is no rock type or rock unit in the northern Cape that can be shown to be older than the Kheis (Rogers, 1910). In the author's opinion, the considerable thickness of arkose and grit in the Groot Modderfontein Member and the predominantly clastic character of the metasediments comprising the remaining parts of the Kheis sequence suggest that such a floor consisted of granitoids and/or other acidic and intermediate igneous rocks. These may have been either reactivated and incorporated in various later intrusions of the Namaqualand Metamorphic Complex or, less likely, the ancient granitic"floor" is simply not exposed.

While the lower clastics and associated felsites and porphyries are probably of continental origin (i.e. accumulated in isolated basins on the old granitic floor and/or in fluvial environment), the extent and thickness of the main clastics in the Groblershoop and Kaaien Formations indicate that they were deposited in a large sedimentary basin, possibly in a shallow-water marine environment. The decrease in thickness of the Kaaien quartzite in both north-westerly and south-easterly directions (p.79) may also indicate that the main body of the Kaaien Formation between the latitudes 28°45'S and 29°45'S comprises mostly metasediments of deltaic origin. The gradual disappearance, upwards in the Kaaien succession, of the feldspathic and arkosic quartzite layers points to the increasing maturity of the morphology of the contintental source-area. The quartzites in the upper part of the Kaaien Formation, which represent the most mature metasediments in the Kheis, mark most probably the last stage in the Kheis deposition.

The inferred paleogeographic change from a continental-type to a marine-type of depositional environment is marked by the first occurrence of intermediate and basic metavolcanics with amygdaloidal structures (in the Marydale Formation). Similar metavolcanics occur also in the Mountain View Member of the Groblershoop Formation, but higher up in the succession they disappear.

Chemical composition of typical Marydale amphibolites (Fig. 6) indicates that these metavolcanics fall in the group of tholeiitic rocks. Their Y/Nb ratio is more than 4 (it varies between 4 and 12) and on the Ti/100-Zr-Y.3 plot (Fig. 6 C) they appear in the field of low-potassium tholeiite (volcanic arc basalt *sensu* Pearce and Cann, 1973, p.295). It should be noted that also the content of Nb, Zr, and Sr in the Marydale amphibolites (Fig. 6 A) corresponds in general to the composition of low-potassium tholeiites (cf. Pearce and Cann, op. cit., p. 293).

Acidic metavolcanics (felsitic porphyry and leptite in Table 13) are mostly confined to the Stuurmansput Member of the Marydale Formation; primary textures in these rocks are usually preserved and determination of their volcanic origin is therefore not difficult. Some of the other rock types such as quartz-sericite schist and certain massive quartzite bands in the lower part of the Groblershoop Formation may also represent acidic metavolcanics or associated metamorphosed pyroclastics and tuffaceous rocks, but in this case intense shearing and recrystallisation of the parent rock would have to be postulated to explain the absence of all primary volcanic features. In the author's opinion the metamorphism in the Kheis Group was generally not high enough to bring about such an intense regional reworking of the parent rocks, and the lithology of the greater part of the Groblershoop and Kaaien Formations is too uniform to be compared with the variability of rock types associated with volcanic arcs.

If the stratigraphic correlation of the Wilgenhout Drift Formation in Table 13 is correct, significant changes must have taken place after the deposition of the Kaaien quartzite. These are suggested by a limited extent of the Wilgenhout Drift Formation as compared with the other Kheis sub-units, and by its variable lithology and greater thickness. However, in the light of the new interpretation of the Karos structure (p. 81 and Fig. 34), the post-Kaaien stratigraphy of the Kheis and the question of the stratigraphic position of the Wilgenhout Drift Formation will have to be critically examined in future.

Supracrustal sequences correlated with the Kheis *sensu stricto* have been reported from various other regions (Martin, 1965, pp. 56-71). It has been suggested that the Kheis strata continue westwards into the Keimoes-Kakamas area west-southwest of Upington (Poldervaart and Von Backström, 1949, Von Backström, 1964); Kheis correlates were reported from western Namaqualand (Joubert, 1971), and the Kheis "System" is also shown on the recently published geological maps, sheets 2817 D (Vioolsdrif), 2818 C (Goodhouse), 2818 D (Dabenoris), and 2819 C (Onseepkans) (Von Backström and De Villiers, 1972). Farther to the west the Kheis "System" was mapped in the Richtersveld (De Villiers and Söhnge, 1959) and in the Warmbad and Lüderitz Districts in the adjoining parts of South West Africa (cf. Martin, 1965). The correlation of these sequences with the Kheis stratotype is substantiated by the similarities in their tectonic and metamorphic development and, in particular, by the continuity of the superposed sets of structures from the Kheis stratotype into the Namaqualand Metamorphic Complex.

Although the similarities in the tectonic and metamorphic history of the Kheis and of its correlates suggest that all the above sequences belong most probably to the same major stratigraphic unit, certain differences exist in their lithostratigraphy which indicate that the individual correlates of the Kheis may not be directly coeval, and that they accumulated in various depositional environments. Two principal types of lithologies can be recognised:

(i) miogeosynclinal sequences (e.g. Kheis stratotype, Kheis correlates in the Richtersveld, and the Kheis in the Keimoes-Kakamas area north-east of the Neusspruit);

(ii) eugeosynclinal sequences (e.g. Kheis correlates in the Namaqualand Metamorphic Complex south-west of the Neusspruit, the Hartebeest Pan Formation and, possibly, also the Copperton Volcanic Pile (Middleton, 1973) exposed in the Namaqualand Metamorphic Complex some 55 km south-west of Prieska).

The boundary between the two principal lithologies of the Kheis *sensu lato* is most distinct in the zone of the Neusspruit line between Kakamas and Keimoes (some 60 km south-west of Upington); on the north-eastern side of this line situated along the south-western limb of the Neusberg syncline (Von Backström, 1961, p. 90), the rock types are similar to those of the Kheis stratotype, whereas on the south-western side of it quartzite of the Kaaien type is absent, and the supracrustal sequence comprises calc-silicate rocks, marbles, and extensive layers of leptite and/or of intermediate and basic metavolcanics (amphibolite and metagabbro). The Neusspruit line, which strikes north-westerly, is much more distinct on the map (cf. Von Backström, 1964) than in the field.

Quartzite present in the eugeosynclinal facies of the Kheis is remarkably different from the Kaaien quartzite in the Kheis stratotype. It is characterised by a restricted occurrence, very limited thickness and by its constant association with metamorphosed aluminous rocks (Joubert, 1974) which were previously regarded as metamorphosed bauxites (Coetzee, 1941).

3.1.2.2. Age relationships

Various interpretations have been offered in the past regarding the age of the Kheis "System" and its relationship to other units in the Precambrian basement of South Africa. Originally, the Kheis was classified as the oldest (pre-Transvaal) sequence in the type area (Rogers and Schwarz, 1899), and later it was correlated with the Kraaipan Formation occurring in the Mafeking and Vryburg Districts farther north (see section 3.1.3.). In the regional stratigraphy it was placed below the Ventersdorp Group (Rogers, 1910). Later the Kheis was almost always correlated with the oldest stratigraphic units found elsewhere in South Africa, most frequently with the Swaziland Sequence (Du Toit, 1939; Martin, 1965; Van Eeden, 1972).

It has been suggested recently that the Kheis is younger than the Swaziland and that it corresponds to some of the pre-Ventersdorp post-Swaziland sequences of the South African Precambrian (Kröner et al., 1973). The oldest granitoids intrusive into the Kheis are younger than those intruding the Swaziland (the former are 2,9 Ga old, the latter between 3,1 and 3,3 Ga old), and the tectonic and metamorphic development of the Kheis is markedly different from that of the ancient greenstone belts (op. cit., p. 298).

The Kheis was placed higher in the Precambrian stratigraphy by Schwarz (1905), who first tentatively correlated the Kaaien Formation with the Black Reef quartzite, and who later suggested that metamorphosed equivalents of rocks from other units in the Transvaal sequence may also constitute parts of the Kheis (Schwarz, 1910). His proposal was criticised by Rogers (1910) and it was generally overlooked in later years. However, the question has been raised again by Nicolaysen (1962) who, in discussion of the radiometric results, pointed to the possibility that the Transvaal rocks and pre-Transvaal "Pniel" (i.e. Seekoebaard) lavas may have metamorphosed equivalents to the west (op. cit., p. 587). This possibility was considered again in the discussion of more radiometric results obtained on rocks from the area under consideration, and a correlation of the amphibole-bearing rocks on Blouputs and Khaboom with the "Zoetlief" was suggested (Nicolaysen and Burger, 1965). These rocks, previously included in the Marydale Formation (Rogers and Du Toit, 1908, p. 40), are interpreted here as members of the Seekoebaard sequence, affected by the Namaqua metamorphism some 1,0 Ga B.P. (see pp. 34 - 36).

The possibility of correlation between the Transvaal Supergroup and some of the supracrustal rocks in the Namaqualand Metamorphic Complex was recently considered by Beukes (1973) who, on the basis of his study in the area south of Warmbad in South West Africa (Sheets 2818 C and D), and with regard to the results of an investigation west of Upington (Geringer, 1973) stated that the Namaqua Mobile Belt (Namaqua Province) represents "the eugeosynclinal facies of the original Transvaal Basin, and the metasediments of the Namaqua Province is (*sic!*) therefore the stratigraphic equivalent of the Transvaal System" (Beukes, op. cit., p. ix). The tentative correlation (of the basic lithostratigraphic units) suggested by Geringer (1973) and upheld by Beukes (op. cit., pp. 183-184) can be summarised as follows:

(i) quartz-feldspar gneiss with subordinate lenses and beds of sillimanite and cordierite schist and gneiss (Houms-Revier Formation - Beukes, 1973) is correlated with the Riemvasmaak Formation (Geringer, 1973), and this, in turn, with the Black Reef Formation of the Transvaal Supergroup;

(ii) schistose biotite and/or amphibole gneiss, sometimes migmatitic, grading locally into porphyroblastic augen gneiss and also comprising subordinate amphibolite, granulite, calc-silicate rocks, marble, sillimanite and cordierite schist and gneiss, as well as lenses of metaconglomerate (Umeis Formation - Beukes, 1973) is correlated with the Biesje Formation (Geringer, 1973) and with the Dolomite "Series" of the Transvaal Supergroup;

(iii) garnet-sillimanite-cordierite-biotite gneiss and granulite (Arus Formation of Beukes, 1973) are correlated with the Good Hope Formation (Geringer, 1973) and with the Pretoria "Series" of the Transvaal Supergroup.

Most recently even the possibility of a closer mutual relationship between the Kheis and Matsap has been suggested when Van Eeden (1972) stated that the rocks shown as Kheis along longitude 22°E on the new Geological Map of South Africa (1970) "are almost certainly Matsap, and those farther west may be of Transvaal age" (op. cit., p. 11). This statement is supported by Smit (1973) who reports that recent fieldwork carried out by the Geological Survey along the Kheis-Matsap contact west of the Langeberg "indicated a conformable relation between the typical quartzite of the Waterberg System and certain basal white quartzite of the Kheis System" (op. cit., p. 48). Beukes (1973, p. 183) also favours a correlation of the Kheis and Matsap and suggests that the Marydale and Wilgenhout Drift Formation can be correlated with the Hartley-Hill lava (i.e. with the Middle Matsap in Table 12). His statement is based on personal communication with

W. Linström and C.A. Smit who, according to Beukes (op. cit., p. 183) found no obvious stratigraphic break between the Kheis and Matsap. No details of field observation, however, are given.

In the author's opinion, a direct correlation between the Kheis stratotype and Matsap sediments of the Langeberg is impossible, mainly because of marked differences in lithology, structure and metamorphism of the two major units (pp. 100-101). Similar differences had already been noted by Stow (1874), who separated the Kheis from the Matsap in his description, but his final interpretation of their mutual relationship is rather inconclusive (op. cit., pp. 663-664). Only subsequent systematic mapping revealed that the Matsap beds are faulted down against the Kheis (Rogers, 1905, p. 77).

The field relationships and structure of the rock units in the area under consideration not only point to marked differences between the Kheis and Matsap, but also to similar differences between the Kheis and Transvaal and Kheis and Ventersdorp. The pre-Ventersdorp age of the Kheis is suggested by the fact that the F_1 and F_2 structures (pp. 102-103, 126-136 and 145-147) are confined to the Kheis, Swartkop and the Hartebeest Pan sequences only, and that the Draghoender Granite, which intrudes the Kheis, is overlain unconformably by the Seekoebaard Formation. Correspondingly, the regional metamorphism associated with the two earliest foldings of the Kheis is absent in the Seekoebaard Formation, and in the Transvaal and Matsap sequences. Thus the correlation of the Kheis stratotype and its possible equivalents in the Namaqua domain (e.g. the Hartebeest Pan Formation and others) either with the Ventersdorp, Transvaal or Matsap as suggested by various authors in the past (see pp. 154-155) cannot be valid.

The question remains as to whether all the rock units north of the Orange River and west of the Langeberg really belong to the Kheis Group. The general north-northeasterly dip (younging) of lithological units in the Namaqua foreland, and the fact that the Matsap synclinorium widens towards the north, would suggest that some of the "Kheis" sequences in the north may actually be younger than the Kheis *sensu stricto*; the outcrops in the northern part of the Kheis stratotype (Fig. 5), however, are separated from those farther north by large tracts of Kalahari sand, and the relationships are therefore not clear.

In accordance with the above geological evidence the minimum age of the Kheis Group is probably greater than 2,9 Ga (U-Pb age of zircons from the Draghoender Granite - see Burger and Coertze, 1973). The maximum age of the Kheis is probably less than 3,1 Ga (Kröner et al., 1973). However, direct radiometric evidence of the post-Swaziland pre-Witwatersrand age of the Kheis has not yet been found. Most of the radiometric data obtained from the Namaqualand Metamorphic Complex so far (Fig. 41) indicate clearly that the radioactive clock has been reset during the major

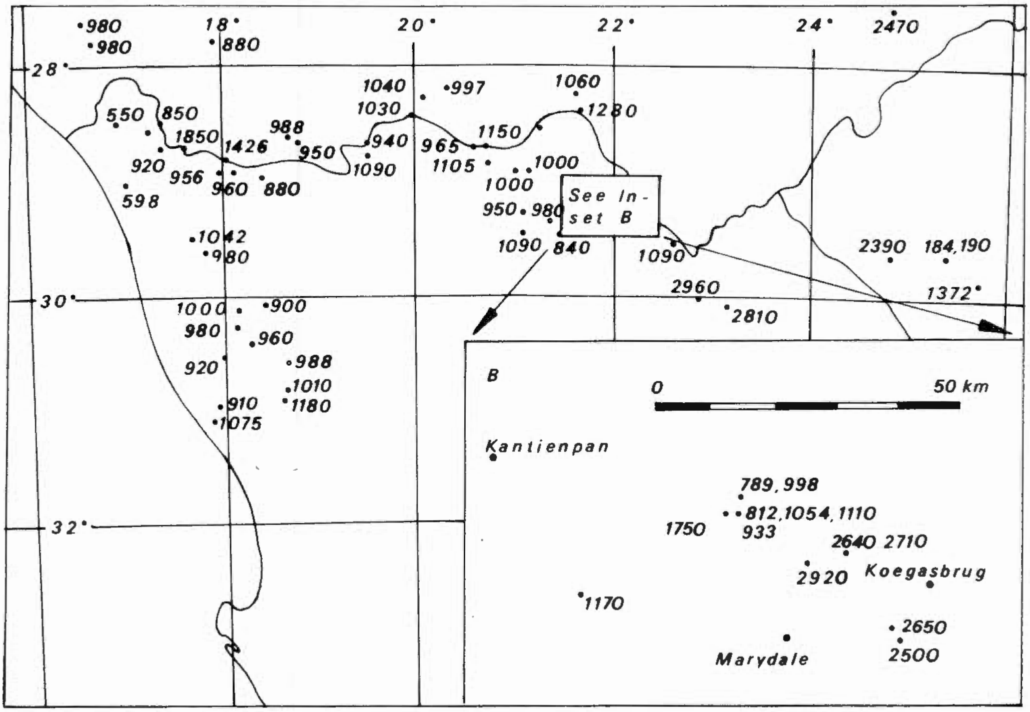

Fig. 41 Isotopic ages from the Namaqua Mobile Belt and some adjacent areas (data from Burger and Coertze, 1973)

isotopic rejuvenation between 1,25 and 0,9 Ga B.P. The radiometric evidence for an Archaean age of the Kheis should therefore be sought in the Namaqua foreland (i.e. in the central and northern parts of the Kheis stratotype).

3.1.3. The Swartkop Sequence

This lithostratigraphic unit, which was originally correlated with the Marydale Formation by Rogers and Du Toit (1908), and which was grouped with the Kheis "System" on the most recent edition of the Geological Map of South Africa (1970), is separated from the Kheis stratotype by the Draghoender Granite. Its description appears therefore in the section dealing with the Kaapvaal Craton (pp. 7-9). The unit is clearly older than the Seekoebaard Formation, and it is most probably older than the Draghoender Granite as well (pp. 9-10 and 12). It is lithologically very similar to the Groot Moderfontein Member (pp. 67 - 68), and its complex structure and metamorphism also suggest that a correlation with the Kheis *sensu stricto* is correct. However, since the direct relationship of the Swartkop sequence with the Groot Modderfontein and Stuurmansput Members is not known, its stratigraphic classification proposed on the attached geological map (Annex. 1) should be regarded as tentative and provisional. It is possible that in future the status of the Swartkop sequence will have to be raised to the rank of a formation.

Sequences remarkably similar to that of the Swartkop succession were described from various other parts of the Kaapvaal Craton: from the Mafeking and Vryburg area (Du Toit, 1905), from southern Botswana (Poldervaart and Green, 1952), from the Schweizer-Renecke District (Van Eeden et. al., 1963), and from some other localities (c.f. Haughton, 1969, pp. 59 - 60). They are characterised by the presence of magnetite quartzite, by complex structures and metamorphism, and by their similar relationship to the pre-Ventersdorp granitoids of the "Draghoender" type (granitoids are intrusive into these successions). All these sequences were included in the Kraaipan Formation (Visser, 1960), which is tentatively correlated with the Swaziland Sequence (Van Eeden, 1972). In the author's opinion, however, the similarities between the Kheis and Swartkop on the one hand, and between the Swartkop and Kraaipan on the other suggest that the Kheis and Kraaipan are coeval, and that the correlation of the Kraaipan with the Swaziland sequence is questionable.

3.1.4. The Hartebeest Pan Formation

The absence of the Kaaien quartzite from the Hartebeest Pan Formation, and the lithology of the sequence suggest that the entire unit belongs to the group of the eugeosynclinal correlates of the Kheis. However, the Neusspruit line, which separates these sequences from the Kheis *sensu stricto*, is not as distinct as in adjoining areas (p. 153); it is obscured by the granite intrusions on Zonder Pan 173. There is also no pink gneiss in the Hartebeest Pan succession - a rock type first described by Poldervaart and Von Backström, (1949, p.456), and believed to be a metamorphic derivate of arkosic rocks (Kröner, 1971); this gneiss is quite common in the area along the Orange River between Upington and the Aughrabies Falls, in western Namaqualand (Joubert, 1971), and in various other sectors of the Namaqua belt, but it is not certain, whether rock units of different origin (i.e. metasediments and metavolcanics) have not been grouped together (Joubert, 1974).

Volcanic members of the Hartebeest Pan Formation, represented by the rock types of the leptite series and by amphibolite, constitute a distinct rock association, the composition and variability of which indicate that the greater part of the original

Hartebeest Pan succession was probably deposited as tephra derived from an ancient island arc. In this succession true volcanics are not abundant. The preponderance of volcaniclastic layers (including also the metamorphosed tuffaceous sediments), and the lithology of the Hartebeest Pan metasediments suggest that the sequence was probably deposited in an oceanic basin trapped between the miogeocline of the Kheis proper and an island arc. Since the eugeosynclinal correlates of the Kheis (p. 153) are found over the extensive area, the length of the basin may have been several hundred km; its width, however, was probably limited, possibly to less than 100 km.

Changes in the depositional environment, namely in its distance from the island arc, in the stability of the basin floor, and in the amount of terrigenous material deposited in the basin, are expressed in the differences between the individual correlates of the Kheis in the Namaqualand Metamorphic Complex. In the Copperton Volcanic Pile, for example, the proximity of the island arc is indicated by the predominance of true volcanics over volcaniclastic rocks. According to Middleton (1973) the Copperton Volcanic Pile is disposed around an oval feature which may represent a resurgent cauldron core. Both the Hartebeest Pan rocks and the Copperton volcanics most probably belong to the basalt - andesite - rhyolite association. On the other hand, the Kheis correlates exposed in the north-western continuation of the Hartebeest Pan Formation (in the Kakamas area) comprise probably more tephra than true eruptives and, in contrast to the Hartebeest Pan sequence, they consist of a rock type which is largely composed of material of possible terrigenous origin (the pink gneiss).

3.1.5. The Seekoebaard Formation

3.1.5.1. Correlation

Amygdaloidal rocks underlying the Black Reef Quartzite in the Transvaal were first described under the name of "Die Vaalgesteine" (Cohen, 1873). A similar unit, but also including sedimentary layers, was mapped by Stow (1874) in the lower parts of the Vaal River, and it was given the name of the "Amygdaloidal and associated rocks of Pniel, Wetberg & C." The name "Ventersdorp Beds" was first used by Hatch (1903, p. 96) for a thick succession of lavas, volcaniclastic rocks and boulder conglomerate in the vicinity of Ventersdorp in the western Transvaal.

Amygdaloidal and associated rocks of Stow's Pniel were later mapped in the Vaal River valley and in the T'Kuip Hills by Rogers (1905). They were placed between the Kheis and Griquatown (i.e. Transvaal) sequences and correlated with the Ventersdorp succession in the Transvaal. Rogers (1906) also separated the Pniel volcanics from the Ongeluk lava of the Transvaal sequence; the two units were originally thought to be older than the Campbell Rand (Stow, 1874).

Later, the name "Zoetlief" was introduced for a succession of lavas and sediments exposed some 40 km north-west of Vryburg, and resting directly on granitic and metamorphic rocks (Du Toit, 1905, pp. 235 - 238). The type section, re-examined more recently by De Wet (1942) comprises three parts:

(i) lower conglomerates, arkoses and tuffaceous sediments;

(ii) middle quartz porphyry;

(iii) upper arkoses and conglomerates, tuffaceous sediments, andesitic and trachytic lavas and tuffs.

In 1907 Du Toit defined the "T'Kuip Series", which he described as lying unconformably upon Zoetlief and being unconformably overlain by the Pniel. This sub-division was extended to apply to all known Ventersdorp occurrences, and Zoetlief, T'Kuip and Pniel were given the rank of "Series" (Rogers and Du Toit, 1909, p. 67). The thickness of the Ventersdorp sequence was originally estimated to be some 3300 m (some 11 000 feet). In the following years, however, the name T'Kuip Series was discarded.

During the initial stages of the modern systematic investigation of the Ventersdorp sequence, its stratotype was re-defined and the type area restricted to the northern Orange Free State between the Odendaalsrus and Klerksdrop goldfields (centred around Bothaville). The entire sequence, which is over 4 000 m thick (some 13 000 feet), was first subdivided into the Lower, Middle and Upper "groups" (Jacobsen, 1940), and the Middle and Upper "groups" were correlated with the Zoetlief and Pniel respectively (Matthysen, 1953). More recently, the Ventersdorp succession in the type area has been subdivided into six formations (Winter, 1965; Strydom, 1968), and the tentative correlation of the middle and upper parts of the sequence with the Zoetlief and Pniel was upheld.

Regarding the age relationships between the Ventersdorp stratotype and its possible correlates in other regions, the following radiometric data are important:

(i) the U-Pb age of zircon from a quartz porphyry considered to occur near the top of the Ventersdorp succession (Van Niekerk and Burger, 1964) - 2,3 Ga;

(ii) the minimum age of the Skalkseput Granite, which is unconformably overlain by the Seekoebaard Formation (Burger and Coertze, 1973, p. 14) - 2,5 Ga;

(iii) the U-Pb ages of zircons from porphyries of the Zoetlief Formation (Van Niekerk and Burger, 1968) - 2,6 Ga;

(iv) the age of deposition of the Dominion Reef (Van Niekerk and Burger, 1969) - 2,8 Ga.

These data indicate that the Seekoebaard Formation is most probably younger than both the Dominion Reef and Zoetlief, and that it may correspond in part or whole to the units occurring in the upper parts of the Ventersdorp stratotype (i.e. to the Allanridge and Bothaville Formations). Because of the great distance between the two areas (some 450 km) and due to the lateral lithofacial changes, however, this correlation of the Seekoebaard Formation is still provisional and will have to be supported by more radiometric data.

3.1.5.2. Depositional environment

The Seekoebaard Formation belongs to a group of sequences which were deposited in a linear sedimentary basin on the Kaapvaal Craton during the Lower Proterozoic. The development of this basin followed after the consolidation of the Archaean greenstone belts, and its initial period was marked by irregularities in the distribution and lithology of the supracrustal cover. While in some parts of the basin subsidence had already started some 2,8 - 2,6 Ga B.P. (e.g. the Dominion Reef, Witwatersrand and Zoetlief), other sectors of the Kaapvaal continental nucleus constituted regions of non-deposition and large-scale plutonic intrusion between 2,9 and 2,5 Ga B.P. (e.g. the south-western part of the Kaapvaal Craton).

The second stage in the development of the basin is characterised by the very limited extent of the areas of non-deposition, and by the progressive increase in the size of the basin (Anhaeusser, 1972). Units such as the Ventersdorp Group in the type area, the Seekoebaard Formation, and sequences around Pniel and in the T'Kuip Hills in the northern Cape accumulated, and earlier irregularities in the basin floor were gradually smoothed. Basal members of some of these units are composed of coarse-grained clastic material, which was transported over a short distance (e.g. the Skalkseput Conglomerate Bed and the basal conglomerate in the T'Kuip Hills).

Sequences such as the Seekoebaard Formation were deposited in an epeirogenic environment on thicker continental crust. Correspondingly, the chemistry and mineral composition of their volcanic members should reflect the same geotectonic conditions. However, only a few chemical analyses of the Ventersdorp lava and of its correlates are available, and the petrography of the sequence is not well known. Data, which may be valuable for the purpose of the reconstruction of the Ventersdorp depositional environment are therefore scarce and can be summarised as follows:

(i) the chemical composition of one sample of the Ventersdorp lava (Hall, 1938) is comparable with the average chemical composition of 144 continental tholeiites given by Hyndman (1972, p. 171). Differences are only in a higher content of SiO_2 in the Ventersdorp lava (54,85 %, compared with the maximum of 54,60 % given for the average continental tholeiite);

(ii) the presence of rock types such as andesite, dacite and trachyte suggests that the associations of volcanics in the Seekoebaard Formation and probably also in the Ventersdorp stratotype are similar to the volcanic association of the Brito-Arctic Province (Turner and Verhoogen, 1951, pp. 188 - 194), in which the tholeiitic flood basalts are accompanied by volcanics of the "acid magma-series" (op. cit., p. 191). Also present are alkaline olivine basalts. However, because of the preponderance of andesite in parts of the Seekoebaard Formation, and also in the Ventersdorp stratotype, the question requires further study;

(iii) The extent and thickness of the lava layers in the Seekoebaard Formation indicate that the volcanics were formed during fissure eruptions; the abundance of the volcaniclastic members suggest that many of the eruptions were mainly explosive;

(iv) pillow structures in some of the lava layers point to deposition in subaqueous conditions.

3.1.6. The Transvaal Supergroup

3.1.6.1. Correlation

It is generally agreed that the Black Reef and Campbell Rand Formations in Griqualand West can be correlated with the Black Reef "Series" and with parts of the Dolomite "Series" in the Transvaal, and that also the remaining members of the Griquatown sequence have their equivalents in the type area of the Transvaal Supergroup in the central Transvaal (Haughton, 1969; Truswell, 1970). For this reason and "to eliminate unnecessary names the Geological Survey decided to use only one set for the triple subdivision" in the two regions (Van Eeden, 1972, p. 17): the Black Reef, Dolomite and Pretoria Series. In the author's opinion, however, such subdivision can be used in a broad sense only, and any detailed stratigraphic classification and nomenclature of the Transvaal must be based on the principles of modern lithostratigraphy. Moreover, the names Campbell Rand and Griquatown "Series" are older than the names Dolomite and Pretoria "Series", and have therefore priority in the northern Cape.

With regard to terminology the problem of the Black Reef is a relatively simple one, since it can be given the rank of a formation without any major change in its original definition, and it occurs at the base of the succession both in the Transvaal and the northern Cape. Major problems appear with the definition of the boundary between the Black Reef and Campbell Rand, because the basal clastics of the Black Reef are separated from the chemogenic and biogenic sediments of the Campbell Rand by a succession of transition beds; occurrences of these transition beds, some 70 km west of Kimberley, were recently studied by Visser and Grobler (1972), who proposed the name Schmidtsdrif Formation for the unit, and indicated that on the official geological map between 90 - 95 per cent of this sequence is included in the Dolomite "Series" (op. cit., p. 270). The upper contact of the Schmidtsdrif is taken where the interbedded clastic sediments disappear, and the lower contact should be taken where first non-clastic layers make their appearance. It is obvious that in the area under consideration the transition beds of the Schmidtsdrif Formation are represented by the Schalksdrift Member, but they are much thinner than the Schmidtsdrif and have a predominantly clastic character. They were therefore included in the Black Reef. In contrast to this the Schmidtsdrif consists of about equal volumes of clastic and non-clastic sediments (Visser and Grobler, op. cit., p. 272).

As a result of the new stratigraphic classification of the transition beds, the Campbell Rand Formation should also be redefined; as interpreted here, the unit comprises only the main succession of the chemogenic and biogenic sediments above the last clastics of the transition beds. It most probably corresponds to the Main Dolomite Stage of the Dolomite Series in the Transvaal (cf. Haughton, 1969).

Next in the succession, the Asbestos Hills Iron Formation, represents a new lithostratigraphic unit, which was previously grouped with the Lower Griquatown "Beds" (Rogers, 1905), and which can be correlated with the Banded Ironstone Stage of the Dolomite Series in the Transvaal.

The Koegas Formation, which was also previously grouped with the Lower Griquatown "Beds", is probably a correlate of the first two "stages" of the Pretoria Series in the Transvaal. Its greater part, however, is lithologically different from both the Timeball Hill and Daspoort, and it overlies the top layers of the Asbestos Hills Iron Formation conformably (p. 51). The Koegasputs Mixtite Member of the sequence is very similar to that of the Daspoort Stage, and the remaining part of the succession, the Ongeluk Volcanics, can be correlated with the volcanics of the Daspoort Stage in the Transvaal almost directly. The Ongeluk succession in the area under consideration is incomplete, indicating that the top of the Ongeluk sequence, and possible equivalents of the Magaliesberg Stage and of remaining parts of the Pretoria Series have been removed by erosion, probably before the deposition of the Matsap Formation.

Finally, the classification of the units next in rank above a formation (i.e. the Lower and Middle Griquatown groups in Annex. 1), which correspond directly to the Lower and Middle Griquatown "Beds" of the old authors, represents in the author's opinion, a useful way of expressing the close association between the individual formations. However, since they do not strictly comply with the stratigraphic code, the names of these units must be regarded as informal.

3.1.6.2. Depositional environment

The third stage in the development of the Lower Proterozoic basins on the Kaapvaal Craton started with the widespread transgression of the basal clastics of the Black Reef. This transgression is evident from the lithology and extent of the Black Reef clastics, and from the regional unconformity between the Black Reef and the underlying sequences in the northern Cape.

There is much evidence that all the members of the Transvaal succession formed in shallow water and that some of the members are chemical rather than detrital sediments (e.g. the Asbestos Hills Iron Formation, parts of the Campbell Rand Formation and some layers in the Koegas Formation). The presence of the banded iron-formation and its distribution also suggest that the Transvaal basin was surrounded by base-levelled land areas (Crockett, 1972). It is possible that the depositional environment consisted of a number of discrete basins, and that marine connections between these basins were only intermittent (op. cit., p. 287).

All these considerations support the idea of a chemogenic rather than volcanogenic origin of the banded iron-formation, of the asbestos-bearing layers, and of the riebeckite-rich rock types. While the banded iron-formation can be interpreted as a chemical precipitate of original siliceous and ferruginous material, the riebeckite probably formed as authigenic or diagenetic mineral in parent saline muds or in other sediments with entrapped sea water (Cilliers and Genis, 1964). Subsequent formation of the crocidolite asbestos is now regarded as a result of burial metamorphism (op. cit., p. 567).

However, the presence of glass shards in the stilpnomelane bands of the Asbestos Hills Iron Formation and of the Koegas Formation, as well as the chemical composition of these bands, suggest that volcaniclastic material may have been an important component of the original Transvaal sediments (Hanekom, 1966; Fockema, 1967). It is also possible that iron and silica present in the Lower Griquatown group could have been derived from the weathering of iron-rich igneous rocks, or could have come directly from magmatic sources (Truswell, 1970, p. 53).

Finally, while the presence of mixtite at the same stratigraphic level of the Transvaal sequence both in the Transvaal and in the northern Cape indicates a widespread glacial activity in early Daspoort time, the lithological differences between the individual occurrences suggest different conditions of sedimentation (Visser, 1971). In the case of the Koegasputs Mixtite Member, its lithology suggests a predominantly glaciomarine origin, and a shallow-water environment of deposition.

3.1.7. The Matsap Formation

The unconformity at the base of the Matsap Formation in the area under consideration, and the characteristic lithology of the Matsap succession, indicate that its correlation with parts of the Waterberg stratotype (e.g. with the Nylstroom Formation) may be possible (Van Eeden, 1972, p. 25). However, the age of the Matsap Formation is not known, and also the question of its relationship to the Lower, Middle and Upper Matsap of the old subdivision (Table 12) is still debatable. Two main problems exist, which remain to be solved:

(i) the question of the stratigraphic boundary between the Transvaal and Waterberg correlates in the northern Cape;

(ii) the question of the Matsap stratotype.

In the author's opinion, the Matsap Formation south of the 29° parallel corresponds to the Upper Matsap of the old subdivision. It overlies the Lower and Middle Griquatown groups unconformably, carries pebbles of Griquatown jasper (typical of the Upper Matsap of the old subdivision - Cullen, 1956), and does not include any volcanics and/or pelites. Its correlation with the Upper Matsap of the old subdivision was also suggested by Leube (1964). This correlation seems to be supported by the relationships between the Lower, Middle and Upper Matsap in the area north of Olifantshoek, where the first two subdivisions progressively disappear in a northerly direction, and where the Upper Matsap appears to transgress over the two older units towards the east, indicating some discontinuity of sedimentation (Haughton, 1969, p. 209).

There remains the question of the correlation of the Lower and Middle Matsap; these two units, which are absent in the area south of the 29° parallel, may not belong to the Matsap *sensu stricto* (to the Waterberg correlates) at all. Their correlation with the Magaliesberg and overlying rocks of the Pretoria Series (Transvaal Supergroup) was suggested by Cullen (1956), and it has also been indirectly supported by other authors, who favour the correlation of the Upper Matsap with the Waterberg and of the Lower and Middle Matsap with older sequences (Haughton, 1969, p. 209).

The lithology of the Matsap Formation indicates that the strata are typical red beds, and the abundant cross-bedding and ripple-marks suggest a shallow-water depositional environment (Truswell, 1970, p. 64).

3.2. Structure

3.2.1. General

The structural framework described in section 2.2. indicates that similar sequences of tectonic phases causing similarly oriented structures can be recognised in all the three major tectonic subdivisions, i.e. in the Kaapvaal, Kheis and Namaqua domains. These phases (F_1, F_2, F_3, and F_4 in section 2.2.) and their relationship to the periods of deposition and plutonic activity suggest that the structural framework of all the three domains was formed and consolidated in two major geotectonic cycles. These are:

(i) the Archaean cycle, including the deposition of the Kheis sequence and of its correlates (pp 151 - 154), their deformation and metamorphism, and the consolidation during the period of a large-scale intrusive activity 2,5 - 2,9 Ga B.P., in which the Draghoender and Skalkseput Granites were emplaced;

(ii) the Lower Proterozoic cycle, starting with the deposition of the Seekoebaard Formation and characterised by the progressive increase in the tectonic activity both on the Kaapvaal Craton and in the Namaqua Mobile Belt; this cycle probably culminated during the post-Matsap deformation, and it was terminated by the plutonism, migmatisation and metamorphism between 0,9 and 1,25 Ga B.P.

The origin of the sets of structural elements described in section 2.2. is related in a systematic way to individual phases of the two geotectonic cycles and characteristic features of the structural pattern can be interpreted, at least qualitatively, in terms of strains, displacements and rotations that occurred at various stages of the Precambrian crustal evolution in the area under consideration.

3.2.2. Pre-Skalkseput deformation

The paleo-strain analysis of the two earliest phases of deformation (F_1 and F_2) involves three steps:

(i) the reconstruction of the deformation fabric ("strain fabric" of Hansen, 1971) as it existed prior to the intrusion of the Archaean granitoids 2,5 - 2,9 Ga B.P.;

(ii) the investigation of the predeformational and syndeformational discontinuities (Schwerdtner, 1973 a; Ramsay, 1967) and their influence upon the distribution of stress and strain in the Kheis, Swartkop and Hartebeest Pan tectonites during the two earliest periods of folding;

(iii) the discussion of the kinematics of the F_1 and F_2 phases, and the establishment of the movement picture of the two earliest deformations.

(i) The reconstruction of the Archaean deformation fabric can be based on a comparison between the younger (Proterozoic) and older (Archaean) sets of structures, because various elements in the individual patterns differ in their distinctiveness, morphology, orientation and distribution, and three of the sets (F_2, F_3, and F_4) also differ in their tectonic style. Characteristic and unique are the fold shapes and fold profiles of the F_1 and F_2 structures, and associated mineral lineation and persistent regional foliation (s_1) in the Kheis and in its correlates. Such a comparison of structures described in section 2.2. indicates that the primary F_1 and F_2 fabrics have not been obliterated, and that only the original orientation of the F_1 and F_2 structures was distorted in the zones of intense F_3 and F_4 refolding. It seems possible therefore that originally the F_2 structural pattern was similar to that shown in Fig. 35, and that the vertical dip of the regional foliation in the Swartkop sequence as well as in the Marydale subdomain and in parts of the Namaqua domain can be ascribed to the re-orientation of s_1-s_2 surfaces in steep shear structures of the F_4 generation. The uniform west-northwesterly dip of the regional foliation in the Groblershoop subdomain is most probably also a secondary feature; it conforms with the west-northwesterly dip of the axial surfaces of F_3 folds in the Matsap synclinorium and, on a regional scale (north of the area under consideration), the distinctiveness of this uniform dip fades out away from the Eselberge fault (away from the contact between the Kheis and Matsap).

The morphology of F_2 folds, the distinctiveness of l_2 lineations, and the widespread occurrence of the F_2 isoclinal pattern in Namaqualand and in the area of the Kheis Group suggest that the F_2 fabric developed as a result of a deformation which occurred over a large area, was accompanied by a regional metamorphism, and was followed by the plutonic intrusions between 2,5 and 2,9 Ga B.P. Such a relationship between deformation, metamorphism, and plutonic activity indicates that the F_2 folding represents one of the most important stages in the Archaean geotectonic cycle, and that it was probably during this episode that the mother geosyncline matured by evolving into a folded orogenic belt.

Many of the F_2 structures were probably formed during flow folding and some can be interpreted as having been formed by shear deformation. A combination of both processes is possible in those cases, where the limbs of isoclinal folds of great amplitude acted as shear planes; the resulting picture is that of intrafolial folds. The detailed mechanics of the F_2 deformation was most probably complex and depended on the nature and properties of the rock units involved, and possibly also on the environment in which the deformation took place. However, the latter of the two factors seems to have been less important, because of the great similarity between the F_2 fabrics of the eugeosynclinal and miogeosynclinal sequences of the Kheis *sensu lato*.

Contrary to this, the restricted occurrence of F_1 folds (p. 127), and the possibility that their amplitude and tightness decreases in the northerly direction (Joubert, 1971, p. 106) suggest that the environment in which the F_1 deformation occurred played a major role during F_1 folding. In the author's opinion, the variable frequency in the occurrence of F_1 folds and the distinctiveness as well as the distribution of other F_1 structures indicate that the mechanics of the earliest deformation (F_1) was markedly different from that of the F_2 phase; the F_1 structures possibly developed in a process of gravity tectonics which affected the eugeosynclinal correlates of the Kheis considerably more than the Kheis Group of the type area itself. It is probably for this reason that primary structures such as cross-bedding, can be recognised mainly in the north-eastern part of the Groblershoop subdomain, and that they are not easily found elsewhere.

No evidence of thrusting associated with F_1 folding was found in the area under consideration, and F_1 thrusting is also absent in western Namaqualand (Joubert, 1971, p. 106). It is therefore unlikely that the obliteration of the contact between the Kheis and its basement was brought about by early intense shear deformation and thrusting, and the absence of the pre-Kheis floor will have to be explained in some other way (p. 151).

The interpretation of the F_1 and F_2 fabrics in terms of their primary orientation is difficult. The present attitude of F_2 structural elements, for example, is a result of the combined effects of the F_2, F_3 and F_4 foldings, and the situation is even more complicated in the case of F_1 structures. Although the results of the present study suggest that the original F_2 axial trend was probably westerly or west-southwesterly, this tentative interpretation is in disagreement with the results of Joubert (1971). In western Namaqualand (op. cit., p. 109) the original strike of the F_2 axial surfaces was north-westerly or north-northwesterly with dips to the north-east. The difference can be explained either as a result of the fact that the primary orientation of F_2 structures in the vicinity of the boundary between the Namaqualand Metamorphic Complex and its foreland was greatly distorted by the subsequent F_3 and F_4 deformations, or changes in the regional trend of the F_2 set of structures developed simultaneously with the F_2 folding as a curvature of the orocline-type.

(ii) The role of predeformational discontinuities seems to have been equally important in both the F_1 and F_2 deformation. Factors such as the distribution of the primary lithofacies, the quality and thickness of the original layering, and the presence of tectonically competent and incompetent rock types (ductility contrast) controlled the distribution of finite strain during the earliest (F_1) deformation and the same factors also affected, indirectly, the strain facies of the F_2 episode. These factors were probably responsible for changes in the tightness of F_1 structures across the fold belt, which indicate an inhomogeneous strain fabric of the F_1 deformation. After the F_1 phase, however, the primary discontinuities became less important, and the Kheis, Swartkop and Hartebeest Pan tectonites were deformed by slip, shear or flow affecting the regional foliation (s_1). It is possible that, in parts where the F_1 folds were not tight enough, tectonic flow involving flattening of preexisting folds occurred; example of similar strain mechanics was described by Schwerdtner, (1970, p. 890).

Syndeformational discontinuities and their influence upon the F_1 and F_2 strain facies were probably equally important. Their origin was related to the anisotropy-creating phase of deformation, during which schistosity and mineral lineation developed, and their active role started in the anisotropic phase, during which numerous slip surfaces were generated parallel to the schistosity (Schwerdtner, 1973b, p. 1234).

According to Schwerdtner (op. cit., p. 1241) the mineral lineation tends to remain parallel to the major axis of the finite-strain ellipse on the schistosity plane during the anisotropic phase of deformation, and this implies that mineral lineation rather than schistosity is a reliable indicator of total-strain direction.

In the case of the F_1 deformation the data are scarce, and do not allow any consideration regarding the direction of the greatest finite shortening and extension, but the inferred primary orientation of the F_2 lineations (p. 168) may suggest that the greatest finite extension during the F_2 deformation in the Kheis fold belt occurred in an east-west direction.

(iii) The kinematics of the F_1 and F_2 deformation and the movement picture during these two earliest tectogenetic phases are far from being clear. However, the data discussed above point to a marked difference between the F_1 and F_2 fabrics, and indicate possible genetic and kinematic differences of the strain fabric and tectonic style of the two sets of structures.

The inhomogeneous strain fabric of the F_1 formation can be interpreted as a result of gravity tectonics which acted in early stages of the development of the mother geosyncline.

The homogeneous strain fabric of the F_2 formation and its uniform isoclinal tectonic style suggest that compressive and/or constrictive strain occurred over an extensive region, and that the F_2 structures developed during the late-geosynclinal tectogenesis. This fabric is comparable with the Phanerozoic late-geosynclinal structures, which are also essentially compressional and most commnly take the form of vast regional arches distorting the previous tectonic patterns (Aubouin, 1965, p.285).

3.2.3. Post-Skalkseput pre-Matsap gravity tectonics

It is widely accepted that downslope gliding under the influence of gravity is one of the most important propelling mechanisms in the rock-deformation. This type of deformation is believed to be related to isostatic movements (the tectonics of Pratt-type isostasy) and, *sensu stricto*, implies a general *creep* of rocks (Hills, 1972), creep being defined as a slow, gradual, more or less continuous permanent deformation under gravitational body stresses, or as any time-dependent deformation which takes place below the yield stress. In geological application it can usually be taken to be elastico-viscous deformation.

Gravity movements are of three basic types : first, those directed towards the trough (syntaphral), second, those directed upwards through the axial plane of the trough (diataphral) and, third, those leading to lateral spreading of the rising welt (apotaphral). The last of these types represents a final stage in the process of gravity folding and produces nappes, thrusts, and recumbent folds directed away from the axial zone (Carey, 1963).

The essential prerequisite for the syntaphral movement of rock masses is a favourable basal slope in the trough, as well as the unconsolidated nature of the sediments and complete filling of the interstitial voids with water. Hubbert and Rubey (1959) showed that the pore pressure, which reduces the internal friction, is greatly responsible for the sliding of rock sheets on the natural slope with angle much lower than the theoretically deduced critical angle of 30°. In fact, slumping on natural slopes as gentle as 1 - 4° has been described by various authors (Lewis, 1971).

Characteristic features of the rock deformation under the influence of gravity comprise both sedimentary and tectonic structures and are briefly summarised in the following list. Those structures which form in the earliest stages of gravity deformation during sedimentation and lithification (e.g. slump bedding and slump folds respectively) cannot be interpreted as conclusive evidence for gravity folding, but represent valuable information as to the mechanical properties of the rock involved and the slope of the basin.

Characteristic features of gravity deformation are as follows:

(i) disruptive bedding and slump bedding, which indicate gravity-induced movement of unconsolidated material;

(ii) intense folding of rocks usually regarded as competent, such as arenite and rudite (Newton, 1973, p. 146). This may indicate high pore-water pressure in original sediments;

(iii) slump folds, which were imposed upon the sediments after their deposition and prior to lithification. These folds occur in stratigraphically determined zones between undisturbed strata, but the boundaries between the slump units are not always distinct (the upper and lower portions contain beds predominantly concordant with undisturbed adjacent strata). Where planes of sliding can be recognised, evidence for both simple and multiple slump events may be found;

(iv) sedimentary boudinage structures, chert breccia layers, pseudoconglomerates, slickensiding on bedding planes (e.g. surfaces of stilpnomelane bands - Fockema, 1967, p. 58), folded clasts, sandstone dikes;

(v) variable intensity of folding; the intensity increases downslope and dies away rapidly across the axis of the trough, where the slope is reversed (Newton, 1973, p. 146). Folds also die out downwards, forming a "wrinkle" above an undisturbed surface (De Sitter, 1964, p. 213);

(vi) general asymmetry and possible overturning in the downslope direction; piled-up, recumbent and nappe-like folds (Helwig, 1970); cascade folds (Harrison and Falcon, 1934);

(vii) curvilinear fold hinges, different attitude of secondary cleavage and of the axial surfaces of the folds, divergent fans of the secondary cleavage planes;

(viii) ductile faulting, *décollement* zones;

(ix) lack of igneous or metamorphic phenomena (except very low-grade regional metamorphism of burial type e.g. riebeckite-stilpnomelane, stilpnomelane-chlorite, and minnesotaite-stilpnomelane associations in the Asbestos Hills Iron Formation and in the Koegas Formation).

Some of these characteristic features of gravity-folding have been mentioned in section 2.2.2.3. (pp. 103-111), and indicate that the deformation of the deposits in the Kaapvaal intrageosyncline and the subsidence of the basin were closely related. The most common structures which occur both in the Seekoebaard and Transvaal sequences are those that originated during sedimentation. The second group of gravity structures is represented by slump folds, which occur in the Asbestos Hills Iron Formation and in the Koegas Formation. The third group comprises both meso- and macroscopic structures, which formed after the deposition and lithification of the Transvaal sequence.

Although the individual gravity structures are recognisable, the geometry of the pre-Matsap "gravity" fabric is often overprinted by the post-Matsap deformation (F_3), which was responsible for refolding and realignment of the north-easterly trending gravity folds along the north-northeasterly F_3 trend.

The association of certain gravity structures with certain parts of the succession indicates that the instability of the basin was growing steadily, and that the deformation was probably most intense during the closing stages of the deposition of the Transvaal sequence. Important is the fact that large-scale thrusts and nappes are absent in the area under consideration, and that cascade folds have also not been found; the presence of the former is usually taken as evidence of large-scale translation of rock masses, and the latter is accepted as an indication of steep slopes in the original basin.

The pre-Matsap gravity-folding was of the flexural-slip type, and it was brought about by buckling rather than by bending. Its rate of formation was controlled by the overall rates of erosion and deposition. The detailed mechanics of deformation in the area under consideration, however, were obscured by the effects of subsequent post-Matsap refolding during the F_3 and F_4 phases.

3.2.4. Post-Matsap deformation

Two sets of structures (F_3 and F_4), which can be recognised in the Matsap Formation, represent important evidence of major paleogeographic changes that occurred after the deposition of the Waterberg Group. The fact that the same two sets (F_3 and F_4) are superposed on the earlier structures in the Kheis and Namaqua domains (F_1 and F_2) indicates that the post-Waterberg (i.e. post-Matsap) deformation also affected extensive regions outside the Kaapvaal Craton. The absence of the earlier sets of structures (F_1 and F_2) in the post-Skalkseput sequences of the Kaapvaal Craton, and the intrusive contacts of the Marydale Formation and of the Swartkop sequence with the Draghoender Granite suggest that the tectonic development of the area under consideration cannot be explained in terms of one continuous orogeny which would have included four consecutive phases of deformation (F_1, F_2, F_3 and F_4), and that the description of this sequence of events in terms of two separate geotectonic cycles (p. 166) is more appropriate.

It should be noted that the efficiency of structural sequence (F_1, F_2, F_3 and F_4) as a means of correlation between the development of adjoining tectonic domains appears to be reasonably well established not only in the area under consideration, but also in various other regions (cf. Hopgood, 1971).

One of the important characteristics of the first post-Matsap fabric (F_3) is the north-northeasterly plunge of linear structures; this is primarily responsible for the general north-easterly to north-northeasterly dip ("younging") of the lithological units (p. 156). Another characteristic feature of the F_3 structures in the Kaapvaal and Kheis domains is their east-southeasterly vergence. Also notable is the fact that the F_3 deformation was not of the same intensity over the entire area, and that it varied both in a lateral and vertical direction; the deformation was more intense in the Matsap synclinorium and in the anticlines of the Transvaal sequence than in the parts of the Seekoebaard Formation closer to the granite basement, in the Transvaal synclines, and also in parts of the Namaqua domain.

In contrast with this, the F_4 fabric is characterised by a general north-westerly trend, by a steep or vertical dip of F_4 axial surfaces, and by a more gradual change in the intensity of the F_4 deformation on a regional scale (its intensity increases in a south-westerly direction). These major differences suggest that the F_3 and F_4 fabric developed during the two separate phases of deformation.

The regional extent of the F_4 structures is confined to the Namaqua Mobile Belt (Fig. 1) and to a zone, some 60 km wide, which forms the northern foreland of the belt. The northern margin of this zone in the area under consideration is defined by the last occurrences of F_4 refolds (p. 122). The southern margin of this zone is the *Namaqua front* which, at different places along its length, appears as a metamorphic transition, as a strike-slip fault, and as an interface between areas yielding radiometric ages of 2,5 - 2,9 Ga and 0,9 - 1,25 Ga respectively. In the area shown in Fig. 9 the front generally coincides with the western margin of the Kheis domain. East and north-east of the front the Namaqua trend is distinct only at places, whereas west and south-west of the Kheis domain, both the regional structural trend and the distribution of various rock types are almost always north-westerly (Vajner, 1974).

The inhomogeneous character of the F_4 fabric in the direction across the Namaqua trend indicates that, in various zones of the belt and in its foreland, the heterogeneous strain states prevailed during the F_4 ductile flow; it is believed that such heterogeneous strain states are set up by the complex and variable displacements within the rock masses in shear belts (Ramsay and Graham, 1970, p. 786). The geometry of the F_4 structures in the Namaqua belt and in the Kheis domain (p. 142-143) indicates that the major part of the F_4 fabric was developed by the mechanism of simple shear and that dextral strike-slip was an important form of displacement.

The F_4 kinematics can be interpreted as ductile flow in a general north-westerly direction which, depending on various physical factors, became gradually concentrated in relatively narrow zones of intense simple shear (the width of such zones was probably in the order of 10-100 m). In the later stages this deformation resulted in strike-slip movement along the limbs of F_4 folds, and the last stage of such deformation is probably represented by the development of wrench-faults (*sensu* Anderson, 1951), such as those in the Doringberg lineament (p. 149).

The F_4 kinematics were markedly different from the mechanism of the preceding F_3 folding. This is suggested mainly by differences between the geometry of the F_3 and F_4 structural elements and by the uniform vergence of the F_3 structures; the F_3 deformation is of a compressional type, characterised by the translation of rock masses perpendicular to the direction of greatest finite extension.

3.2.5. Wrench-fault tectonics in the Doringberg lineament

The Doringberg fault, here regarded as one of several major fractures belonging to one important lineament (p. 149), was first interpreted as part of a "sinuous zone of compression within the Matsap geosyncline" and this zone was thought to have followed the Doringberg, Langeberg and Korannaberg hilly ridges in the northern Cape (Du Toit, 1954, p. 215). The tectonic movement along the western side of the Doringberg was described as simple high-angle thrusting (Du Toit, op. cit.). It is difficult, however, to explain the facts summarised earlier (p. 149 and above) in terms of simple high-angle thrusting. Mainly the very steep or vertical dip of the faults, the displacement indicated by the separation and offset of the geological features on both sides of the fault (see Annex. 1), and also the close relationship between the F_4 structures and fractures in the zone of the Doringberg lineament, suggest that the movements in the zone have not been simple, and that thrusting was not the main phenomenon.

Of particular interest is the fact that displacement along the Doringberg fault and along some of the other major fractures in the lineament is almost consistently dextral. This means that the part of the Doringberg fault striking north-westerly (Fig. 40) is a master fault (first-order shear) and that its north-northwestern continuation in the vicinity of Koegas represents a secondary fault (second-order splay fault). Primary stress in the zone of the Doringberg fault acted probably in a northerly direction (Fig. 42).

A similar relationship between the master faults and secondary faults exists in the north-western part of the lineament (Fig. 40), but the strike of the master faults there is 345° (compared with some 315° for the Doringberg fault). However, it is only in this north-western part of the lineament that the

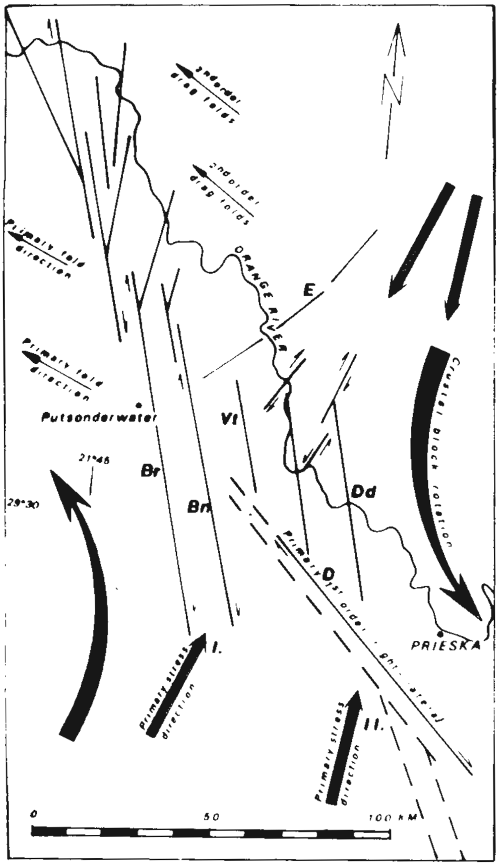

Fig. 42 Simplified and stylised diagram showing faults, principal stress directions and postulated crustal block rotation in the zone of the Doringberg fault;

Abbreviations are:
D - Doringberg fault;
Dd - De Duinen fault;
Vt - Vaalbult fault;
Bn - Brulpan fault;
Br - Brakbos fault;
E - Eselberge fault

"primary fold" structures associated with the first-order shear are definable (the most frequent direction of plunge of these is 335° - Fig. 42. The other set of minor folds (maximum concentration some 310°) would represent the second-order drag folds of Moody and Hill (1956).

It should be stressed that not all first-, second- and third-order faults and associated fold directions which, according to Moody and Hill, may theoretically result from directed compression, are fully definable in a particular area such as the one discussed here. The main reason for this is probably the fact that the classification proposed by Moody and Hill does not make any allowance for simple or rotational-shear type of failure and that the stress distribution at a particular point in a solid is, according to Chinnery (1966), a tensor quantity and cannot be discussed in terms of vectors. The classification of Moody and Hill also does not take into consideration relative ages of various structures, their relative scale and importance, and spatial relationships among the higher- and lower-order structures (Prucha, 1964; Badgley, 1965). Hence it follows that not all structures theoretically defined and predicted by Moody and Hill will necessarily develop in a particular wrench-fault zone.

Nevertheless, Moody and Hill's classification is probably still useful for the determination of the angles α (the azimuth of the primary principal-stress direction or of the maximum stress axis of the stress ellipsoid) and β (the angle of shear, i.e. the angle between the primary principal stress direction and the first-order shear). For the master faults in the north-western part of the Doringberg lineament α is some 25° and β some 40°.

The difference between the strike of the master faults in the north-west and the Doringberg fault in the south-east seems to point to the re-orientation of the primary stress-field in a process of continuous deformation affecting the Namaqua Mobile Belt, and its foreland. It is suggested here that this re-orientation was related to anti-clockwise rotation of crustal blocks on both sides of the lineament (Fig. 42).

Although the major movements in the zone of the Doringberg lineament occurred during the Namaqua tectogenesis (0,9 - 1,25 Ga B.P., cf. Kröner et. al., 1973), some indications exist that the zone was probably active also during the Phanerozoic: parallel to the Doringberg fault strikes the body of the Uitspanberg syenite (some 20 km west of Prieska), which is evidently of post-Transvaal pre-Karoo age (Rogers and Du Toit, 1908, pp. 93-94), and closely associated with the Doringberg is the kimberlite dyke on the farm Soetvlei some 40 km south-southeast of Prieska (Du Toit, 1908). The Doringberg fault is still seismically active (Krige and Maree, 1951). The relationship between the strike-slip and dip-slip components during these later movements is not clear, mainly due to the lack of a post-Matsap sedimentary cover in central and north-western parts of the lineament.

The relationship between ductile flow, ductile shear and brittle deformation in the Namaqua Mobile Belt and in its foreland indicates that the strike-slip movement in the mobile zone (i.e. the movement along the limbs of some of the F_4 folds in the Namaqua Mobile Belt) was transformed into a movement oblique to the mobile belt in the zone of the Namaqua foreland. Such a relationship is also known from some other mobile belts and has been discussed recently by Harland (1971) who introduced the terms *transpression* and *transtension* to describe intermediate or oblique relative movements in which the well-established extension, compression and transcurrent movements can combine in zones between large crustal blocks. In the author's opinion, transpression as a mode of the Namaqua tectogenesis in the area under consideration gives the best explanation of the close relationship between fold structures and fractures in the Namaqua Mobile Belt and in its foreland.

3.3. Metamorphism

Three types of metamorphic mineral assemblages can be recognised in the area under consideration:

(i) assemblages of low-grade regional metamorphism of burial type;

(ii) assemblages of polyphase regional metamorphism;

(iii) assemblages of cataclastic metamorphism.

(i) Mineral assemblages of burial metamorphism are represented by the associations riebeckite-stilpnonelane, stilpnomelane-chlorite and minnesotaite-stilpnomelane in the Asbestos Hills Iron Formation and in the Koegas Formation. These minerals, currently interpreted to be products of diagenesis or low-grade metamorphism (Lepp, 1972, p. 269), are indicative of pt-conditions of the lawsonite-albite facies (Winkler, 1967) and, according to experimental data, they may have formed at temperatures of more than 200° C (200-450°C) and at H_2O- pressures of 5-8 kb (op. cit.., p. 169). The actual temperature of their formation was probably in the region of 200-250°C, because in the banded iron formation above this temperature fayalite instead of riebeckite would have become the stable phase (cf. Genis, 1964, p. 572).

The presence of stilpnomelane, which is usually regarded as a mineral of the greenschist facies or of the lawsonite-glaucophane-jadeite facies of burial metamorphism, indicates that the pressure operating during recrystallisation of the Transvaal sediments may have been of the order of some 8 kb (cf. Winkler, 1967, Fig. 39).

The combination of the extreme physical conditions of high pressure (7-8 kb) and very low temperature (possibly only 200-250°C) theoretically corresponds to a depth of burial of some 30 km. However, since the maximum thickness of the upper part of the Transvaal sequence and of the overlying Matsap could hardly have exceeded some 10 km, load pressure alone can by no means account for the 7-8 kb necessary. Winkler (op. cit., p. 172) points to the fact that, even where supplemented by a tectonic overpressure of 2 kb, the total confining pressure at a depth of 10 km will be approximately 5 kb. However, the "internally created gass overpressure" (Winkler, op. cit., p. 10) is thought to be responsible for the presence of high pressure - low temperature mineral assemblages in cases where the great thickness of geosynclinal sediments did not exist (as, for example, in the western Alps).

The temperature postulated for the burial metamorphism in the area under consideration was lower than the maximum temperatures of burial metamorphism reached in the Witwatersrand basin during the same period; according to Saggerson (Saggerson and Turner, 1972, p. 155), upper greenschist to lower amphibolite grades were achieved in the deepest parts of this basin. The higher metamorphic grade there is attributed to the higher thermal state during early Precambrian time (op.cit., 1972, p. 155), i.e. to geothermal gradients higher than those of the Phanerozoic.

It is possible that the assemblage of zoisite/epidote + albite ± chlorite, found in the "altered" Seekoebaard lava (Table 5) developed during the same process of burial metamorphism although it is usually regarded as a characteristic assemblage of the lowest-temperature subfacies of the Barrovian-type facies series.

(ii) The metamorphic grade of the Kheis Group, of the Namaqualand Metamorphic Complex, and also of the Swartkop sequence is best documented by the mineral assemblages found in metavolcanics and by those in metasediments of a pelitic and semipelitic parentage. The most important of these assemblages, which reflect the pt-conditions during regional metamorphism, are the index mineral assemblages listed in Table 19. A comparison between these suggests that the highest metamorphic grade has been reached by the rocks of the Namaqualand Metamorphic Complex, and that the metamorphic grade of the Swartkop sequence is the lowest of the three units compared.

<table>
<tr><th colspan="2">Unit</th><th>Swartkop sequence</th><th>Kheis Group</th><th>Namaqualand Metamorphic Complex</th></tr>
<tr><td rowspan="10">Index mineral assemblages</td><td rowspan="6">Rock types of basaltic and andesitic parentage</td><td colspan="3">actinolite - epidote</td></tr>
<tr><td colspan="3">actinolite - epidote - chlorite - quartz</td></tr>
<tr><td colspan="3">hornblende - epidote - actinolite - quartz</td></tr>
<tr><td rowspan="3"></td><td colspan="2">plagioclase $An_{>10}$ - hornblende - quartz</td></tr>
<tr><td colspan="2">plagioclase $An_{>10}$ - hornblende</td></tr>
<tr><td>plagioclase $An_{>10}$ - hornblende - garnet
hornblende - clinopyroxene - garnet</td><td>?</td></tr>
<tr><td rowspan="4">Rock types of pelitic and semipelitic parentage</td><td colspan="3">biotite - chlorite - quartz</td></tr>
<tr><td>?</td><td>biotite - muscovite - garnet (± staurolite)</td><td>biotite - andalusite - staurolite</td></tr>
<tr><td colspan="2" rowspan="2">?</td><td>biotite - sillimanite - garnet</td></tr>
<tr><td>biotite - sillimanite - cordierite</td></tr>
</table>

Table 19 Index mineral assemblages in the Swartkop sequence, in the Kheis Group and in the Namaqualand Metamorphic Complex

The Swartkop sequence contains mineral assemblages of both the lower and upper greenschist facies; this may be explained either as a result of later retrogressive recrystallisation superposed on an earlier upper-greenschist metamorphism, or as a result of primary variation in the metamorphic intensity. The latter explanation is probably less feasible because the transition between the lower- and upper-greenschist mineral assemblages does not follow a systematic pattern, and because it cannot be described in terms of a metamorphic zonation which would have resulted from progressive metamorphism. Even if such a progressive metamorphic zonation was definable, it would be difficult to explain that the change from lower to upper greenschist assemblages takes place over a distance of only several tens of metres.

The mineral associations in the Kheis Group, as well as their distribution and the relationship between the deformation and crystallisation, point to a complex metamorphic history of this unit. The oldest metamorphic feature in the Kheis is the lepidoblastic and nematoblastic schistosity s_1 (p. 134) which is distinct in metapelites and metamorphosed semipelites of the Groblershoop Formation and in the Marydale Formation, but indistinct in the quartzites of the north-eastern part of the Groblershoop subdomain. It developed under conditions of the upper greenschist to lower amphibolite facies. The development of this schistosity was followed by the crystallisation of garnet (Plate 8.1.) and by the post-tectonic crystallisation of hornblende (Plate 8.2.) and biotite. During the second stage of metamorphism conditions of the upper amphibolite or lower granulite facies were reached in the southern part of the area. The high grade of metamorphism there is documented by the occurrence of the assemblage hornblende-clinopyroxene-almandine (V 4377 in Table 14). Later retrogressive metamorphism is documented by the presence of actinolite, epidote and chlorite; these minerals usually display no preferred orientation and often grow at the expense of older hornblende and/or biotite.

The first two stages of recrystallisation in the Kheis rocks were probably related to the earlier periods of deformation (F_1 and F_2), and the retrogressive stage can be linked to the post-Matsap deformation, namely to the closing stages of the F_4 event. The data summarised in Section 2 indicate, however, that crystallisation outlasted the deformation during the second and third metamorphic stage and that the time relationships between crystallisation and deformation can not be explained in terms of simple simultaneous interaction between the two processes.

The zoning which developed during the first two stages of metamorphism follows a general north-westerly direction and the metamorphic intensity increases from north and north-west to south and south-east (from the greenschist facies to the upper amphibolite facies or the lower granulite facies in parts of the farms Stuurmansput and Irene). The position of the individual isograds is difficult to define, mainly because of the high percentage of rock-types unsuitable for such purpose (the Kaaien quartzite, for example, constitutes more than 50 per cent of the area of the Kheis outcrop). The retrogressive zoning seems to follow a north-westerly or north-northwesterly pattern.

The metamorphism in the Namaqua domain is best documented by the mineral assemblages of the Hartebeest Pan Formation; these indicate that conditions of high-grade metamorphism of the low-pressure high-temperature type have been reached at places farther away from the Namaqua front.

The intensity of the low-pressure high-temperature metamorphism increases towards the contacts with granitoids of the Hartebeespan and Sonderpan type and, on a regional scale, from the north and north-east to the south and south-west (Fig. 43). This pattern may be explained as a feature of contact metamorphism that originated at a greater depth than the classic shallow-contact metamorphic hornfels facies series; it is similar to the pattern of the Abukuma-type metamorphism, but no unusually high temperature subfacies, so typical in the Abukuma area (Miyashiro, 1961) have been recognised in the Hartebeest Pan Formation.

The age of the low-pressure high-temperature metamorphism in the Namaqua domain is most probably related to the age of emplacement of the Hartebeespan and Sonderpan granitoids. Since the structural setting of these granitoids suggest their post-Matsap age (the emplacement probably took place in the early stages of the F_4 phase of deformation), the second metamorphic event in the Namaqua domain falls in the period of the Namaqua tectogenesis (*sensu* Kröner et al., 1973). This relationship is in agreement with the relationships between the F_4 deformation, plutonism and metamorphism (M_4) in western Namaqualand (cf. Joubert, 1971, pp. 155 and 158). However, the final solution of this problem will have to wait until radiometric ages for the granitoids in the Namaqua domain become available.

Earlier metamorphism, which was almost completely overprinted by the low-pressure high-temperature metamorphism in the area of the isograd "sillimanite-in", is documented by the existence of s_1 schistosity. This planar structure developed prior to the isoclinal folding F_2 which is post-dated by the intrusions of the Hartbeespan Granite and Sonderpan Granodiorite.

Plate 8.1. Rotational texture in garnet. Groblershoop Formation, farm Keukendraai (x35)

Plate 8.2. Hornblende porphyroblasts growing across the schistosity. Groblershoop Formation, farm Stillerus (x28)

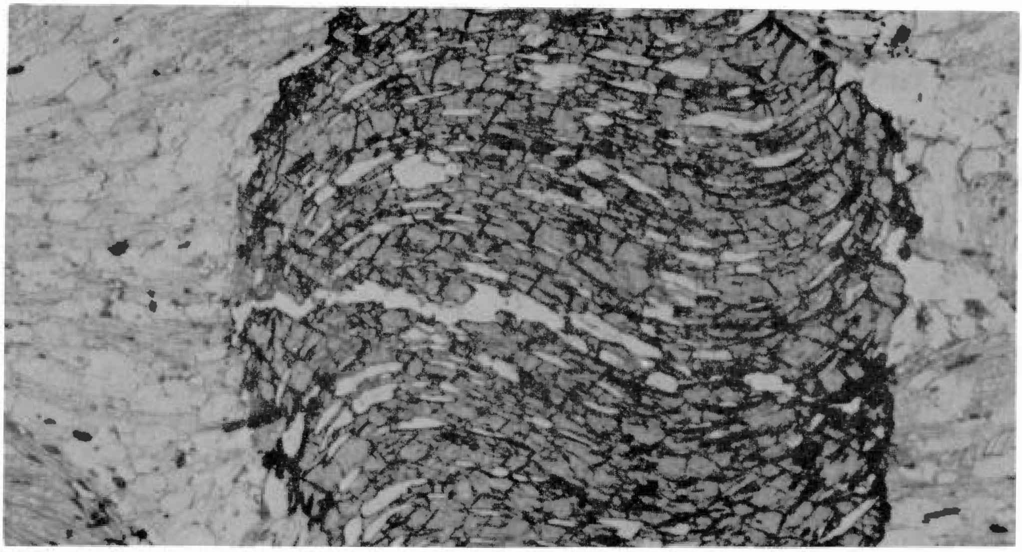

Plate 8.1.

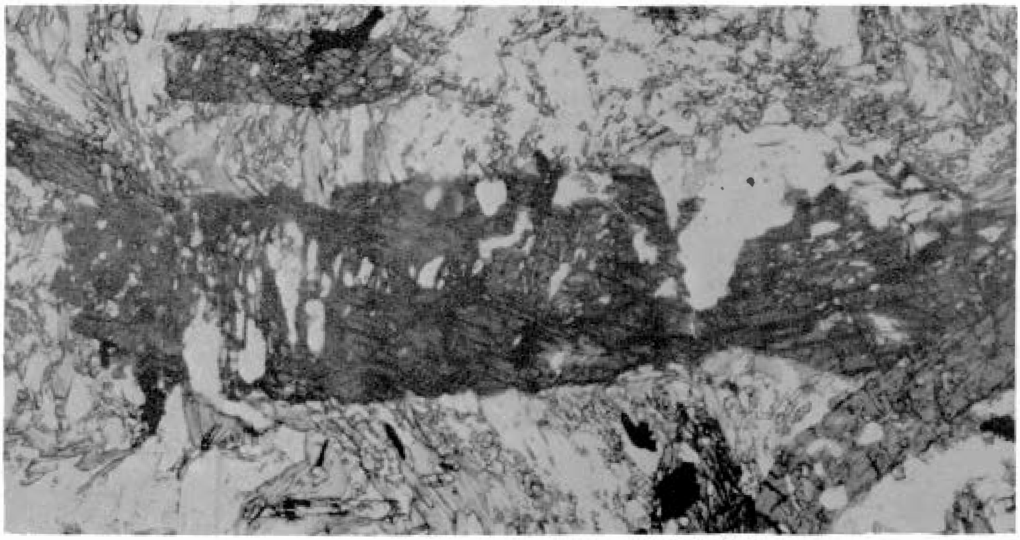

Plate 8.2.

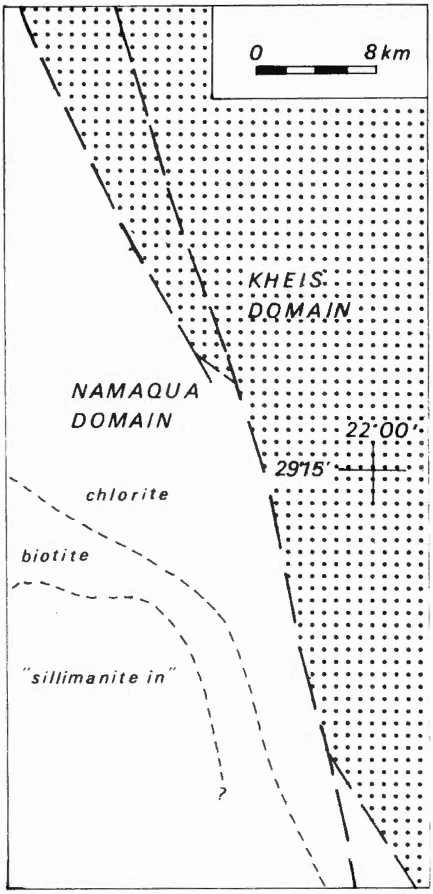

Fig. 43 Metamorphic isograds in the Namaqua domain east of 21°45'E meridian

The mineral assemblages of the late retrogressive metamorphism in the Namaqua domain are very similar to those of the late retrogressive metamorphism in the Kheis, and it seems possible that in both these domains the retrogressive metamorphism is related to the late stages of the F_4 phase of post-Matsap deformation.

(iii) Mineral assemblages of cataclastic metamorphism, which occur in the zones of post-Matsap thrusting and shearing developed under conditions of the lower greenschist facies. Several stages of deformation and recrystallisation can be recognised; the most representative sequence of these events is described in section 2.1.2.5. (pp. 36 - 37).

3.4. Remarks on the geochemistry of granitoids

Three groups of granitoids in the area under consideration are represented in Fig. 8 (p. 91):

- (i) Draghoender and Marydale Granites (numbers 2583, 4425, and 4388 respectively);
- (ii) Skalkseput Granite (number 4424);
- (iii) Brakbos, Eindgoed and Hardeberg granitoids (numbers 4366, 3562 and 481 respectively).

The first two groups are of pre-Ventersdorp age (c. 2,9 and 2,5 Ga respectively, cf. Burger and Coertze, 1973, pp. 14 and 16, and pp. 10 and 12 above), the last group comprises granitoids which have not yet been dated; the Hardeberg Granodiorite (most probably younger than the Matsap Formation) and the Brakbos Granite and Eindgoed Granite, which constitute discordant intrusive bodies in the Namaqualand Metamorphic Complex and probably belong to the ± 1,0 Ga age group.

Chemical composition of seven representative samples is given in Fig. 8 and following relationships are illustrated:

(i) Major and trace elements analytical results; these indicate that with the exception of the Hardeberg Granodiorite (V 481) the potassium content decreases with the increasing age of the rock type analysed (cf. 3,12 and 2,76 per cent of K_2O in the Draghoender and Marydale Granites compared with 5,34 per cent K_2O in the Eindgoed Granite)

(ii) Abundance of K plotted against K/Rb ratio (Fig 8 B); this diagram shows that also the content of Rb is generally lower in older granitoids. The K/Rb ratio varies between 183 (V 4425) and 257 (V 4366);

(iii) Abundance of K plotted abainst Rb (Fig. 8 C);

(iv) Abundance of K plotted against Ba (Fig. 8 D); this diagram shows only a limited range of variation (K/Rb = 30 - 67,6) and also points to the fact that the Ba content is high not only in the older intrusives, but also in the Brakbos Granite;

(v) Abundance of Ba plotted against Sr (Fig. 8 E).

In comparison with the analyses of three granitoids from the northern Cape (Hunter, 1973, p. 7 and Table XIII - G, H, and I) the above results also display a wide range of geochemical characteristics and indicate that more systematic work is required before the geochemical relationships of the three age groups of granitoids in the area under consideration can be defined.

3.5. Crustal evolution of the Namaqua Mobile Belt

The geotectonic development of the Namaqualand Metamorphic Complex was initiated with subsidence and deposition of the supracrustal sequences such as the Hartebeest Pan Formation and its possible correlates (pp. 158-159). The clastic material in these sequences was derived from both continental and oceanic sources; some of the rock types described in the literature as pink gneiss, for example, are most probably of terrigenous parentage (cf. Kröner, 1971), whereas rocks, such as leptite, amphibolite, leucogneiss and granulite can possibly be interpreted as metamorphosed tephra and metalava derived from ancient island arcs (pp. 158 - 159). The lithology and distribution of these sequences suggest that their deposition took place in an oceanic basin (or in a series of basins) of eugeosynclinal type (p. 153).

The radiometric age of these sequences is not known, but it is accepted that they are older than the Kibara Group (Clifford, 1972, p. 33), which occurs in the Kibaride Belt and is dated at c. 1,3 - 2,1 Ga (Cahen, 1970). As a result of this uncertainity regarding the age of the supracrustal sequences in the Namaqualand Metamorphic Complex, two alternative models for the crustal evolution of the Namaqua Mobile Belt can be considered which are based on the following basic presumptions:

(i) the supracrustal sequences are of Lower Proterozoic age (c. 2,0 - 2,5 Ga B.P.) and represent geosynclinal equivalents of the Ventersdorp, Transvaal and Waterberg sequences on the Kaapvaal Craton. Although this correlation is not substantiated by the recent investigation (pp. 156), the lack of conclusive radiometric data necessitates that the applicability of this model is discussed here;

(ii) the supracrustal sequences in the Namaqualand Metamorphic Complex are generally older than 2,5 Ga, and the crustal evolution of the belt can be explained in terms of the two major geotectonic cycles (p. 166).

(i) The first possibility has been considered by several authors (see pp. 154 - 156), and it is supported by field observations in western Namaqualand and in adjoining parts of the Richtersveld and South West Africa (Blignault, 1972; Beukes, 1973; Ward, 1974). Of particular importance is the statement that the well-developed and ubiquitous regional foliation/banding in the Namaqualand Metamorphic Complex is superposed on the Vioolsdrif Granite dated at c. 1,8 Ga B.P. (Blignault, 1972, p. 24). The correlation of the Namaqua supracrustal sequences with the 1,8 - 2,5 Ga old sequences on the Kaapvaal Craton also leans on the assumption that no obvious break exists between the Kheis and Matsap (cf. Beukes, 1973, p. 183). In the author's opinion, however, the possibility cannot be excluded that the above inferred relationships are inconclusive, and that structures and sequences of different age may have been correlated. The surfaces of regional foliation (s_1) in the Namaqualand gneisses were reactivated during the later deformation (Joubert, 1971, p. 134), and it is possible that "s_1" in the Vioolsdrif Granite developed as a result of this later refoliation. This means that the regional foliation in the Namaqualand Metamorphic Complex may be older than the similarly oriented planar surfaces in the Vioolsdrif intrusive; the granite, in this case, would *postdate* the first major period of deformation and metamorphism in the Namaqualand Complex. The relationship between the Kheis and Matsap (pp. 100 - 101 and 156) also indicates that direct correlation of the two successions is not justified.

However, assuming that these objections against the Lower Proterozoic age of the Namaqualand supracrustal sequences are not valid, and that most of the parent material of the

Namaqualand gneisses did form during the period between c. 1,8 and 2,5 Ga B.P., we have to consider a hypothetical model, explaining the crustal evolution in the Namaqua belt in terms of a single geotectonic cycle. The duration of such a cycle (according to this hypothetical model) was some 1,6 Ga, and in this interval subsidence, deposition, complex deformation, metamorphism and final consolidation marked by the posttectonic intrusions c. 0,9 Ga B.P. occurred. This sequence of events is probably compatible with present-day tectonic processes at convergent plate boundaries, where a new continental crust is formed in arc-trench systems (Dickinson, 1973). Whatever the details of the process, the applicability of this model to the crustal evolution of the Namaqua Mobile Belt would support the hypothesis of the gradual growth of continents throughout Precambrian and Phanerozoic time by incremental additions in the form of successive peripheral orogenic belts (Dickinson and Luth, 1971, p. 403).

(ii) The second model, which is based on the postulated pre-Witwatersrand age of the Kheis and its correlates (pp. 156 - 157), and which implies the existence of two major geotectonic cycles in the history of the Namaqualand Metamorphic Complex (p. 166), explains the evolution of the Namaqua Mobile Belt in terms of major reactivation of the old Archaean crust in post-Waterberg time. The feasibility of this model depends on the acceptance or rejection of the correlation between tectonic events in the Namaqualand Metamorphic Complex and those in the Kaapvaal domain, as suggested and documented in previous sections. It also depends on the vindication or confutation of the view that essentially the whole mass of the Earth's continental crust was formed early in the Precambrian, and that the thickness of the crust has not changed significantly since c. 2,5 Ga B.P. (Condie, 1973, p. 2981).

If the Precambrian tectonic development of the Namaqualand Metamorphic Complex followed the pattern of two major geotectonic cycles defined above (p. 166), then the Namaqua Mobile Belt represents a Proterozoic vestigeosyncline (*sensu* Clifford, 1968, p. 306), in which only limited sedimentation occurred after c. 2,5 Ga B.P. and prior to the Namaqua tectogenesis. Indications exist that these Proterozoic geosynclinal sediments were largely removed by later erosion and that the rock types now exposed in the belt represent an infrastructure (*sensu* Wegmann, 1935) which moved into giant upwellings at about 1,0 Ga B.P. (Nicolaysen and Burger, 1965, p. 500). These indications are contained in the complex structural pattern of the Namaqualand Metamorphic Complex, in the presence of granulite-facies rocks in western Namaqualand (Joubert, 1971, pp. 38 - 46) and, last but not least, in the type of strata-bound Cu-Pb-Zn mineralisation associated with the ancient volcaniclastic sequences (e.g. the Copperton orebodies in the Copperton Volcanic Pile, some 55 km south-west of Prieska, Aggeneys orebodies some 55 km west-southwest of Pofadder, mineral occurrences near Pypklip some 35 km south-west of Kakamas, etc.). All these occurrences resemble strata-bound base metal deposits commonly present in Archaean volcaniclastic rocks, for example in the Canadian Shield (cf. Douglas, 1970, p. 154 - 155).

The upwelling of the infrastructure was most intense in the central zones of the belt. In these zones the metamorphic grade is much higher than in the marginal parts of the belt, and syntectonic granitoids of the Hartbeespan type (p. 88) are widespread. The grade of metamorphism and the volume of syntectonic granitoids show a rapid decrease over a relatively short distance across the belt (over some 10 - 15 km), and the marginal parts of the belt are marked by shearing, retrogressive metamorphism, and by widespread high-level posttectonic intrusions. Such a gradation indicates strong vertical movements in the central parts of the belt. According to some authors, the type and magnitude of the upwelling of the infrastructure suggest that the Precambrian mobile zones such as the Namaqua Mobile Belt, may represent cryptic suture zones which developed as a result of Alpine-type orogeneses. In such orogeneses the crust attains almost twice the normal thickness, large volumes of granitoids are generated by partial melting, and radiometric clocks are widely reset (Burke and Dewey, 1972, p. 604). Unroofing of the belt such as the Alps and Himalayas could reveal a tectonic pattern similar to that now observed in the Namaqualand Metamorphic Complex.

The plate tectonic model, however, is not the only possible explanation for the Mediterranean-type orogeny, and two other alternative models have recently been discussed by van Bemmelen (1972, p. 567 - 571):

(i) a model, in which radiogenic heating of the continental crust is responsible for crustal doming;

(ii) a model of mantle diapirism.

The view that alternative explanations may exist for the development of Phanerozoic orogenies was also expressed quite recently by Rutland (1973) who, in discussing the evolution of the Cordilleran orogenic belts, concluded that some orogenic processes are controlled by a global thermal cycle, independent of ocean-floor spreading (op.cit., p. 841). This reopens the possibility that some of the Precambrian orogenies were also independent of ocean-floor spreading (Shackleton, 1969), and that at least some of the Precambrian mobile belts are not closed oceans, but in situ features situated within the ancient crustal blocks.

The absence of extensive Kibaran geosynclinal sequences (Clifford, 1972, p. 33) and the widespread occurrence of metamorphosed supracrustal rocks of Archaean type (the Kheis and its possible correlates - p. 153) suggest that after the early structural consolidation c. 2,5 Ga B.P. (cf. Kröner et.al., 1973) the Namaqualand Metamorphic Complex formed part of an Epi-Early Proterozoic Platform (*sensu* Semikhatov, 1972, p. 276). Reactivation of the Namaqua segment of this platform during the Lower Proterozoic culminated in the Namaqua tectogenesis c. 0,9 - 1,25 Ga. B.P. and was probably confined to an ancient zone of crustal weakness (*sensu* Crockett and Mason, 1968). Although the type, age and magnitude of the movements in this zone can be deduced from the characteristic tectonic features of the mobile belt (e. g. the upwelling of the infrastructure - pp 185 - 186, the strike -slip movement in the Doringberg lineament - pp. 149 and 176 , the tectonic zoning in the belt - pp. 144 - 145, etc.), the driving forces of the Namaqua tectogenesis remain to be defined. It is possible that the reactivation of the Archaean crust in the Namaqua Mobile Belt was triggered off by crustal radiogenic heating of the granitic crust which was thickened c. 2,5 - 2,9 Ga B.P. Such heating could have been responsible for melting and the ascent of plutonic masses (Schuiling, 1972 and 1973; van Bemmelen, 1972) and for the final reset of radioactive clocks between o,9 - 1,25 Ga B.P.

Finally, the movements that occurred after the Namaqua tectogenesis, did not leave any significant imprint on the pre-Namaqua fabrics of the region; some of these later movements are associated with the Doringberg lineament (e.g. seismic activity - cf. Krige and Maree, 1951), others are believed to have affected old drainage channels running northwards toward the Orange River in northern Namaqualand (G. T. Lamont, 1967 - pers. comm. in: Crockett and Mason, 1968, p. 537). This points to the possibility that some parts of the Precambrian crustal framework in the belt remained labile long after the Namaqua tectogenesis, and indicates that the basement structure played an important role in subsequent geological events (e.g. in the Late Precambrian development of the Gariep basin along the western margin of the Namaqualand Metamorphic Complex - cf. Joubert and Kröner, 1972, pp. 51 - 52).

4. CONCLUSIONS

1. Supracrustal sequences and intrusive rocks present in the area under consideration belong to three major geotectonic units. These are:

(i) the Kaapvaal Craton;
(ii) the Kheis Group;
(iii) the Namaqualand Metamorphic Complex.

(i) The Kaapvaal Craton comprises granitoids older than c. 2,5 Ga (i.e. Draghoender and Skalkseput Granites), and supracrustal sequences of various ages. The earliest of these, the Swartkop sequence, is intruded by the Draghoender Granite.

Younger than c. 2,5 Ga are the Seekoebaard Formation (a correlate of the Ventersdorp Group), the Transvaal sequence, and the Matsap Formation (a Waterberg correlate).

(ii) The Kheis Group is a sequence of metasediments and metavolcanics which differs from the Seekoebaard, Transvaal and Matsap successions of the Kaapvaal Craton in its lithology, regional metamorphism and complex structural pattern. It is intruded by the Draghoender Granite, and probably of pre-Witwatersrand age.

(iii) The Namaqualand Metamorphic Complex is situated within the Namaqua Mobile Belt and comprises both supracrustal rocks (the Hartebeest Pan Formation), and intrusive rocks (mainly granitoids). The supracrustals are probably of pre-Witwatersrand age, whereas the granitoids were emplaced much later, possibly during the Namaqua tectogenesis c. 0,9 - 1,25 Ga B.P.

2. The tectonic development of the Namaqua Mobile Belt and its foreland in the area under consideration started in the Archaean (> 2,5 Ga B.P.); during the Archaean geotectonic cycle the Swartkop sequence, the Kheis Group and the Hartebeest Pan Formation were deposited, deformed and metamorphosed. The syntectonic to early posttectonic Draghoender Granite was emplaced during the closing stages of the Archaean cycle, c. 2,9 Ga B.P., and the late posttectonic Skalkseput Granite was intruded c. 2,5 Ga B.P.

3. The consolidation of the Archaean crust was followed by the second geotectonic cycle, which started in Lower Proterozoic times, when the Seekoebaard Formation, the Transvaal Supergroup and the Matsap Formation were deposited on the Kaapvaal Craton. The pre-Matsap fabric of the Transvaal and Seekoebaard sequences displays characteristic features of gravity tectonics indicating that deformation of the deposits on the Kaapvaal Craton and subsidence in the intracratonic basin were closely related. The instability of the basin increased steadily and the most intense movements preceded the deposition of the Matsap. However, no evidence of large-scale translation of rock masses (i.e. large-scale thrusts and nappes) was found.

4. The post-Matsap deformation was characterised by a continuous increase in the tectonic activity, both on the Kaapvaal Craton and in the Namaqua Mobile Belt, culminating during the second phase of the post-Matsap diastrophism (F_4). The tectonic cycle ended with large-scale granitic intrusions in the Namaqua Mobile Belt with the last of these intrusions occurring c. 0,9 Ga B.P.

5. The regional foliation s_1, which is deformed by isoclinal folds of the F_2 generation, occurs in the pre-Skalkseput Swartkop sequence, in the Kheis Group, and in the supracrustal sequences of the Namaqualand Metamorphic Complex. Two sets of later structures (F_3 and F_4) are superposed on this Archaean fabric; the second of the two, which is closely related to the Namaqua tectogenesis (c. 0,9 - 1,25 Ga B.P.), fades out completely in the Kaapvaal Craton within a distance of some 60 km north-east of the front of the Namaqua Mobile Belt.

6. The Namaqua front, which separates the Namaqualand Metamorphic Complex and the Kheis Group, appears at different places along its length as a metamorphic transition, as an oblique-slip fault, and as an interface between the areas yielding radiometric ages of c. 2,5 - 2,9 Ga and 0,9 - 1,25 Ga respectively.

7. The Doringberg fault and associated major fractures in the Namaqua foreland constitute an important tectonic lineament, which originated during the Namaqua tectogenesis. The faults are of an oblique-slip type and caused right-lateral displacement.

8. The regional metamorphism in the Namaqua Mobile Belt is of low pressure/high temperature type; it probably followed after an earlier period of progressive metamorphism, the existence of which is documented by the presence of s_1 schistosity in the Kheis, Swartkop and Hartebeest Pan metamorphites. Late retrogressive metamorphism under conditions of the lower greenschist facies occurred in the area along the Namaqua front, and was probably related to late movements during the Namaqua tectogenesis.

9. Mineral assemblages in the Transvaal sequence indicate that low-grade metamorphism by burial was operative in the Lower Proterozoic basin on the Kaapvaal Craton.

10. The diastrophism in the Namaqua Mobile Belt was confined to a major zone of weakness in which crustal doming and subsequent large-scale upwelling of the infrastructure occurred during the Lower Proterozoic. The crustal doming was accompanied by the ascent of plutonic masses, and culminated in the Namaqua tectogenesis c. 0,9 - 1,25 Ga B.P., when the mobile belt was structurally consolidated.

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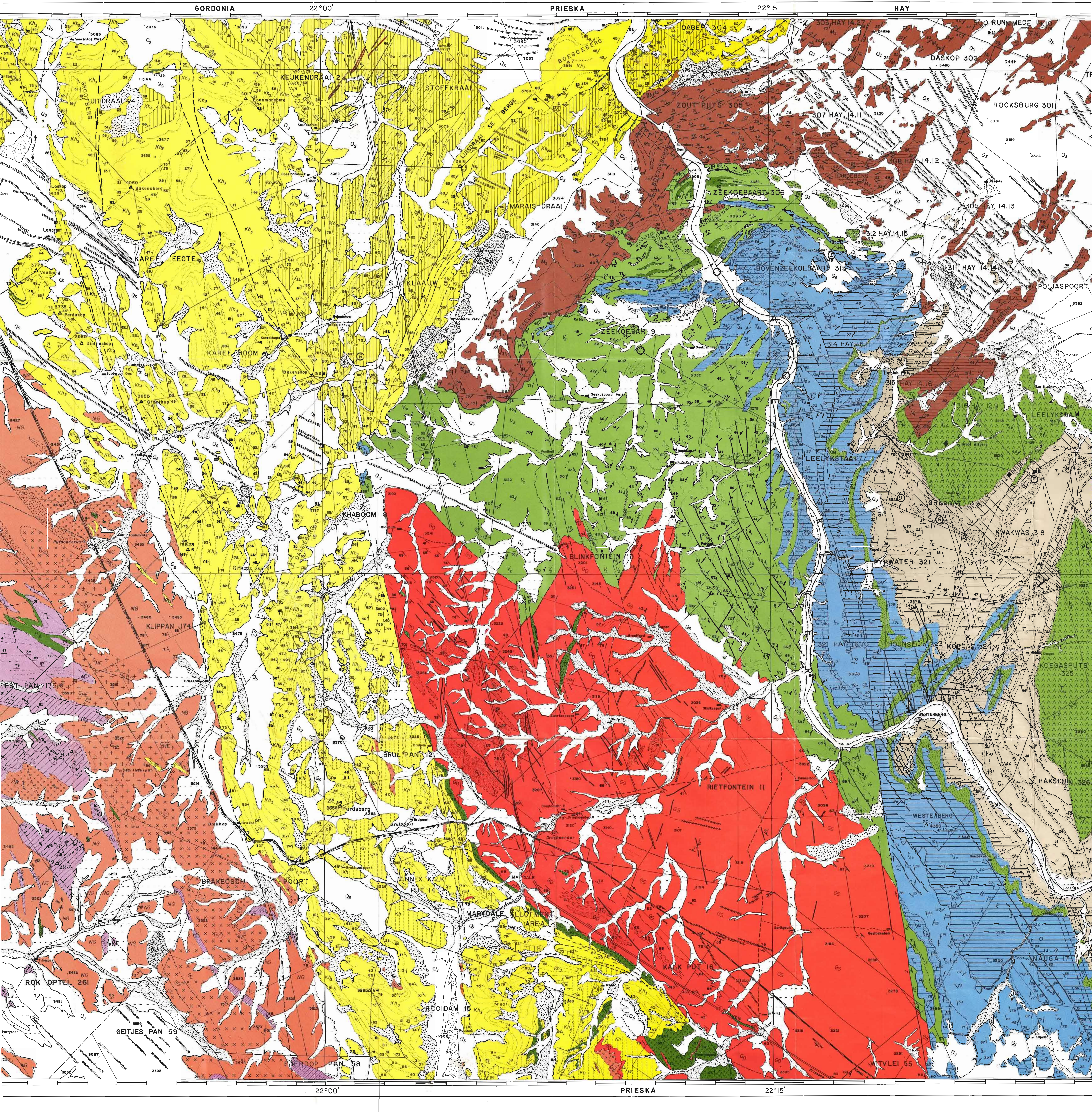

GORDONIA
22°00'
PRIESKA
22°15'
HAY
KEUKENDRAAI 2
STOFFKRAAL
BOEGOEBERG
UITDRAAI 44
GROOTBERG
KAREE LEEGTE 6
EZELS KLAAUW 5
KAREE BOOM
MARAIS DRAAI
DABEP 304
303 HAY 14.2
300 RUNNIMEDE 17.10
DASKOP 302
ROCKSBURG 301
ZOUT PUTS 305
307 HAY 14.11
308 HAY 14.12
ZEEKOEBAART 306
309 HAY 14.13
312 HAY 14.15
BOVENZEEKOEBAART 313
311 HAY 14.14
POLJASPOORT
ESELBERGE
ZEEKOEBAART 9
314 HAY 16.11
315 HAY 14.16
316 HAY 12.9
LEELYKSDAM
LEELYKSTAAT
KHABOOM 8
GRAGGAT 316
KWAKWAS 318
BLINKFONTEIN 10
PYRWATER 321
KLIPPAN 174
321 HAY 16.10
HOUNSLOW 323
KOEGAS 324
KOEGASPUTS 325
BRUL PAN 12
RIETFONTEIN 11
HAKSCHA 326
WESTERBERG
BRAKBOSCH 13
POORT
ANNEX KALK PUT 14
MARYDALE ALLOTMENT AREA
KALK PUT 16
NAUGA 17
ROK OPTEL 261
ROOIDAM 15
GEITJES PAN 59
EIERDOP PAN 58
WITVLEI 55
ORANGE RIVER
22°00'
PRIESKA
22°15'

GEOLOGICAL MAP OF THE MARYDALE - BUCHUBERG AREA, NORTHERN CAPE

SCALE 1 : 100 000

Kilometres 2 0 2 4 6 8 10 Kilometres

LEGEND

	Alluvium, silt					EARLY TERTIARY TO RECENT DEPOSITS
	Talus					
	Dune					
Q_S	Older sand, deflation residua					
	Surface limestone, calcrete					
	River-terrace gravel					
d	Dolerite dyke, dolerite sill					POST-KAROO
D_w	Tillite, siltstone		Dwyka Formation	KAROO GROUP		
G_B	Biotite granite	Brakbos Granite		NAMAQUALAND METAMORPHIC COMPLEX		PRECAMBRIAN
G_{El}	Biotite granite, fine-grained, flecky	Eindgoed Granite				
G_{SO}	Non-porphyritic hornblende-biotite granodiorite and granite	Sonderpan Granodiorite				
G_{HE}	Porphyritic hornblende-biotite granodiorite and biotite granite suite	Hartbeespan Granite				
NG	Undifferentiated granitoids in the area of poor outcrops					
G_E	Biotite-muscovite and muscovite-biotite granite	Elandslaagte Granite				
G_π	Porphyry					
G	Serpentinite					
G	Gabbro, hyperite, olivine hyperite					
H_L	Leptite, leucogneiss, schist		Hartebeest Pan Formation			
H_A	Amphibolite					
H_{AL}	Amphibolite and leptite					
H_G	Biotite leptite, garnet leptite ("granulite")					
H_P	Sillimanite-biotite gneiss					
H_M	Migmatite (sillimanite, biotite, garnet, cordierite)					
H_m	Mylonite, phyllonite					
d A	Mafic and ultramafic dykes and sills: gabbro, diabase, amphibolite					
G_H	Cataclastic and/or mylonitic biotite granodiorite	Hardeberg Granodiorite				
M_2	Lithic sandstone, lithic graywacke, conglomerate	Eselberge Member	Matsap Formation	WATERBERG GROUP		
M_1	Quartzose sandstone, subquartzose sandstone, conglomerate	Bushridge Member				
T_{4b}	Andesitic lava with interbedded tuff and minor chert		Ongeluk Volcanics	MIDDLE GRIQUATOWN GROUP	TRANSVAAL SUPERGROUP	
T_{4a}	Red jasper layer in the andesitic lava	Grasgat Member				
T_{3k}	Fine- and coarse-grained mixtite	Koegasputs Mixtite Member	Koegas Formation	LOWER GRIQUATOWN GROUP		
T_{3j}	Limestone, silicified limestone, chert					
T_{3i}	Shale, argillaceous quartzite, conglomerate, chert, pseudoconglomerate, thin layers of carbonate	Kwakwas Member				
T_{3h}	Quartz-chlorite fels with the intercalations of red semipelite and argillite					
T_{3g}	Riebeckite slate with the Upper Asbestos Zone at the base	Middelwater Member				
T_{3f}	Quartz-chlorite fels					
T_{3e}	Riebeckite slate					
T_{3d}	Minnesotaite slate, minor riebeckite slate	Westerberg Member				
T_{3d-i}	Jasper, slate, semipelite	Above three members undifferentiated				
T_{3c}	Upper banded iron-formation	Weilbach Member	Asbestos Hills Iron Formation			
T_{3b}	Diabase	Hounslow Diabase Sill				
T_{3a}	Lower banded iron-formation	Nauga Member				
T_{2b}	Shale, slate	Transition Shale Member	Campbell Rand Formation			
T_{2a}	Dolomite, minor shale and arenite, limestone, chert	Windpomp Member				
T_{1b}	Shale, siltstone, minor carbonate layers	Schalksdrift Member	Black Reef Formation			
T_{1a}	Quartzite, gritty quartzite, siltstone	Potdans Quartzite Member				
V_2	Andesite, quartz andesite, dacite, tufflava, tuff and tuffite with subordinate marble layers	Blinkfontein Member	Seekoebaard Formation	VENTERSDORP GROUP		
V_{1b}	Sandstone, feldspathic sandstone, phyllite, tuffaceous sediments, tuffs, minor layers of welded tuff, tufflava and lava	Waterval Member				
V_{1a}	Conglomerate					
G_S	Biotite-muscovite granite and adamellite		Skalkseput Granite			
G_{Sa}	Leucocratic muscovite granite and adamellite					
G_{Sd}	Hornblende diorite	Kameelboom Diorite				
G_D	Muscovite-biotite and biotite granite, granite-gneiss		Draghoender Granite			
G_{Da}	Biotite-muscovite granite and adamellite					
$G_{D\pi}$	Biotite adamellite porphyry	Roosterpoort Porphyry				
$G_{D\gamma}$	Perknite					
Kh_3	Quartzite, minor quartz-sericite schist		Kaaien Formation	KHEIS GROUP		
Kh_{2b}	Mica schist, quartz-sericite schist, minor quartzite		Groblershoop Formation			
Kh_{2a}	Quartz-sericite schist, epidote-chlorite schist, tremolite-actinolite schist	Mountain View Member				
Kn	Biotite gneiss, augen gneiss, migmatite					
Kh_{1b}	Amphibolite, hornblende schist, minor leptite and leucogneiss, occasional porphyry and magnetite quartzite	Stuurmansput Member	Marydale Formation			
Kh_{1a}	Sheared metavolcanics, magnetite quartzite, arkose, grit, phyllite, occasional marble	Swartkop Member	Marydale Formation ?			

Pegmatite

Quartz

◆ Kimberlite

Geologic contact (mapped - inferred - transitional)

21 Strike and dip of strata (bedding, bedding foliation)

\+ Horizontal strata

68 Strike and dip of foliation (axial plane, crenulation)

Strike of vertical foliation

70 Strike and dip of fracture cleavage

Trend and plunge of linear structures

Fault (mapped - inferred or concealed)

Shear zone

Aerial trend

Mine (existing - out of production)

National road

Main and secondary roads

Other roads

Single track railway

District boundary

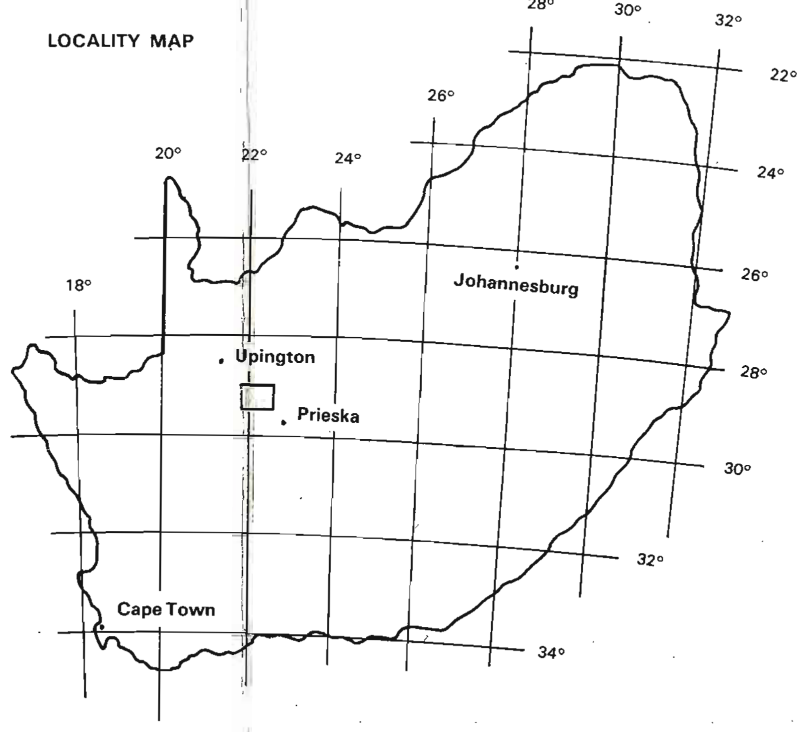
△10 3450 Trigonometric beacons (height in feet)

• 3456 Spot height (in feet)

Homestead

Corner beacon and farm boundaries (fences)

LOCALITY MAP



Mapped and compiled by V. Vajner 1971-1973
Drawn by S. Schickerling
Chamber of Mines Precambrian Research Unit
Department of Geology, University of Cape Town

GENERAL PROJECT PLANNING & CONTROL MODEL

(CONTRACTORS CAN SIMPLIFY THESE INPUTS AND OUTPUTS TO SUIT THEIR OWN SYSTEMS)

INPUTS

NS & INTERDEPENDENCIES

T ED	ACTIVITY PREDECESSOR DATA					
	ACTIV. NO.	S/P	LAG	ACTIV. NO.	S/P	LAG
RUPTED.	ONLY USED IF PRECEDENCE NEWORK IS THE INPUT					

② ACTIVITY — B. of Q. RELATIONSHIP

ACTIV. NOS.	B. of Q. ITEM NOS.	QTY.	UNIT
E.G. 35	(THE CLAUSE ITEM NO. IN THE BILL OF QUANTITIES) 46-7·1	580	M²

③ RESOURCE REQUIREMENTS (FOR EACH ACTIVITY)

ACTIV. NOS.	ACTIV. DURN.	WORK TEAM			REQD. WORK, MATERIALS		
		PLANT/LABOUR	LEVEL	OUTPUT	TYPE	QTY.	UNITS
35	20	CARPENTERS LABOURERS	2/DAY 2/DAY	—	FORMWORK	580	M²
23	—	LOADERS	2/DAY	80 M³/DAY	SOFT EXCAVN.	8000	M³
55	20	(E.G. A SUPPLY ACTIVITY)	—	—	PIPES (SUPPLY)	1000	M

P
TEM
C/C
1
2
3

⑤ PROJECT INDIRECT COST CENTRES

COST CENTRE CODE	COST CENTRE DESCRIPTION	B. of Q. ITEM OR ACCT. NO.	ALLOWBLE TARGE COST			NETWORK DATA	
			TIME RELATED	INITIAL SUM	FINAL SUM	START NODE	FIN. NODE
21·00	INSURANCE	5	R60/MTH.	—	—	1	198
32·13	CRUSHER	26·7 P&G ITEM NO. MEASURED ITEM	R200/MTH	R2 000 COST OF ERECTION	R1 000 COST OF DISMANTLING	32	68

⑥ DATA FROM BILL OF QUANTITIES (AS TENDERED)

ITEM NO.	B. of Q. ITEM DESCRIPTION	BILL QTY.	TENDER RATE	ESTIMATOR'S COST			
				LABOUR	PLANT	MATLS.	SUBC.
46-7·1	F/WORK TO BRIDGE DECK	580 M²	R15·00 (R/M² INCL. PROFIT)	R 2·80	R 6·20	R 4·20	—
				(EXCLUDING THE MAIN CONTRACTOR'S PROFIT)			

ERIALS AVAILABLE PER UNIT OF TIME (FOR WHOLE CONTRACT)

ME TIO	UNIT	NORML COST	O/TIME COST	MATERIALS	RES. CODE	NORMAL LEVEL	O/TIME RATIO	UNIT
%	CARP. HRS.	R1·50 (PER CARP. HOUR)	R2·00 (PER O/TIME CARP. HR.)	E.G. CONCRETE	CO.	100 (PER DAY)	20%	M³

⑧ GENERAL PROJECT TIME DATA

FOR WHOLE CONTRACT		INTERIM DATES						
START DATE	COMPLETION DATE	ACTIVITY OR EVENT NUMBERS	COMPLETION DATE	DATES OF PAID HOLIDAYS	DATES OF UNPAID HOLIDAYS	NORMAL WORKING HOURS PER WEEK	(OVERTIME IS SPECIFIED IN 7)	NORMAL WORKING DAYS IN WEEK

⑨ CASH FLOW DATA — PAYMENTS / RECEIPTS

FUTURE PAYMENTS		FUTURE RECEIPTS						
ITEM DESCRIPTION	EXPECT. DELAYS	RETENTION				CERTIFICATE RECEIPTS	EXPECTED P.&G. RECEIPTS	
		PERCENTAGE RETENTION	MAIMUM LIMIT	PAYBACK DATES	PAYBACK AMOUNT		VALUE OF P&G* RECEIPTS	DATES AT WHICH MONEY RECEIVED
E.G. LABOUR PLANT HIRE OVERHEADS	1 WEEK 2 MONTHS —					EXPECTED AVERAGE PAYMENT DELAY BY CLIENT		

(* P.&G. PLUS RETENTION MONEY)

TE ON THIS CONTRACT

CTUAL ABOUR OST	MATERIALS TO DATE				SUBCONTRACTORS			OVERHEADS		
	ITEM	QTY.	DATE INCURRED	AMT.	NAME	DATE INCURRED	AMT.	COST CENTRE	DATE INCURRED	AMT.
761.00	CEMENT	400	24/3/73	R900·00	ABZ STEEL-FIXERS	30/3/73	R700·00	INSURANCE	30/3/73	R150·00
306.00	SAND	600	"					TRANSPORTATION	"	R920·00
OM FORE-N'S SITE PORT.	BASECOURSE (IMPORTED)	1200	"							TOTAL COST ALLOCATED

⑫ INTERIM CERTIFICATE DATA

B. of Q. ITEM	B. of Q ITEM DESCRIPTION	QTY. TO DATE	UNIT	REV. TOTAL QTY.	ADDITIONAL REVENUE	
46-7·1	F/WORK TO BRIDGE DECK	170	M²	— [QTY. FINAL ESTIMATED IN SITU]	DAYWORKS MATERIALS ON SITE	R500 R9000

⑪ WORK PROGRESS

ACTIV. NOS.	REMAINING DURN.	REMAINING WORK QTY.	DATE OF UPDATE
35	15	410 M²	30/3/73

⑬ FINANCIAL DATA

RECEIPTS FROM CLIENT TO DATE		PAYMENTS BY CONTRACTOR TO DATE	
DATE	AMOUNT	DATE	AMOUNT
	ACTUAL MONEY FROM CLIENT TO CONTRACTOR		ACTUAL CASH PAID OUT BY CONTRACTOR

DATA PROCESSING SYSTEM

OUTPUTS

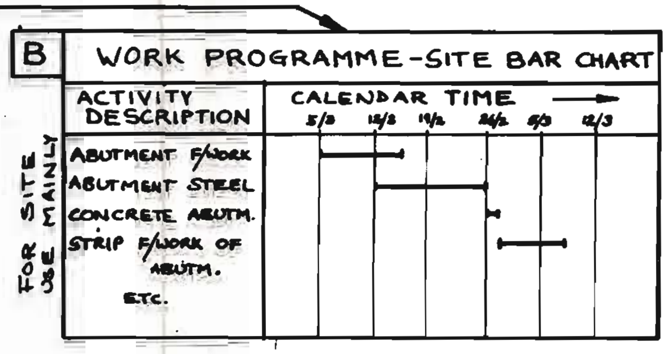
A WORK PROGRAMME — CALENDAR DATES

FOR PLANNERS RECORDS ONLY

ACTIV. NOS.	ACTIVITY DESCRIPTION	SECN. CODE	ACTIV. DURN.	CRITICAL ?	ACTIV. BOUNDARY TIMES				FLOAT	
					EST	EFT	LST	LFT	TOTAL	FREE
29	E.G. ABUTMENT FORMWORK	A/MENT	10DAYS	*	5/2	15/2	5/2	15/2	0	0

B WORK PROGRAMME - SITE BAR CHART

FOR SITE USE MAINLY

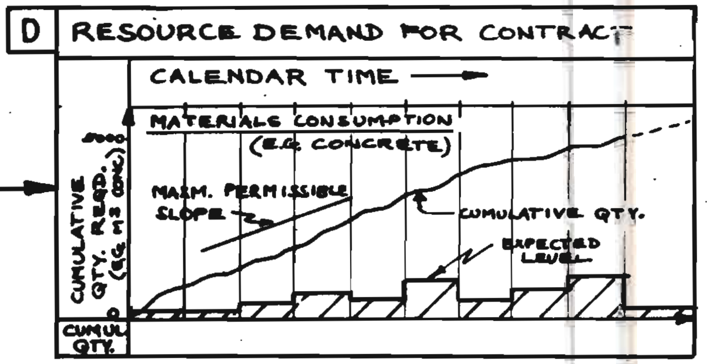


C WORK

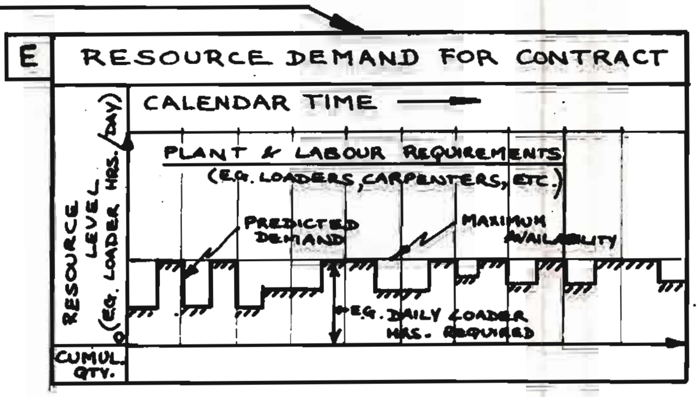
FOR TOP MANAGEMENT USE

ACTIVI DESCR
CONSTR ABUT CONSTRU DEC ETC. (SEE FIG. 5

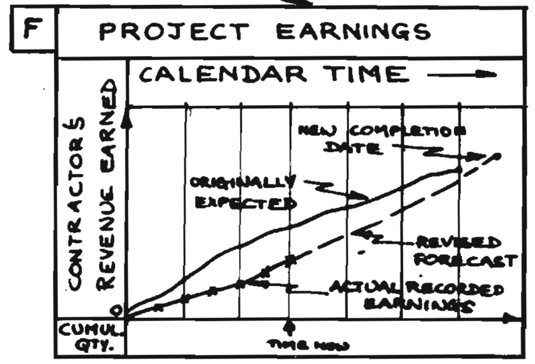
D RESOURCE DEMAND FOR CONTRACT



E RESOURCE DEMAND FOR CONTRACT



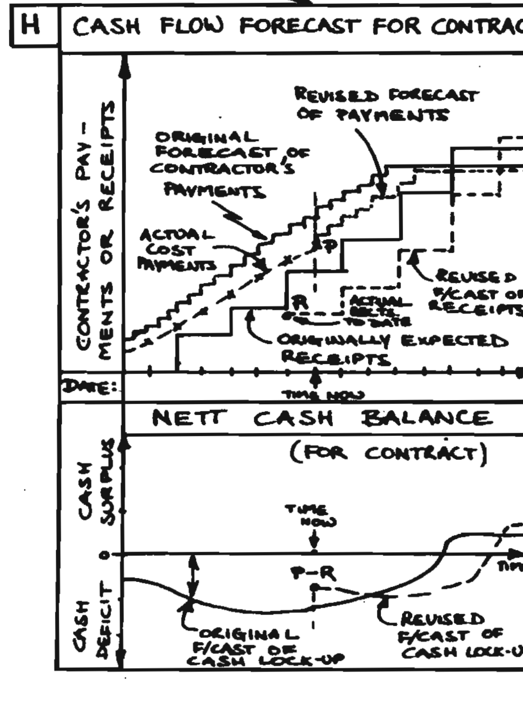
F PROJECT EARNINGS



G STANDARD COST REPORT

C/C CODE	COST CENTRE DESCRIPTION	FINAL % OF TOTAL	QUANTITY				PLANT		LABOUR		PLANT+LABOUR		UNIT COSTS	
			ESTIM.	REVD.	COMPLD.	UNIT	ACTUAL	TARGET	ACTUAL	TARGET	ACTUAL	TARGET	ACTUAL	TARGET
24·00·00	E.G. FORMWORK	12,5% AS A PERCENT OF THE TOTAL ESTIMATED CONTRACT COST	Q (TOTAL)	Q' (TOTAL)	q (TO DATE)	M³	(COSTS)				C	C'	$\frac{C}{q}$ (TO DATE)	$\frac{C'}{q}$ (TO DATE)

H CASH FLOW FORECAST FOR CONTRAC



J PRIME COST ANALYSIS REPORT

MAIN COST CENTRES	ADDITIONAL SUB COST-CENTRES	FINAL % OF TOTAL	TARGET COSTS FROM ESTIMATOR		ACTUAL EXPENDITURE		% INCR. OR DECR.		FORECAST TO COMPLETION		
			FOR MONTH	TO DATE	FOR MONTH	TO DATE	FOR MONTH	TO DATE	ESTIMATOR TARGET	PROBABLE ACTUAL	% INCR. OR DECR.
LABOUR	CARPENTERS ETC.	30% 8%	a	A	b	B	$\left(\frac{b-a}{a}\right)100$	$\left(\frac{B-A}{A}\right)100$	E	$E\left(1+\frac{B-A}{A}\right)=D$	$\left(\frac{D-E}{E}\right)100$
PLANT	EXCAVATORS LOADERS ETC.	25% 12% 5%									
MATERIALS	CEMENT FORMWORK ETC.	35% 9% 10%									
SUBCONTRACTORS	STEELFIXERS	10% 3%							(FOR REVISED BILL QUANTITIES)		

NOTE: THE INPUTS AND OUTPUTS SHOWN ON THIS DIAGRAM ARE DISCUSSED IN CHAPTER 5 OF THIS THESIS.