The Geology of an Area West of Welkom, O.F.S.

(degree blocks 2825 A and B and 2826 A)

BY

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ABSTRACT.

Rocks present in the mapped area range from Early Precambrian (Basement granite) to the most recent deposits of aeolian sands, alluvium, gravel and calcrete.

Outcrops of Ventersdorp rocks are scarce and widely scattered. Nevertheless, agglomerates and felsic lavas of the Makwassie Quartz Porphyry Formation, fanglomerates, quartzites, volcanic breccias, tuff, mafic massive lavas and pillow lavas of the Rietgat Formation, quartzites of the Bothaville Formation and plateau lavas of the Allanridge Formation could be distinguished and studied. The latter were all grouped together in accordance with the lithostratigraphic classification of Winter (1976), because of the proximity to his type area.

Overlying the Ventersdorp Supergroup are shales and/or tillite of the Karoo Sequence. Bore holes drilled to the east (outside) of the mapped area proved that Dwyka glacial deposits are preserved in pre-Karoo valleys and/or valleys excavated through ice movement. Here, the Dwyka Formation consists of tillite, varved shales and a glacio-fluvial unit, viz. the sandstone-siltstone-shale unit. In the western sector of the mapped area Ventersdorp rocks are directly overlain by black, micaceous shales of the Ecca Group (Prince Albert Formation). The Whitehill Formation is probably not present as one continuous layer over the whole of the mapped area, and only occurs in a few isolated pockets. As a result the Prince Albert Formation is in most cases overlain by grey shales of the

Tierberg Formation which grades from shales and mudstones (marine deposits) upwards into rhythmic layers of grey shales and sandstones (deltaic deposits).

The transitional zone between the Ecca Group (Tierberg Formation) and the overlying Beaufort Group is exposed on the farm Basberg 416. The Beaufort Group in this area shows the typical features of a fluvial deposit, viz. coarse-grained channel-axis facies which laterally grade into finer-grained and thin-bedded channel-marginal facies and levee mudstone deposits. The latter sediments were most probably deposited on the flood plain of a braided river.

Intrusive rocks consist of post-Karoo dolerites (sills and dykes) and the kimberlite intrusions at Rovic Diamond Mines.

Nodular and laminated calcrete deposits are the most abundant calcrete deposits in the area under investigation.

Aeolian sands cover large tracts of this area and occur mainly as aeolian sheet deposits but also as dunes of variable magnitude.

The Vaal River Gravels and the alluvial sands and silts of the Vet and Sand Rivers are the most significant alluvial deposits present in the mapped area.

Pans of variable shapes and sizes have originated through the erosion of paleo river channels by subsequent wind action.

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1 INTRODUCTION.

1.1 Location and Communication.

The area under discussion covers some 7506km^2 of which approximately 0,3% is located in the Transvaal, and the rest in the north-western Orange Free State, between longitudes 25°00′E and 26°30′E and latitudes 28°00′S and 28°30′S as indicated in figure 1.

Larger towns in this area are Hertzogville and Bultfontein. Further, the area consists of parts of the districts of Christiana, Boshof, Hoopstad, Wesselsbron, Welkom, Bultfontein, Brandfort, and Theunissen.

The area is crossed by a number of tarred roads. From Hertzogville tarred roads lead to Christiana, Hoopstad, Bultfontein, and Dealesville, and from Bultfontein tarred roads lead to Bloemfontein, Wesselsbron, and Odendaalsrus. A large number of secondary dirt roads are present which supply ample communication links between various points.

1.2 Drainage Systems.

Major drainage systems present in this area are the Vaal River (north-western corner) and the Vet and Sand Rivers (in the eastern part of the mapped area). Smaller drainage systems, e.g. Barberslaagte, only contain water during the rainy seasons. Most of the pans present in this area can also be considered as belonging to one or other now choked drainage system (see chapter on Pans).

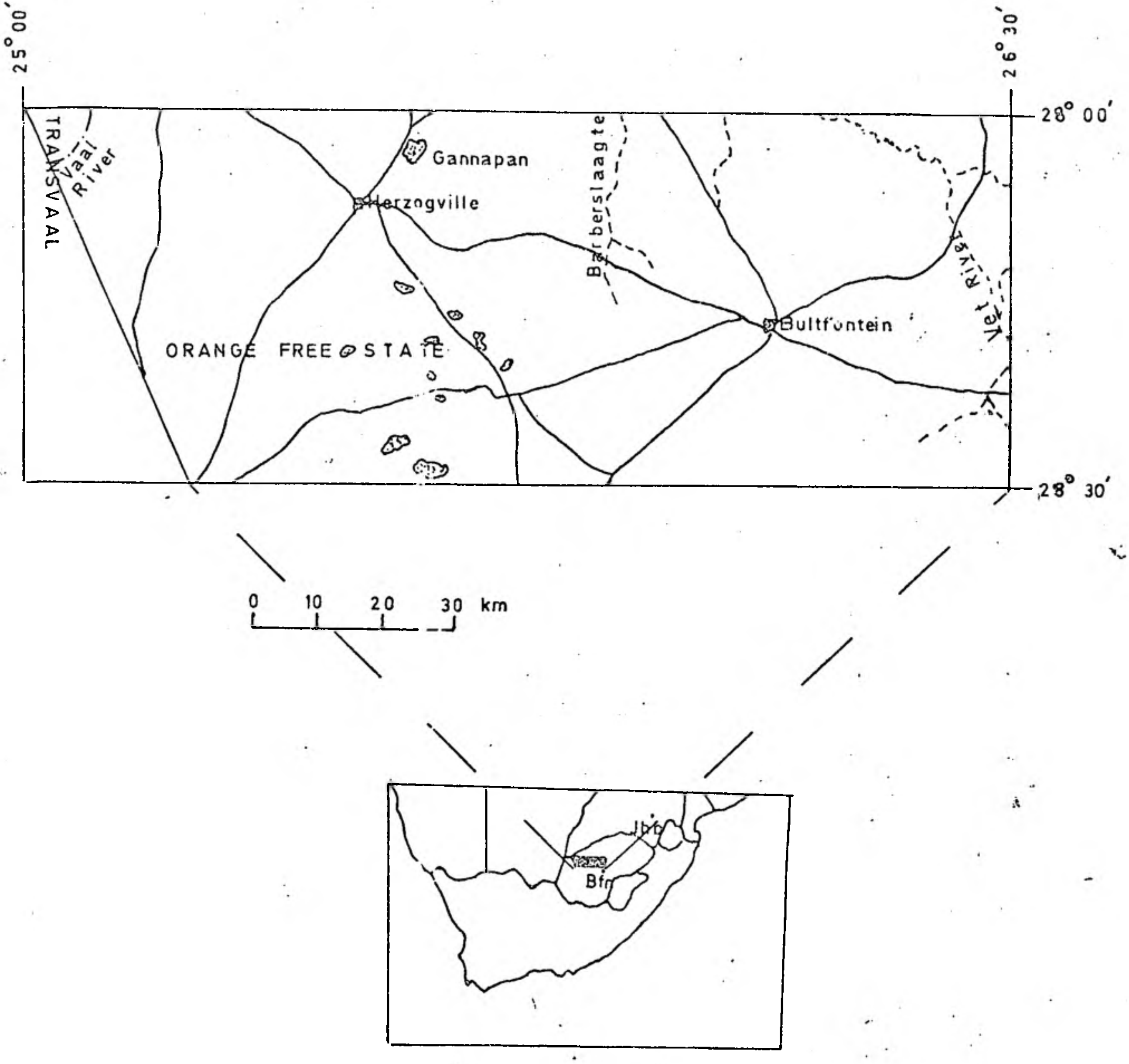

Figure 1.1 Locality map of the study area

Table 1.1 Geological successions in the mapped area.

Period			
Tertiary to Quatenary			Aeolian sand Alluvium Calcrete
Cretaceous			Kimberlite
Jurassic			Dolerite
	Supergroup	Group	Formation
Permian	Karoo	Beaufort	
		Ecca	Tierberg Whitehill Prince Albert
Carboniferous			Dwyka
Middle Precambrian	Ventersdorp	Pniel sequence	Allanridge Bothaville
		Platberg	Rietgat Makwassie
Early Precambrian	Basement granite		

1.3 Previous Work and General Lithology.

The geological successions present in the mapped area can be grouped together as in table 1.1 .

The presence of Archaean granites in the Wesselsbron Arch is described by Winter (1965), and was observed during this investigation on the farm Geduld 37.

Various small outcrops of Ventersdorp rocks were observed (for localities see table 3.1). These were all classified according to Winter (1965, 1976) because of the closeness of his type area.

Rocks belonging to the Dwyka Formation were noted by Söhnge et al. (1937) in the vicinity of the farm Beth-el-pella 623. None of the latter deposits were, however, encountered during the investigation of this area. The only positive evidence of Dwyka glacial deposits was observed in bore holes, drilled outside (to the east) of the mapped area. These are considered to have been deposited in pre-Karoo valleys or valleys excavated by glaciers (Vos and Hobday, 1977).

Rocks belonging to the Prince Albert and Whitehill Formations, situated to the west and south-west of the mapped area, are discussed by Kleynhans (1979) and Joubert (1973) respectively. Further, Coetzee (1960) described rocks belonging to the Ecca Group in the vicinity of the Vet and Sand Rivers.

The transitional zone between the Ecca and Beaufort was taken in accordance with the findings of Visser and Loock (1974). The latter zone was observed at Basberg 416 to the east of the Bultfontein - Bloemfontein road.

The occurrence of post-Karoo dolerites in this area is discussed according to the findings of Rhodes and Krohn (1972) and Meyboom and Wallace (1978). Further, an excellent description of the kimberlite intrusion at Rovic Diamonds is given by Geringer (1969) and Wagner (1971).

The different types of calcrete present in the mapped area were classified according to Netterberg (1969). Calcretes and gravels in the vicinity of the Vaal River are described by Butzer _et al._ (1973), Van Riet Lowe (1952), Cooke (1946) and Söhnge _et al._ (1937), whilst Coetzee (1960) noted the alluvial deposits of the Vet and Sand Rivers.

A description of the pans in the western Orange Free State is given by De Bruiyn (1971). Butzer (1974) contributes the presence of pans to the blocking of palaeo-stream channels, whilst Mayer (1973) rather contributes their origin to tilting along the Griqualand - Transvaal Axis away from the Vaal River which led to a reduction of the gradient on the pediplaned surface to the south-east of the Vaal River.

2 ARCHAEAN GRANITE.

2.1 Introduction.

According to Winter (1965, p. 123), the Ventersdorp formation unconformably overlies Archaean granites in the Wesselsbron Arch. Similar features were observed at Geduld 37 in the northeastern sector of the mapped area. Here, lavas and arkose, belonging to the Rietgat Formation, directly overlie Archaean granites. The presence of granite appears to confirm the extension of the Wesselsbron Arch to this area.

Since these granites are very extensively weathered, rock samples for the purpose of petrological studies had to be gathered at random localities.

2.2 Composition.

Microscopic observations revealed the following features:

(1) A medium to coarse-grained mozaic texture with quartz grains of up to 3mm in diameter are present.

(2) Microcline is the most abundant feldspar mineral present within the granite. These minerals may reach 5mm or more in diameter.

(3) Albite is present in minor amounts.

(4) Flaky biotite is recognized by alteration to Fe-oxides and other products. Muscovite is interstitial.

(5) Occasional graphic intergrowth.

It is especially the presence of microcline that distinguishes these granites from the Makwassie Quartz

Porphyry (see Ventersdorp Supergroup), since no indication of microcline was found in any of the latter.

2.3 Pegmatites.

The presence of pegmatites is a fairly common feature in these granites. They vary in size from a few centimetres to some 2 m or more in length. In the larger pegmatites, quartz and feldspar minerals reach up to 10 and 25 cm, respectively. Further, it was noted, that especially the larger pegmatites appear to be vertically emplaced.

In areas where the granites are severely weathered, these pegmatites may serve to distinguish between Makwassie Quartz Porphyry and Archaean granites, since no pegmatites were observed in the former (see Ventersdorp Supergroup).

2.4 Vein-quartz.

Veins, consisting of milky quartz, are present in these Archaean granites, as well as in Makwassie Quartz Porphyry (see Ventersdorp Supergroup). They very seldom reach thicknesses of more than 10 cm. In some instances, they cut across some pegmatites, which indicates that these veins have a post-pegmatite emplacement history.

2.5 Aplitic Veins.

The size of these veins may vary from a few millimetres to approximately 1 m in width. In general, the material present in these veins consists of quartz and feldspar minerals, embedded in a very fine matrix. In the larger veins, minerals microscopically visible are virtually absent, and the rock consists of a bluish-grey, very fine grained material only.

The following microscopic observations were made;

(1) Quartz grains may reach up to 3 mm in diameter.

(2) Microcline grains may reach up to 4 mm in diameter.

(3) Muscovite is interstitial and in the matrix.

(4) The above-mentioned minerals are embedded in a cryptocrystalline matrix with angular, poorly sorted fragments of quartz, some microcline and ore.

(5) Quartz grains are predominantly mono-crystalline.

(6) Some of the quartz and microcline grains appear to have been brecciated.

(7) Graphic intergrowths are present.

(8) Abundant palagonitized glass is present in a very fine matrix in veins that consist of fine material only.

Except for the fine matrix in the material present in the aplitic veins, its composition is similar to that of the massive granites which could imply that these aplitic veins represent younger emplacements of Archaean granites. The presence of microcline rules out the possibility that these are veins for the Makwassie or other Ventersdorp material.

3 THE VENTERSDORP SUPERGROUP.

3.1 Introduction.

Being so close to Winter's (1976) type area of the Ventersdorp Supergroup and as mapping in the Northern Cape (Visser et al., 1975/1976, Liebenberg, 1977, and Kleynhans, 1979) has shown the applicability of Winter's subdivision to those areas, his lithostratigraphic subdivision is also used in the area mapped.

Outcrops of rocks belonging to the Ventersdorp Supergroup are shown in Table 3.1 .

Table 3.1 Localities of outcrops of the Ventersdorp Supergroup.

Farm Name	Formation	Type of Rock
Honiglaagte 1234 Honigkop 1002	Makwassie Quartz Porphyry	Quartz porphyry
Goudkop 1496 (Boshof - Christiana road).	Rietgat	Amygdaloidal and non-amygdaloidal lavas, tuff quartzites.
Vryheid 1316 (Boshof - Christiana road).	Rietgat	Volcanic breccia
Onrust 382 HO Cawoods Hope 324 HO (north of Vaal River).	Allanridge Andesite	Andesitic lavas

Table 3.1(continuous)

Farm Name	Formation	Type of Rock
Sweet Home 280 Wildebeestfontein 471 (south of the Boshof -- Bultfontein road).	Makwassie Quartz Porphyry Rietgat Bothaville	Quartz porphyry Amygdaloidal and non-amygdaloidal lavas, tuff. Arkose and sub-arkose.
Geduld 37 and Pietersrust 30 (north-eastern corner of map).	Rietgat	Amygdaloidal and non-amygdaloidal lavas, volcanic breccia, tuff and arkose.
Goudkoppie 461 (Welkom - Bultfontein road).	Rietgat	Poorly sorted fanglomerate.
Vaalkoppies 8 (Welkom - Bultfontein road).	Makwassie Quartz Porphyry	Quartz porphyry (sheared).
Vaalbank 186 (Welkom - Bultfontein road).	Rietgat	Quartzite with conglomerate lenses.

From table 3.1 it is evident that the only outcropping formations are:-

(1) Makwassie Quartz Porphyry Formation.

(2) Rietgat Formation.

(3) Possibly Bothaville Formation.

(4) Allanridge Andesite Formation.

3.2. The Makwassie Quartz Porphyry Formation.

The following features serve to distinguish this formation;

(1) The rock has a felsic nature.

(2) It has a porphyritic nature, showing large feldspar and/or quartz grains, embedded in a finer-grained matrix.

(3) Feldspars may reach a length of up to 2cm.

(4) The rock shows a reddish colour when weathered and a dark, blue-grey colour when fresh. In some instances, these colours can be used to distinguish between different lava flows.

Different outcrops of the Makwassie Quartz Porphyry Formation in this area differ slightly from one another in texture as well as in composition. For the purposes of comparison the various microscopic features of each outcrop are shown in Table 3.2 .

3.2.1 The Outcrop at Honiglaagte 1234, Honigkop 1002, and Goudkop 1496 (Fig. 3.1).

Two different types of quartz porphyries are present here, viz;

(1) A bluish-grey type (marked A in Fig. 3.1).

(2) A brown type (marked B in Fig. 3.1).

3.2.1.1 The Bluish-grey Quartz Porphyry (A on fig. 3.1).

This type of porphyry crops out on two small high points, together constituting the hill called Goudkop, which is elevated some 30m above the surrounding plain. The total area of outcrop is approximately 1 km^2.

The following field observations were made;

(1) Different lava flows display different colours, e.g. the top flows tend to weather in a brighter reddish-brown colour than the other flows. Using this as criterion three different flows are distinguished.

(2) In the two higher flows large feldspars (up to 1cm in length) are quite abundant, whilst in the lower flows these are relatively scarce.

(3) Quartz and feldspar grains are embedded in a very fine-grained matrix.

The high point to the south is traversed by a large number of milky quartz veins, with jasper being present in isolated cases only. One of these veins reaches a thickness of 0,5m. The dip of the latter is 45° and the strike 250°. Smaller veins (thicknesses usually less than 5cm) also show the same strike.

3.2.1.2 The Brown Type of Quartz Porphyry (B on fig. 3.1).

This porphyry crops out to the west of Goudkop, where it is located on a low rise. It differs from the above-mentioned porphyry, in that it is predominantly brown in colour, and has dark green spots (see table 3.2 for composition of spots). Phenocrysts of feldspar are present in minor amounts and may reach up to 1,5cm in length.

3.2.2 The Outcrop at Sweet Home 280 and Wildebeestfontein 471 (Fig 3.2).

This outcrop is located to the east and west of the local farm road. Here the quartz porphyry forms the "floor" on which the sedimentary units and lavas of the Rietgat Formation were deposited. A more detailed study of this area will be given under section 3.3.

Field observations show the following;

(1) Dark, bluish-grey colour.

(2) Massive appearance.

(3) Sparse macroscopic feldspars and quartz grains.

3.2.3 The Outcrop at Vaalkoppies 8.

This outcrop forms a prominent ridge to the west of the farm house with a height of between 5 and 20m above the surrounding plain.

Field observations are as follows;

(1) Different lava flows display different colours, e.g. the top flow tends to weather in a brighter red colour than the other flow. Using this as criterion two different flows are distinguished.

(2) The rock consists almost entirely of submacroscopic material.

3.2.4 Age of the Makwassie Quartz Porphyry.

According to Van Niekerk and Burger (1978), the age of the Makwassie Quartz Porphyry can be set at 2 643 ± 80 m.y. which is the age for the crystallization of the zircon.

What is so characteristic about this formation in the mapped area, is that no indication of any metamorphism could be detected. However, the original mineralogy has been thoroughly altered through saussuritisation and reaction between matrix and phenocrysts. This is a fundamental change and not just a normal weathering process. It would thus appear that the area under investigation was stable for at least 2 643 m.y., except perhaps for a few periods of block faulting in the western part of the area.

3.2.5 Conclusion.

The Makwassie Quartz Porphyry Formation represents the oldest formation of the Ventersdorp Supergroup present in the mapped area. In general, the quartz porphyry consists of quartz and feldspar phenocrysts (both plagioclase and K-feldspars). The absence of microcline in its composition, is a noteworthy feature by which these porphyries can be distinguished from Archaean granites. Flow textures and β-quartz grains may all serve as features which indicate the volcanic origin of these porphyries.

Piling up of volcanic material in the vicinity of the feeder channels must have occurred in order to explain the "highs" of Makwassie Quartz Porphyry, against which sediments and lavas, belonging to the Rietgat Formation have

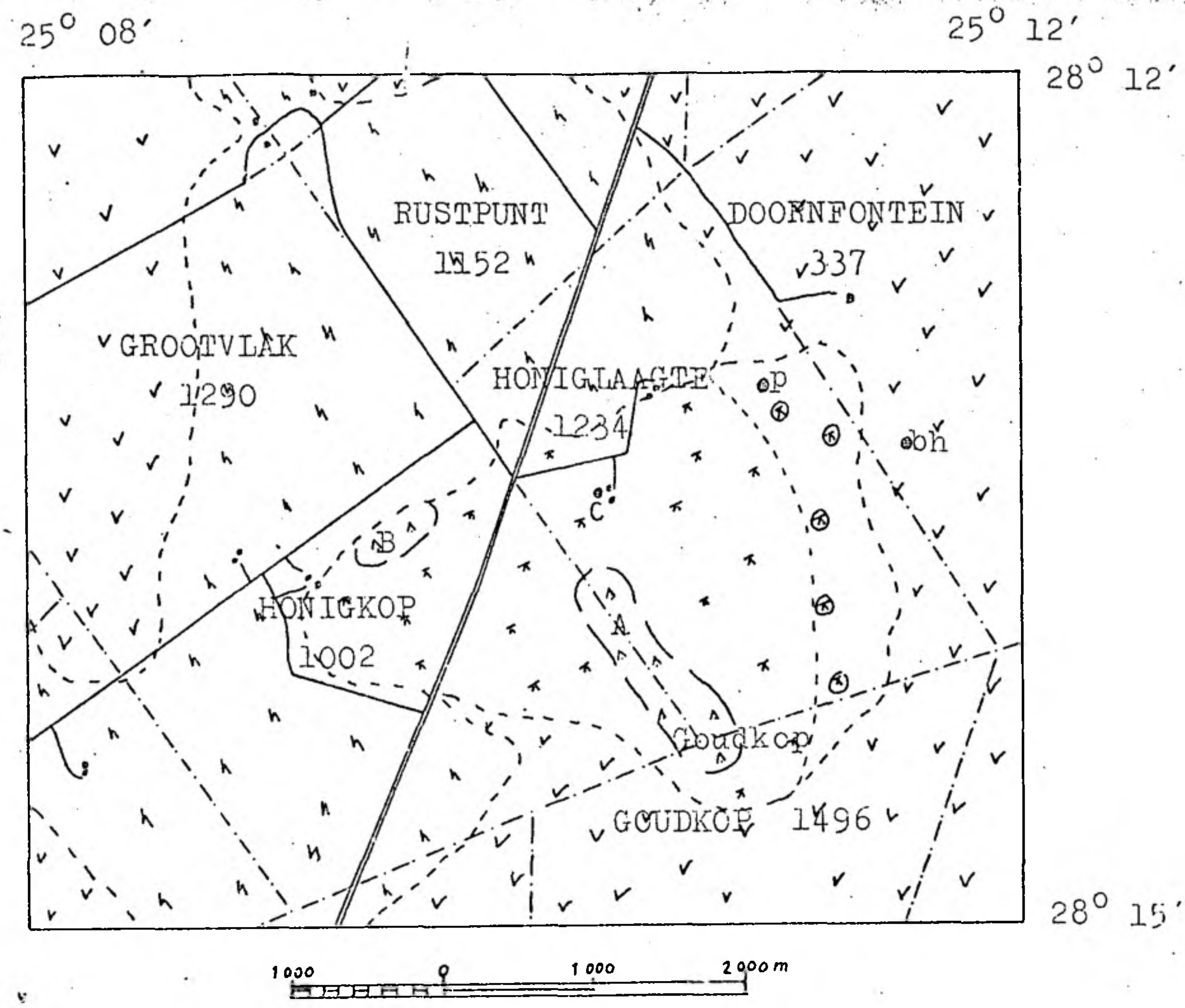

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Figure 3.1 The Ventersdorp distribution at Honiglaagte 1234, Honigkop 1002, and Goudkop 1496.

Legend

- Calcrete
- Dolerite
- Postulated sub-outcrop of Rietgat Formation (possible exposure at C).
- Postulated sub-outcrop Bothaville and Allanridge Formation.
- Makwassie Formation-quartz porphyry (A and B type, see text).
- op — Pit
- obh — Bore hole

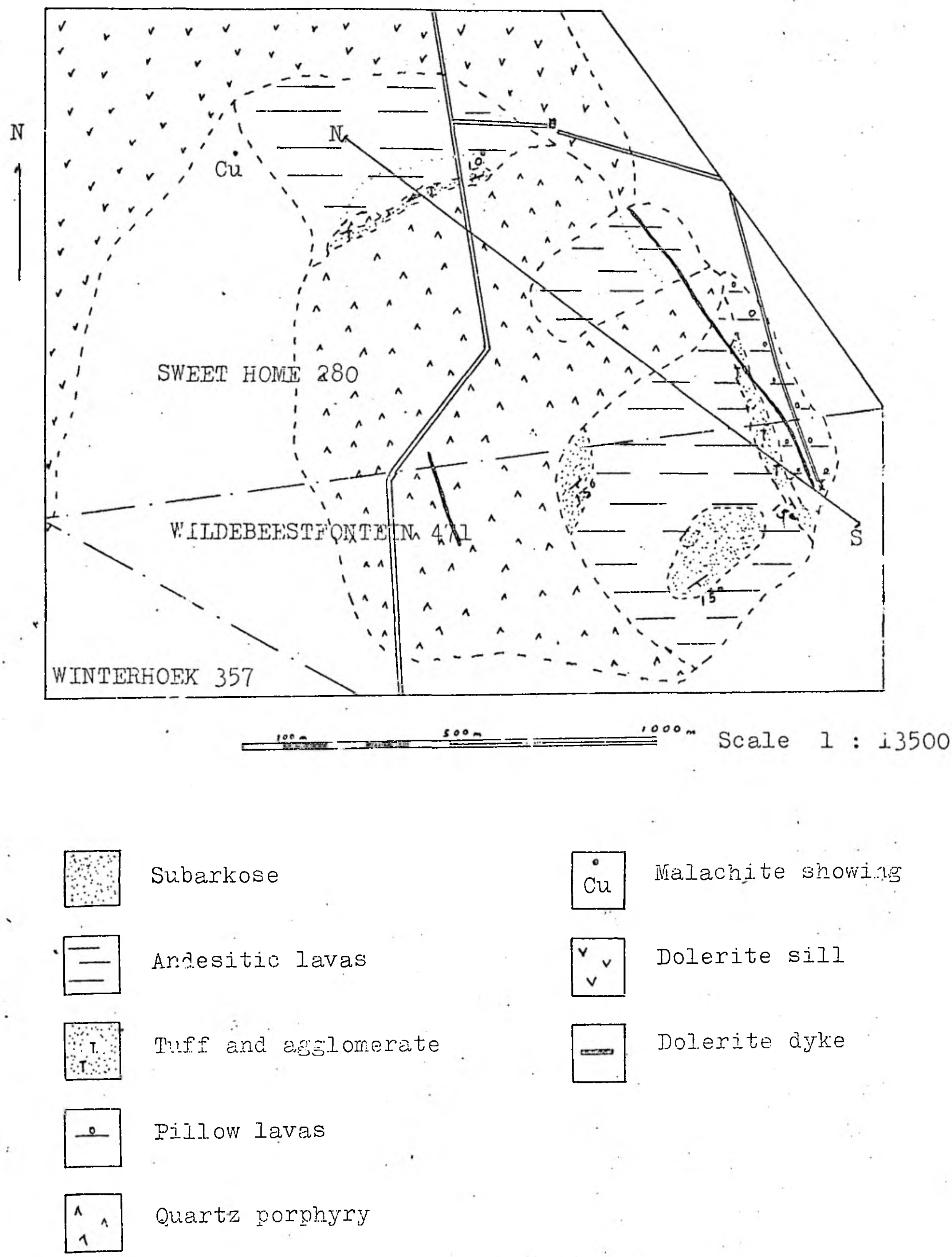


Figure 3.2 The Ventersdorp Supergroup at Sweet Home 280 and Wildebeestfontein 471.

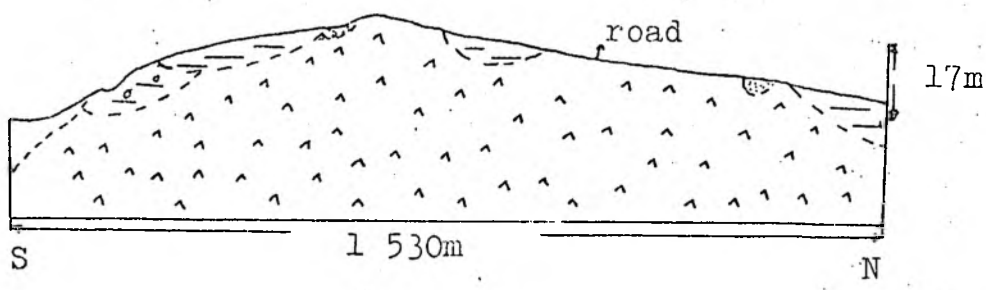


Figure 3.3 Section at Sweet Home 280 and Wildebeestfontein 471 (for legend see fig. 3.2).

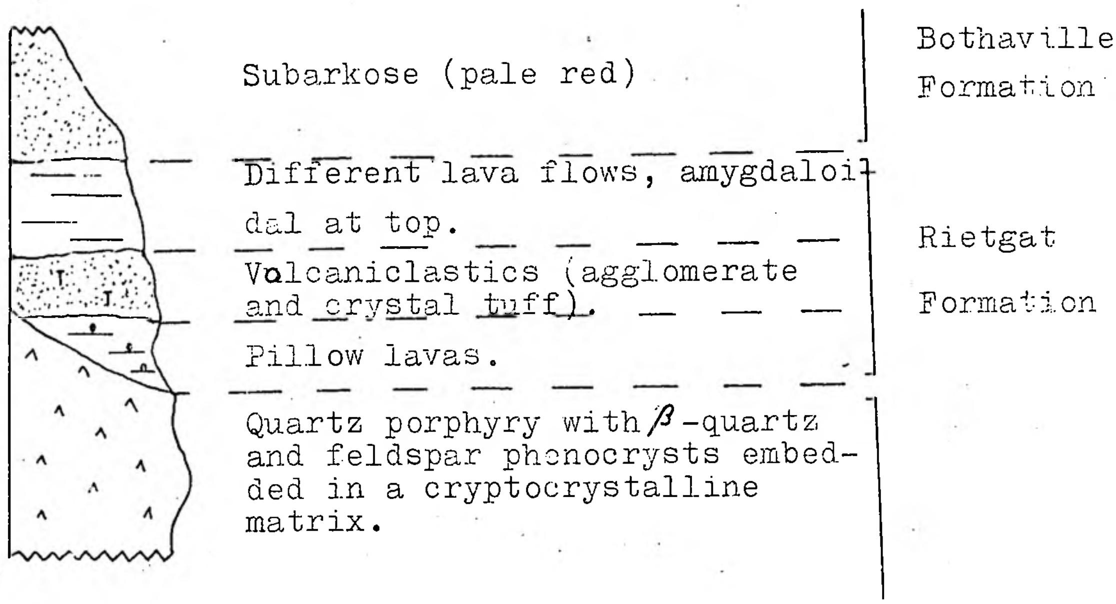


Figure 3.4 Stratigraphic succession at Sweet Home 280 and Wildebeestfontein 471.

Table 3.2 Microscopic features of the Makwassie Quartz Porphyry.

Locality	Quartz Phenocrysts					Feldspar Phenocrysts					Matrix	
	Grain size (mm)	Shape of grain	Crystallinity %mono %poly	Extinction.	Other features	Type of feldspar albite = ab orthoclase = ort	Grain size (mm)	Shape	Orientation of laths	Other features	Composition	Other features
Honiglaagte 1234 Honigkop 1002 Goudkop 1496 (bluish-grey type).	0,3 — 2,0	Large grains show β-quartz outline. Some smaller grains are angular.	80% 20%	Undulatory extinction is scarce.	Occasional graphic intergrowth.	ab/ort ratio undeterminable because of intense rock alteration.	0,5 — 10	Euhedral to subhedral	Random	Highly sericitized	Cryptocrystalline quartz and other minerals too small to identify.	Flow structures.
(brown type)	>0,5	β-quartz outline	85%) 15%)	do	Quartz phenocrysts in the rock are scarce.	ab/ort = 15/85	> 0,5	do	do	do	do	Green spots composed of nests of chlorite and epidote with associated magnetite has developed by reaction between the matrix and feldspar phenocrysts
Sweet Home 280 Wildebeestfontein 471	0,5 — 4,0	Most of the larger grains show β-quartz outlines, smaller grains (> 0,9 mm) are predominantly angular.	80% 20%	do	Occasional graphic intergrowth.	ab/ort = 60/40	0,5 — 3,0	do	do	do	do	do
Vaalkoppies 8	0,5 — 3,0	Some β-quartz grains are present.	10% 90%	do	Only a minor amount of quartz phenocrysts are present.	ab/ort ratio undeterminable because of intense rock alteration.	>1,0	do	do	do	do	Flow structures are defined by streaks of sericite and palagonitized glass, some of which are devitrified.

been deposited (Potgieter and Locke, 1978; Kleynhans, 1979).

3.3 The Rietgat Formation.

According to Winter (1965) and Visser et al. (1975/6) the Rietgat Formation consists of andesitic lava flows, volcaniclastics and sedimentary units. The different occurrences of the Rietgat Formation differ slightly from one another, and will be discussed separately.

3.3.1 The Occurrence at Honiglaagte 1234, Honigkop 1002 and Goudkop 1496 (Fig. 3.1).

Near the northern end of Goudkop excavations for a silo are reputed to have exposed a badly weathered, poorly sorted conglomerate with gritty greywacke matrix. It could not be established beyond doubt that the material lying around actually did come from the excavation.

If the material actually did come from the excavations, their locality relative to the Makwassie paleo-high as well as their nature and composition point to correlation with the Rietgat Formation.

Approximately 1,5km to the north-east of Goudkop a bore hole is present which was drilled some 35 years ago. Unfortunately no log data could be obtained for the latter. Some of the core from this bore hole is still present near the site of drilling. Although the pieces of core are no longer in sequence the various core diameters confirm the following broad sequence:

(1) Amygdaloidal mafic lava (large-diameter core).

(2) Quartzite and amygdaloidal and non-amygda-

loidal mafic lava (medium-diameter core)

(3) Arenite and quartz porphyry (small-diameter core).

Thin sections were made from some of the lavas and quartzites obtained from the core, and the following observations were made.

(1) Lavas:

(a) Small amygdales of ± 1mm in diameter are most abundant. These consist of chalcedony only.

(b) Large amygdales may reach 7mm or more in diameter. These usually consist of both chalcedony and polycrystalline quartz. One of these was found to have a rim and core of chalcedony, whilst the intermediate area is occupied by polycrystalline quartz.

(c) Chalcedony veins connecting some of the larger amygdales, are also present.

(d) In general, the rock consists of plagioclase (andesine) laths, of approximately 1mm in length, which are embedded in a fine-grained, sometimes glassy matrix.

(e) The greenish colour of the rock can be contributed to the abundance of chlorite, an alteration product of Fe-Mg minerals of which no remnants are present, as well as some of the amygdales.

(f) Volcanic glass is abundant.

(2) Quartzite:

(a) At least 90% of the rock consists of quartz. Microcline makes up about 1% of the rock by volume. The rest of the feldspars (9%) are in a state of decomposition and could not be identified.

(b) The size of the quartz grains vary between 0,3 and 1mm in diameter. They are angular to subangular, and show no brecciation or preferred orientations.

(c) Sorting of grains is fair.

(d) Very little matrix is present and thus individual grains are mostly in contact with one another.

The correlation of the quartzite in the medium-diameter core is problematical: it can be assigned to the Bothaville Formation in which case the overlying amygdaloidal lava should be assigned to the Allanridge Formation. Some of the amygdaloidal and non-amygdaloidal mafic lava and arenite should then be assigned to the Rietgat Formation overlying the Makwassie Formation (quartz porphyry). Alternately, the quartzite and other arenite can be considered as interbedded sediments in lavas of the Rietgat Formation overlying the quartz porphyry (Makwassie Formation).

Winter (1976, p. 44) mentioned that the Rietgat sediments are similar to those of the Kameeldoorns Formation which represents poorly sorted, first-cycle sediments (Liebenberg, 1977). The Bothaville arenites, on the other hand, are mature, second-cycle sediments (Liebenberg, 1977), being quartzites to subarkoses. For this reason the quartzite from the old bore hole should possibly represent Bothaville Formation, the overlying mafic lavas Allanridge Formation and the underlying mafic lavas and arenite Rietgat Formation.

3.3.2 The Outcrop at Vryheid 1316.

Here, volcanic breccias of the Rietgat Formation are exposed in two pits situated to the west of the farm house. Overlying these breccias are calcretes and in some instances, weathered dolerites. The rock consists of a microcrystalline, quartz-rich matrix in which clasts of variable sizes and compositions are embedded. Different layers can be recognised (fig. 3.5) which tend to pinch out laterally.

Figure 3.5 Volcanic breccia at Vryheid 1316 (Ca = calcrete, dol = dolerite, l = different layers).

The following clasts were observed (percentage of total clast population is given in brackets).

(1) Quartz porphyry (70%). These clasts range in size from 50cm and smaller in diameter. The high percentage of these clasts points to a source of Makwassie Quartz Porphyry close by.

(2) Vein quartz (2%). These clasts are predominantly angular. They were most probably derived from the quartz veins present in the Makwassie Quartz Porphyry.

(3) White to light-grey quartzites (20%). These clasts are predominantly angular and may reach 20cm or more in diameter. Similar quartzites were observed in Rietgat sedimentary units, exposed as cores, to the northeast of Goudkop.

(4) Amygdaloidal lavas (7%). These clasts are predominantly angular, but a few rounded clasts were also observed. Similar lavas are present in the Rietgat Formation to the northeast of Goudkop.

(5) Minor amounts (± 1%) of the following were also observed; (a) Lydite

(b) Chert

(c) Schist (possibly from basement)

The size of the clasts can be summarized as follows;

10% of the total population are larger than 30cm.

70% of the total population are 10 - 30cm.

20% of the total population are smaller than 10cm.

In general the smaller clasts (1cm and smaller) are more angular than the larger clasts.

3.3.2.1 Genesis of the Volcanic Breccia.

Winter (1965, p. 31), observed similar features in agglomerates of the Makwassie Quartz Porphyry Formation. The large proportion of quartz porphyry clasts, as well as the presence of Rietgat sedimentary rocks and lavas would, however, indicate that these lavas have originated during or after Rietgat times.

The matrix of the rock consists of an admixture of fine angular quartz grains of not more than 0,2mm in diameter, which are embedded in a cryptocrystalline to glassy ground mass. Fisher (1966, 1960), and Parsons (1969) described similar rocks as pyroclastic breccias, which may occur over fairly large areas and attain reasonable thicknesses.

3.3.3 The Outcrop at Sweet Home 280 and Wildebeestfontein 471 (Fig. 3.2).

This outcrop is located to the east and west of the local farm road. Figures 3.3 and 3.4 are sections, indicating the stratigraphical position of this outcrop.

The following rock types are present here;

(1) Pillow lava.

(2) Massive, amygdaloidal to non-amygdaloidal andesitic lava.

(3) Volcaniclastics.

3.3.3.1 Pillow Lava.

The following observations were made in the field;

(1) They occur at the lower end of the succession.

(2) Long axis measured for these pillows are as follows:

	Long axis.	% of total population.
(a)	80 - 50cm	60
(b)	50 - 30cm	30
(c)	others	10

(3) Inter-pillow openings are occupied by milky quartz and jasper.

(4) In general, the rock is very badly weathered and it is only the general pillow outlines that are well preserved (fig. 3.6).

Figure 3.6 Pillow lava at Sweet Home 280 and Wildebeestfontein 471.

A study of thin sections has revealed the following;

(1) In general, the rock consists of plagioclase (andesine) laths of approximately 1mm (long axis), which are embedded in a very fine-grained matrix.

(2) Small euhedral pigeonite crystals (± 0,3mm in diameter) are present. These occupy less than 1% of the total minerals of the rock.

(3) Chlorite and epidote present in the rock are alteration products of Fe-Mg minerals.

(4) No amygdales were observed.

(5) The pinkish colour of the rock can be contributed to the presence of iron oxides.

3.3.3.2 Andesitic Lavas.

Three different lava flows, overlying the pillow lavas, could be distinguished. Each flow varies from amygdaloidal-rich (top and bottom) to amygdaloidal-poor in the centre. Amygdales present in the bottom flows are also larger than those present in the higher flows. In some instances thin layers of tuff are present between the different rock types.

Thin sections revealed the following.

(1) In general, the rock consists of plagioclase (andesine) laths of not more than 1mm in length, embedded in a very fine-grained sometimes glassy matrix.

(2) A large percentage of small amygdales are present. These consist of chalcedony only and have rims that are in most cases chloritized. Their sizes vary between 0,5 and 1mm in diameter.

(3) In the lower flows, amygdales of more than 6mm in diameter are present. These also consist of chalcedony only.

(4) In one of the higher flows, a plagioclase (oligoclase) phenocryst with size 5 x 1mm was detected.

(5) Secondary ore minerals present in the rock are the alteration products of Fe-Mg minerals.

3.3.3.3 Volcaniclastics.

Volcaniclastics appear at the northern and southern outcrops. At the latter the rock consists of well-bedded (fig. 3.7) crystal tuff, dipping about 15° and sandwiched between the underlying pillow lava and the overlying andesitic lavas.

In the northern outcrop tuff and agglomerate are interbedded; the latter has clasts of Makwassie quartz porphyry. The tuff has the following characteristics:

(1) It is a lithic tuff showing well developed bedding planes (fig. 3.7) defined by light and dark (coarser and finer-grained material) bands.

(2) The bedding is predominantly horizontal but dips up to 40° in various directions prevail, indicating the deposition of volcanic ash on a very uneven surface, forming small basins.

(3) The lower 5cm consists of a small-pebble conglomerate with quartz and feldspar clasts up to 1cm in diameter.

Microscopic observations have revealed the following.

(1) At least 80% of the rock consists of quartz, the rest being feldspar.

Figure 3.7 Horizontal-bedded crystal tuff at Sweet Home 280.

(2) In general the quartz grains are angular to sub-angular and vary in size between 0,3 and 1mm (in diameter).

(3) Most of the grains show undulatory extinction.

(4) A minor proportion of β-quartz grains are present which indicates that very little material was derived from the underlying Makwassie Quartz Porphyry Formation.

(5) A small amount of microcline (± 1%) could be identified. The other feldspar minerals are in an advanced state of decomposition and could thus not be identified. Nevertheless, the microcline indicates that the rock has a partially granitic provenance.

(6) Sorting of the grains is fair.

(7) Very little matrix is present between grains. In most cases individual grains are in contact with one another.

(8) A small proportion of iron oxide minerals is distributed throughout the matrix.

3.3.4 The Outcrop at Geduld 27 and Pietersrust 30 (Fig. 3.8).

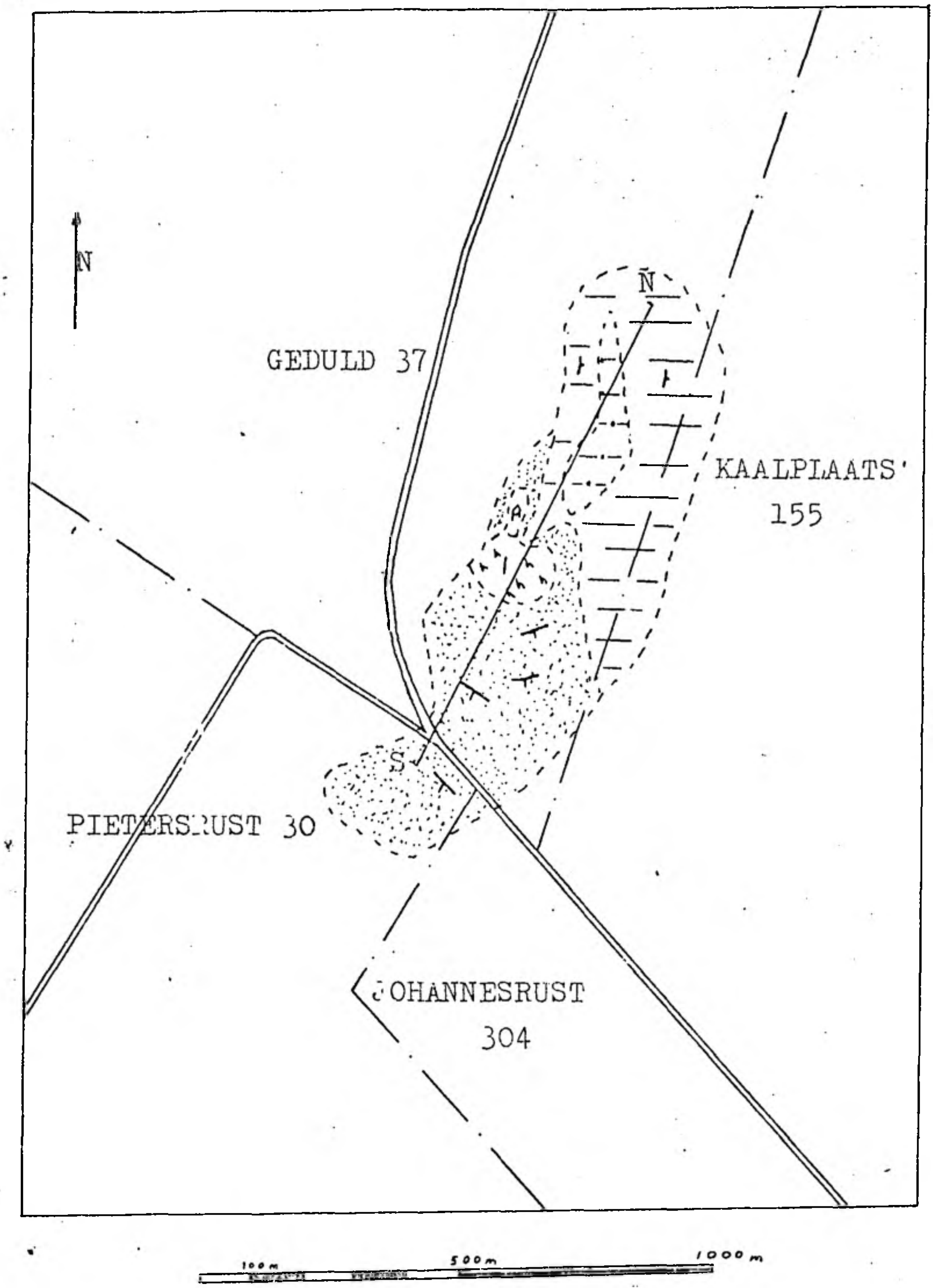
Here the Rietgat Formation consists of andesitic lavas and arkose as well as a volcanic breccia. A section, indicating the formation's stratigraphical position is given in fig. 3.9 and 3.10.

3.3.4.1 The Arkose.

These arkose were exposed in trenches situated to the south of the hill. Horizontal bedding and tabular cross-bedding are the most common sedimentological features in these arkose (fig. 3.11). Further, these arkose are blue-grey in colour and are fairly even-grained. The dip and strike of the arkose was found to vary between 14° - 16°

Legend for Figures 3.8 and 3.9

- Andesitic amygdaloidal lava.
- Andesitic fine-grained lava
- Dark-grey to grey arkose.
- Volcanic breccia
- Granite



Scale 1 : 13500

Figure 3.8 The Outcrop of Archaean Granite and Ventersdorp Rocks at Geduld 37 and Pietersrust 30 (For legend see previous page).

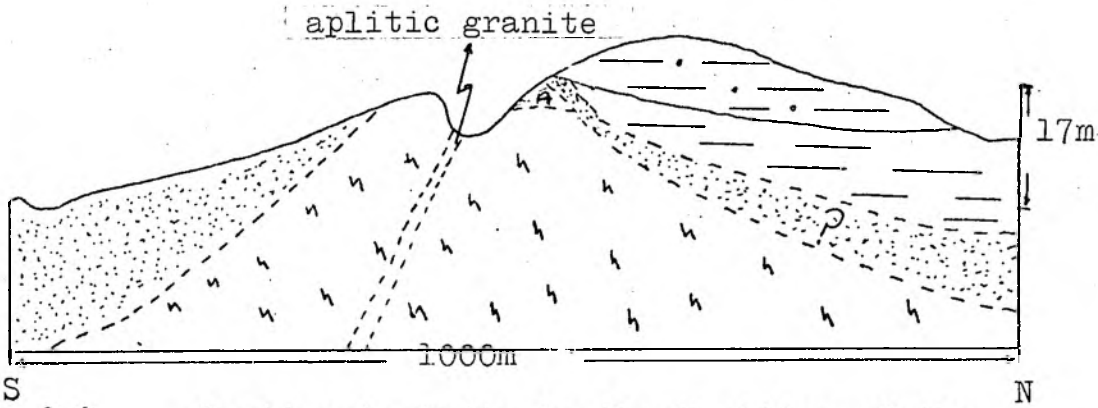


Figure 3.9 Section to Indicate the Position of the Archaean Granite and Ventersdorp Rocks at Geduld 37 (For Legend See Fig. 3.8)

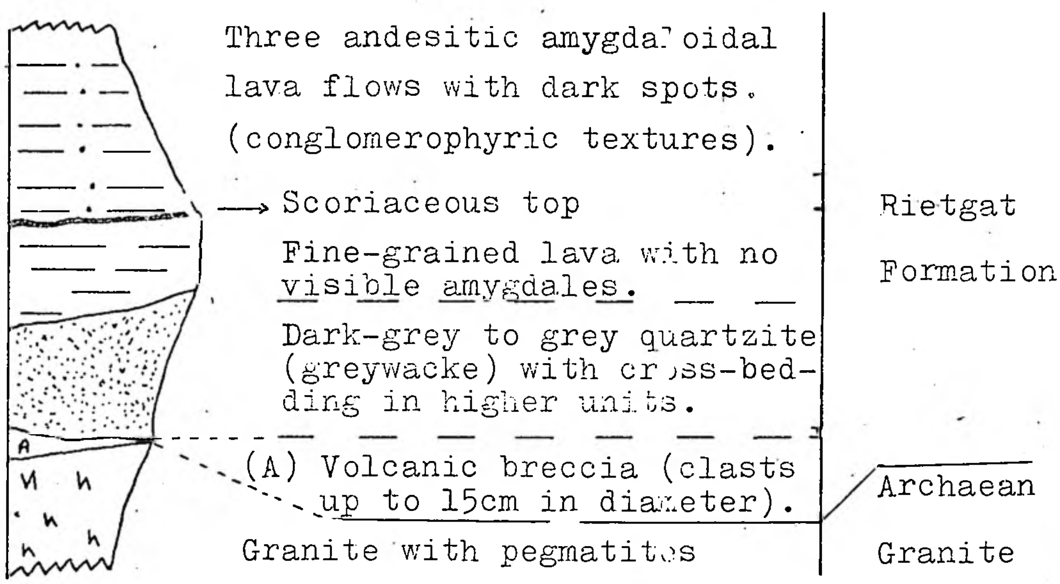


Figure 3.10 Lithostratigraphic Section of the Rock Succession at Geduld 37.

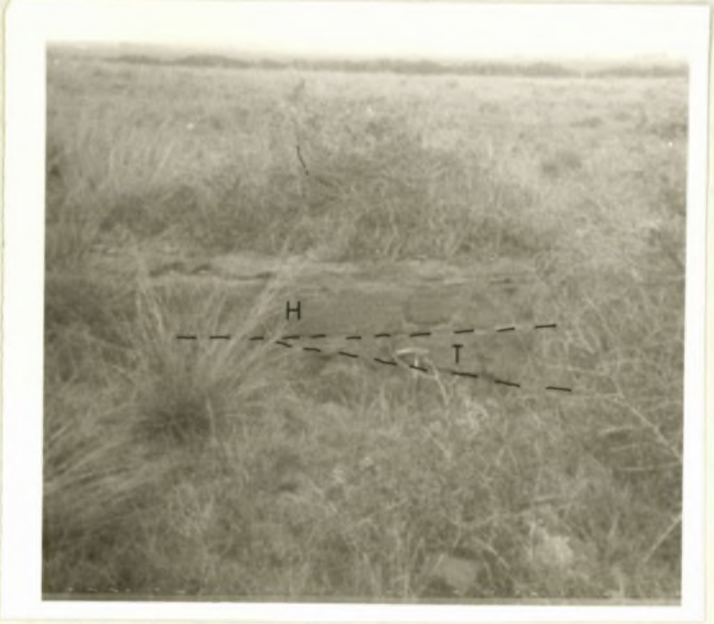


Figure 3.11 Cross-bedding in arkose at Geduld 37.
T = Tabular cross-bedding, H = Horizontal bedding.

and 48° - 83°, respectively. One tabular cross-bedded unit was found to have a strike of 115° and dip of 30°.

Considering the information gathered from the above-mentioned trenches, it would appear that the dip of the arkose diminishes in a direction away from the hill. Further, the strike was found to be orientated more or less perpendicular to a line to the centre of the present highest point on the hill.

The following microscopic features were observed;

(1) The composition of the rock is as follows;

Quartz	70%
Feldspar	30%

(2) The feldspars are so highly altered that in most cases the composition could not be determined. However, microcline could be positively identified in a few grains. The presence of the microcline indicates that at least some of the material was derived from a granitic terrain.

(3) Approximately 90% of the quartz grains are angular to sub-angular.

(4) No prefered orientations of quartz grains could be detected.

(5) The grain size is between 0,3 and 1mm in diameter.

(6) The matrix comprises approximately 30% of the rock. This then results in grains very seldom being in contact with one another.

From the above-mentioned features, it can be concluded that the rock is a poorly sorted, first-cycle sediment, for which the material was derived from the adjacent, underlying Archaean granites.

3.3.4.2 Andesitic Lavas.

These are located to the north and east of the hill. The lavas are fine-grained, have a blue-green colour, and are with or without amygdales. None of these lavas were detected to the south of the hill.

The lowermost flow has a fairly homogeneous appearance, with no visible amygdales but a scoriaceous top (fig. 3.12). The higher lavas can be subdivided into three separate facies, viz;

(1) A bottom flow, which consists of a lava with large amygdales. The latter may reach 6mm or more in diameter. Further, large dark "spots" (conglomerophyric texture) of up to 5cm in diameter are present here (see below).

(2) An intermediate flow, in which the amygdales as well as the dark "spots" diminish in size from bottom to top.

(3) The top flow, where amygdales as well as the dark "spots" are smaller than in any of the previous lavas. In some instances the latter may even be absent.

Figure 3.12 Scoriaceous top on lowermost lava at Geduld 37

Microscopic observations of these lavas has revealed the following;

(1) The majority of plagioclase (andesine) laths

are 1mm and less in length. A few individual laths were found to reach lengths of up to 4mm.

(2) Less than 1% of the minerals present are pigeonite.

(3) The above-mentioned minerals are embedded in a very fine matrix of partly devitrified, palagonitized glass.

(4) Amygdales may consist of chalcedony and/or polycrystalline quartz.

(5) The dark "spots" present in the rock, is the result of chloritisation (conglomerophyric texture).

3.3.4.3 The Volcanic Breccia.

This breccia consists of angular to sub-angular boulders of not more than 15cm in diameter, derived from the Archaean granites. The matrix in which these boulders are embedded consists of fine, angular quartz grains of not more than 0,3mm in diameter. The latter appears similar to the matrix of the breccia at Vryheid 1316.

The breccia at Geduld 37 is developed over a limited area only, with a thickness estimated to be not more than 3m. The extreme range in size, poor sorting and heterolithological nature of the clasts point to derivation from the vent (wall rock = granite, plus new vent material) and, in accordance with Parsons (1969, p. 275 - 276) can be classified as a pyroclastic vent breccia.

3.3.5 The Outcrop at Goudkoppies 461.

The Rietgat Formation in this area consists of a poorly sorted conglomerate with no associated lavas.

3.3.5.1 Composition of the Conglomerate.

(1) White to light-grey boulders of quartzite (fig. 3.13). The quartz content of these boulders is at least 90%. In general they are angular to sub-angular, and only in a few isolated cases were they found to be fairly well rounded. The size of these boulders vary between 50cm and smaller in diameter, with the most abundant boulder size being between 10 and 25cm in diameter. Further, they represent approximately 80% of the total clast population present in the conglomerate. Because of their high percentage of quartz, these quartzites could not have been derived from formations of the Ventersdorp Supergroup older then the Rietgat Formation and are therefore considered to have been derived from the Witwatersrand Supergroup.

(2) Clasts and pebbles having a granitic composition, are present in minor proportions. Microscopic observations made from these clasts, have revealed that these are similar in composition to the Archaean granites and aplitic granite vein material present at Geduld 37. This would then indicate that some of the material present in the conglomerate was shed from the Wesselsbron Arch.

(3) Tuff and amygdaloidal to non-amygdaloidal lavas are present as angular to well rounded pebbles, with sizes ranging between less than 1cm and up to 10cm in diameter. Since these clasts have an mafic composition, their provenance could be the Klipriviersberg Group.

(4) The milky quartz clasts present here, seem to resemble the quartz present in veins in the Archaean granites at Geduld 37.

Figure 3.13 Fanglomerate at Goudkoppies 461. (Q = quartzite, l = mafic lava, m = matrix).

Figure 3.14 A layer of matrix in the fanglomerate at Goudkoppies 461 (m = matrix, c = clasts).

(5) The matrix in which the above-mentioned boulders and clasts are embedded consist of fine, angular to sub-angular material, the composition of which is described below. In some areas thicknesses of up to 30cm of finer-grained interbeds are present in which traces of horizontal bedding can be observed (fig. 3.14). In thin sections it was found that most of the matrix material consists of more readily erodable material, e.g. material derived from Archaean granites (granite and aplitic granite), as well as, to a minor extent, some mafic lavas which were most probably derived from the Klipriviersberg Group.

(6) The ratio of matrix to clasts is highly variable from point to point.

3.3.5.2 Reasons for Considering the Conglomerate as Belonging to the Rietgat Formation.

Considering the characteristic differences between Dwyka tillite and Ventersdorp conglomerates as suggested by Pienaar 1956, p. 38) the following features can be used to indicate that the rocks are Ventersdorp conglomerates.

(1) Tillite is less compact.

(2) Hackly shale is only present within Dwyka tillite.

(3) The matrix of Ventersdorp conglomerates is dark and quartzitic, that of the Dwyka is an impure admixture of shale and siliceous material.

According to Winter (1965, p. 51-53), similar conglomerates are present in the Kameeldoorns Formation.

Considering the conglomerates at Goudkoppies 461 in relationship to the nearby Rietgat sedimentary rocks (at Geduld 37) and Makwassie Quartz Porphyry (at Vaalkoppies 8), it is evident that the difference in topographic height between these different outcrops is not more than 30m. Taking the thickness of different formations of the Ventersdorp Supergroup into account (Winter, 1965) and considering the topography, it can be deduced that all the outcrops of Ventersdorp rocks in the vicinity of Goudkoppies 461 lie on more or less the same topographic heights. To consider the conglomerates at Goudkoppies as part of the Kameeldoorns Formation would thus imply the postulation of faulting, during which these conglomerates were uplifted high enough, in order to lie on these topographic height . Such faulting could not be proved.

The conglomerate at Goudkoppies 461 was not considered as belonging to the Bothaville Formation, since Winter (1965, p. 105) has stated that the Bothaville rocks tend to pinch out against the Wesselsbron Arch in the extreme south. Bothaville conglomerates could thus not have accumulated in these southern negative areas of the Wesselsbron Arch. The primitive, first-cycle characteristics and obvious short distance of transport of the conglomerates differ fundamentally from the second-cycle nature and other characteristics of the Bothaville Formation.

From the above it can be stated with reasonable confidence that these conglomerates at Goudkoppies belong to the Rietgat sedimentary facies.

3.3.5.3 Formation of the Conglomerate at Goudkoppies 461.

According to Winter (1965, p. 99, 102), coarse conglomerates of Rietgat age are present close to some major faults. Further, he states that the Wesselsbron Arch, in the southwest, is encircled by Rietgat sediments.

Taking into account that the Wesselsbron Arch is present to the north, viz. at Geduld 37, the possibility that the conglomerate at Goudkoppies was shed from this Arch, cannot be ruled out. Further, a large number of pre-Platberg (Winter, 1976, and Olivier, 1965) faults are present to the east of Goudkoppies. The fact that Kameeldoorns sediments were not preserved in positive areas (Winter, 1965), would also apply to the conglomerates of the Rietgat Formation.

From the above discussion, it would appear that the provenance of the conglomerate at Goudkoppies was most probably located to the east. A more exact position of the provenance could not be established, since the outcropping area of the conglomerate is fairly small and contained no sedimentological features which could be measured to deduce the direction of transport.

The presence of the large percentage of Witwatersrand quartzites in these conglomerates, could indicate the presence of a Witwatersrand sub-outcrop situated to the east of Goudkoppies. Such sub-outcrops, underneath the Ecca shales, are present at the St. Helena Mine. Unfortunately the true location of such a Witwatersrand occurrence could not be located near the Goudkoppies area.

These conglomerates must have been deposited close to major faults, which would explain the presence of the large angular boulders. Transportation of material was most probably conducted by gravitation and surface runoff, which gave rise to the bad sorting of the material. Taking all its features into account, the conglomerate as a whole, can be considered a fanglomerate.

3.3.6 The Outcrop at Vaalbank 186.

This outcrop consists of arkose only. Directly overlying the arkose, are dolerites and in some places, Ecca shales. The following field observations were made;

(1) Widely scattered pebbles of up to 5cm in diameter are present in the arkose. Only in isolated cases were these pebbles found to be fairly closely spaced. These pebbles consist of;

(a) Non-amygdaloidal andesitic lavas.

(b) Vein quartz.

(c) Quartzite pebbles which were most probably derived from the Witwatersrand Supergroup.

(d) Clay-pellets.

(2) Horizontal bedding and trough cross-bedding is a most common feature in these arkose.

(3) The mean orientation of two trough axes were found to be 252°.

(4) The mean orientation of the trough cross-bedding is 240°.

The orientations of the trough-axis, as well as the trough cross-bedding, indicate that the direction of transportation of the material was from the northeast.

It is thus reasonable to accept that the provenance of the arkose is also located to the northeast. If this is true, the Wesselsbron Arch, of which an outcrop is present to the north of this area, viz. at Geduld 37, could be the source of the material.

The following microscopic observations were made;

(1) The rock clasts consist of:

Quartz	75%
Feldspar	25%

(2) Quartz grains are between 0,3 and 1mm in diameter and are angular to sub-angular.

(3) Feldspar minerals are altered, and could thus not be identified with certainty.

(4) Approximately 30% of the rock consists of matrix, which results in grains very seldom being in contact with one another.

(5) In general, the rock is poorly sorted.

The above-mentioned microscopic features were also observed in the quartzites at Geduld 37. Although the presence of clay pellets and widely scattered clasts of various composition is typical of the Bothaville Formation, the arkosic nature does not support this: the Bothaville Formation normally is subarkosic. This, together with the fact that the Bothaville Formation tends to thin out against the Wesselsbron Arch (Winter, 1965 and 1976) points to these quartzites being rather part of the Rietgat Formation.

3.4 The Bothaville Formation.

Two small patches of subarkose overlies the Makwassie quartz porphyry and Rietgat lavas on a Makwassie high on Wildebeestfontein 471 and Sweet Home 280 (see fig. 3.2). Microscopic observations have revealed the following.

(1) Minor amounts of β-quartz grains of approximately 1,5mm in diameter.

(2) At least 90% of the rock consists of quartz grains, and the rest being feldspars.

(3) In general the quartz grains are angular to sub-angular and vary in size between 0,3 and 1mm (in diameter).

(4) Very little matrix is present between grains. In most cases individual grains are in contact with one another.

(5) A small proportion of iron oxide minerals is distributed throughout the matrix.

Field relations show the quartzites overlie the the Makwassie Quartz Porphyry Formation and the andesitic lavas of the Rietgat Formation, and could thus be considered as belonging to a second sedimentary unit of the Rietgat Formation (fig. 3.2 , 3.3 and 3.4). However, the maturity of the quartzite (subarkose) is more consistent with the typical quartzite of the Bothaville Formation and is considered as such in the interpretation of the geological setup.

Sedimentological features as discussed before point to these sediments as a correlative of the Bothaville Formation.

For similar reasons as discussed before (section 3.3.1), reworked sedimentary rocks (subarkose) found in an old bore hole on Honiglaagte 234 could possibly belong to the Bothaville Formation.

3.5 The Allanridge Formation.

According to Winter (1965, p. 57- 64), the Allanridge Formation consists of a green-grey to dark green-grey, usually fine-grained or slightly porphyritic, amygdaloidal lava.

3.5.1 The Outcrop at Onrust 382 HO, and Cawoods Hope 324 HO.

The Ventersdorp lavas present here, have a distinctly green-grey colour and no sedimentary interbeds are present. These lavas are considered as belonging to the Allanridge Formation, in accordance with Kleynhans (1979) who mapped the area to the west, and P.J. Botha (in preparation) who is currently mapping the area to the north.

The following microscopic observations were made:

(1) Small plagioclase laths of not more than 1mm in length, are present.

(2) Pigeonite grains of up to 2mm in diameter were observed.

(3) Amygdales are less than 1mm in diameter and consist of chalcedony only.

(4) The above-mentioned minerals are embedded in a fine-grained, sometimes glassy matrix.

For reasons discussed before (section 3.3.1) some of the mafic lavas in the old bore hole on Honiglaagte 234 can possibly be correlated with the Allanridge Formation.

3.6 The Relationship between the Rietgat Formation and the Archaean Granites at Geduld 37.

Whether or not the andesitic lavas of the Rietgat Formation are in contact with the Archaean granites, could not be determined. However, in one locality they are only separated from the granite by about 3m of volcanic breccia. It is, however, certain that the lower sedimentary units of the Rietgat Formation, in this area, are in contact with the Archaean granites. Since these arkose all show a dip away from the granites, it can be concluded that these granites formed a ridge against which the sediments of the Rietgat Formation were deposited. The presence of some microcline in these arkose indicates that the provenance was at least in part, of a granitic nature (stated elsewhere).

Overlying the arkose in the central and north-eastern part, are andesitic lavas which dip away from the Archaean granites. Considering that the Bothaville Formation, to the south, tends to pinch out against the Wesselsbron Arch, and that the Allanridge lavas may thus directly overlie the Rietgat Formation to the south (Winter, 1965, p. 99 - 105), these andesitic lavas could be considered as of Allanridge age. However, as the underlying arkose is probably a Rietgat type, the lavas most probably belong to the same succession and will be assiged to the Rietgat Formation.

3.7 Conclusion.

The Makwassie Quartz Porphyry Formation is the oldest Formation of the Ventersdorp Supergroup, present in the mapped area. These porphyries formed isolated piles (ridges), against, and over which, sediments and lavas of the Rietgat Formation were deposited. During Rietgat times sedimentation alternated with volcanic activity, giving rise to a cyclic succession of sediments, volcaniclastics and lavas, which is such a characteristic feature of the Rietgat Formation.

In areas where faulting occured, e.g. in the Wesselsbron Arch, sediments of Rietgat age accumulated in negative areas. In areas of block faulting, fanglomerates developed probably as the facies closest to the faultscarp in the half-grabens so formed. These fanglomerates attained their greatest thicknesses and coarsest, most poorly sorted facies closest to these major faults. Farther away, they thinned out rapidly into a better sorted, finer, arkosic sediment.

The Rietgat Formation is followed by a pronounced period of denudation, which is known as the Pniel unconformity (Winter, 1976). During this period highs consisting of older Ventersdorp and other rocks were completely or partially removed by erosion. The material so removed by erosion was deposited as a second-cycle succession of mainly arenitic sediments in a beach environment (Liebenberg,1977) (Bothaville Formation). The Bothaville Formation grades upwards into a monotonous sequence of andesitic plateau lava, viz. the Allanridge Formation (Liebenberg, 1977), which concluded the Ventersdorp era.

4 THE KAROO SEQUENCE.

4.1 Introduction.

The Karoo Sequence in the area under investigation consists of the following subdivisions:

(1) The lower portion of the Beaufort Group.

(2) The Ecca Group: Tierberg Formation.
Whitehill Formation.
Prince Albert Shale Formation.

(3) The Dwyka Formation.

Reliable borehole data for this area are scarce. The writer has thus investigated cores, obtained from boreholes drilled to the east of this area. In these, only rocks of the Dwyka Formation and Ecca Group were found. A full discussion of the borehole data obtained, will be given in the appropriate sections.

4.2 The Dwyka Formation.

To gain a better understanding of the Dwyka glacial period in this area, it is thought best to discuss the western and eastern sectors of this area under separate headings. Since most of the area is covered by aeolian sand and thus no distinct line can be drawn which separates the eastern and western sectors, the western sector will be tentatively considered as the area to the west of Bultfontein and the eastern sector as the area to the east of Bultfontein, respectively.

4.2.1 The Dwyka Glacial Period in the Western Sector.

Outcrops of Ventersdorp rocks are present on the farms Honiglaagte 1234 and Vryheid 1316 (in the Boshof area), and Sweet Home 280 and Wildebeestfontein 471 (in the Bultfontein area). These outcrops of Ventersdorp rocks, represented "highs" from which material was shed during the period of glaciation, and it is thus reasonable to assume that they have never been covered by glacial deposits.

Stratten (1972) postulated a Kimberley glacial valley along which glacial débris had been transported, and a Bloemfontein Arch from which material had been shed. Rovic Diamonds (see chapter on Kimberlites) is situated 33 km to the southwest of the Ventersdorp outcrop at Sweet Home 280 and Wildebeestfontein 471. Here, varved shales directly overlie Ventersdorp rocks. If these varved shales are considered as the higher portions of the Dwyka glacial deposits, a glacial valley with tillite at its base, may well be present to the south of Rovic Diamonds.

No varved shales or tillite were observed in the northeastern sector of this area. The writer has, however, evidence to suggest that the Vaal River (see chapter on Vaal River Gravels), is aligned parallel to a pre-Karoo valley. Drilling within the Vaal River's drainage basin could thus reveal Dwyka deposits.

4.2.2 The Dwyka Glacial Period in the Eastern Sector.

No outcrop of Dwyka could be detected in this area. An attempt was thus made to gain as much reliable borehole data as possible for the unraveling of the glacial deposits here. These boreholes are situated near the Theunissen - Welkom road (between Star Diamonds and the Sand River), which is to the east of the mapped area.

The Dwyka Formation in this area consists of the following members; (Fig. 4.1)

(3) Sandstone-siltstone-shale.

(2) Varved shales.

(1) Tillite.

4.2.2.1 The Tillite.

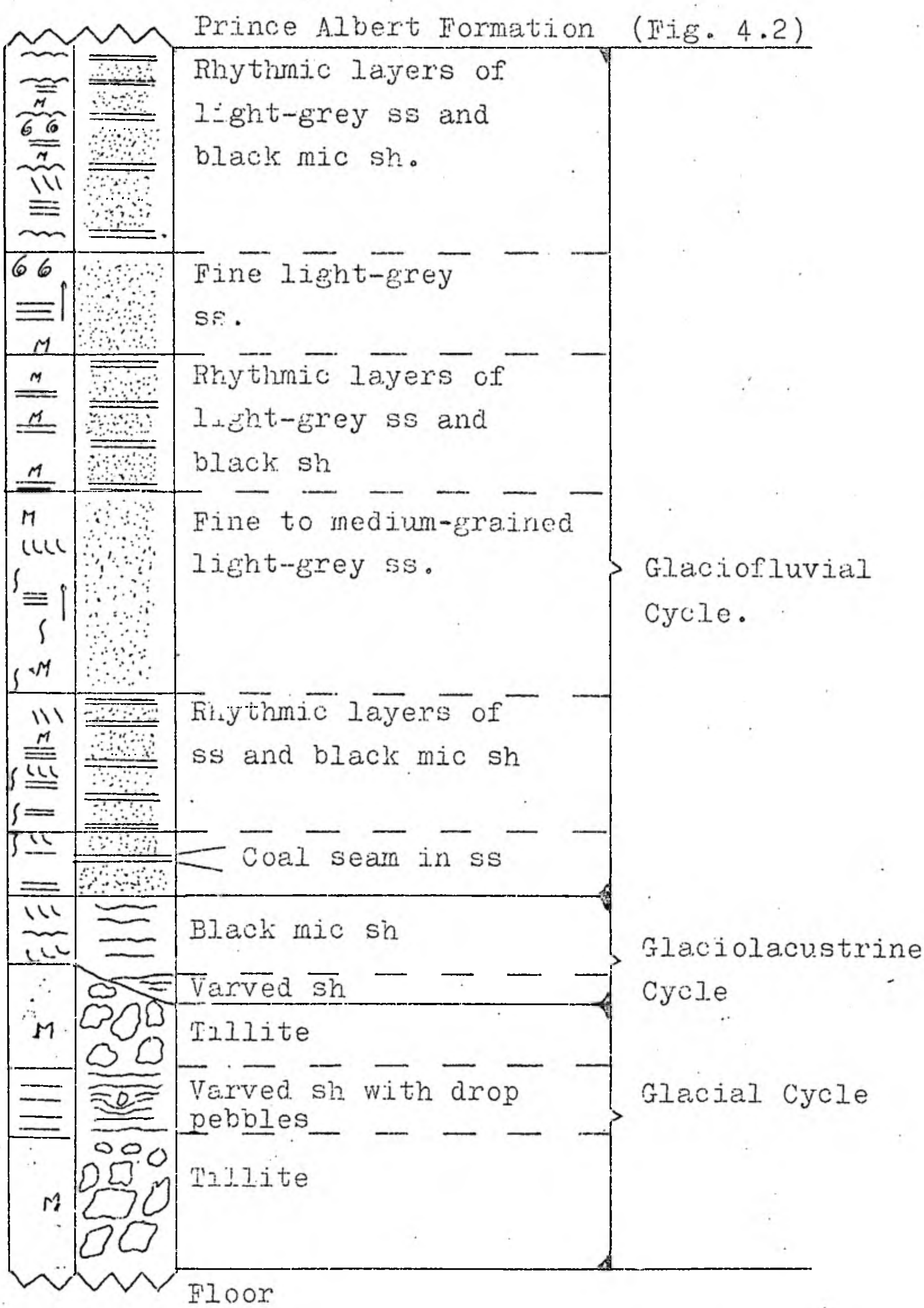
Clasts within the tillite vary in composition and probably largely depend on the pre-Karoo rocks over which the ice movement has occurred. In some instances, clasts of andesitic lava composition predominate, whilst in other instances granitic clasts are more abundant. In general, the tillite consists of a poorly sorted rock, containing clasts (usually angular) from 5 cm in diameter upwards embedded in a fine, sometimes shaly, or even quartzitic, matrix.

The following types of clasts were observed in the tillite;

(1) Granite. Where an abundance of granitic clasts are present, these may be related to a provenance in the Wesselsbron Arch. Here, according to Winter (1965, p. 123), Archaean granites are uplifted high enough to occur as outcrops (also see chapter on Archaean granites).

(2) Andesitic lavas. These consist of amygdaloidal and non-amygdaloidal lavas, which have most probably

Figure 4.1 Composite stratigraphic column of the Dwyka Formation.



Legend for Figure 4.1

	Horizontal bedding
	Flaser bedding
	Ripple-drift lamination
	Tabular cross-bedding
6 6 6	Slumping
	Bioturbation
M	Massive bedding
↑	Direction of arrow indicates direction of coarsening.
ss	Sandstone
sh	Shale
mic	Micaceous

been derived from Rietgat and/or Allanridge lavas.

(3) Pink and grey quartzites. These seem to correspond very well with the impure quartzites (feldspathic) present in the sedimentary units of the Rietgat Formation.

(4) White quartzites. The colour and purity of these quartzites indicates that they were derived from the Witwatersrand Supergroup. The path of derivation has most probably occured via the Kameeldoorns and/or the Lower Rietgat Formations.

(5) Chert. These are relatively scarce. Their provenance may be sought in the Rietgat sedimentary units or in the Transvaal succession. As no other clasts of Transvaal origin could be detected, it would appear that these were most likely derived from the Rietgat sedimentary units.

(6) Quartz Porphyry. These are present in isolated cases only. Their provenance is the Makwassie Quartz Porphyry Formation.

4.2.2.2 Varved Shales.

Where this unit is present, it overlies older tillite deposits. Further, it usually consists of alternating purple and green facies of not more than 5 cm in thickness.

Drop-pebbles, very seldom more than 3 cm in diameter, of quartzite, granite, or chert are quite frequently encountered in these shales.

4.2.2.3 The Sandstone-Siltstone-Shale Unit.

This unit consists of medium to coarse-grained, micaceous sandstones, interlayered by dark to very dark, micaceous shales. In most cases this unit directly overlies tillite, but exceptional cases are known where it overlies varved shales.

The following features are quite common in this unit;

(1) Upward coarsening of individual facies.

(2) Bioturbation in sandstones. Burrows are predominantly vertical with only a minor proportion being horizontal.

(3) Flaser bedding.

(4) Ripple-drift lamination in both sandstone and shales.

(5) The coarser sandstones are predominantly massive, whilst finer sandstones are usually horizontally bedded or planar cross-bedded.

(6) Coal seams of up to 1 m are present in some of the lower sandstone units.

(7) Higher up in this unit micaceous, black shales predominate, with sandstones occurring as lenses of 30 cm or less in thickness.

4.2.3 Genesis of the Dwyka in the Eastern Sector.

The different rock types of the Dwyka Formation, as discussed above, are not necessarily all present in any one borehole. In some instances, none of these units were observed, in which case shales belonging to the Prince

Albert Formation directly overlie Ventersdorp strata. In other instances only the sandstone-siltstone-shale member is present and rests directly on pre-Karoo rocks. This has led the writer to conclude that Dwyka sediments in this area, were not deposited as one continuous sheet, but were formed in pre-Karoo valleys or valleys excavated through ice-movement, as proposed by Vos & Hobday (1977, p. 219). These valleys have apparently been elongated in a north - south direction (Stratten, 1972).

Von Gottberg (1970, p. 103) found that the elongation of roche moutonnées coincides with the directions deduced from striations and chatter marks. In the far east of the mapped area, Ventersdorp rocks crop out along a more or less north - south line. On the farm Vaalbank 186 Prince Albert shales directly overlie Ventersdorp rocks, indicating that no Dwyka was deposited here. From this it can be concluded that these Ventersdorp outcrops may represent roche moutonnées. If this is true, a glacial valley, with the same north - south trend can be postulated on one, or possible both sides of these outcrops (Von Gottberg, 1970, p. 103).

4.2.3.1 Genesis of the Tillite.

Tillite will accumulate in regions where melting of the ice sheet occurs. Taking into account that glaciers have moved along glacial valleys, this would imply that deposition of glacial material will necessarily have to accumulate within these valleys. Depending mainly on the prevailing climatic conditions, competency of the ice sheet, and availability of erodable material, variable thicknesses of tillite may accumulate within these glacial valleys. In areas where these tillites are overlain by varved shales, the latter represent glaciofluvial or glaciolacustrine deposits.

4.2.3.2 Genesis of the Varved Shales.

These shales represent glacial outwash materials, which have been deposited mainly within glacial lakes. This was concluded from the large number of drop pebbles present within these varves. The drop pebbles also indicate that during the deposition of the varves free floating masses of ice were present on the lake's surface.

The layers enriched in red iron oxide present in these varves indicate that during certain periods of their formation oxidational processes dominated. On the other hand, greenish facies represent reducing (anaerobic) conditions.

4.2.3.3 Genesis of the Sandstone-Siltstone-Shale Unit.

According to Le Blanc Smith and Erikson (1979, p. 78) an upward-coarsening arrangement of depositional facies, can be accommodated in a prograding outwash delta model, which consists of sediments from a fluvioglacial environment. Further, he states that such sediments have accumulated from melt waters which originated in the retreating Gondwana ice sheet.

Theakstone (1976, p. 680) ascribes the formation of dark grey shales to anaerobic, reducing conditions which existed in the depositional environment. Such conditions must have prevailed during the deposition of the sandstone, since cases were observed where sandstones are intensely mixed with dark shales.

Coal seams present in this unit tend to swell and pinch over fairly short distances. Le Blanc Smith and Erikson (1979, p. 82) explains such a phenomenon by the palaeotopography and the loci of clastic input. This must also be applicable to shales and mudstone facies, since either shales or sandstone may directly overlie tillite in the cores investigated.

The retreat of the Gondwana ice sheet is marked by the occurrence of the sandstone-siltstone-shale unit. At the base this unit consists of black shales which have most probably originated in a neritic environment, dominated by anaerobic, reducing conditions.

With the further retreat of the Gondwana ice sheet the competency of the glacial streams must have increased, giving rise to the formation of rhythmic layers of sand and/or silt, interlayered by thin bedded-black muds. At certain stages the deposition of sand must have dominated, since sandstone facies of up to 20 m in thickness are present in some cases.

Overlying the above-mentioned sandstone facies are rhythmic layers of sandstone, siltsone, and black shale. Where the thickness of the shales is greater than the thickness of the sandstone and siltstone it was considered as the transitional zone between the Dwyka Formation and Ecca Group.

4.3 The Ecca Group.

The following formations, belonging to the Ecca Group, are present in the mapped area;

(3) Tierberg Formation

(2) Whitehill Formation

(1) Prince Albert Formation

Because of the low relief, as well as the extensive cover of aeolian sands, rocks of the group do not normally appear as outcrops. Dolerite intrusions have displaced individual units of the Ecca succession by some 20 or more metres vertically, which further complicates the study of these rocks. Localities in this area where the contact of individual units of the Ecca succession could be observed, are also scarce. To overcome these problems as much reliable bore hole data (diamond as well as percussion drilling) as possible have been used. Where bore hole data, especially those obtained from percussion drills, were found unreliable, they were rejected immediately.

This is very important, as every farmer seems to have adopted his own geological interpretation over the years. One feature that can, however, be accepted with reasonable accuracy, is the occurrence of "swart room" (very dark-grey shales) in bore holes. This can be contributed to the fact that the very dark-grey shales of the Prince Albert Formation have a very low groundwater potential. Where these shales are penetrated during drilling operations, they leave a black, creamy mess ("swart room"), which clogs around the drill, complicating drilling operations. Drilling is thus stopped as soon as these shales are encountered.

Rocks belonging to the Ecca Group situated to the west and south-west of the mapped area are discussed by Kleynhans (1979) and Joubert (1973) respectively. Unfortunately, Joubert (1973) has not subdivided the Ecca Group into the Prince Albert, Whitehill, and Tierberg Formations, as is currently accepted, and Kleynhans (1979) has only mentioned the presence of the Prince Albert Formation in the area mapped by him. Although the area mapped by Nel (1977) (an area to the south of Hopetown) is fairly remote from the area under discussion in this writin , his subdivision of the Ecca Group into the Prince Albert, Whitehill, and Tierberg Formations is the nearest attempt at such a classification and was thus accepted as a basis for subdivision of the Ecca Group in the area under discussion.

4.3.1 The Prince Albert Formation.

According to Nel (1977, p. 43-45) the Prince Albert Formation consists of the following;

(1) A lower member, consisting of blue-grey, laminated shales with lenses of calcite.

(2) A higher, black, carbonaceous member, with a fairly high mica content.

4.3.1.1 Field Observations.

The only region where the lower member was observed is located to the north of the Vaal River (Cawoods Hope 324 HO). Here it is covered underneath 3m or more of hardpan calcrete. Rocks belonging to the Ventersdorp succession crop out some 500m to the north of the site where these shales were encountered. From this it can be concluded that these shales were deposited in a pre-Ecca valley and are thus, in some cases, able to directly overlie Ventersdorp rocks. Over the rest of the mapped area only the higher member is present.

To gain a better understanding of the shales belonging to the higher member, a few outcrops will be discussed.

(1) At Kalkpan and Wolwepan (both on the old Hertzogville - Dealesville road) black, micaceous shales are present in excavations on the rim of these pans. These shales are massive, with no indication of calcitic nodules or sandstone lenses. Overlying these shales are variable thicknesses of hardpan, and nodular calcrete.

(2) On the western rim of Presentpan (on the Hertzogville - Christiana road), the black shales are in some instances directly overlain by the Whitehill Formation. To the north of Presentpan calcareous nodules and siltstone lenses were observed in the shales.

(3) On the farm Zamenkomst 610 (to the east of the Hertzogville - Dealesville road) black shales are overlain by greenish siltstones, approximately 2m in thickness. According to Nel (1977, p. 45) such siltstones are located on top of the Whitehill Formation, and thus belong to the Tierberg Formation. As no Whitehill rocks could be observed, it can be concluded that Prince Albert shales, present in this area, are directly overlain by rocks of the Tierberg Formation.

(4) At Rovic Diamonds black shales directly overlie varved shales. No sandstone lenses or calcareous nodules are present in the shales (see chapter on Kimberlite).

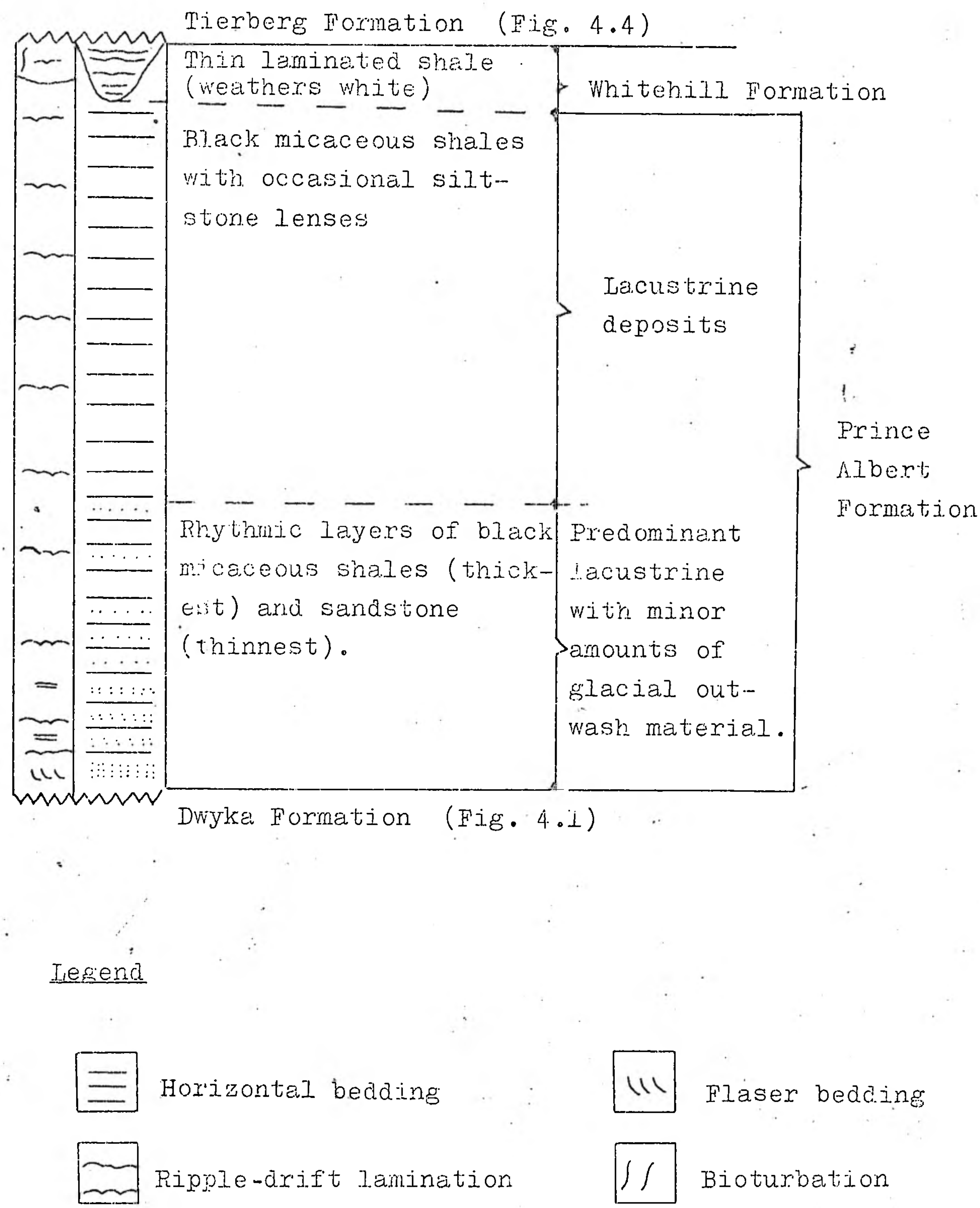
(5) On the farm Boskop 165 (on the Hertzogville - Bultfontein road) black Prince Albert shales are present underneath ± 20m of Tierberg shales.

From the foregoing it can be concluded that the higher member of the Prince Albert Formation which occurs as outcrops within the mapped area, consist predominantly of a homogeneous type of rock (shale), with sandstone lenses and calcareous nodules present in fairly isolated cases only.

Considering the data obtained from bore holes located to the east of the mapped area (Fig. 4.2), this picture changes slightly. Here, glaciofluvial sediments of the Dwyka Group grade into lacustrine shales of the Prince Albert Formation. Black, micaceous shales, resembling Prince Albert shales, are present within these glaciofluvial (Dwyka) sedimentary rocks. To distinguish between the above-mentioned sedimentary units, the author proposes a transitional zone, in which the predominantly glaciofluvial sedimentary units and the predominantly lacustrine sedimentary units are separated (see composite stratigraphical interpretation of bore hole data, Fig. 4.1 and 4.2).

The thickness of the Prince Albert Formation probably depends on the palaeotopography of the pre-Ecca floor. This was concluded from the bore hole data obtained

Figure 4.2 Composite stratigraphic column of the Prince Albert and Whitehill Formations.



from outside (east) of the mapped area, where thicknesses of Prince Albert shales vary between 140m and 180m.

4.3.1.2 Genesis of the Shales.

Visser and Loock (1978, p. 186-188) propose a shallow-water environment for the formation of these shales. Greensmith (1978, p. 107) postulates that water depth has very little or no controlling influence upon the formation of black muds. He ascribes the origin of these muds to the strong oxygen deficiency in the water immediately overlying the sea floor.

The environment in which the shales originated must have varied considerably from east to west. In the western sector of the area, these shales are fairly homogeneous in composition, which indicates that depositional conditions were fairly stable during this period.

These shales most probably originated through the deposition of muds, from suspension in an environment remote from all shorelines. Deltaic conditions had thus very little influence on the formation of the Prince Albert shales [present] in the western sector.

Data obtained from bore holes outside (east of) the area indicate that these Prince Albert shales had a different genesis. In the lower portion siltstone/sandstone lenses of up to 30cm in thickness are present. As suggested by Visser and Loock (1978) for similar deposits, cross-bedding and slumping (in the higher portions of individual lenses) indicate that the material was most probably deposited by turbidity currents. Upwards these lenses thin out rapidly. In the higher portions of the shales, siltstone/sandstone lenses occur in isolated cases only.

It is proposed that these siltstone/sandstone lenses can, to some extent, be ascribed to minor amounts of glaciofluvial outwash, as discussed for the higher unit of the Dwyka Formation. With progressive melting of the Gondwana ice sheet, rising of the water level resulted in the transgression of the sea, resulting in more stable conditions for the deposition of the muds. In areas where the depositional zone for these shales became remote enough from the shoreline shales of the western sector type originated.

4.3.1.3 Provenance.

Material for the formation of these shales was most probably derived from Dwyka sediments, Ventersdorp rocks, and Archaean granite, as these appear to be the most abundant pre-Ecca rocks within this area.

4.3.2 The Whitehill Formation (Fig. 4.2).

Rocks belonging to the Whitehill Formation appear to be absent over most of the mapped area. The bore hole data obtained outside (east of) the area have shown no indication of Whitehill Formation.

The only outcrop of Whitehill Formation appears near Presentpan, to the south of the Hertzogville - Christiana road. Shales belonging to the Whitehill Formation can be observed in a region located between the western rim of Presentpan and the gravel road father west (Fig. 4.3). The following features were noted;

(1) The measured thickness does not exceed 3m.

(2) It either overlies the dolerite sill present in this area, or shales belonging to the Prince Albert Formation.

(3) It weathers into white or very light-grey slabs, with patches enriched in iron oxides.

(4) Gypsum is present between individual slabs, and appears to be the weathering product of the Whitehill rocks (see also chapter on pans).

(5) Ripple-marks, and in some isolated cases, bioturbation, are present.

Figure 4.3 The Whitehill Formation to the west of Presentpan.

(7) In localities where these shales are in contact with the intrusive dolerite sill, individual layers were slightly tilted.

The absence of the Whitehill Formation over most of the area, may be ascribed to one or both of the following reasons:

(1) The Whitehill Formation does not occur as one continuous layer over the whole of this area. Instead, it occurs as fairly small, isolated patches only.

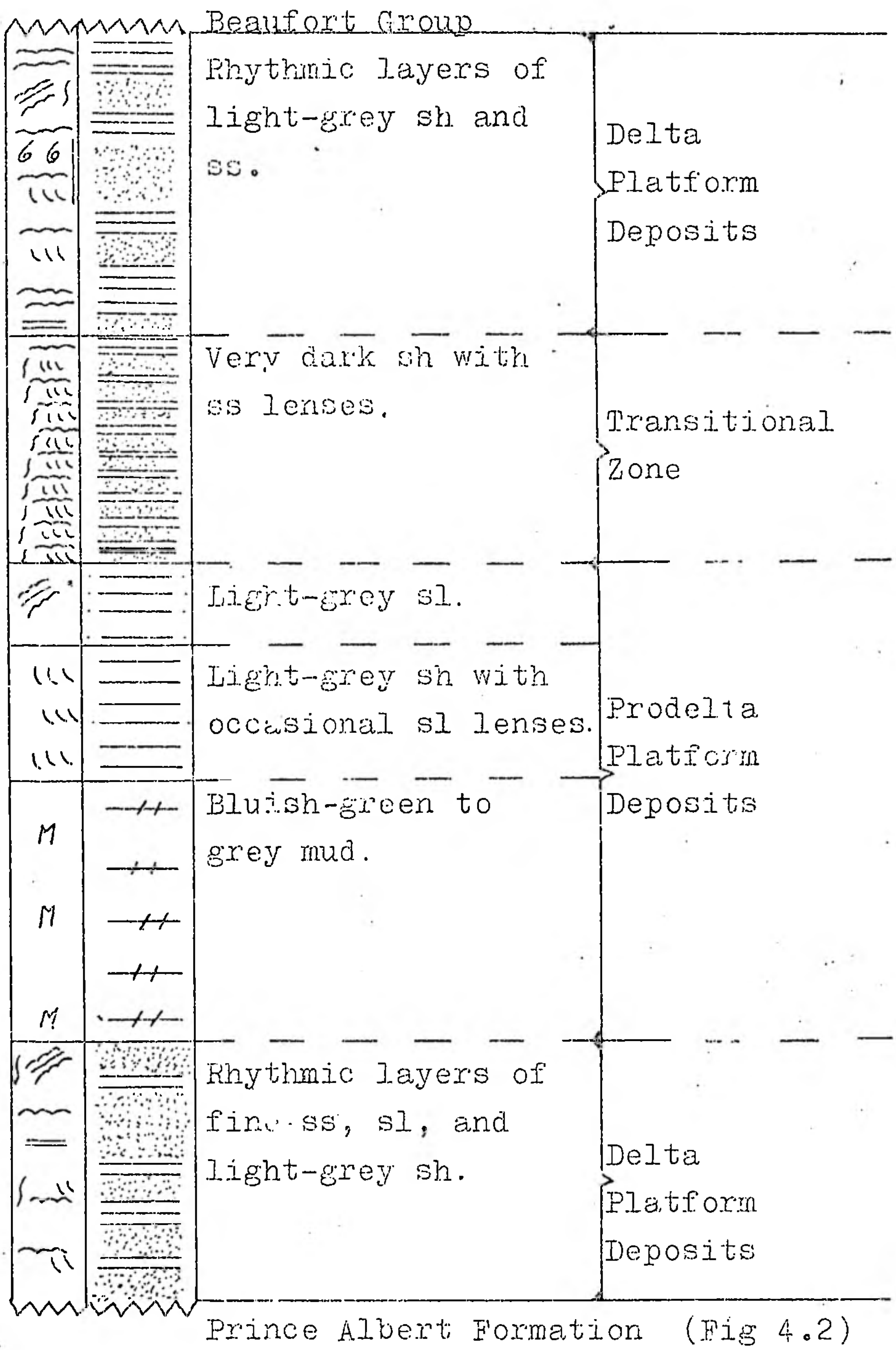
(2) Both Whitehill and Prince Albert rocks tend to become calcified during weathering. Where these rocks are intensely calcified, all original sedimentary features are lost. From this it may be concluded that the White-hill Formation may indeed be present over larger areas but because of intensive calcrete formation can no longer be positively identified as such.

4.3.3 The Tierberg Formation (Fig. 4.4).

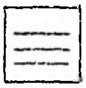
Since the Whitehill Formation is absent over most of the mapped area, the transition from the Prince Albert Formation to the Tierberg Formation was taken at the first appearance of greenish siltstone, a criterion also used by Nel (1977, p. 45). These siltstones are very characteristic in that they show rounded structures, from 1mm to 5mm in diameter, which are enriched in iron oxides on weathered surfaces.

These siltstones are also quite frequently en-countered on top of dolerite sills where they occur as rather small, isolated patches. Dolerite sills tend to be located along the contact of two lithologically diffe-

Figure 4.4 Composite stratigraphic column of the Tierberg Formation.



Legend for Figure 4.4

 Horizontal bedding

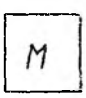
 Flaser bedding

 Ripple-drift lamination

 Climbing ripple lamination

 Slumping

 Bioturbation

 Massive bedding

 Direction of arrow indicates direction of coarsening

ss Sandstone

sl Siltstone

sh Shale

mud Mudstone

rent rock types (see chapter on dolerites). Taking the above-mentioned features into account, it is thus in some instances possible to ~~note~~ observe the transition between Prince Albert and Tierberg rocks along the contact of a suitable dolerite sill.

4.3.3.1 Lithology and Genesis.

Overlying the above-mentioned siltstones, are bluish-green mudstones. At Boskop 165 (on the Hertzogville - Bultfontein road), these mudstones reach thicknesses of up to 20m (according to local bore hole data).

These mudstones can be distinguished from the Prince Albert shales by the following features:

(1) Their colour, which is much lighter than that of the Prince Albert shales.

(2) They are less micaceous.

(3) In most cases they have a massive appearance, with very little, if any, sedimentary structures.

(4) They are non-carbonaceous.

The above-mentioned features were also observed in most cores obtained from bore holes drilled outside (east of) the mapped area. In one core, however, it was noted that siltstones occupy the position usually held by the above-mentioned mudstones. As these mudstones are considered to have been deposited on a prodelta platform (Visser and Loock, 1978, p. 186), the occurrence of siltstone instead of mudstone is a function of the depositional environment; in the case of the siltstone deposition must have taken place closer to the delta front than is the case for the mudstone.

Overlying these mudstones are rhythmic layers of shale, siltstone, and sandstone. Terblanche (1979) assigned these to the Carnarvon Sandstone Formation in the Carnarvon district. The type area for the latter formation is, however, located too far south of the mapped area, and as these sediments represent delta platform deposits (Visser and Loock, 1978, p. 186-187), they will for the purpose of this study be considered as an integral (upper) part of the Tierberg succession.

The immediate transition between the mudstone and the overlying shale-siltstone-sandstone unit was observed in one bore hole situated outside (east of) the mapped area. Here very dark-grey shales, resembling shales of the Prince Albert Formation, are interlayered with small sandstone lenses, usually not more than 5cm in thickness. Bioturbation is a most common feature in these sandstone lenses. From the analysis of Reineck and Singh (1973, p. 266), of similar sedimentary setups, it can be deduced that this unit was most probably deposited in the transitional zone situated between prodelta platform and delta platform.

The genesis of similar units have been explained as follows and probably hold true for the present area. Stagnant waters, immediately overlying the sea floor, originated during neritic conditions and gave rise to the deposition of the black muds (Greensmith, 1978, p. 107-108). During periods of flood on the delta plain large volumes of unconsolidated sediments were able to accumulate on the delta front. Turbidity currents, originating on these overloaded delta fronts, were thus able to transport the coarser sediments further into the lake. The latter would have been impossible under normal conditions (Kuenen 1964, p. 24).

With the deposition of the sands, stagnant conditions must have ceased which explains the biological activity within the sandstone lenses. During the deposition of the overlying black muds conditions became stagnant once more, destroying animal life. These cyclic conditions have been repeated a large number of times over a considerable period of time, since some 60m of this rhythmic unit was observed in the above-mentioned bore hole.

From the bore hole data obtained outside (east of) the mapped area it was noted that the above-mentioned unit is overlain by another unit of shales and sandstone. The shales are, however, much lighter in colour, whilst the sandstones are fine-grained and may attain thicknesses of up to 10m or more. These sandstones are usually massive (bottom), grading upwards into cross-bedded facies, with occasional slumping and flaser bedding at the very top. This rhythmic unit is the highest in the sequence of the Ecca Group that could be detected in cores obtained from bore holes east of the area mapped. The latter rhythmic unit seems to coincide well with the Tierberg rocks at Basberg 416 and thus a more detailed description of it will be given below.

4.3.3.2 The Tierberg Formation on the Farm Basberg 416 (Fig. 4.5).

The outcrop is situated to the east of the Bultfontein - Bloemfontein road. Here, rocks belonging to the upper division of the Tierberg Formation, are present (Fig. 4.6). Individual units in this locality consist of upward-fining cycles of sandstone (base) and shales (top). The different facies within any one unit can be studied in reasonable detail and will be discussed below under separate headings.

4.3.3.2.1 The Sandstone Facies.

Since the sandstones present in the various rhythmic units all show the same major features, they will be discussed under one heading. Major features are;

(1) Sandstones are all fine-grained ($<$ 0,2mm), with angular, poorly sorted grains. Less than 5% plagioclase is present.

(2) They are light-grey in colour.

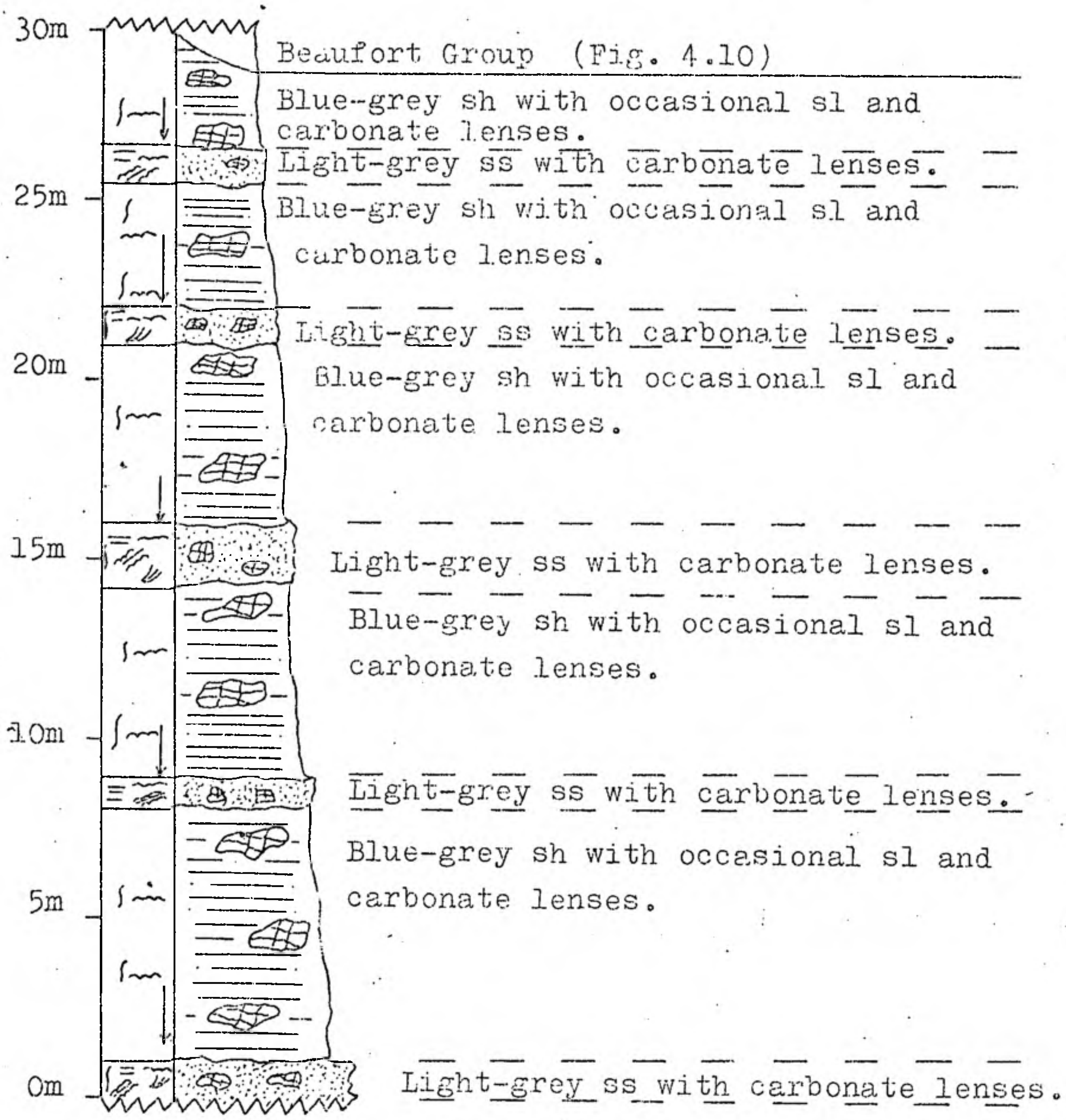
(3) They are predominantly horizontally bedded with minor occurrences of trough cross-bedding.

(4) Ripple-drift lamination is a most common feature.

(5) Bioturbation is present in isolated cases (Fig. 4.7). Only vertical burrows were observed. These burrows are usually 0,5cm and less in diameter.

(6) Calcareous concretions are most abundant in the lower sandstone facies.(Fig. 4.8).

Figure 4.5 True lithostratigraphic section of the Tierberg Formation at Basberg 416.



Legend for Figure 4.5

- Horizontal bedding
- Ripple-drift lamination
- Trough cross-bedding
- Climbing ripple lamination
- Bioturbation
- Direction of arrow indicates lirection of coarsening

- ss Sandstone
- sl Siltstone
- sh Shale

Figure 4.6 Sandstone (ss) and shale (sh) units at Basberg 416.

Figure 4.7 Bioturbation in the siltstone lenses at Basberg 416.

Figure 4.8 Carbonate concretions in the sandstone facies of the Tierberg Formation at Basberg 416.

Figure 4.9 Massive carbonate concretions in the Tierberg sandstones, with climbing ripple and ripple-drift lamination, at Basberg 416.

Calcareous concretions in these sandstones show the following:

(1) Ripple-drift lamination and climbing ripples, are most common features noticable on weathered surfaces (Fig. 4.9).

(2) The size of individual concretions is usually from 20cm to well over 80cm in diameter (Fig. 4.8).

In most cases the bedding present in the concretions is continuous with the bedding in the sandstone facies. From this it can be concluded that the concretions have originated after the deposition of the sands and that they represent replacement of original material without destroying original structures.

The following microscopic features were observed in the calcareous concretions:

(1) It is the matrix only that is calcified.

(2) Grains of quartz having the same angular shape and poor sorting as those observed in the sandstones are present in this calcareous matrix.

(3) The same percentage of plagioclase grains present in the sandstone are also present in the concretions.

(4) In some instances light-grey patches which weather positively are noticeable on weathered surfaces. Under the microscope these patches appear as rims enriched in iron oxides around a spot almost free of iron oxide. These structures thus appear to have formed by the leaching of iron oxides from a central region, and are not biogenetic in origin.

The above-mentioned features are further proof that the concretions have originated through the calcification of the sandstone's matrix. In some instances the growth of these concretions caused a volumetric expansion so that overlying sediments were slightly displaced and appear in the field as areas of updoming.

4.3.3.2.2 The Shale Facies.

Unfortunately these shales are very badly weathered and thus sedimentary structures could not be studied in detail. However, upward thinning of individual facies is a very common feature. Since these facies are very uniform over the whole of the succession they are discussed under one heading.

The following features are very common:

(1) A light-grey colour.

(2) Large calcareous concretions of 3m or more (long axis) and 60cm in thickness are present.

(3) Bioturbation is confined to the siltstone lenses in the shales. These "worm tubes" are either horizontal or vertical and attain diameters of up to 5mm. Lengths of up to 8cm were observed in horizontal tubes.

(4) Ripple marks were observed in areas where these siltstones were not so badly weathered.

Two different types of calcareous concretions were observed:

(1) Massive concretions.

(2) A replacement type of concretion,

Both concretions have originated through the replacement of shales by carbonate, the only difference being that in (1) shales have been completely replaced, whilst in (2) remnants are still visible in patches, a situation which was also confirmed in thin sections. Further, these concretions are not limited to a specific zone in the shales, as they were found at different levels.

These concretions have definitely contributed large volumes of carbonate for the formation of calcrete, as a large number are encrusted by calcrete.

4.3.3.2.3. Genesis of the Tierberg Formation at Basberg 416.

This unit has most probably originated on the outer fan of a prograding delta and can thus be associated with a lobe fringe deposit as described by Mutti (1977) for similar rock sequences. After the deposition of the sediments, their subsequent distribution was most likely conducted by bottom currents, giving rise to sedimentary structures such as ripple marks (in shales) and ripple lamination (in sandstone).

The light colour of the shales, as well as the presence (although sparse) of bioturbation points to deposition on the sea floor during non-stagnant periods. Life on the delta plain must have been limited to easily decayable organic matter as no fossils were observed in the rocks.

During the further progradation of the delta Tierberg sediments were covered by delta plain sediments The latter can be recognized as a fluvial cycle. The beginning of this cycle was then considered as the transitional zone which separates the Beaufort from the Ecca type of sedimentation.

4.4 The Beaufort Group.

The transitional zone between the Ecca and Beaufort was taken at the appearance of the first prominent sandstone (Visser and Loock, 1974). In the area under investigation, these sandstones are predominantly arkosic, with a medium to coarse-grained (occasionally gritty, with pebbles in the lower portions) texture. Further, they usually show fluvial features.

As the locations of individual outcrops are fairly small, and situated far from one another, noteworthy outcrops will be discussed separately. Such outcrops are located at;

(1) Basberg 416

(2) Erweesrant

(3) Lubbefontein 81 and Zaaiplaats 514.

4.4.1 The Outcrop at Basberg 416.

The outcrop is situated to the east of the Bultfontein - Bloemfontein road. This is the only outcrop in the area under discussion where the transitional zone between the Ecca and Beaufort can be followed with certainty. Figure 4.10 is a true lithostratigraphic section of the lower portion of the Beaufort Group at Basberg 416.

4.4.1.1 Field Observations.

The following features were observed in these sandstones;

(1) Individual sandstone layers tend to grade laterally from coarser to finer.

(2) Sandstones vary in grain size from sand to

grit and usually have an arkosic composition.

(3) Tabular cross-bedding as well as horizontal bedding is a most common feature (Fig. 4.11 , 4.12). Trough cross-bedding has not been observed in these sandstones. Ripple lamination was observed in some sandstone layers.

(4) Mud-pebble conglomerate is present in the lowest units which are in contact with the Ecca shales as well as in some parallel-bedded units.

(5) Pebbles of up to 5cm in diameter are present on the lower parts of some cross-bedded layers. These pebbles are predominantly granitic in composition.

(6) Tabular cross-bedded layers of 30cm in thickness are the most common in these sandstones and are usually separated from one another by horizontally-bedded layers.

(7) Facies of horizontally-bedded layers are generally 5-10cm in thickness.

(8) The mean direction of transport of material is 280°.

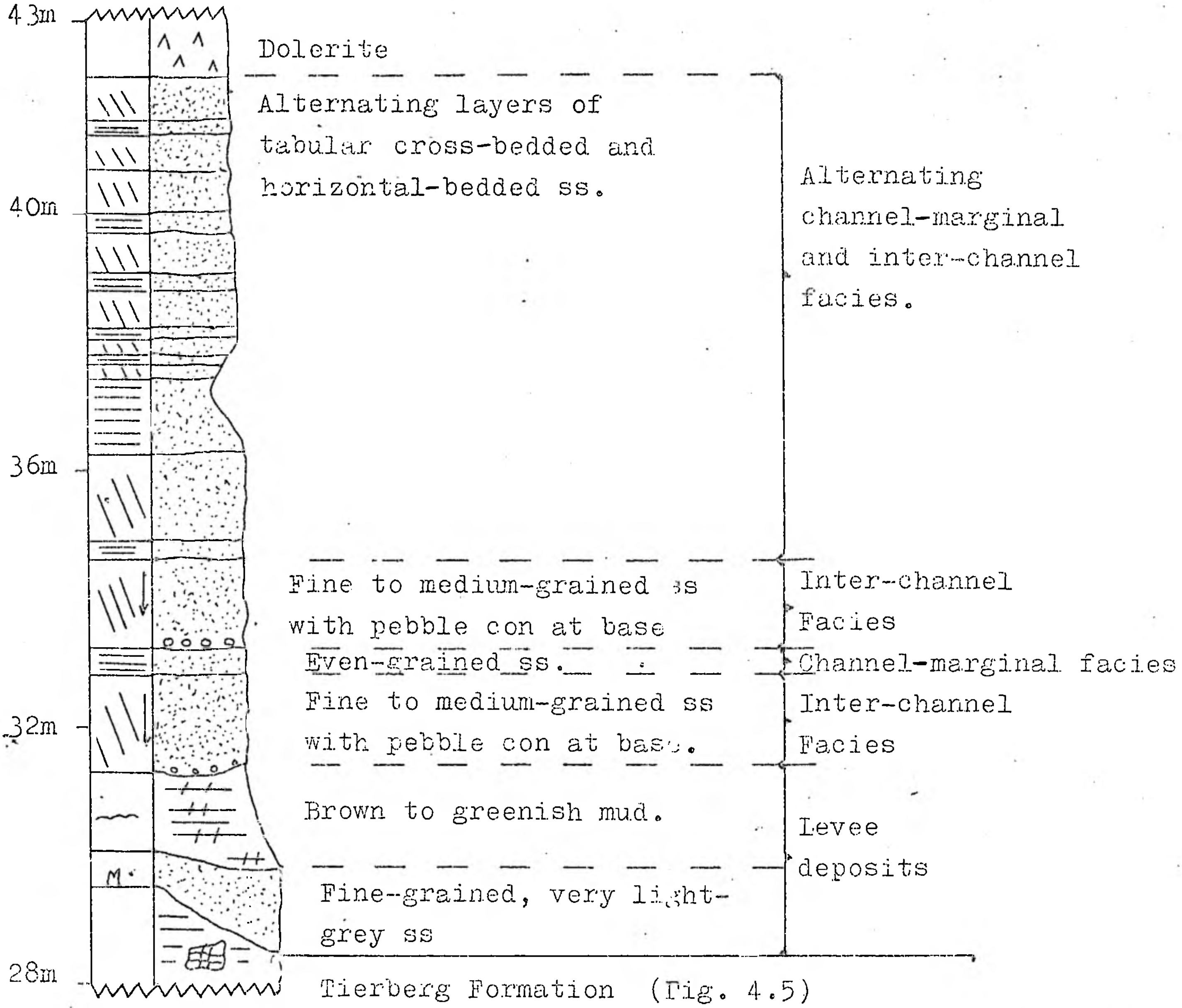
(9) Some isolated cases of bioturbation were observed in these sandstones. No fossilised plant remains were, however, observed.

4.4.1.2 Microscopic Observations.

The following minerals are quite common in these sandstones;

(1) Quartz grains. The grain size is usually of the order of 0,1-2,0mm, depending on the general coarseness of the rock. Most of the grains show undulatory extinction.

Figure 4.10 True lithostratigraphic section of the Beaufort Group at Basberg 416



Legend for Figure 4.10

	Horizontal bedding
	Ripple-drift lamination
	Tabular cross-bedding
M	Massive bedding
↓	Direction of arrow indicates direction of coarsening.
ss	Sandstone
mud	Mudstone
con	Conglomerate

Figure 4.11 Beaufort sandstones at Basberg 416 (t = tabular cross-bedded units, h = horizontally bedded units).

Figure 4.12 Tabular cross-bedded units in Beaufort sandstones at Basberg 416.

Figure 4.13 Beaufort sandstones at Basberg 416 (t = tabular cross-bedding (channel-axis facies), h = horizontally bedded channel-marginal facies, l = levee mudstones).

Figure 4.14 Beaufort sandstones at Basberg 416 (see fig. 4.13 for symbols).

Further, the highest percentage of these grains are monocrystalline. Quartz grains usually occupy some 70-80% of the total grain population.

(2) Microcline. The grain size of these minerals varies with the coarseness and sorting of the grains in the rock.. In some thin sections, they were found to be smaller than 0,1mm, whilst in other thin sections, sizes of 0,5-2,0mm are quite common.

(3) Plagioclase (albite). These minerals are usually between 0,1-0,5mm in diameter. Together with the microcline grains, these occupy between 20 and 30% of the total grain population.

In general, these sandstones consist of angular grains, embedded in a cryptocrystalline matrix of variable proportion, enriched in iron oxides. This then results in a very poorly sorted rock.

4.4.1.3 Provenance.

The monocrystalline quartz grains present within these sandstones were most probably derived from massive plutonic rocks (Blatt et al., 1972, p. 277). According to Kerr (1959, p. 268), microcline and albite are minerals to be found in a granitic environment. Also, considering the presence of granitic pebbles in the lower portions of some cross-bedded units, it would appear that the sandstone as a whole has a predominantly granitic provenance.

The direction of transport (280°) points to a provenance located to the east-southeast of Basberg 416.

4.4.1.4 Genesis of the Beaufort Group at Basberg 416.

Since the Beaufort sediments at Basberg 416 were deposited on a delta plain of a prograding delta (previously mentioned), they seem to fall well in line with the inter-channel and levee deposits of Mutti (1977, p. 110). Features like coarse-grained channel-axis facies, which laterally grade into finer-grained, and thin-bedded channel-marginal facies (Mutti, 1977, p. 110), are common in these sandstones (Fig. 4.13 , 4.14). A mudstone which differs in colour and texture from the Tierberg shales, is located in the southern part of the outcrop. These can be correlated with Mutti's (1977, p. 110) levee mudstones, whilst the underlying, almost massive and fine-grained sandstone appears to be of the inter-channel facies.

The material present in these sandstones may either have been deposited by meandering rivers or braided rivers. Of these, the braided rivers have the highest flood velocities (Miall, 1977, p. 9). Considering that the sandstones consist of pebbles and coarse to medium-grained sands, a fairly high flood velocity must be proposed to justify the occurrence of the coarse material within these sandstones. These features suggest that the sandstones have originated in the flood plain of a braided river.

The deposition of predominantly foreign material in these channels points to the fact that they were cut into Tierberg sediments prior to the infilling of the channels. All the eroded Tierberg shales were, however, not removed from the channels floors, as is indicated by the presence of mud pebbles on the bottom of some sandstone facies.

In the higher cross-bedded units scours, filled with pebbles of a granitic nature, are fairly common. Such scours most probably have originated during catastrophic floods within the active regions of the river channel.

Comparing the above-mentioned features, with those obtained by Miall (1977, p. 46-47), the type of braided river which best suits the Basberg deposit would be the Bijou Creek type which represent the deposits of ephemeral streams, characterized by catastrophic floods (Miall, 1977, p. 48, Visser and Dukas, 1979, p. 152).

4.4.2 The Outcrop at Erweesrant.

This hill is located to the southwest of Bultfontein. These sandstones have a characteristic white colour and grade from cross-bedded (bottom to almost massive at the top).

Microscopic observations have revealed the following:

(1) The white colour of the sandstone can be contributed to the high (± 95%) percentage of quartz grains.

(2) Albite is the only other mineral present.

(3) Grain sizes range from 0,05 - 0,2mm in diameter.

(4) Very little matrix is present in the rock.

(5) Grains are predominantly angular.

(6) The rock is very poorly sorted.

Considering the above-mentioned features, they most probably represent the channel-marginal to inter-channel facies of the fluvial cycle (Mutti, 1977, p. 111).

4.4.3 The Outcrop at Lubbefontein 81 and Zaaiplaats 514.

This outcrop is situated to the south of the Theunissen - Brandfort road. The Beaufort succession in this area consists of an arkosic sandstone, similar to the one described for Basberg 416. The only difference in this deposit is the absence of a pebble conglomerate on the base of some cross-bedded facies.

Trough cross-bedding, resulting from the downstream migration of lunate bars in the palaeochannel is a most common feature in these sandstones (Fig. 4.15 , 4.16). One trough was found to be some 16m in width, with an orientation (trough axis) of 175° (Fig. 4.16). Measurements made on other trough cross-bedded facies gave mean transport directions of 162°. This would imply that the provenance was situated to the north.

Considering that this rock also consists of quartz, microcline and albite grains, the provenance appears to be of a granitic nature (see provenance of the Beaufort rocks at Basberg 416). Taking the transport direction of material into account, the provenance may well have been located within the Wesselsbron Arch (see chapter on Archean granites).

Figure 4.15 Trough cross-bedding in Beaufort sandstones at Lubbefontein 81 (T = trough axis).

Figure 4.16 Large-scale trough cross-bedding in Beaufort sandstones at Lubbefontein 81 (T = trough axis).

4.5 Conclusion.

The Karoo Sequence in the area under discussion commenced with the deposition of the first glacial deposits on a floor consisting predominantly of Ventersdorp rocks. During this glacial period ice sheets moved along pre-Karoo valleys or valleys excavated by ice movement. Where melting of an ice sheet's front occurred, glacial debris was piled up. Most of these valleys were quite deep, so that the deposition of tillite and varved shales only took place within them. With a steadily warming climate, the Gondwana ice sheet retreated, leaving behind variable thicknesses of glacial outwash material. During this period, plant life flourished in certain areas, which gave rise to the presence of coal lenses in some of the coarser units of the glacial outwash sediments.

With the further retreat of the Gondwana ice sheet, conditions became more and more neritic. Close to the sea floor, stagnant conditions prevailed, which resulted in the formation of very dark shales of the Prince Albert Formation. This period was concluded with the deposition of laminated shales of the Whitehill Formation in a few selected areas.

With a regression of the sea, coarser sediments, e.g. silt and fine sands, were once more transported deeper into it, marking the beginning of the Tierberg Formation.. The latter period was rather short-lived and once more followed by a period of neritic conditions, during which prodelta muds were deposited. Non-stagnant conditions on the sea floor gave rise to the formation of non-carbonaceous, light-grey mudstones and shales.

Along the shore line deltas developed at the larger estuaries. These deltas, because of the ample supply of material from the inland, were able to build outwards fairly rapidly. In this manner the prodelta platform muds overlain by siltstone, were formed. Further upwards in the succession these siltstones are overlain by thin rhythmic layers of sandstone and shale. In some instances stagnant conditions once more came into existence during the deposition of the rhythmic sandstone-shale facies.

With the further advancement of the delta front, non-stagnant conditions once more dominated. This period is marked by the deposition of thickish sandstone lenses which rapidly pinch out laterally and upwards and grade into thicker, fairly constant, shale facies.

With the still further progradation of the delta, the above-mentioned sediments were overlain by fluvial sediments of the delta plain environment, marking the beginning of the Beaufort Group. Some of these rivers on the delta plain, had fairly high erosional powers, which enabled them to carve channels into underlying Tierberg shales. After the excavation of these channels deposition of inland material was conducted by ephemeral streams. These streams are fossilised as (1) inter-channel facies, which consist of pebble conglomerates on the channel's base and grade upwards into tabular, cross-bedded, medium-grained sandstone (2) as channel-marginal facies which appear as horizontally bedded, more even-grained, sandstones and (3) as levee deposits which predominantly consist of mudstone and fine silt or sand.

5 INTRUSIVE ROCKS

Intrusive rocks in the area under investigation are as follows;

(2) Kimberlite

(1) Post-Karoo dolerite

5.1 Post-Karoo Dolerite.

Post-Karoo dolerites present in this area usually occur as sills, found between the following rock types;

(1) Ventersdorp and Prince Albert shales.

(2) Prince Albert shales and the Whitehill Formation.

(3) Prince Albert shales and the Tierberg Formation (in areas where the Whitehill Formation is absent).

(4) Tierberg Formation and Beaufort Group.

(5) In the lower part of the Beaufort Group.

In areas where dykes grade into sills, e.g. at Basberg 416 (on the Bultfontein - Bloemfontein road), the dolerite intrusion cuts obliquely across some of the above-mentioned rock types.

5.1.1 Regional Tectonics.

Rhodes and Krohn (1972, p. 20) are of the opinion that the intrusion of post-Karoo dolerites can be related to the regional tectonics of the Karoo basin and that they are independent of older basement structures. Applying their findings to the area under investigation, it would appear that dolerites present here, have intruded through Ventersdorp rocks. The author has thus investigated all outcrops of Ventersdorp rocks present within this area for such dolerite occurrences. The only location where such dolerites were detected, is situated on the farms Sweet Home 280 and Wildebeestfontein 471 (see chapter on Ventersdorp Supergroup). Two dolerite dykes are present here within the Ventersdorp rocks and both show a north-south strike.

Dyke I. This dyke (width approximately 2 m) is intrusive into Makwassie Quartz Porphyry Formation. It is a medium-grained dolerite in which the plagioclase laths attain lengths of up to 10 mm in an ophitic mass of plagioclase and Fe-Mg minerals of smaller dimensions.

Dyke II. This dyke (width approximately 1,5m) is intrusive into the pillow lavas of the Rietgat Formation. It consists of a fine-grained dolerite with no large plagioclase laths. Farther to the north this dyke intrudes into Ecca shales and in this area the dyke seems to grade into a dolerite sheet, which has a northerly dip, and an east - west strike.

On the farm Vryheid 1316, to the west of the Boshof - Christiana road, a dolerite sill was found to directly overlie the Rietgat Formation (see chapter on Ventersdorp Supergroup).

5.1.2 Occurrence of Dolerite Intrusions in the Ecca Group.

Field observations show that most of the dolerite occurrences in the area under investigation are in the form of sills. These dolerite sills usually have a very low dip (1^{o} - 5^{o}). Very few linear structures were observed on aerial photographs, indicating the scarcity of dolerite dykes.

Feeder channels of the dolerite sills in Ecca rocks must be present in this area. These are most probably covered by aeolian sand and/or concealed underneath dolerite sills.

Lombaard (1952, p. 184-185) states that dolerite intrusions consist of dykes and sills, as well as conical sheets of which the bases are located in one or other sill. Further, he states that conical sheets are scarce or even absent, north of $29^{o}30'$S. Semicircular structures, such as are elsewhere formed by conical sheets, were also observed on satellite photos from the area under discussion. The author is thus convinced that a large number of dolerite intrusions in this area can be explained by the conical sheet concept. The bases of these conical sheets were found to be connected to feeder channels in pre-Karoo rocks. This can be demostrated at Wildebeestfontein 471 (see Ventersdorp Supergroup) where dolerite dykes, present within Ventersdorp rocks, tend to grade into dolerite sheets in areas where they intrude Ecca rocks.

5.1.2.1 Mechanism of Dolerite Intrusions.

The following principles have an effect on the intrusion of an igneous body;

(1) Intrusion will always occur from an area of

higher pressure to an area of lower pressure.

(2) The path of intrusion will always occur along regions that offer the least resistance.

Zones that would offer the least resistance to an intruding magma may be as follows (also see Meyboom and Wallace, 1978);

(1) The contact between two lithologically different rocks, e.g. Prince Albert shales and the Whitehill Formation.

(2) Joints within the rock that is being intruded

(3) Post-Karoo faults will not be considered here, as no evidence of these is present in this area.

Taking the above-mentioned features into account, it would imply that a basaltic magma will move along the contact of two lithologically different rock types, as long as jointing within the host rock is limited. Reaching an area of jointing, the magma will tend to flow upwards along these joints, and thus "jump" from a lower to a higher stratigraphical position in the host rock.

This phenomenon was observed to the west of Presentpan (on the Hertzogville - Christiana road). Here, a lower dolerite intrusion is present on the western rim of the pan. This intrusion is overlain by the Whitehill Formation. Farther to the west, a dolerite ridge (height ± 20m) is present. This intrusion appears to overlie the Whitehill Formation. A more detailed study (Fig 5.1) showed that both dolerite occurrences belong to the same sheet. Here the "jump" of the dolerite intrusion, from a lower to

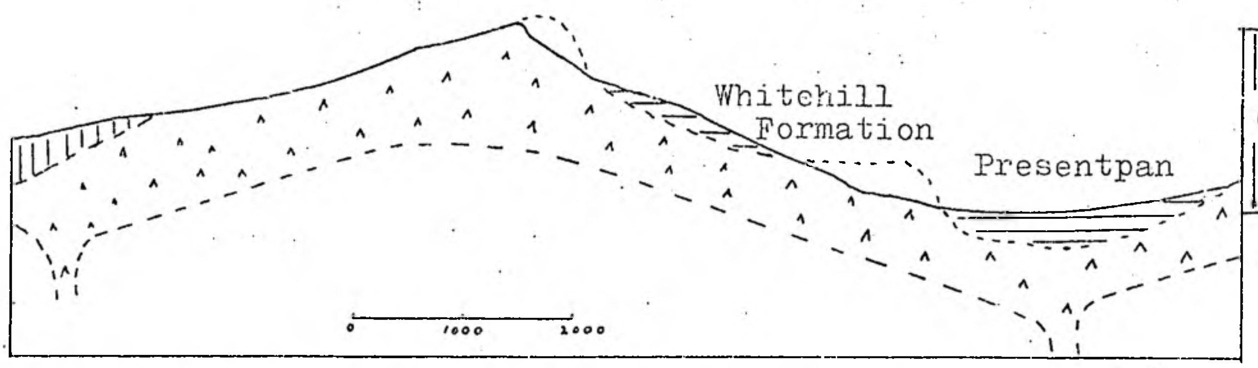


Figure 5.1 The Dolerite sheet at Presentpan.

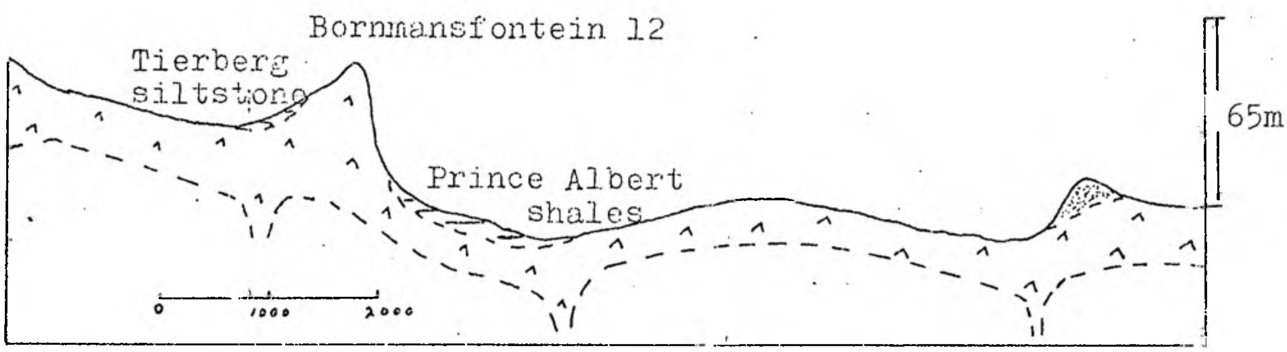
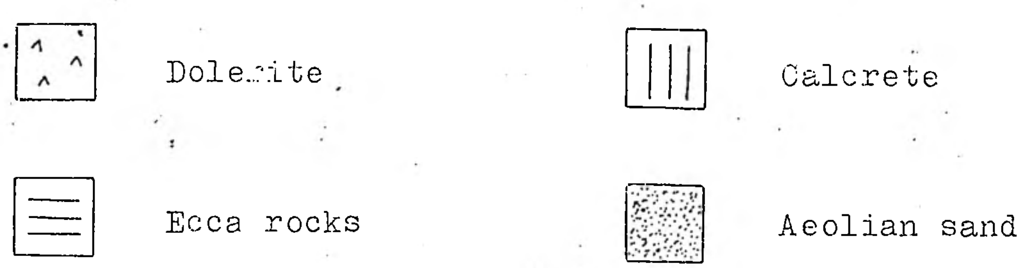


Figure 5.2 The Dolerite sheet at Bornmansfontein 12.



Legend of Figure 5.1 and 5.2.

a higher stratigraphical position within the host rock is thus one way in which this phenomenon can be explained satisfactorily. Similar results were obtained from the dolerite occurrence to the north of Presentpan.

Taking the above-mentioned dolerite occurrence at Presentpan into account, it would appear that it is part of a conical sheet, with Presentpan occupying more or less the centre of the cone. A section (Fig. 5.2) at Bornmansfontein 12 (on the Hertzogville - Bultfontein road) shows the same features as those described for Presentpan.

Rietfontein se Pan (on the Hertzogville - Boshoff road) appears to show the same features as Presentpan, in that it is also surrounded by dolerite sills. To the north of the pan, the dolerite intrusion reaches a thickness of some 70m. It would thus appear that the thickness of a dolerite intrusion depends on the availability of basaltic magma, as well as the ease with which the overlying strata can be displaced.

5.1.3 Occurrence of Dolerite Intrusions in the Lower Portion of the Beaufort Group.

Rocks of the Beaufort Group crop out in a few small isolated areas only. At Basberg 416 and Erweesrant dolerite sheets overlie lower Beaufort rocks. None of the above-mentioned locations were, however, suitable for a study on the intrusive nature of dolerite into lower Beaufort rocks, and thus an intrusive relationship between dolerite and the lower portion of the Beaufort Group could not be formulated.

5.1.4 The Undulating Appearance of Dolerite Intrusions.

The conical sheet concept explains this phenomenon very effectively. In areas where the feeder channels through the pre-Karoo rocks are fairly closely spaced, the flanks of various conical sheets may join. Considering that a dolerite always intrudes from a lower to a higher stratigraphical position in the host rock (previously mentioned), the position where the flanks of two different conical sheets merge, will thus be located at the highest position (also see Meyboom and Wallace, 1978). During aggradation, the overlying, softer, sedimentary material will be removed (see chapter on pans). This will result in the merging spots remaining as domes.

A section drawn from the centre of one conical sheet to the centre of the other conical sheet, via the dome (Fig, 5.1 and 5.2), shows that the dolerite intrusions as a whole attain an undulating appearance. If the latter is now extended over the area between Hertzogville and Bultfontein the dolerite occurrences present here probably formed during a single major event, during which different intrusions merged, resulting in the formation of one undulating dolerite sill. Meyboom and Wallace (1978) have noted similar dome and basin structures in the Bongolo Valley.

5.1.5 Lateral Continuity of Dolerite Intrusions.

Dolerite was not found as one continuous layer over the whole of the mapped area. This may well be the result of one or more of the following features;

(1) Some dolerite was removed during the latest stage of denudation.

(2) In areas where feeder channels in pre-Karoo rocks are too far apart, the flanks of conical sheets could not merge, thus leaving areas barren of dolerite.

5.1.6 Metamorphic Effect of Dolerites.

5.1.6.1 The Ecca Group.

The metamorphic effects of dolerite on the adjacent Ecca shales vary from place to place. In some instances, contact metamorphism caused only slight induration, whilst in other areas lyddite has developed.

The best example of lyddite development in the area was observed on top of a dolerite sill on the farm Rustpan 747 on the southern Hertzogville - Christiana road where about 30 cm of lyddite is exposed. The sill crops out to the north of the farm house. The above-mentioned spot must have been very popular during the Stone Age, as a fairly large amount of man-made artifacts are preserved among the rubble. On the farm Rosendal 518, to the north of Inkpan, only a thin indurated zone is present on top of the dolerite sill. Over the rest of the area contact zones between dolerite and the overlying host rocks are scarce. The latter can be ascribed to aggradational processes during which most of the metamorphic material on top of dolerite sills were removed.

Ecca shales present underneath a dolerite sill can be observed on the farm Basberg 416. These shales are only slightly harder than their equals in other areas. The metamorphic effect of dolerite on underlying Ecca shales must thus have been less than that on the overlying Ecca shales, a phenomenon also recorded by Du Toit (1920, p. 15-17).

5.1.6.2 The Lower Portion of the Beaufort Group.

As previously mentioned, dolerite sheets overlie Lower Beaufort rocks at Basberg 416 and Erweesrant. Here, the contact metamorphic effect of dolerite has caused the lower Beaufort sandstones in its immediate vicinity (± 10 cm) to be indurated

5.1.7 Conclusion.

The mafic magma which gave rise to the formation of dolerite sheets intruded through Ventersdorp rocks in dykes of variable widths and lengths. Once the magma left these dykes in the Ventersdorp rocks they were distributed along weak zones within the Ecca and Beaufort (where present) sedimentary rocks. In areas where these dykes have merged they appear as an undulating dolerite sill.

Considering that the Ecca Group in this area very seldom reaches more than 100m in thickness and that the thickness of these dolerite intrusions vary from less than 20m to some 70m, it would seem logical to conclude that only one undulating dolerite sill can be postulated in the area under investigation.

5.2 Kimberlite.

The only kimberlite intrusion in the area under investigation is found at Rovic Diamonds Ltd. Rovic Diamonds Ltd is situated near the Hertzogville - Dealesville road approximately 50 km from Hertzogville. The Rovic Diamond mine is known in various other writings by its older name, viz. Roberts Victor Mine. Other diamond mines in the vicinity are situated to the west, but these are outside the area under investigation and will thus not be considered in this writing.

A detailed study of the mineralogy and the emplacement history of the kimberlite at Rovic Diamonds was conducted by Geringer (1969). Geringer's study is used in this investigation to obtain a better understanding of the geology of the area under investigation.

5.2.1 General Geology at Rovic Diamonds.

More than 10 m of calcrete was observed in the older excavations on the mining site. These calcretes consist mainly of calcified sand under a cover of red aeolian sand of 1-3 m thickness. No outcrops of any other rocks were observed.

The following types of rocks were observed on the mine dumps during the investigation of the mining site:

(1) Kimberlitic rocks.

(2) Dolerite (medium-grained).

(3) Ecca sediments belonging to the Prince Albert and Tierberg Formations.

(4) Ventersdorp amygdaloidal lavas.

(5) Geodes of iron-bearing carbonaceous rocks.

According to Geringer (1969, p. 11-12), the following section may be drawn;

	Thickness	Depth
Ecca sediments (very dark-grey and light-grey shales)	91 m	0 - 91 m
Dwyka sediments (sandy, grey shales with lava clasts)	2 m	91 - 93 m
Ventersdorp amygdaloidal lavas	unknown	+93 m

Geringer (1969, p. 12) is, however, not very certain about the above-mentioned thicknesses, as the core logging was apparently of a low standard. No mention is, however, made of the Whitehill Formation by Geringer (1969). Since the author himself has not observed any rocks on the mine dumps that could possible represent Whitehill sediments it would appear that it is absent in this region.

The presence of Beaufort sandstone as inclusions in the kimberlite at Rovic Diamonds is mentioned by Geringer (1969, p. 20) and Wagner (1971, p. 49). This then inevitable implies that the Ecca shales, which today are the uppermost older sedimentary rocks in the area on which younger sediments e.g. calcretes and aeolian sands are deposited, were overlain by higher sedimentary strata at the time of the kimberlite intrusion.

6 CALCRETE DEPOSITS.

6.1 Introduction.

Calcrete covers large tracts of the area investigated. The largest of these deposits are usually situated on plains. Some smaller deposits are found on higher ground where they generally form thin crusts over dolerite and Ecca rocks.

In terms of the classification of Netterberg (1969, p. 23 - 39) two main types of calcrete were recognised, viz.

(1) Nodular calcrete, which at Rovic Diamond Mines (see chapter on kimberlite) attains a thickness of more than 10 m.

(2) Hardpan calcrete, which very seldom reaches thicknesses of more than 3 m.

6.2.1 Nodular Calcrete.

Nodules ranging up to 4 cm or more in diameter are most frequently found on some pan floors and in areas where the overlying sand cover has been removed. It is of special interest to note that these nodules are only observed in areas where a considerably large amount of unconsolidated material, e.g. aeolian sand, is present. This points to the conclusion that the formation of small nodular calcrete is promoted in environments where soil moisture movement is possible and where enough fine material is present. The finer materials may serve as nuclei around which lime, being distributed by soil moisture movement, can be precipitated. The volume of calcrete nodules present in any particular environment will now depend on the amount of lime distributed by the soil moisture as well as the time over which precipitation has occured.

6.2.2 Hardpan Calcrete.

This type of calcrete is usually underlain by nodular calcrete (Netterberg, 1969, p. 29), but cases do exist where they directly overlie older strata.

6.2.2.1 Gravelly Hardpan Calcrete (Netterberg, 1969, p. 31).

This type is present to the north of the Vaal River where it is associated with some of the Older Gravels (see chapter on Vaal River Gravels).

6.2.2.2 Laminated Hardpan Calcrete (Netterberg, 1969, p. 30).

This is one of the most common type of hardpan calcretes present in the mapped area. In general these are located on higher ground, away from drainage channels. A large outcrop is present to the east and west of the Hertzogville - Dealesville road (approximately 21 km from Hertzogville).

In some instances small fragments of light-grey Tierberg shales are present within these calcretes (fig. 6.1). This indicates that this calcrete has originated by replacement of the above-mentioned shales. Where total calcification of Ecca sediments has occurred, undulatory lamination is a most common feature (fig. 6.2).

Figure 6.1 Uncalcified remains of Tierberg shales in a calcrete deposit (c = calcrete and s = shales).

Figure 6.2 Laminated hardpan calcrete (l = laminated calcrete and n = nodular calcrete).

6.2.2.3. Shattered Hardpan Calcrete. (Netterberg, 1969,p.31)

These were observed in isolated cases where they overlie dolerite sills. Here the calrete may have originated through seepage, or the in situ weathering of Ecca shales, which once overlay these dolerites. Where the layers are less than 10 cm in thickness, they have most probably originated through seepage.

6.3 Genesis of Calcrete.

6.3.1 Influence of Climate.

Older writers believed that the formation of calcrete is solely dependant on the climate of the region in which they occur. Mason et al. (1959, p. 568) verified these previous statements, in rather ascribing the formation of calcrete to subsurface waters percolating to the surface in seepage areas. In these seepage areas, carbonate-enriched water is evaporated, resulting in the precipitation of lime in the form of calcrete.

Chilingar et al. (1967, p. 175) arrive at an origin for calcrete similar to that of Mason et al. (ibid) and stated that the formation of calcrete is dependant on the upward movement of soil moisture during periods when evaporation exceeds precipitation. According to Netterberg (1969, p. 224), the latter can only have an effect if the water table is between 1 and 2,5 m below the surface. At higher depths, transpiration and CO_2 loss are responsible for the formation of nodular calcrete.

The mean annual rainfall in the area under investigation is low (approximately 550 mm p.a.). However, most of the rain occurs during the summer months, with the rest of the year being fairly dry (Butzer, 1974, p. 16). The downward seepage of rainwater into the soil is thus limited to these short periods of high rainfall only. For the rest of the year evaporation dominates, resulting in the upward movement of soil moisture by capillary action. These upward moving soil moistures are able to dissolve carbonates, and carry them in solution to regions, in or above the soil, where evaporation takes place. Here lime is then concentrated in the form of calcrete.

Similarly, dissolved carbonate in subsurface waters will be precipitated from solution in seepage areas where, and as with soil moisture, evaporation takes place.

6.3.2 Other Features.

6.3.2.1 Temperatures of the Fluid.

Colder waters are able to hold more carbonate in solution than warmer water. If these colder subsurface waters now percolate to the surface in seepage areas, they will become supersaturated when heated by solar energy. This may then result in some of the lime being precipitated (see also Krauskopf, 1967, p. 53).

6.3.2.2 Carbon Dioxide Content of the Fluid.

During the decay of organic material in soils, carbon dioxide is released, and as it is one of the heaviest natural gases, a larger concentration of it will be present beneath the soil surface than on top. Krauskopf (1967, p. 66) states that this carbon dioxide concentration can be as high as 1 atm. From this it can be concluded that water percolating to the surface in seepage areas, are transported from a higher to a lower carbon dioxide concentration. Once exposed to surface conditions, these waters will lose some of their dissolved dioxide and precipitation of lime is possible.

6.3.2.3 Evaporation of the Fluid.

It is obvious that precipitation of lime will occur in places where carbonate-bearing waters are evaporated. Evaporation may either take place in the soil itself or in regions where the water table is high enough to reach the surface.

6.3.2.4 Concentration of Carbonates in the Fluid.

The readiness with which lime will be precipitated from a solution is directly proportional to the concentration of carbonate in the solution, with the concentration again a function of temperature.

6.3.2.5 Presence of Nuclei.

Krauskopf (1967, p. 67) states that if a solution is supersaturated with carbonates precipitation can be speeded up through addition of carbonate crystals. Siesser (1973, p. 545-550) has found that sand grains surve as nuclei around which carbonate can be precipitated. Abundant sand and other finer material which may serve as nuclei are present in the area under investigation and serve to stimulate precipitation of lime from solution.

6.3.2.6. Organic Activity.

Shell organisms are usually found in areas where a constant supply of surface water is present. In the area under investigation the only locations that receive a steady supply of surface water appear in the immediate surrounding of the Vaal, Vet and Sand Rivers. The rest of the area is dry with very little surface water, and thus it is not considered that organic activity played an important role in the formation of calcrete in this area.

6.3.3 Origin of Lime Necessary for the Formation of Calcrete.

Lime can be derived from the following rocks:

(1) Carbonate rocks.

(2) Rocks containing minerals enriched in calcium.

(3) Unconsolidated sediments.

(4) Fossils.

6.3.3.1 Weathering of Carbonate Rocks.

The carbonate rocks of the area under investigation can be divided into the following subdivisions:

(1) Young carbonates e.g. calcrete. Calcretes in this area are usually situated in regions that are ideal for the precipitation of lime. Leaching of carbonates from calcretes will thus only lead to a better

distribution of lime and not necessary to an increase or decrease in the volume of the calcrete deposit itself.

(2) <u>Older carbonate rocks.</u> In the eastern section of this area, a "boulder-like" limestone concretion is present in the Tierberg shales and sandstones. Where these "boulders" have weathered away completely "pothole-like" structures are left behind. These limestones may well be considered as a source rock for the calcretes.

(3) <u>Sedimentary rocks with a calcareous matrix.</u> Sandstones of the Tierberg Formation very frequently have a calcareous matrix which can then also serve as a source rock in the formation of calcrete.

6.3.3.2 <u>Rocks Containing Minerals Enriched in Calcium</u>.

These rocks can be subdivided as follows;

(1) <u>Igneous rocks</u>. Dolerite outcrops cover large areas. Most of the calcium in these rocks is contained in the plagioclase and Fe-Mg minerals. Through weathering of these minerals calcium is set free. Some of the Ventersdorp igneous rocks also contain calcium-bearing minerals from which calcium will be freed through weathering.

(2) <u>Sedimentary rocks</u>. Small-pebble conglomerates are present in some of the Ventersdorp (Rietgat) outcrops as well as in certain Beaufort sandstones. The anorthite-rich plagioclases in these conglomerates can supply lime on weathering.

During the investigation of areas of poor drainage, it was noted that Ecca shales and mudstones (if present) are undergoing intense calcification (fig. 6.3). This phenomena can be brought about by one or both of the following processes;

(1) The exchange of calcium ions between the shales or mudstones and the surrounding environment and/or

(2) The weathering of calcium-bearing minerals in these shales and mudstones.

In areas of poor drainage lime is being precipitated in situ. In areas of better drainage lime is less abundant which implies that it is most probably kept in solution and thus transported from its source by water.

6.3.3.3 Leaching of Unconsolidated Sediments.

Aeolian sand deposits on the south-eastern rims of pans are sands mostly derived from the pans themselves (also see chapters on pans and on aeolian sands). These sands are generally underlain by nodular calcrete. In some instances these calcretes are fairly pure, but in most cases they consist of nodular concretions, up to 4 cm in diameter, embedded in a sandy matrix. This has led the investigator to the conclusion that these calcretes have originated through the leaching of lime from the overlying aeolian sands.

During wind erosion of these pans, calcium-bearing minerals are concurrently eroded with detrital material. After the deposition of these materials, calcium is released by weathering of the calcium-bearing minerals, resulting in the formation of lime. Subsurface waters are then responsible for the further distribution of lime as well as the formation of calcrete nodules in these aeolian sands.

6.3.3.4. Fossils.

Very few fossils of either plant or animal origin were observed during the investigation of the area. Thus, only a minor amount of lime could have been contributed by fossil remains.

6.3.4 Conclusion.

From all the above-mentioned possibilities concerning the origin of lime, by far the most important are the Ecca shales (Tierberg and Prince Albert Formation). Most of the calcrete deposits were found to contain small remnants of Ecca shales. The alteration of calcareous nodules (present in Tierberg shales) into calcrete was observed on the Farm Basberg 416 (on the Bultfontein - Soutpan road).

Since dolerite can also contribute calcium it must be considered a noteworthy source rock for the formation of calcrete. Its contribution was, however, far less than that of the Ecca Group.

Other rock types present in this area crop out in isolated areas only and can thus not be considered as having contributed much calcium necessary for the formation of the extensive calcrete cover.

Fig. 6.3 Section through a typical Calcrete Deposit.

A Aeolian sand.

B Nodular calcrete.

C Hardpan calcrete.

D Ecca shales (Prince Albert or Tierberg).

E Dolerite.

No thicknesses are given in the above section, as they tend to vary considerable over fairly short distances. It is also not essential that all the subdivisions (viz. A, B, C, D and E) need be present in any one area. The sequence in which the subdivisions follow, nevertheless hold over most of the area under investigation, e.g. should B be absent in a particular area, C would be overlain by A, etc.

The following are some of the most common sequences to be observed in this area;

(1) A,B,C,D and E present. Mostly in areas covered by 2 m or more of aeolian sand.

(2) A,C and E present. Mostly in areas where Ecca shales have been totally calcified.

(3) C,D and E present. Mostly in areas where deposition of aeolian sand is limited.

7 AEOLIAN SANDS.

7.1 Introduction.

Large parts of the area under investigation are covered by aeolian sand. The colour of these sands varies from red to brown to light grey, depending on the type of environment in which they have been deposited.

Two types of aeolian sand may be distinguished, viz.

(1) Aeolian sands deposited as sheets. These sands are encountered over most of the area. They vary from a few mm to 5 m or more in thickness, with the greatest of these thicknesses being attained in the northern and eastern parts of this area. Small dunes, generally not exceeding 10 cm in height, are readily found on these sand surfaces.

(2) Aeolian sands deposited as dunes. Dune-like sand deposits in this area are usually situated on the south-eastern rims of pans. Here they may attain thicknesses of 8 m or more. A few other dune-like deposits were observed on the north-western side of dolerite outcrops.

7.2 Climate.

Flint (1959, p. 365) suggested that the mean annual rainfall for a region is not the only factor controlling ~~cannot solely be kept responsible for~~ the formation of aeolian sand deposits. To justify the latter statement he states; "At Elizabethville, north-east of the sand region, the annual mean is 47 inches, but of this amount only 1,3 inches falls during the 6-month dry season. Because of this strong seasonality it would be unrealistic to apply a 16-inch threshold deduced from less seasonal areas on other continents and suggest that annual rainfall was formerly 30 inches less than today. It is more likely that, with such seasonality, only a moderate reduction of today's rainfall could cause movement of sand during the dry seasons."

The investigation of this area was conducted during a period of drought. This has enabled the author to deduce certain features concerning the movement of older aeolian sands, which would not have been possible, had the area received its normal annual rainfall. The reactivation of sand was especially recognizable in some ploughed fields, where, because of the drought, very little vegetation was present. Large deflation hollows were formed in these fields during this period. Taking Flint's (1959, p. 365) statement into account, it would thus appear that the reduction of rainfall has also caused the reactivation of older aeolian sands in this area.

Glennie (1970, p. 173-193) states that the colour of some aeolian sands is dependent on the climatic conditions of the area in which they are found. He also states that red sands are more abundant in semi-arid regions with a high variation in seasonal rainfall.

According to available meteorological reports the mean annual rainfall is fairly low;

Boshof area	452 mm
Hertzogville area	±420 mm
Bultfontein area	±650 mm

Further, most of the precipitation occurs during the summer months. It is thus possible that the red colour observed in some of these aeolian sands is partly the result of prevailing climatic conditions in the area (Glennie, 1970, p. 173-193).

7.3 Genesis of the Sand.

Aeolian sand present in this area mainly consist of quartz grains (at least 95%), with minor amounts of feldspar, mica and heavy minerals. Whether or not these sands have originated in the Kalahari is debatable, but the author is convinced that at least 95% of these sands consist of locally derived material, or material transported over fairly short distances only. This conclusion is based on the fact that most dune deposits are situated in the vicinity of wind-deflated hollows (also see Visser *et al.*, 1975, p. 157-158).

Quartz, because of its mineralogical stability, is usually more resistant to chemical and physical weathering than feldspars and most mafic minerals found in igneous rocks. This may then well explain the high percentage of quartz grains present in these aeolian sands.

Aeolian sands may have been derived from the following rock types;

(1) Ventersdorp rocks present in this area mainly consist of quartzites, andesitic lavas and felsic rocks (quartz porphyry). These rocks do, however, not weather very readily, and as only isolated outcrops are present within this area, they have most probably not contributed much material for the formation of aeolian sands.

(2) Ecca sedimentary rocks present in this area mainly consist of sandstone, siltstone and shale. Of these, the sandstones have most probably contributed most of the material present in aeolian sands. In the western region where these sandstones are the most abundant large sheets of aeolian sands are present. The farmers have been unable to distinguish between aeolian sands and sandstones in percussion drill holes so that, with few exceptions, data on the thickness of sand cover could not be obtained in this way.

(3) Dolerite. During the weathering of dolerite, iron oxides are freed from iron-bearing minerals. These iron oxides are then circulated by soil moisture and precipitated in suitable environments, often interstitially between grains. The rest of the minerals present in dolerites, when weathered, usually produce clay minerals, which is virtually absent in aeolian sands.

7.4 Dunes.

7.4.1 Dunes Situated on the South-Eastern Rims of Pans

These dunes consist of material derived from the adjacent pans (see chapter on pans). Further, it was found that dunes that extend from the pan floor upwards are more calcified than dunes that are more remote from the pan of which material is being derived.

A dune that extends from the pan floor upwards is located on the farm Nooitgedacht 343, some 4 km west of Hertzogville. This dune reaches a height of approximately 30 m above the pan floor. Most of the sand in this dune is calcified, except for that located at the very top of the dune. Lime may have originated from one or both of the following; (a) erosion of calcium-bearing minerals from the adjacent pan, (b) leaching of lime from underlying strata.

A more remote type of dune is located on the farm West Rietfontein 472, approximately 1 km to the south-west of Rietfontein se Pan, near the Boshof - Hertzogville road. This dune consists predominantly of red aeolian sand, with calcrete occupying the lower portions only. The thickness of the aeolian sand varies between 5 to 20 m. The vegetation present on the dune is typical of the "Kalahari Thornveld" as described by Acocks (1975). This deposit of aeolian sand should not be considered "old" because of the ample vegetation present on it, but should rather be seen as an area of continual aeolian sedimentation.

7.4.2 Dunes Situated Near Dolerite Outcrops.

These dunes are characteristic in that they are predominantly elongated along some of the north - south and east - west striking dolerite outcrops, and not at right angles to the prevailing wind direction. Further, it is not always possible to directly connect them with one or other pan in the immediate area.

Most of these dunes originate in that sand is blown against inselbergs, e.g. Vaalkop, which is situated on the farm Naudesfontein 263, approximately 35 km south of Christiana. In this case, only the foot of Vaalkop is covered by sand. In areas where these inselbergs are not elevated high enough above the surrounding plains, total covering by aeolian sand is possible, e.g. in areas to the west of Hertzogville.

7.5 Colour of Aeolian Sands.

The colour of aeolian sand usually depends on the minerals that encrust the quartz grains. If hematite is present, the sand will have a red colour, whilst an abundance of lime will result in the sand attaining a light-brown or light-grey colour. In areas where none of the above-mentioned colouring agents are present sands will show the colour of the rock from which they have been derived (Glennie, 1970, p. 173-193).

7.5.1 Surface Waters.

If aeolian sands are deposited in surface waters, the following processes may occur;

(1) If the grain was encrusted by either hematite or lime, this crust can be removed by chemicals in these waters.

(2) If the water has a high salinity, sand grains may serve as nuclei around which salts can precipitate (see chapter on calcretes).

(3) Aeolian sands can be incorporated in alluvium.

From the above-mentioned features it can be concluded that aeolian sands, deposited in surface waters, will lose at least some of their properties. This phenomenon was observed in the following regions;

(1) Pans in this area are usually surrounded by

red aeolian sands. None of these red sands were, however, observed on any of the pan floors, except for rather short periods after the last thunderstorm.

(2) The flood plains of the Vaal, Vet, and Sand Rivers, as well as their immediate tributaries, are all surrounded by red sands. The sands present in their flood plains, all have a light-grey to light-brown colour.

7.5.2 Soil Moisture.

The colouring agents, hematite and lime, are predominantly distributed by soil moisture. During the dry seasons, moisture is moving upwards in the soil by capillary action. In its upward movement iron molecules and lime are simultaneously transported upwards. According to Mason et al. (1959, p. 568) and Flint (1959, p. 359-361), precipitation of iron oxides and lime will occur in regions where the soil moisture is evaporated.

The following colours of sand result from the abovementioned process;

(1) Red Sands. These sands obtain their colour from the iron oxides that encrust them. They are generally unconsolidated, which allows a free movement of air within the sand itself. Iron, entering these sands (by iron-bearing solutions) will thus be oxidized very readily, resulting in the formation of hematite and other, red, iron oxides. The latter oxides are mostly precipitated on quartz grains, as no duricrust, and very little ferricrete nodules are present in these sands.

The intensity of the sand's colour will depend on the amount of iron present in the environment. Where an ample supply of iron is present, e.g. in areas where sands overlie dolerites, the red colour of the sand is much more intense.

During the investigation of the area very few plant remains have been found in these aeolian sands. This phenomenon may well be ascribed to the high oxidation rate in these sands, by which plant material is removed very rapidly.

(2) Light-grey and Light-brown Sands. These sands are more abundant in areas where calcretes and/or Ecca shales are present. Lime that is precipitated in these sands will encrust quartz grains, resulting in the lighter colour of the sand deposit as a whole (see also chapter on calcretes).

8 ALLUVIAL DEPOSITS.

8.1 Introduction.

Only three prominent rivers are present in the area under investigation. They are the Vaal, Vet, and Sand Rivers. Other smaller drainage systems are either blocked by aeolian sands or tend to form part of an internal drainage system which is connected to one or other pan. Because of the latter, these smaller drainage systems are discussed in the chapter on Pans.

The alluvial deposits of the different rivers show characteristic variations, and thus the following subdivisions were made;

(1) The Vaal River alluvial deposits consist of coarse as well as fine-grained material.

(2) The Vet and Sand River alluvial deposits. These deposits consist predominantly of sand and silt, with only a few minor lenses of coarser material.

8.2 Development of the Lower Vaal River Basin.

The part of the Vaal River present in this area is considered by Butzer *et al.* (1973) as belonging to the Lower Vaal River, a concept which is accepted throughout this writing.

Van Riet Lowe (1952, p. 135-137) completed a study on the Vaal River from Klerksdorp to Barkly West, a distance of well over 450 river km. From this study he concluded that the Vaal River as a whole is gradually eroding its way in a southerly direction; "The southward migration of the Vaal is due to the fact that it has eroded or `eaten into ' the less resistant deposits of the Karoo System that overlie extensive sheets of more resistant, but generally gently south-sloping Ventersdorp Diabase."

The author agrees with the statement of Van Riet Lowe (1952, p. 135-137) concerning the erosion of the Vaal River along less resistant rocks, as a similar observation was made by Butzer (1974) on drainage basins to the east of Kimberley. All the Karoo rocks have, however, not been removed by the Vaal, as Prince Albert shales were observed by the writer in a borehole (depth $\pm$ 20 m) and in a nearby pit, on the farm Cawoods Hope 324 HO (X_1 on map, fig. 8.1). These Prince Albert shales are overlain by laminated hardpan calcrete, which indicates that these calcretes were most probable derived from the Prince Albert shales (see chapter on calcretes).

The southward migration of the Vaal River as a whole, as proposed by Van Riet Lowe (1952, p. 135-137), is in the writer's opinion a little far-fetched. Kleynhans (1979) and P.J. Botha (in preparation) who mapped the areas to the west and north, respectively, have found no southerly inclination of Ventersdorp rocks over such large areas. Liebenberg (1977, p. 76) on the other hand, proposes a possible easterly dip of 10° on Allanridge lavas. It would thus appear that the Vaal River's flow pattern can best be ascribed to the aggradation of softer Karoo sediments along a pre-Karoo valley. Where dolerites have intruded these Karoo sediments, the flow pattern could deviate slightly from the latter.

Dwyka tillite, if present in this area, was thus not exposed during the aggradation of the Vaal River. This then would explain why only a minor amount of banded iron formation is present in the gravels of this area. The few pebbles of banded iron formation that are present in the gravels must have been transported into the area by waters of the Vaal River or its immediate tributaries.

On more or less the same level as the current river bed a dolerite sill is present. This sill is covered by various thicknesses of Vaal River gravels.

8.3 The Vaal River Alluvial Deposits.

During his investigation of the Vaal River Basin in the area under investigation, the author found that in the immediate vicinity of the current river bed large sand and silt banks are present. This is quite different from the Vaal River to the east of Christiana (outside the area investigated) where gravels are present in the active river bed itself. These alluvial sand and silt banks must therefore be very young; in fact they must have been deposited only after the completion of the Vaalharts Weir which must have hindered the normal flow of the Vaal River to such an extent, that their deposition on the current level was possible.

Gravels are present on the north-western banks of the river, but no such gravels could be detected on the south-eastern banks in this area. This may well be the result of the meandering of the Vaal River in this area, eroding its way in a south-easterly direction. It is, however, noteworthy to mention that near Christiana gravels are present on the southern banks of the Vaal River. The latter are, however, not considered in this writing as they do not form part of the area under investigation.

According to Söhnge et al. (1937, p. 21) Older Gravels are present to the south of the Vaal River on the farm Beth-el-pella 623. These gravels are resting on terraces of up to 15m from the current river bed. These were most probably deposited by the small tributary of the Vaal River which flows through this area.

8.3.1. Gravels.

During the investigation of the Vaal River Gravels in this area, the following rock types were observed;

(1) Pebbles consisting of Ventersdorp rocks viz.
 (a) Ventersdorp lavas (mafic)
 (b) milky quartz and jasper
 (c) quartzites
(2) Dolerite pebbles and boulders.
(3) Pebbles, possibly derived from Dwyka tillite, viz.
 (a) chert (onyx) (could also have been derived from lavas).
 (b) banded iron formation.

In the further discussion of the Vaal River Gravels the following subdivisions will be made in accordance with Butzer et al. (1973, p. 344-356);

(1) Older Gravels
(2) Younger Gravels

(3) Sedimentary units post-dating the Younger Gravels.

8.3.1.1 <u>Older Gravels.</u>

Cooke (1946, p. 251) and Van Riet Lowe (1952, p. 141) distinguished two categories of Older Gravels, viz.

(1) Basal Older Gravels. They consist mainly of diabase and/or dolerite as well as more resistant material e.g. quartzites, jasper, agate, chert and banded iron formation.

(2) Older Gravels (Red Older Gravels or Potato Gravels) which mainly consist of more resistant material e.g. quartzites, jasper, agate, chert and banded iron formation.

Cooke (1946, p. 251) is convinced that there is no considerable time interval between the deposition of the Basal Older Gravels and the Older Gravels. To justify this he states that the Older Gravels underwent additional reworking after derivation from the Basal Older Gravels. This then also explains why Basal Older Gravels are poorly sorted, coarse-pebble to boulder grade, whilst Older Gravels are well sorted in the coarse-pebble grade.

The occurrence of Basal Older Gravels at different heights above the current river bed is interpreted by Cooke (1946) as representing the different resting stages in the downward cutting of the ancient river. Further, he also states that Basal Older Gravels were deposited in old hollows of the original river bed.

According to Butzer <u>et al.</u> (1973, p. 348) the

Older Gravels must have been redistributed by tributaries of the Vaal, as well as by rainwash. He further states that they may be found as unconsolidated gravels or as a calcreted conglomerate.

Only a small part of the Vaal River drainage basin is present in the area under investigation (Fig. 8.1). Thus the author considered it best to adopt the classification of these gravels by Butzer _et al._ (1973), Van Riet Lowe (1952) and Cooke (1946).

The Older Gravels (Red Older Gravels or Potato Gravels) in this area are found on terraces 4 - 10 m above the current flood level of the Vaal River. Their thicknesses vary from 0,2 - 2 m (Fig. 8.2). These thicknesses can be obtained fairly accurate as diggers were in most cases only working these gravels.

Further, the Older Gravels consist of well rounded pebbles, ranging in composition from agate, onyx, jasper, milky quartz, to banded iron formation and minor amounts of lavas. The size of these pebbles is usually in the range of 7 cm and smaller. The matrix in which they are embedded may either consist of sand or calcrete. An intensely calcified matrix may be observed in the region marked X_2 on figure 8.1 In the region marked X_3 the pebbles lie in a sandy matrix.

According to Butzer _et al._ (1973, p. 345) the above-mentioned Older Gravels are usually found on terraces elevated 20 to 90 m above the current flood level of the Vaal River. The rounding as well as pebble size and composition of the gravels in the area under discussion seem to fit these Older Gravels better than any other gravels described elsewhere in this chapter. Further, if aggradation in the area investigated was slower than in those described by Butzer et al. (1973, p. 345), it would be possible for Older Gravels to prevail on these relative lower terraces.

The Basal Older Gravels in the area under investigation, directly underlie the above-mentioned Older Gravels. They consist mainly of diabase and/or dolerite boulders as well as minor amounts of quartz, jasper, agate, onyx, etc. According to local sources, thicknesses of 25 m have been attained in this area. These gravels were, however, hardly ever exploited by diggers, and thus only the top part is found in excavations.

8.3.1.1.1 Dating of Older Gravels.

Dating of the Older Gravels according to Butzer et al. (1973, p. 348-349) is poor, in that materials suitable for radiometric dating appear to be absent. A crude estimation of 4,8 m.y. B.P. was nevertheless made by him from gravels at Windsorton.

8.3.1.1.2 The Concentration of Diamonds.

From these gravels only the Older Gravels (Red Older Gravels and Potato Gravels) were exploited by diggers in the search for diamonds. Cooke (1946, p. 252) explains this by stating that the Older Gravels are a 10% concentrate of the Basal Older Gravels, and thus the concentration of diamonds in the former are 10 times higher than in the latter. As a result, digging is stopped as soon as boulders of diabase and/or dolerite are encountered.

8.3.1.2 Younger Gravels.

Cooke (1949, p. 62-65, 1946, p. 254-257) and Van Riet Lowe (1952, p. 143) divided Younger Gravels into the following grades, viz.

(1) Younger Gravels I; situated on terraces 6 to 12 m above the river floor.

(2) Younger Gravels II; situated on/or near the river's banks.

(3) Younger Gravels III; situated on the river floor itself.

According to the above-mentioned authors, these different grades need not always be present. Further, Younger Gravels I and II are not always distinguishable because of the absence of proper markers. They also found that the Younger Gravels consist of less rounded boulders (30 cm or more in diameter) and pebbles of diabase and/or dolerite. Pebbles of quartzite, jasper, chert, etc. are present in minor amounts. They distinguished between Older Gravels and Younger Gravels in that the former are better rounded than the latter. Younger Gravels are generally covered by calcified sands or silt.

Butzer et al. (1973, p. 350-351) also divided the Younger Gravels into three grades, viz units "A", "B", and "C". He is, however, of the opinion that the calcified sands that cover the Younger Gravels belong to another period of deposition. Further he states that the Younger Gravels are also diamond-bearing, and thus have been worked by diggers.

A trace of gravels, possibly belonging to the Younger Gravels were found in the vicinity of X_4 (fig. 8.1). These gravels consist of diabase and dolerite boulders as well as minor amounts of quartzites, chert and jasper. In general these gravels are less rounded than the Basal Older Gravels. It is, however, very difficult to place these gravels with absolute certainty as X_4 is the only location where a type of gravel different from the Older Gravels was detected.

Calcified sands were observed in the vicinity of X_5 (fig. 8.1) where they are uncovered in a large trench which is partly submerged in water. If these calcified sands are the same as those described by Van Riet Lowe (1952, p. 143), it would imply that the Younger Gravels in the area under investigation are submerged underneath the current flood level of the Vaal River (also see Söhnge et al., 1937, p. 22).

8.3.1.2.1 Dating of the Younger Gravels.

Van Riet Lowe (1952, p. 143) determined the age of the Younger Gravels from the faunal fossils present in them. He set the age at Middle to Upper Pleistocene. Butzer et al. (1973, p. 351-352) also determined a Middle Pleistocene age for these gravels.

8.3.2 The Youngest Sedimentary Units (Fig. 8.1).

These deposits consist mainly of material currently deposited by the Vaal River as well as material transported into the river by surface runoff. As the river bed in this area is submerged, the only recent deposits that could be studied are the fine sand and silt deposits on the banks of the river.

8.4 The Vet and Sand River Alluvial Deposits (fig. 8.3).

In the south-east of the area under investigation the Vet River has eroded into dolerite as well as Ecca shales and sandstones. The valleys formed by the latter action reach widths of 1 km or more and depths of between 20 and 70 m. On the farm Vaalkoppies 8, next to the Bultfontein - Odendaalsrus road, the Vet River has eroded into Ventersdorp lavas.

To the north, the Vet and Sand River are currently eroding into older alluvium. On the Bultfontein - Odendaalsrus road the river channel depth of the Vet, as well as the Sand River is more than 5 m lower than the flood plain of these rivers. Below the junction of the Sand and Vet Rivers, the flood plain increases notably in width. On the Bultfontein - Wesselsbron road it attains almost a record width of about 6 km. The current river channel in this area is 8 to 12 m lower than the flood plain. According to Coetzee (1960, p. 109-110), the alluvium may attain thicknesses of up to 20 m. He also states that the bottom of the alluvium consists of conglomerate which rests on Ecca rocks. Further, the sediments are cross-bedded with small lenses of conglomerate. Fossil wood as well as the remains of a mammoth have been found in these sediments (Coetzee, 1960, p. 109-110).

To the north of the Vet River's flood plain (below its junction with the Sand River) large sheets of aeolian sand are present. Prevailing wind directions in this area are usually from the north-west. The point which needs to be stressed in the above-mentioned discussion is that large amounts of aeolian sands are blown into the flood plain of the Vet River by the prevailing winds.

Because of the abundant vegetation on the flood plain of the Vet River, winds blowing over it from the northwest will lose their competency and deposition of aeolian material is possible (also see chapter on aeolian sands). After blowing through this vegetated area, the wind is undersaturated with material and active wind erosion may now take place. The latter may than serve to explain the sudden drop in relief from the north as well as the gradual rise in relief to the south of the Vet River. Another explanation for the sudden drop in relief to the north of the Vet River may be the dolerite sill that is present underneath the aeolian sand. It could have formed a scarp to the north of the flood plain.

For a rather small stream like the Vet River to attain such high thicknesses of alluvium, a considerable amount of material must have been deposited by wind and/or water on the flood plain. If more material is blown into the flood plain of the Vet River by wind action than is transported away by its waters, filling up of the flood plain is possible. Further, aeolian sands blown into a fluvial environment may be redistributed by water, thus obtaining an alluvial appearance (also see chapter on aeolian sands). Since at present the competency of the Vet River is low, because of the low relief of the area through which it flows and its low water level, it is only able to erode material deposited in the immediate vicinity of the current river channel.

The latter may than serve to explain the great thicknesses of alluvium in the flood plain of the Vet River, as well as the high banks of the current river channel.

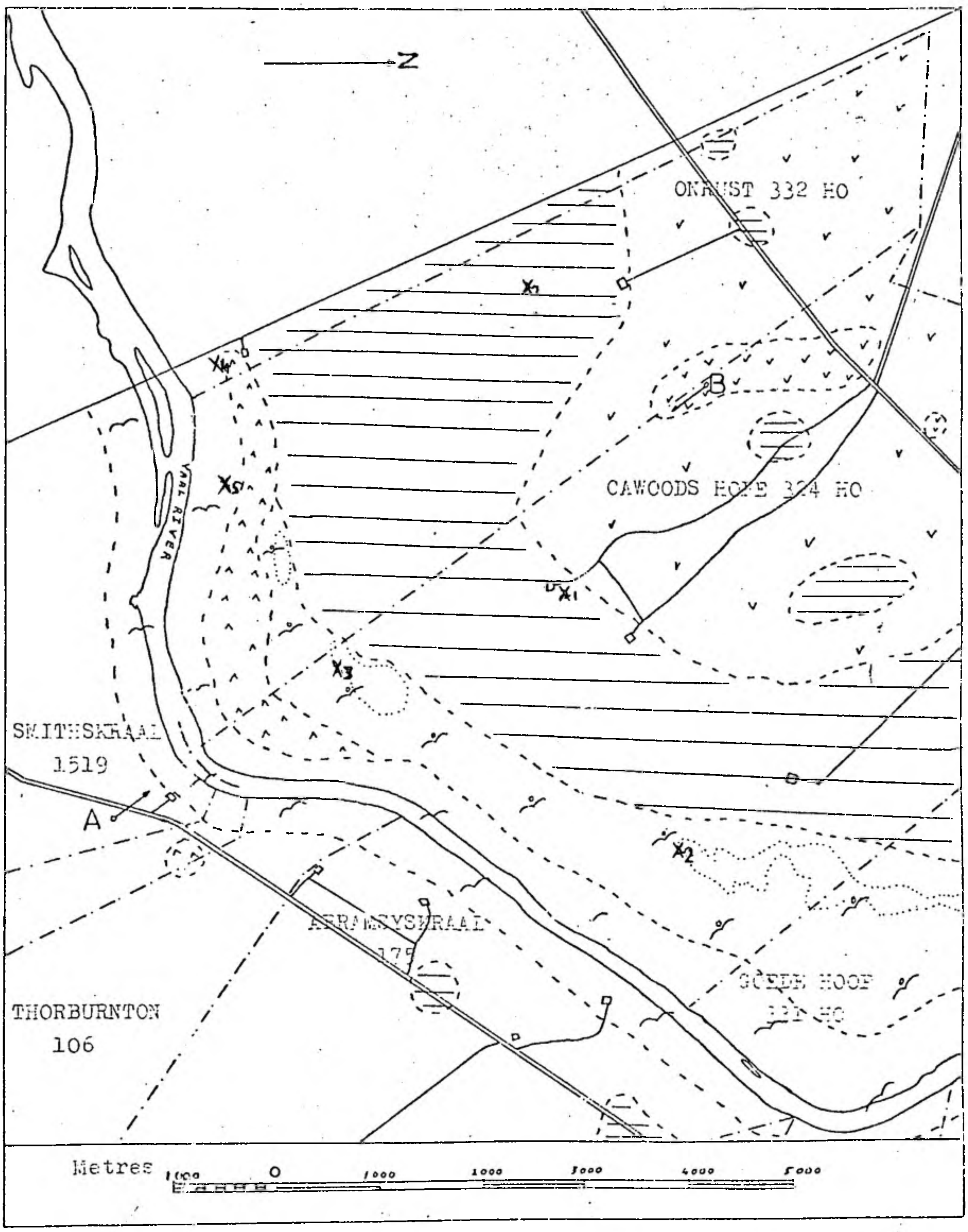
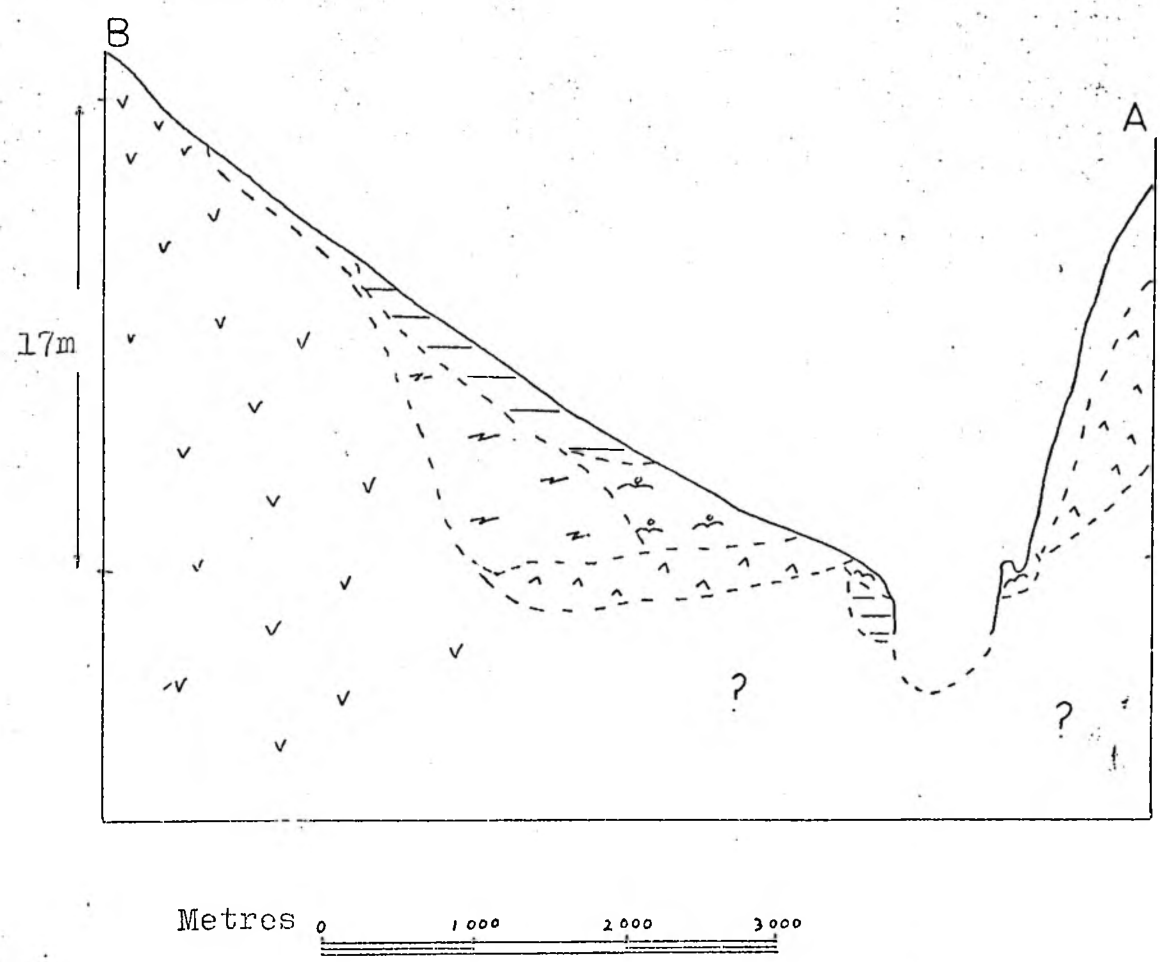


Fig. 8.1 Map of the Vaal River and Adjacent Area.

(For legend see fig. 8.2)

Figure 8.2 Section at Cawoods Hope 324 HO.



Legend of Figures 8.1, 8.2

Allanridge Formation.

Alluvial sand and silt.

Prince Albert Formation.

Vaal River gravels.

Dolerite.

Red Sands.

Calcrete.

Diamond Diggings.

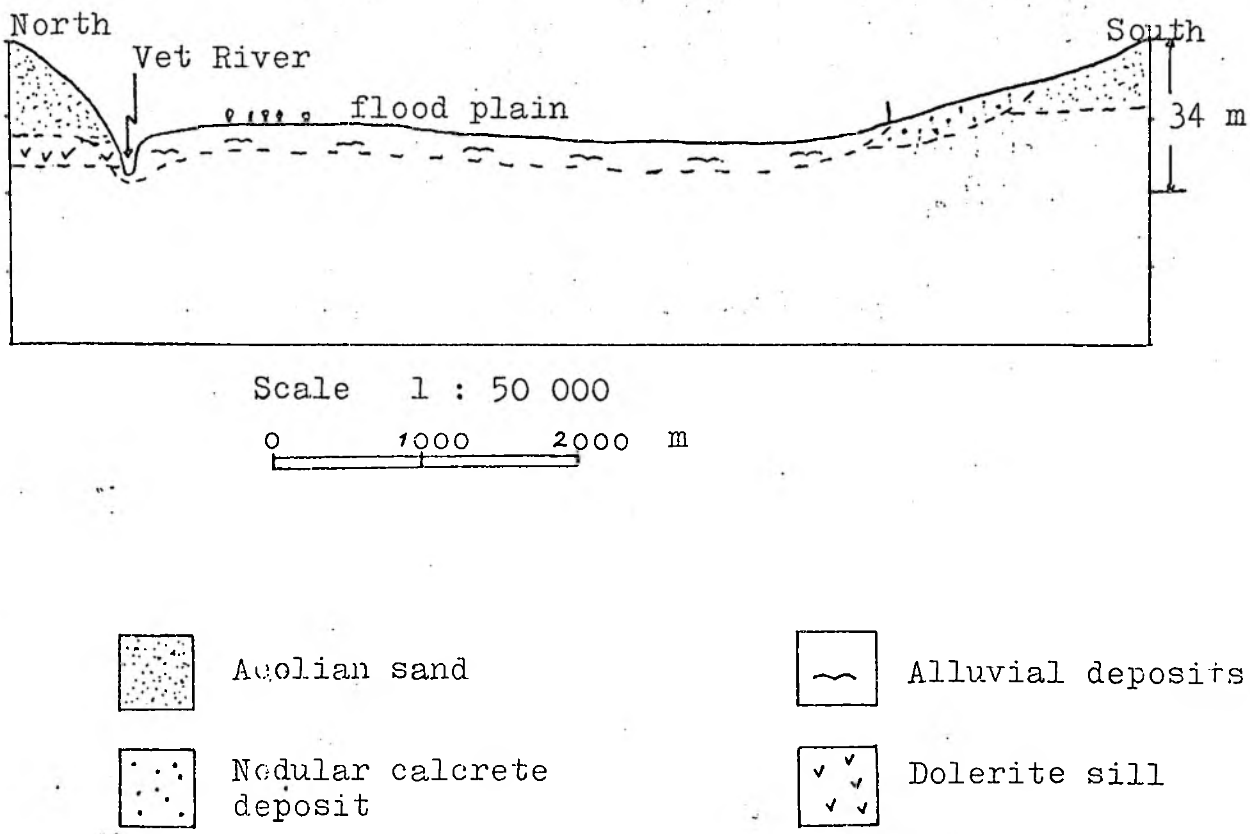


Figure 8.3 The flood plain of the Vet River.

9 PANS

9.1 Introduction.-

During the investigation of this area, a great number of pans were noted which vary from tens of metres to a few kilometres in diameter. The largest pan present in this area is Swinkpan (to the east of the Hertzogville - Dealesville road) with a diameter of well over 5 km. Another most common feature of pans is the fact that they are positioned in areas of low relief and poor drainage.

In this thesis pans are considered as local depressions surrounded by higher plains or ridges. Drainage from surrounding areas should also be towards the pan and not away from it (Butzer, 1974, p. 2) except for periods of exceptionally high rainfall.

9.2 Morphology.

According to King (1951, p. 55-59) the landscape of the area under investigation can be considered as being of "old age". The following features have led the author to accept King's statement:

(1) The relief of the area, in general, is very low.

(2) River channels connecting the different pans are generally not actively increasing the depth of their channels and are thus quite frequently blocked by alluvium and/or aeolian sands.

(3) The barriers separating different drainage systems are low and underdeveloped.

During the investigation of the area sand dunes of variable heights were observed on the south-eastern rims of pans. These dunes, depending on their size, have a noteworthy effect on the drainage pattern to the south-east. Thus to the east of Grootpan, on the Bultfontein - Hoopstad road, the river channel was blocked by aeolian sands, derived from this pan and because of this, the river had to divert its course.

A similar phenomenon was observed to the south-east of the Bultfontein - Boshof road (to the west of the Dealesville - Hertzogville road). Here a large area is submitted to wind erosion, resulting in the piling up of sand to the south-east of this depression. A number of pans are situated to the south-east of this dune. The drainage systems linking these pans to one another have been drowned completely by sand. With further advancement of the dune, these pans may well be drowned by sand.

9.3 Size and Shape of Pans.

Two types of pans were distinguished in the area under investigation:

(1) Elongated pans.

(2) Circular pans.

9.3.1 Large Pans.

9.3.1.1 Elongated Pans.

These pans are aligned along certain preferred directions. During closer investigation it was observed that they are aligned in accordance with the local drainage pattern (Hugo, 1974, p. 78-82). Two types of elongated pans were observed;

(1) Small pans, usually not more than 250 m in length. A large number of these pans are developing along current drainage systems. They are mostly situated in areas "drowned" by aeolian sheet deposits, e.g. to the west of Bultfontein. Upon closer investigation it was found that these pans represent river channels, that are at places blocked by aeolian sand.

(2) Larger pans, of more than 250 m in length. These pans were found to have developed along current as well as paleo-drainage systems. Most are, however, bordered by dolerite outcrops. It would thus appear that the shape of some of these pans can be ascribed to two features, viz. (a) the development of a hollow by river action, and (b) the later limitation of further development by dolerite outcrops.

9.3.1.2 Circular Pans.

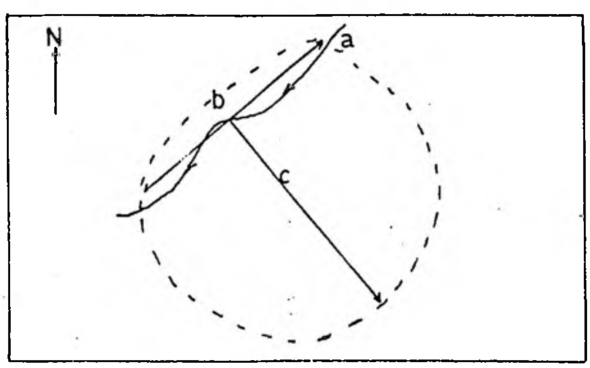
Some of these pans show no apparent alignment. On closer investigation it was, however, observed that most pans are situated in the vicinity of paleo as well as current river channels. Two types can be distinguished;

(1) Small pans, of not more than 150 m in diameter.

These pans are most abundant in areas with an abundance of aeolian sands, e.g. to the west of Bultfontein. Some of these pans show no relationship with any drainage pattern and are thus discussed separately. The majority occur in between smaller elongated pans, and thus it would appear that their excistence can be ascribed to the same features as those obtained for elongated pans.

(2) Larger pans, of more than 150m in diameter. These pans are usually situated in deeper depressions than elongated pans. It would thus appear that erosion was more active or active over a longer period of time than is the case with elongated pans of the same diameter.

As stated elsewhere, a pan floor will spread in a down-wind direction. If an elongated pan which is not limited by a dolerite ridge to the south-east is aligned in a south-westerly direction, spreading of the pan floor in a south-easterly direction will ensure the enlargement of the pan. Assuming that b (fig. 9.1) was the original length of the elongated pan, and that the pan floor is spread along c a circular pan will originate as soon as b and c are equal in length. Gannapan, situated to the north-west of Hertzogville, may serve as an excellent example of this type of circular pan.



a = River channel

b = Original length of elongated pan

c = Spreading direction of the pan floor

Figure 9.1 Spreading of a pan floor.

9.3.2 Small Pans.

Small pans of not more than 150m in diameter, which show no relationship with current or paleo-streams, are developing in the following regions:

(1) On top of dolerite sills where they are usually 1 - 3 m lower than the surrounding plain. A black clay is present on most of the pan floors. These pans most probably represent erosional hollows, brought about by chemical weathering of the dolerite and subsequent erosion by wind action.

(2) On aeolian sheet deposits. A large number of these pans are developing to the north and east of Bultfontein. They are considered as wind-deflated hollows, since wind erosion is especially active during the dry months of the year when ploughed fields are left with no vegetation.

9.4. Formation of Pans.

To gain a better understanding of the formation of pans, the effect of weathering on various rock types present in this area will be discussed first.

(1) Ecca sedimentary rocks are usually soft and easily weathered, so that they are generally present in low-lying regions.

(2) Dolerite sills and dykes tend to occur as ridges and hills of variable heights, from which it can be concluded that they are generally the most resistant to weathering processes.

(3) Other rock types, e.g. those of the Ventersdorp succession, are present in isolated cases only, and thus have no noteworthy effect on the formation of pans.

A period of aggradation must have preceded pan formation. This conclusion is reached because dolerites, now present on the higher regions were definitely intrusive (see chapter on dolerites). As dolerites are more resistant to weathering and erosion, aggradation was predominantly conducted along outcropping Ecca and higher sedimentary rocks (Butzer, 1974, p. 16). The cone-shaped nature of dolerite intrusions (see chapter on dolerites) thus gave rise to the formation of hollows, in that Ecca sediments, present within the individual cones, were eroded. Presentpan (on the Hertzogville - Christiana road) may serve as an excellent example.

The Ecca Group consist of shale, siltstone, and sandstone. Material derived from these rocks during weathering can thus be transported out of this area by streams of a fairly low competency. As these streams must have been fairly small (no large paleo-river bed was detected in this area), they can be considered tributaries of one of the following rivers;

(1) Vaal River.

(2) Vet River.

(3) Sand River.

(4) Modder River (to the south of the mapped area).

During this process of aggradation hollows (river-channels) originated which served as the preliminary structures from which pans originated. The latter was also observed by Mayer (1973, p. 186-187) in the Hartz River drainage basin, between Lichtenburg and Delareyville, as well as by Butzer (1974), p. 3, 16).

Most pans are grouped together along certain preferred directions. These directions (see map II) coincide with current as well as paleo-stream directions (Hugo, 1974, p. 81). From this it can be concluded that pans developed along paleo-streams.

The next step necessary in the formation of pans, is the blocking of stream channels. This can be brought about by one or both of the following;

(1) Through lowering of the gradient by aggradation, the stream will lose its competency. Aeolian sands blown into these channels will thus no longer be removed efficiently by the stream. This will then result in the blocking of the channels. This phenomenon was widely observed to the north of Bultfontein where vast tracts of aeolian sands are present.

(2) Tilting. Mayer (1973, p. 192) proposed that the area to the south-east of the Vaal River was tilted along the Griqualand West - Transvaal Axis away from the Vaal River thus losing the original gradient towards the Vaal River.

After the blocking of the stream channels, wind erosion took an active part in the further development of the pan.

9.4.1 Wind Erosion.

For wind to act as an effective erosion agent, vegetation has to be absent, or at least sparse. It would thus appear that pans originated in the most sparsely vegetated areas of the blocked stream channels, e.g. river bars, which according to Wilson (1971, p. 189) are very actively eroded by wind.

Allen (1970, p. 97) states that grains (quartz) of 0,10 mm in diameter are the easiest eroded by wind. Further erosion of fine silt by wind requires the application of about the same force as the entrainment of coarse sand. Ecca shales are the most abundant sedimentary rocks in areas where the largest concentration of pans occur. Because of the large amount of silt derived from these Ecca shales, the author thought it necessary to formulate a way in which fine silt can be eroded effectively by wind.

9.4.1.1 Erosion of Silt.

During the rainy season some pans are covered by vegetation. These pans also provide drinking water for the animals. Animals entering these pans will destroy the vegetation and leave imprints in the wet clayey soil. These imprints, when dried, will be disintegrated by wind into fine dust. This dust is largely blown away (Bagnold, 1954, p. 90-91). Mud-cracks forming during dry spells may have the same effect on the erosion of silt (Glennie, 1970, p. 6).

Animals entering pans in the dry seasons to lick salty patches will disturb the upper, dried-out soil surface, and as such active erosion of silt will take place through the subsequent wind action (Allen, 1970, p. 98).

The possibility of animals carrying material attached to their skin and hoofs out of pans, is not considered of importance.

Sand grains are usually transported (by wind) through saltation. If these sand grains, whilst in motion, move over a surface covered by silt, the impact of the sand grains will cause silt grains to rise, and be eroded by wind (Allen, 1970, p. 98). This can be considered a very important feature in this area, as large amounts of aeolian sands are present in the immediate vicinity of most pans.

9.4.2 Enlargement of Pans.

The enlargement of any one pan depends on the efficiency with which material can be removed from its rim by wind or water. This will largely depend on the resistance to weathering and erosion of the rocks or material present on the various rims.

The north-western rim of Gannapan (to the north-east of Hertzogville) consists of dolerite. As dolerite is the most resistant rock in this area, enlargement of the pan in a north-westerly direction is considered as very slow. Enlargement of the pan floor must thus be in a south-easterly direction.

The wind direction in this area is predominantly from the north-west (according to the Bloemfontein Weather Bureau). Material derived from the pan floor (by wind) is thus deposited on the south-eastern rim of the same pan.

This feature can be observed over the whole of the area.

Rain in this area usually occurs in thunderstorms, during which material is dislodged from these deposits by surface run-off and transported back into the pan, as witnessed by dongas of variable depths. However, very little of the material derived by the above-mentioned processes could be detected on the pan floor. According to Wilson (1971, p. 187-189), wind erosion can only be effective if there is a constant replacement of material. It would thus appear that material deposited on the pan floor by the above processes, is rapidly removed again by wind erosion.

All the material derived from the pan floor is not necessarily deposited on the south-eastern rim of this pan. Some of it is most probably deposited outside the drainage area of the pan from which it has been eroded. The dunes present on the south-eastern rims of pans will gradually move in a down-wind direction (viz. south-east), resulting in an extension of the pan floor in the same direction.

Pans with no dolerite ridges to the north-west, e.g. the pan situated to the west of Bultfontein, appear to enlarge in a north-westerly direction.

9.4.3 Deepening of the Pan.

Pan floors are usually covered with a clayey soil. Underlying this soil are shales of the Prince Albert Formation or in isolated cases, dolerite sheets. These shales form impermeable water barriers (see chapter on Prince Albert Formation). It would thus appear that most of the groundwater present in these pans is contained in the soil cover.

For wind erosion to be effective, the surface over which the wind blows has to be dry. Deepening of the pan will thus stop as soon as the top soil is moistened by capillary action from the ground-water table (Hugo, 1974, p. 78-82). This phenomenon was widely observed by the author, especially in salt pans.

Kinsman (1976, p. 276-277) describes two features that can cause precipitation on salt flats at night, viz.

(1) when the atmospheric relative humidities exceed the equilibrium vapor pressure of the brine, and

(2) the low conductivity and heat capacity of halite, which permit halite to cool relatively rapidly at sunset and bring about local super-saturation conditions of water vapour.

During the morning of the next day, water precipitated by the above-mentioned means, will have to be evaporated, before any active erosion of the pan floor can take place This will then hinder active wind erosion for a considerable time of the day. In this case the concentration of the brine, in the salt pan thus has an effect on the erosion of the pan floor.

9.5 Economic Potential of Pans.

De Bruiyn (1971) has subdivided pans into various categories. During the investigation of the area it was found that all pans are more or less brackish, have a clayey soil cover and are able to support vegetation. The writer will thus only distinguish between salt pans and gypsum pans.

9.5.1 Salt Pans.

Quite a number of salt pans are present in this area, but very few of them are currently being exploited. The reason for this is that most of them are not very large and far from railway stations. Some salt pans are polluted by a certain type of algae (Coetzee, 1962, p. 156-161), which impart an objectionable smell to the salt. Because of this, the value of the salt is lowered, and it is therefore usually not economically possible to develop these salt pans.

There are two customary ways of obtaining brine, viz. by the drilling of bore-holes, or the digging of trenches into the pan soil. From these, brine is pumped into evaporation dams. The scraping of salt directly from the pan surface has not been observed, as the salt concentration on the pan surface is not high enough. In cases where large amounts of salt were produced over the past decades, the brine was diluted and vegetation is able to get a hold on the pan floor again.

9.5.1.1 Origin of the Salt.

As most pans containing economical salt concentrations in this area lie on rocks of the Ecca Group, it is most probable that most of the salt is derived through the leaching of these rocks. Some relationship between salt pans and Ecca shales has to exist, as salt pans appear to be more abundant in areas where these shales reach higher thicknesses. Two possibilities exist for the entrapment of salt in these shales;

(1) The shales are of marine origin. Salt water was thus entrapped in them during their formation. According to Borchert and Muir (1964, p. 190), a 1000m thick succession of marine sediments will retain enough salt to form an equally extensive evaporite deposit of 3,6 m in thickness. Taking the mean thickness of the Ecca shales in this area into account, it would appear that a equally extensive evaporite deposit of some 0,3 m would be possible in some areas.

(2) According to Borchert and Muir (1964, p.13), salt remains in plant material are incorporated into the humus and not immediately released back into the environment. Some of the shales belonging to the Prince Albert Formation have a fairly high carbon content, which proves that organic material was present during the deposition of these shales (also see chapter on Prince Albert Formation). If the salts present in the organic matter were released afte the consolidation of the shales, entrapment of additional salt in these shales is possible.

Salts may also be deposited by thermal springs flowing into pans. The Florisbad thermal spring which is situated to the south of the mapped area may serve as an example of the latter. Salts are also released through the oxidation of plant remains and such salts can then be transported from the environment of oxidation into pans.

9.5.1.2 Concentration of Salt in Pans.

The volume of salt present in any one pan situated within the mapped area. depends on the following factors;

(1) The concentration of salt in the source rock.

(2) The volume of source rock present within the drainage area of the pan.

(3) The size of the drainage area.

(4) Ground water movement within a drainage area.

If ground water is able to leave the drainage area of any one pan, salts (in solution) will also be able to leave this area. This will then cause a reduction in the volume of salt within this drainage area, The same is applicable to surface waters.

The following features may determine the economic viability of a salt pan;

(1) Pans should be concentrated in regions where evaporation exceeds precipitation. If the opposite occurs, brine in the pan will be diluted to such a degree that exploitation of the pan will have to be stopped. The latter situation can be noted in this area during periods of exceptionally high rainfall.

(2) Plants should not extract their water from these pans as this decreases the salt content within the pan (Borchert and Muir, 1964, p. 13).

(3) The ratio of surface area to the total volume of the lake should be as large as possible, as this will determine the rate of evaporation (Borchert and Muir, 1964, p. 14).

(4) The thickness of the pan soil should be a minimum. Most of the ground water present in a pan is contained in the pan soil. Hugo (1974) observed this phenomenon at Soutpan (situated to the south of the mapped area and stated that the highest volume of ground water is to be found at the contact of the pan soil and the underlying Ecca shales. If bore holes were extended deeper into these Ecca shales, a reduction in the volume of ground water was experienced. The thickness of the pan soil will have the following effects on the concentration of the brine:

According to Hillel (1971, p. 191), transmission of water from the ground water table by capillary action is as high as 8 mm/day with a groundwater table of 90 cm below the surface. If the ground water table is 360 cm below the surface a meagre 0,12 mm/day is obtained. During the investigation of this area the author has quite frequently observed that farmers were exploiting smaller pans on their property. In all cases it was found that the soil cover of these pans did not exceed 3 m in depth. The economic viability of these smaller pans may well be dependant on the thin soil cover, as well as the effect of this thin soil cover on the transmission of water from the ground water table, which effects the concentration of the brine.

9.5.2 Gypsum Pans.

Only a few gypsum pans are present in this area (table 9.1). None of these are currently being exploited.

Table 9.1 Location of Gypsum Pans.

Name of pan.		Location.
Endor 866	———	Endor 866, Rooibloem 93, Zwartkoppiesfontein 21, Eikeboom 621. (on the Boshof - Bultfontein road, 16km from Boshof).
Presentpan	———	Presentpan 350 (on the Hertzogville - Christiana road, 14km from Hertzogville).
Voëlpan	———	Dankbaar 251 (to the north of the Hertzogville - Bultfontein road).

At Endor 866 gypsum is present on the eastern rim of the pan over an area of some 1000ha (Visser et al., 1963, p. 18). Only about 40 ha are considered as proven, with a 45% gypsum content in the clay.

At Presentpan gypsum is present on the north-western rim of the pan but not in the pan itself. Here gypsum is contained in the weathered shale of the Whitehill Formation which crops out in dongas at the rim of the pan. Further, these shales reach thicknesses of up to 3 m. The deposit is spread over approximately 15 ha and reserves are estimated at 25 000 ton of pure gypsum (Visser et al. 1963, p. 18).

Voëlpan is the only pan in this area where gypsum was observed on the pan floor itself.

9.5.2.1 Formation of Gypsum.

The occurrence of gypsum on the rim of Presentpan, but not in the pan itself, illustrates that the formation of gypsum in this area depends on the availability of sulphur. According to Krauskopf (1967, p. 273) sulphuric acid can be formed during the weathering of sulphur-bearing minerals. If sulphuric acid then reacts with calcium carbonates, gypsum can be formed.

A high percentage of carbon from which oil could be distilled was found in the shales at Presentpan (see chapter on Whitehill Formation). The carbon points to anaerobic conditions for the formation of the shales and the usual presence of sulphides. These sulphides may now react with calcretes present in this area, resulting in the formation of gypsum.

The leaching of gypsum from these shales will depend on the availability of water. As this area has a fairly low annual rainfall (of the order of 40 cm), leaching of gypsum will be slow. This may then explain why gypsum is not very readily encountered in the pan itself.

Martin (1963), who worked in the Swakopmund and Walvis Bay areas, found that in regions where calcrete is abundant the formation of gypsum is dependant on the availlability of sulphates.

Siesser and Rodgers (1976) found pyrite and non-evaporitic gypsum intimately associated in South West African continental-slope sediments where samples were collected at water depths of 632 and 900 m. It was found that gypsum had originated through the interaction of sulphide-enriched and calcium-enriched fluids. If gypsum can form in this manner under marine conditions where an appreciable concentration of gypsum is present in solution, the existence of gypsum in non-marine environments may well have the same genesis.

9.5.3 Vegetation in Pans.

During the investigation of this area the following features were observed regarding the vegetation in pans:

(1) Vegetation is more abundant during dry spells (observations made by local farmers).

(2) In pans where large volumes of brine are currently being extracted vegetation is getting a hold on the pan floor.

The water table is lowered during the extraction of brine as well as during the dry spells. From this it can be concluded that the water table has a noteworthy effect on the vegetation on the pan floor. If the ground water table is kept sufficiently low, water entering the pan floor will seep downwards, taking soluble salts with it. During this period very little, if any, salt will be brought to the surface (from the brine) by capillary action (Hillel, 1971, p. 187-190). The salt concentration in the top soil is thus lowered, enabling vegetation to get a hold on the pan floor. As most of these soils have a clayey nature, only these plants that are adapted to these soil conditions will flourish during this period.

Plant life on the pan floor is terminated as soon as one of the following occurs:

(1) If precipitation is too low to sufficiently wet the top of the pan soil.

(2) If the rainfall increases, the ground water table may rise, causing brine to rise to the surface of the pan, thus creating conditions that are unbearable to plant life.

9.6 Age of Pans.

The age of pans is set by Hugo (1974, p. 81) to be just over 10 000 years which coincides with the age of the Vet River alluvial deposits (Coetzee, 1960, p. 109-110).

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MAP I The Geology of an Area West of Welkom

LEGEND

RECENT DEPOSITS
- Sand
- Vaal River Gravels
- Alluvium
- Calcrete

INTRUSIVES
- Kimberlite
- Dolerite (dykes are marked Jd)

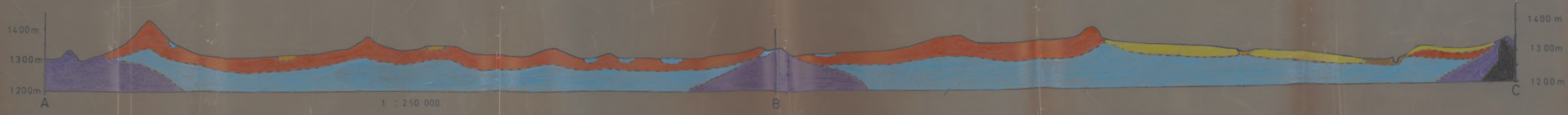
KAROO SUPERGROUP
- Beaufort Group
- Ecca Group
  - Dwyka Formation (no outcrop)
  - Tierberg Formation
  - Whitehill Formation
  - Prince Albert Formation

UNCONFORMITY

VENTERSDORP SUPERGROUP (Formations not differentiated on map)
- Pniel sequence
  - Allanridge Formation
  - Bothaville Formation
- UNCONFORMITY
- Platberg Group
  - Rietgat Formation
  - Makwassie Quartz Porphyry Formation

UNCONFORMITY

BASEMENT GRANITE



MAP II PANS AND PRESENT AS WELL AS PALEO-DRAINAGE DIRECTIONS

LEGEND

DRAINAGE DIRECTION ⟶

BLOCKED DRAINAGE —+—