EXPLANATION: SHEET 2924 (1:250 000)
TOELIGTING: BLAD 2924 (1:250 000)

KOFFIEFONTEIN

GEOLOGICAL SURVEY
GEOLOGIESE OPNAME

REPUBLIC OF
SOUTH AFRICA

REPUBLIEK VAN
SUID-AFRIKA

Department of Mineral and Energy Affairs
Departement van Mineraal- en Energiesake

Republic of South Africa
Republiek van Suid-Afrika

GEOLOGICAL SURVEY
GEOLOGIESE OPNAME

THE GEOLOGY OF THE KOFFIEFONTEIN AREA

by/deur

P. K. ZAWADA, M.Sc.

Explanation of Sheet 2924
Toeligting van Blad 2924
Scale/Skaal 1:250 000

Plaaslike Prys • Local Price

Op aanvraag beskikbaar of raadpleeg die nuutste uitgawe van die Katalogus van Publikasies van die Geologiese Opname/Available on request or consult the latest edition of the Catalogue of Publications of the Geological Survey

Buitelands • Other Countries

Selling Price $US 10,00
For postage and handling add
$US 10,00 for surface mail
or $US 40,00 for airmail

Printed by and obtainable from the Government Printer, Bosman Street/Private Bag X85, Pretoria, 0002/0001, Tel. 323-9731 × 260, 269, and from the Chief Director, Geological Survey, Private Bag X112, Pretoria, 0001/280 Pretoria Street, Silverton, 0184.

Gedruk deur en verkrygbaar by die Staatsdrukker, Bosmanstraat/Privaatsak X85, Pretoria, 0002/0001, Tel. 323-9731 × 260, 269, en van die Hoofdirekteur, Geologiese Opname, Privaatsak X112, Pretoria, 0001/ Pretoriastraat 280, Silverton, 0184.

ISBN 0-621-14484-3

DEPARTMENT OF MINERAL AND ENERGY AFFAIRS
DEPARTEMENT VAN MINERAAL- EN ENERGIESAKE

GEOLOGICAL SURVEY
GEOLOGIESE OPNAME

CONTENTS

THE GEOLOGY OF THE KOFFIEFONTEIN AREA

by

P. K. Zawada

Abstract

The rock types underlying the area fall into three different age groups, namely Archaean granite, andesitic lava, quartz porphyry and immature sediments of the Ventersdorp Supergroup straddling the boundary between the Proterozoic and Archaeozoic eonothems, while the Karoo Sequence of Phanerozoic age covers most of the area. The Ecca and Beaufort Groups of the Karoo Sequence have been extensively intruded by dolerite of Jurassic age. Quaternary deposits cover large parts of the map area.

The basement granite outcrops in two places. A sequence of clastic and volcanic rocks of the Bothaville Formation (Ventersdorp Supergroup) overlies basement granite towards the south. The overlying amygdaloidal andesite has been identified as the Allanridge Formation.

Further north near the confluence of the Riet and Modder Rivers quartz porphyry of the Makwassie Formation outcrops. This unit rests directly on basement granite. The overlying amygdaloidal andesitic lava is lithologically similar to the Allanridge Formation.

The Dwyka Formation overlies the Ventersdorp Supergroup, is of Carboniferous age, and comprises tillite, diamictite, limestone and varved shale. This formation was deposited under glacial and fluvio-glacial conditions of sedimentation with a south-southwesterly palaeo ice-flow. The Prince Albert, Whitehill and Tierberg Formations together make up the Ecca Group which attains a thickness of between 345 and 364 m. With the exception of the upper part of the Tierberg Formation, this group, especially the Whitehill Formation, consists predominantly of dark-grey shale with beds of carbonaceous shale which were deposited under quiet-water anoxic conditions. The upper part of the Tierberg Formation comprises sandstone and siltstone mainly arranged in upward-coarsening sequences displaying evidence of traction currents. These sediments were probably deposited in a deltaic environment. The thinner upward-coarsening sequences have been interpreted as discrete incursions (crevasse splays) of sediment-laden waters transported either through crevasse channels or through overbank flooding into the basin due to exceptional flood conditions. The thicker upward-coarsening sequences are considered to represent small-scale delta lobes prograding across platform muds. These high constructive delta lobes prograded northeastwards into a shallow embayment (approximately 12 m deep) and were probably part of a larger deltaic complex outside the area.

The Ecca–Beaufort lithostratigraphic contact has been placed at the base of the first prominent sandstone overlying the predominantly argillaceous sediments of the Tierberg Formation. This contact clearly demarcates the point below which argillaceous sediments predominate and above which arenaceous sediments characterise the Beaufort Group.

A petrographic study of the sandstones of the Ecca and Beaufort Groups indicates that there is very little difference in the composition and textural properties between the Ecca and Beaufort Groups. It is suggested that these sandstones were derived from a predominantly volcanic and metamorphic source area.

A geochemical analysis of mudrocks from both the Ecca and Beaufort Groups suggests that the palaeosalinity of the water in which the Tierberg Formation and the lower part of the Beaufort Group was deposited, was fresh and/or brackish.

The Quaternary sediments of the area comprise calcrete, wind-blown sand and alluvium. The wind-blown sand either occurs as a thin sheet cover or as low dunes.

The Ventersdorp Supergroup of the area exhibits a broad anticlinal structure trending northwest. The overlying Karoo Sequence is structurally undeformed with only localised upturning of strata adjacent to dolerite dykes.

The mining of diamonds, especially at Koffiefontein and Jagersfontein, has been of considerable economic importance to the area. In addition, a uranium deposit occurring in the Edenburg district may be of economic interest, especially in view of its shallow depth. A number of salt pans occur in the map area, some of which have been exploited in the past.

Uittreksel

Die gesteentes wat die gebied onderlê kan in drie verskillende ouderdomsgroepe verdeel word, naamlik Argeïese graniet en andesitiese lawa, kwartsporfier en onvolwasse sedimente van die Ventersdorp Supergroep wat Proterosoïes tot Argeïes in ouderdom is, terwyl die Karoo Opeenvolging, wat die grootste deel van die gebied beslaan, van Fanerosoïese ouderdom is. Die strata van die Ecca en Beaufort Groepe is op uitgebreide skaal deur doleriet van Jura-ouderdom ingedring. Kwartêre afsettings dek groot gedeeltes van die kaartgebied.

Die vloergraniet dagsoom slegs op twee plekke. 'n Opeenvolging van klastiese en vulkaniese gesteentes van die Bothaville Formasie (Ventersdorp Supergroep) oorlê die vloergraniet na die suide. Die oorliggende amandelhoudende andesiet is as die Allanridge Formasie geïdentifiseer.

Verder noord, naby die samevloei van die Riet- en Modderrivier, dagsoom 'n kwartsporfier van die Makwassie Formasie. Hierdie eenheid rus direk op die vloergraniet. Die oorliggende amandelhoudende andesitiese lawa is litologies verwant aan die Allanridge Formasie.

Die Dwyka Formasie oorlê die Ventersdorp Supergroep, is van Karboonouderdom en bestaan uit tilliet, diamiktiet, kalksteen en gewarfde skalie. Die formasie is onder glasiale en fluvioglasiale sedimentasietoestande met 'n suid-suidwestelike paleo-ysvloei afgeset. Die Prins Albert, Whitehill en Tierberg Formasie vorm saam die Ecca Groep wat 'n dikte van 345–364 m bereik. Met die uitsondering van die boonste gedeelte van die Tierberg Formasie bestaan hierdie groep, veral die Whitehill Formasie, hoofsaaklik uit donkergrys skalie met lae van koolstofhoudende skalie wat onder stilwater anoksiese toestande afgeset is. Die boonste deel van die Tierberg Formasie bestaan uit sandsteen en sliksteen wat hoofsaaklik in opwaarts-growwerwordende opeenvolgings gerangskik is en tekens van traksiestrome vertoon. Hierdie opwaarts-growwerwordende opeenvolgings is geïnterpreteer as diskrete instromings (spleetwaaiers) van sedimentbelaaide water, wat weens buitengewone vloedomstandighede óf deur die spleetkanale óf as 'n ooroewervloed tot in die kom vervoer is. Die dikker opwaarts-growwerwordende opeenvolgings word as kleinskaalse deltalobbe, wat oor die modderplatforms geprogradeer het, beskou. Hierdie hoogs-konstruktiewe deltalobbe het noordooswaarts in 'n vlak see-inham (ongeveer 12 m diep) geprogradeer en was waarskynlik deel van 'n groter deltaïese kompleks buite hierdie gebied.

Die litostratigrafiese kontak tussen die Ecca en Beaufort Groepe is aan die basis van die eerste prominente sandsteen wat die oorheersend kleiige sedimente van die Tierberg Formasie oorlê, geplaas. Hierdie kontak dui die vlak waaronder kleiige sedimente oorheers en waarbo sandige sedimente die Beaufort Groep kenmerk, duidelik aan.

'n Petrografiese studie van die sandstene van die Ecca en Beaufort Groepe dui aan dat daar baie min verskil in die samestelling en teksturele eienskappe tussen die Ecca en Beaufort Groepe is. Daar word voorgestel dat hierdie sandstene van 'n oorheersend vulkaniese en metamorfe brongebied afkomstig is.

'n Geochemiese ontleding van die moddersteen van beide die Ecca en Beaufort Groepe dui aan dat die paleosaliniteit van die water waarin die Tierberg Formasie en die onderste gedeelte van die Beaufort Groep afgeset is, vars en/of brak was.

Die Kwartêre sedimente van die gebied bestaan uit kalkreet, waaisand en alluvium. Die waaisand kom as 'n dun plaatbedekking of as lae duine voor.

Die Ventersdorp Supergroep in die gebied toon 'n wye antiklinale struktuur wat noordwes strek. Die oorliggende Karoo Opeenvolging is tektonies onvervorm, met slegs plaaslike opbuiging van lae langs dolerietgange.

Die ontginning van diamante, veral by Koffiefontein en Jagersfontein, was van groot ekonomiese waarde vir die gebied. Bykomend kom 'n uraanafsetting in die Edenburg distrik voor wat van ekonomiese betekenis kan wees, veral omdat dit nie diep geleë is nie. 'n Aantal soutpanne kom in die kaartgebied voor, en sommige is in die verlede ontgin.

1. INTRODUCTION

The physiography of the area can be described as a flat monotonous landscape comprising large plains studded with flat-topped hills which are capped by dolerite. The low-lying areas are normally underlain by easily weathered shale, siltstone and sandstone on which low sand dunes occur in places. The area is drained by the Orange, Riet and Modder Rivers. Towards the south the Orange River has incised a deep valley into the terrain.

The rocks underlying the area vary considerably in age. Granite of Archaean age (Swazian Erathem) represents the basement. Andesite, quartz porphyry and immature sediments of the Sodium Group and Ventersdorp Supergroup straddle the Randian–Vaalian boundary whilst the Karoo Sequence that underlies much of the area is of late Palaeozoic age. The strata of the Ecca and Beaufort Groups of the Karoo Sequence have been extensively intruded by dolerite of Jurassic age. Quaternary deposits comprising calcrete, wind-blown sand and alluvium represent the youngest deposits and cover large areas of the map.

2. SWAZIAN GRANITE

Only two outcrops of granite were recorded in the area and are described separately:

(a) The occurrence on Sheet 2924 BA (Modderrivier) on the farm Riet River Settlement West 110 is described by Potgieter (1974) as a white, medium-grained granite with clearly visible biotite flakes. The rock has a schistose fabric on account of a preferred alignment of the biotite flakes. It is equigranular with quartz, plagioclase (oligoclase), orthoclase and biotite as the major minerals.

(b) The granite occurring on Sheet 2924 BA (Modderrivier) on the farm Waterfall 133 on the northern bank of the Riet River is light coloured and medium to coarse grained and consists mainly of quartz, orthoclase and chlorite (Potgieter, 1974). Much of the anhedral quartz is graphically intergrown with subhedral orthoclase. Chlorite occurs as aggregates of single crystals possibly derived from secondary alteration of amphibole and biotite grains. Small crystals of an unidentified ore mineral are also present.

3. VENTERSDORP SUPERGROUP

Nel (1977) mapped a sequence of rocks with an exposed total thickness of 80 m along the Orange River on the farms Wicklow 218 and Soetgat 84, approximately 12 km northwest of Hopetown as part of the Ventersdorp Supergroup. He subdivided this sequence into a basal sedimentary unit, a pyroclastic unit and an andesitic lava unit (Fig. 1). The sedimentary interval is 40 m thick and comprises mainly

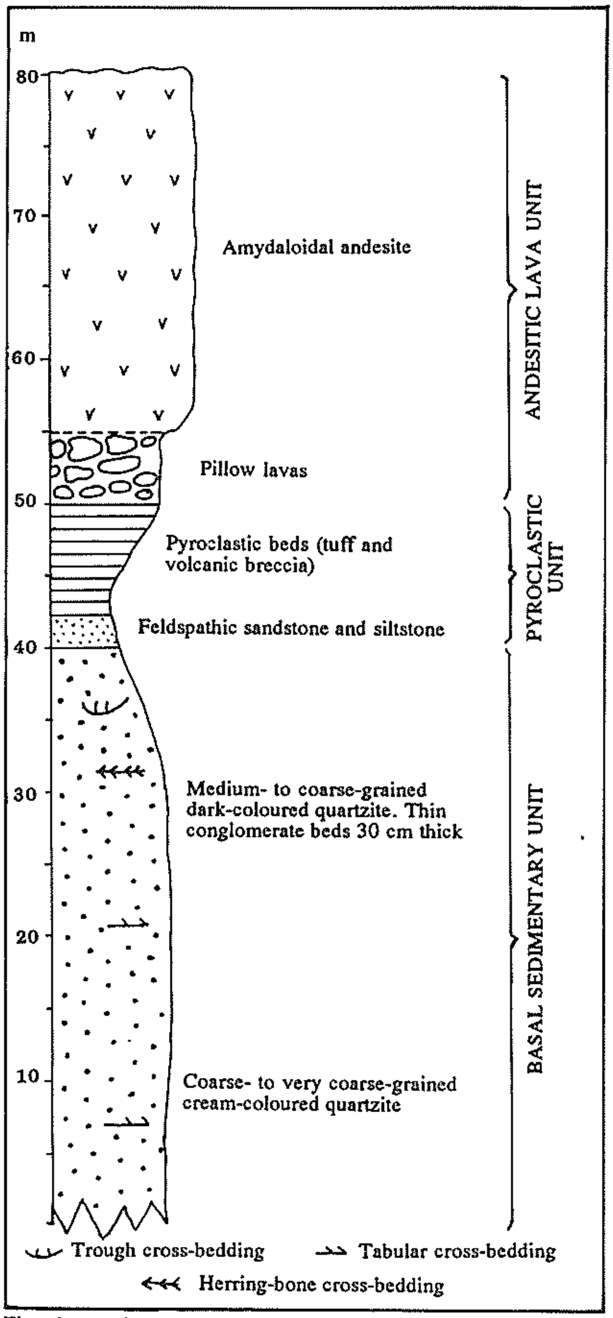

Fig. 1 — Lithological succession on Wicklow 218 (after Nel 1977).

medium- to coarse-grained, poorly sorted quartzite. Trough, planar and herring-bone cross-bedding were recorded in the quartzite. Thin conglomerate beds, 30 cm thick, containing dark-coloured cherty pebbles are present in this unit near Hopetown. Nel (1977) suggested that these sediments were deposited in a beach and tidal environment. The pyroclastic interval (Fig. 1) attains a thickness of 10 m and consists predominantly of tuff and volcanic breccia with a basal part characterised by feldspathic sandstone and siltstone. The overlying andesitic lava interval comprises amygdaloidal lava; the amygdales having been filled with calcite. Its basal part is characterised by the presence of round and oval-shaped pillow lavas. Nel (1977) described these rocks as plateau lavas on account of their sheet-like geometry and the extensive lateral continuity of the individual lava flows.

No attempt was made by Nel (1977) to correlate the various units with established stratigraphic units except to mention that his sequence of rocks are of Ventersdorp Supergroup age. Examination of the lithological section given by Nel (1977) for the Orange River area suggests that the basal sedimentary unit forms part of the Bothaville Formation, with the overlying amygdaloidal andesites belonging to the Allanridge Formation.

A small outcrop of amygdaloidal lava in Karoo sediments occurs on Bergplaats 1159 approximately 8 km northwest of Fauresmith. The outcrop is small (approximately 2 m^2) and comprises a grey-green amygdaloidal lava which is extensively weathered and sheared. It is tentatively suggested that this lava is part of the Allanridge Formation.

3.1 Makwassie Quartz Porphyry Formation

The Makwassie Quartz Porphyry Formation occurs near the confluence of the Riet and Modder Rivers (2924 BA), the largest outcrops being on Riet Fontein West 107 and Kook Fontein 108. Smaller exposures occur adjacent to the Kimberley–Hopetown highway on Sheet 2924 BA.

Potgieter (1974) originally referred to this unit as the Ritchie Quartz Porphyry Formation and gave a detailed description, followed by Potgieter and Lock (1978) who categorised the rocks as rhyolitic lava, eutaxitic ignimbrite and rheoignimbrite with the eutaxitic ignimbrite (eutaxite) being the most abundant. The eutaxite is light olive-grey with dark fiamme (collapsed pumice fragments). The rheoignimbrite is characterised by an abundance of flow banding.

An exposure of Makwassie Quartz Porphyry lies adjacent to basement granite on Waterfall 133 although no visible contact with the granite was noted. According to Potgieter and Lock (1978) no major unconformity exists between this unit and the overlying andesite (Allanridge Formation).

4. KAROO SEQUENCE

4.1 Dwyka Formation

Much of the information on the Dwyka Formation which follows is derived from Visser *et al.* (1977–78). This formation forms the basal part of the Karoo Sequence. On and adjacent to basement highs the Dwyka Formation is, however, absent, resulting in the Ecca Group sediments resting directly on either granite gneiss or on lavas and acid extrusives of the Ventersdorp Supergroup or its correlatives. The average thickness of the Dwyka Formation is about 50 m (Visser *et al.* 1977–78). Nel (1977) recorded a thickness of 30 m in the Hopetown area, whereas Du Toit (1907, p. 181) gave a thickness of 120 m north of Hopetown. This variation in the thickness recorded by several workers is ascribed to the considerable undulation of the underlying basement topography.

The basal part of the Dwyka Formation comprises bluish-grey, unbedded, unsorted tillite consisting of erratics up to 4 m in diameter set in a sandy to argillaceous matrix. Many of the erratics are polished, facetted and striated. The composition of the erratics is dependent on the nature of the underlying basement and hence the erratics are amygdaloidal andesites throughout much of the area. Towards the north of the area (Modder River Station) where basement granite is present many of the erratics are, however, composed of granite gneiss and quartz porphyry. It was suggested by Visser *et al.* (1977–78) that 90 per cent of the erratics were locally derived and had not been transported far. The matrix of the tillite comprises sand-sized and argillaceous material. Mineralogically the matrix consists of clay mixed with angular to rounded grains of quartz, feldspar, epidote, garnet, chert, mica, chlorite, iron oxide and secondary calcite. Locally thin lenses of bedded "tillite" are found in the unbedded rock. Visser *et al.* (1977–78) suggested that the former is of glaciolacustrine and fluvioglacial origin. Boulder shale constitutes much of the Dwyka Formation and comprises an argillaceous matrix with scattered pebbles and boulders (Fig. 2). The shale may be contorted indicating plastic flow. Varved shale, characterised by a succession of alternating dark and light-coloured laminae occurs sporadically. The top of the varved shale is regarded as the top of the Dwyka Formation (Fig. 2). Limestone occurs as lenses of up to 1 m in thickness and is normally found in the boulder shale.

In an investigation of the Dwyka Formation in the southwestern Cape, Theron and Blignault (1973) recognised sequences of sediments that they referred to as cycles. According to these authors each cycle comprises a basal zone of massive tillite representing true glacial deposits and an upper terminal zone of stratified sediments representing proglacial deposits. Visser *et al.* (1977–78) attempted to identify similar cycles in the map area and noted only two in an area near Hopetown. The first cycle shows a marked thickening and is ascribed to a local palaeoflow. According to Visser *et al.* (1977–78) these cycles represent two major glacial advances, the massive tillite of the basal zone of each cycle representing

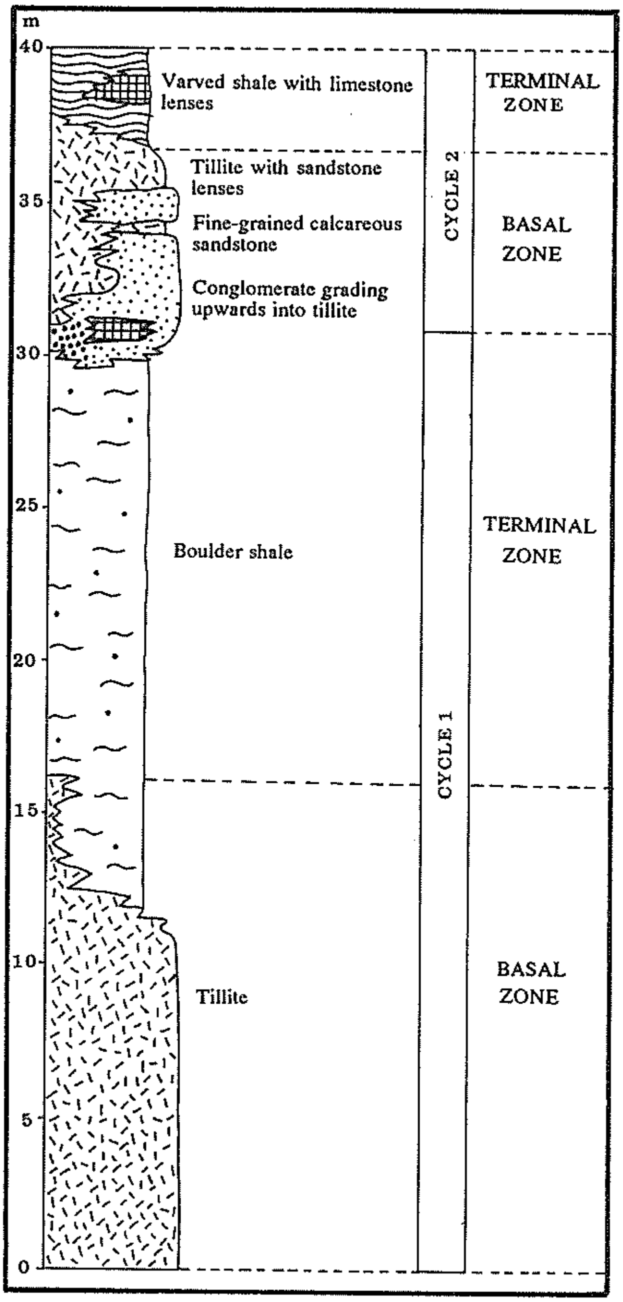

Fig. 2 — Lithological profile through the Dwyka Formation in the Hopetown-Douglas area (after Visser *et al.* 1977–78).

deposition at or near the ice front. The lenses of bedded diamictite and conglomerate are thought to represent till that has been reworked by melt waters during the retreat of the ice front. Sandstone lenses were deposited by glacial outwash in a braided-river stream environment. The carbonate lenses have been interpreted as evidence of climatic amelioration where cold water saturated with carbonate underwent an increase in temperature resulting in the precipitation of calcium carbonate. The boulder shale is thought to represent deposition distal to that of the ice front. Following glacial retreat a body of water would have developed in front of the ice sheet. Isolated icebergs would, however, still have existed and as melting continued, glacial sediments within the icebergs would have been released and deposited into the open body of water where sedimentation through the settling of clay-grade material was taking place. The varved-shale interval represents deposition under quiet-water conditions well removed from clastic influx where deposition occurred through the settling of clay-grade material.

The direction of movement of the ice sheets was in a predominantly south-southwesterly direction with a fanning out of the ice sheets around Hopetown (Visser *et al.*, 1977–78).

4.2 Ecca Group

On sheet 2924 the Prince Albert and Whitehill Formations are grouped together since they are too thin to be shown separately.

4.2.1 Prince Albert Formation

The Prince Albert Formation attains a relatively constant thickness of between 34 and 46 m in the area (Visser *et al.*, 1977–78). The basal contact is taken at the first appearance of black carbonaceous shale that lacks rafted pebbles and erratics overlying the varved sediments of the upper part of the Dwyka Formation. Although the Prince Albert Formation appears to be homogeneous there are lithological differences enabling the subdivision of the formation (Visser *et al.*, 1977–78) which is illustrated in Fig. 3. The basal black carbonaceous shale attains a thickness of between 8 and 14 m. The overlying dark bluish-green to grey massive shale is easily distinguished from the underlying black shale on account of its colour, silty and intercalated sandstone lenses and the presence of concretions (Fig. 3). Within this greenish-grey massive shale two horizons of iron-rich beds and carbonate concretions are present. The grey to olive-green micaceous shale lying above the massive shale is the thickest individual unit of the Prince Albert Formation and attains a thickness of between 20 and 30 m (Fig. 3). These shales are micaceous and contain illite and chlorite as the dominant clay minerals. Much of this unit is devoid of iron-rich beds and concretions. Towards the top of this unit characteristic beds showing snuff-box weathering may be observed. The top of the Prince Albert Formation has a distinctive 2–3-m thick grey silty shale that, according to Visser *et* *al.* (1977–78), forms a good marker horizon in the area. This unit has a characteristic mottled appearance due to the presence of chlorite.

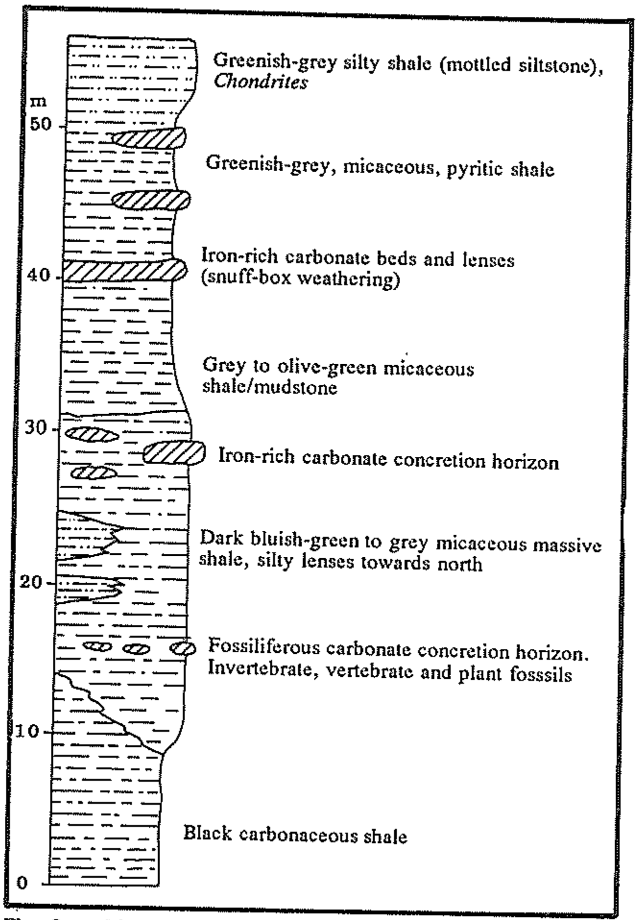

Fig. 3 — Lithological profile of the Prince Albert Formation (after Visser *et al.* 1977–78).

The absence of ripple marks and bedding indicates low-current velocities. Deposition of much of the Prince Albert Formation occurred in conditions of quiet water, with little current mixing, enabling anoxic conditions to develop and thus accounting for the basal carbonaceous shale. Much of the Prince Albert Formation was deposited by clay-grade material settling out of suspension. Occasional thin sandstone and siltstone lenses, however, testify to deposition under slightly higher energy conditions.

4.2.2 Whitehill Shale Formation

The Whitehill Formation varies in thickness between 10,82 and 18,20 m (Cole, 1978). There is, however, a regional thinning of the Whitehill Formation northwards from 16 m recorded on the farm Hayfield 177 northeast of Hopetown (McLaren, 1974) to 7 m on Mauritsfontein 26 just north of the map area. The contact of the Whitehill with the Prince Albert Formation is well defined since the former consists mainly of thinly laminated carbonaceous shale that weathers white. The siltstone units of the Whitehill are characterised by lenticular bedding. A decrease in the proportion of siltstone occurs southwards through the study area. Small specks of carbon may be seen in hand specimen and Cole (1978) noted that the average value of fixed carbon was 4,35 per cent with a maximum value of 10 per cent. Visser *et al.* (1977–78) noted the presence of thin ferruginous bands in the Whitehill Formation due to the decomposition of pyrite.

According to Cole (1978) the widespread occurrence of lenticular bedding in the siltstone units suggests that the depositional environment was subtidal. Although lenticular bedding is characteristic of muddy sediments deposited in a subtidal environment (characterised by alternating slack and faster flow), it may also originate in a prodelta environment (Reineck and Singh, 1975). Rapid colour changes that are related to textural differences may also be indicative of a prodelta environment. The presence of carbonaceous material allied to the absence of bioturbation in the Whitehill Formation indicates quiet-water and anoxic conditions where organisms were unable to colonise the substrate.

4.2.3 Tierberg Formation

The Tierberg Formation attains a thickness of approximately 300 m in the map area and represents the uppermost unit of the Ecca Group. The poor outcrop does not allow for accurate thickness measurements and this figure should therefore be regarded as tentative. Visser *et al.* (1977–78) proposed a threefold lithological subdivision of the Tierberg Formation (Fig. 4). The basal unit of the Tierberg Formation which they informally termed the "basal shale-mudstone" comprises light-green to greenish-grey shale with interbedded siltstone and fine-grained sandstone and attains a thickness of approximately 125 m. X-ray diffraction indicates that the shale consists of illite, sericite, chlorite, feldspar and quartz. Scattered calcareous concretions occur mainly in the lower part of the unit.

The overlying unit, termed "dark shales" by Visser *et al.* (1977–78) comprises a monotonous succession of soft, thin-bedded, bluish-grey to black shale with abundant carbonate concretions. It attains a thickness of approximately 150 m and can extend almost up to the base of the Beaufort Group sediments (Fig. 4). Zawada (1987) termed this unit "dark-grey shale", with patchily developed parallel lamination being present towards the top. The shale reveals furthermore, pencil-like

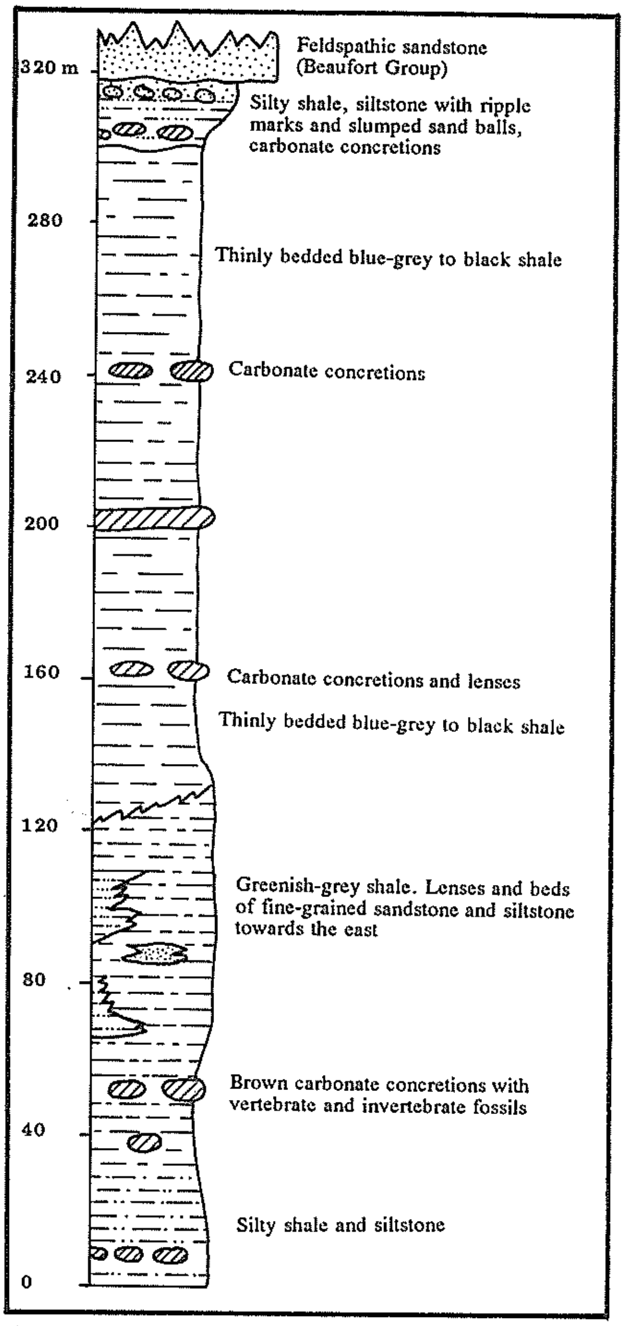

Fig. 4 — **Lithological profile of the Tierberg Formation (after Visser *et al.* 1977–78).**

weathering. Kidney-shaped concretions and nodules (5–20 cm diameter), spherical septarian nodules or cone-in-cone structures occur sporadically. These concretionary horizons rarely extend laterally for more than 10 m. In general, the blue and dark-grey shales of the Tierberg Formation contain a small amount of organic carbon and syngenetic pyrite compared with the shales of the Prince Albert and Whitehill Formations.

Visser *et al.* (1977–78) termed the upper unit of the Tierberg Formation the "upper siltstone". According to them these upper siltstones attain a thickness of between 10 and 15 m in the study area (Fig. 4). Much of the unit comprise hard greenish and bluish-grey shale, siltstone and fine-grained sandstone that grade upwards into sediments of the Beaufort Group.

Visser *et al.* (1977–78) suggested that since much of the Tierberg Formation lacks organic carbon, the climate had warmed appreciably precluding the growth of forests and thus resulting in little organic matter reaching the depository. The fine-grained nature of the Tierberg Formation and the absence of current-produced structures indicate that sedimentation occurred through the settling of clay-grade material. A major change in environment occurred, however, in the "upper siltstones" where higher sedimentation rates and increased flow regimes occurred as a direct result of uplift in a southerly source area. The "upper siltstones" have been interpreted by Visser *et al.* (1977–78) as belonging to delta lobes which formed part of a large deltaic complex.

4.3 The transition zone between the Ecca and Beaufort Groups

Although Visser *et al.* (1977–78) described the sediments and depositional environments of the siltstone facies at the top of the Tierberg Formation briefly, Zawada (1987) has made a detailed sedimentological analysis of these sediments from the top of the dark shales, through to the upper siltstones to the lower beds of the Beaufort Group. The Ecca–Beaufort transition zone is a particularly interesting sequence of sediments since it records a gradational change in lithology due to a progressive change in depositional environment from predominantly open-water to terrestrial conditions.

A generalised lithological section through the transition zone is presented in Fig. 5. It can be seen that the transition zone may, for convenience sake, be subdivided into an upper and lower part. The lower part shows a gradational lower contact with the underlying dark-grey shales of the Tierberg Formation. These shales grade upwards into thinly bedded siltstones and mudstones showing parallel and lenticular lamination. The bed thickness of the interbedded siltstone and mudstone varies from 1–3 cm towards the base to 5 cm at the top. A very fine-grained sandstone, 0,50–1,0 m thick, overlies the above unit. This sandstone shows a sharp basal contact and parallel lamination and wave ripples. The top displays

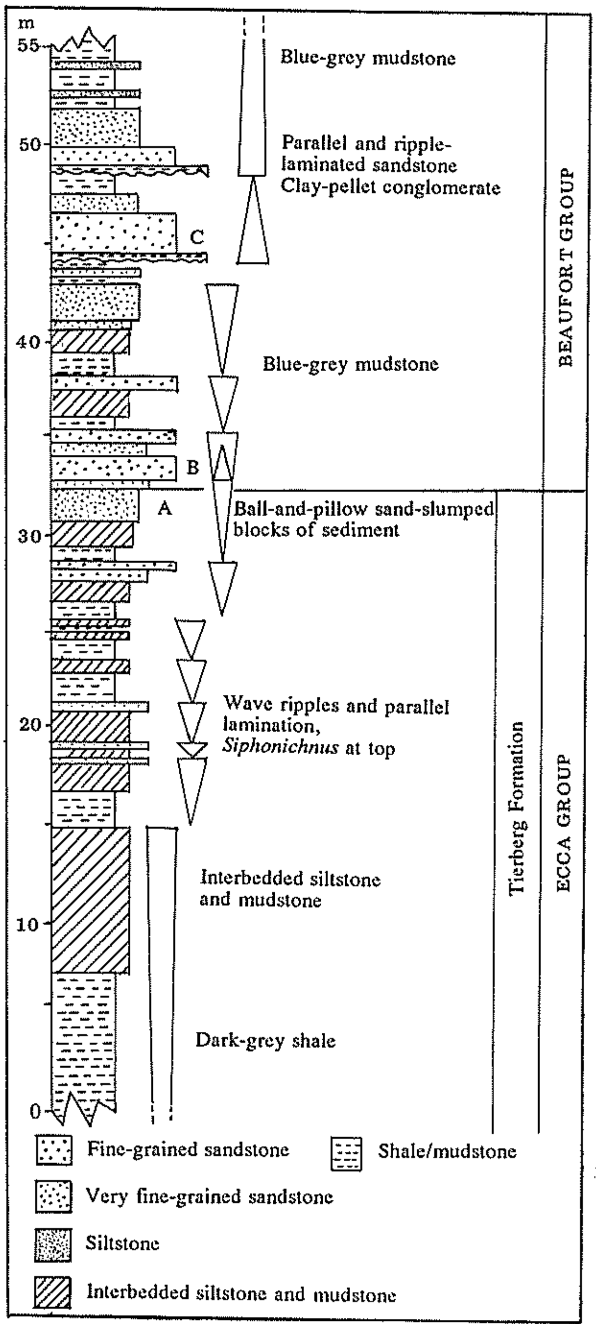

Fig. 5 — Lithological profile of the transition zone between the Ecca and Beaufort Groups.

planed-off ripple crests and bioturbation in the form of straight vertical tubes. These trace fossils have been identified as *Siphonichnus* (Fig. 6).

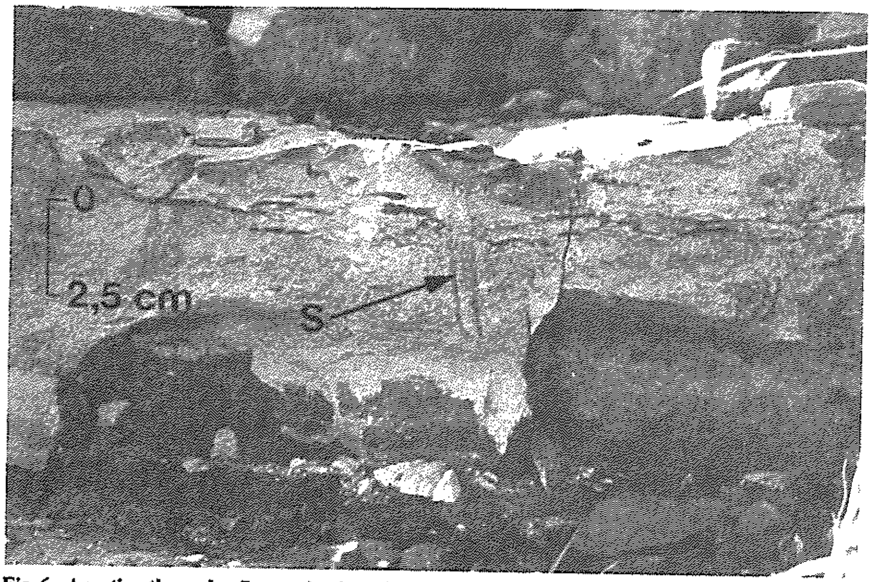

Fig. 6 – A section through a fine-grained sandstone showing a vertical *Siphonichnus* burrow marked "S".

The sequence of sediments described from the dark-grey shale, interbedded siltstone and mudstone through to a very fine-grained sandstone is repeated up to five times in vertical profile throughout the map area.

The upper part of the transition zone is characterised by generally thicker and coarser-grained beds with thinner intervening mudstone. It is usually marked by the presence of a prominent siltstone unit ("A" in Fig. 5) displaying ball-and-pillow structures and small blocks of slumped sediment (Figs 7 and 8). This siltstone unit may be traced throughout much of the study area. The overlying sandstone ("B" in Fig. 5) is approximately 5–6 m thick and is laterally more continuous than the lower thinner sandstones. This sandstone fines upwards in grain size with the lower parts displaying poorly developed parallel lamination. Towards the top of the sandstone, ripple lamination and thin bands of discontinuous mudrock occurs. The top of the transition zone is marked by an erosionally based fine-grained sandstone ("C" on Fig. 5) displaying a thin clay-pellet conglomerate at the base. This sandstone has been traced throughout much of the study area on account of its yellowish colour. It is feldspathic, poorly sorted and displays localised low-angle foreset development. It is also characteristic in that it displays a consistent association of sedimentary structures from the base to the top. Above the clay-pellet conglomerate a zone of well-developed parallel lamination occurs which in turn is overlain by a ripple-laminated zone.

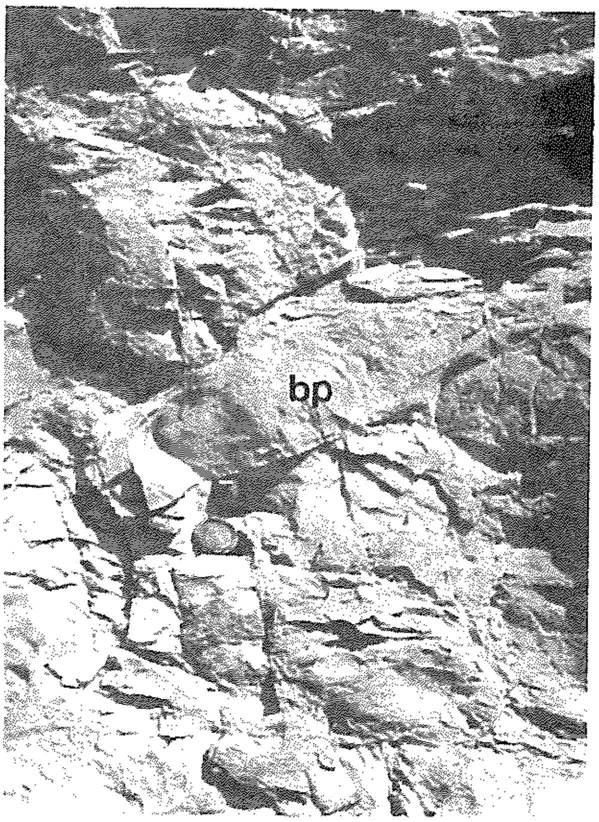

Fig. 7 – A siltsone showing an example of a ball-and-pillow structure marked "bp". (Lens cap for scale measures 52 mm in diameter)

Much of the transition zone has been interpreted as being deposited under deltaic conditions. However, there do appear to be two different scales of delta sedimentation in the area. The thinner upward-coarsening sequences noted towards the base of the transition zone are interpreted by Zawada (1987) as discrete incursions (crevasse splays) of sediment-laden waters transported either through crevasse channels or through overbank flooding into the basin due to exceptional flood conditions. The thicker upward-coarsening sequences towards the top of the transition zone have been interpreted as small-scale delta lobes prograding out and across platform muds. These high constructive delta lobes prograded northeastwards into a shallow embayment (approximately 12 m deep)

Fig. 8 – The same siltstone as in Fig. 7, showing a slumped block of sediment marked "sb". Note that the lamination (marked "L") in the slumped block is approximately 90° to the bedding in the undisturbed rock. (Lens cap for scale measures 52 mm in diameter.)

and were probably part of a larger deltaic complex outside the area. The top of the transition zone, marked by upward-fining lenticular sandstone units have been interpreted as a braided-river stream environment characterised by ephemeral flow conditions. Numerous clay-pellet conglomerates record increased river discharge whilst thin mudstone drapes represent periods of bedform emergence during low river discharge (Zawada, 1987).

The lithostratigraphic contact between the Ecca and Beaufort Groups has been positioned at the base of the first prominent laterally continuous sandstone overlying the predominantly argillaceous sediments of the Tierberg Formation (Zawada and Cadle, 1988). This contact clearly demarcates a point below which argillaceous sediments predominate and above which arenaceous sediments characterise the strata of the Beaufort Group (Fig. 5). Although a number of thin sandstones occur below the lithostratigraphic contact they are not considered to seriously affect the definition of the Tierberg Formation being predominantly argillaceous and that of the Beaufort Group being arenaceous. Such a contact may be clearly identified in the area and even where outcrop is particularly poor it is still the best means of identifying the position of the Ecca–Beaufort contact. This contact is likely to be located at differing stratigraphic levels from place to place, mainly as a result of variable sandstone development. This, however, should not be regarded as a disadvantage since the contact is a lithostratigraphic one with no connotation of time.

4.4 Beaufort Group

The sediments of the Beaufort Group in the central and western parts of the map area comprise fine-grained sandstone, siltstone, blue-grey massive mudstone and occasional clay-pellet conglomerate. The basal part of the Beaufort Group is arranged into a number of thin upward-coarsening sequences of sediment that are similar to the upward-coarsening package of sediment recording crevasse and small-scale delta-lobe deposition in the upper part of the Tierberg Formation. Approximately 13 m above the Ecca–Beaufort contact thin clay-pellet conglomerates are noted at the base of the fine- to medium-grained yellowish sandstone (sandstone C in Fig. 5). This unit as well as other units above it are distinctive as they all grade from clay-pellet conglomerate at the base to fine- to medium-grained sandstone displaying parallel lamination formed in the upper flow regime and to sandstone displaying micro cross-lamination formed in the upper part of the lower flow regime. These units are interpreted as braided-river stream deposits recording periods of ephemeral flow (Zawada, 1987). The clay-pellet conglomerates record the renewed activation of a channel whilst thin argillaceous drapes represent periods of a lower river stage.

The Beaufort Group in the eastern part of the area comprises clay-pellet conglomerate, dark-grey and purple-coloured mudstone, siltstone and coarse arkosic grits.

Brynard *et al.* (1982) had, on the basis of closely spaced shallow boreholes, been able to identify four environments of deposition in the eastern part of the area, namely a deltaic transition which includes sediments they considered as the upper part of the Ecca Group and which Zawada (1987) correlated with the Beaufort Group in the western part of the area, a zone of fluviatile sediments, lacustrine mudstones and finally, coarse arkosic grits of alluvial-fan origin (where rivers terminate on alluvial plains). Much of the work done by Brynard *et al.* (1982) was confined to the zone of fluviatile sedimentation. They suggested that a lacustrine delta complex developed on a river flood plain. Such a delta is thought to have formed in a water body of low wave energy and littoral drift. The channel system feeding this lacustrine delta was fan-shaped comprising small-scale bifurcating channels. It was also suggested by Brynard *et al.* (1982) that the delta on Mooifontein is similar to the type I and II deltas described by Coleman and Wright (1973) in which low wave energy, low littoral drift and a high suspended load were factors in the growth and development of the delta. The vertical sequence of facies in the Mooifontein delta is illustrated in Fig. 9.

4.5 Petrography of the sandstones of the Ecca and Beaufort Groups

A petrographic study of the sandstones from the Ecca and the Beaufort Groups has shown that there is little difference in composition and textural criteria between the two groups (Zawada, 1987). Feldspar, rock fragment and quartz values indicate that the sandstones may be classified as feldspathic litharenites. Both sandstone groups are moderately sorted and subangular according to Power's (1953) visual scale of roundness. All the sandstones may be described as immature, primarily on the basis of their high clay-matrix content, sorting and angularity. This may indicate that during the deposition of the Ecca and Beaufort sandstones, current action was weak, or that deposition was rapid so that sediments were not subjected to effective sorting, winnowing and abrasive processes.

A provenance-related study indicates that the source area responsible for providing material to the Ecca and Beaufort Groups was predominantly volcanic and metamorphic in nature. There is, however, also evidence of an acid (possibly granitic) provenance (Zawada, 1987).

4.6 Geochemistry of argillaceous rocks from the Ecca and Beaufort Groups

A preliminary geochemical investigation of mudrocks of the Ecca and Beaufort Groups in the Fauresmith area was carried out by Zawada (1984). In this study 24 mudrock samples were collected and analysed for major, and, more specifically, for trace elements. It was found that across the Fauresmith district ($\pm$ 7 500 km^2) a distinct trace-element difference exists between the Ecca and Beaufort Groups. It has proved possible to identify two geochemical facies based on the trace elements V, Ni, Cu, Zn, Sr, Rb and Zr. This study was subsequently extended to include 38 samples from a larger sampling area which also indicated a similar geochemical difference between the mudrocks of the Ecca and Beaufort Groups. These results are shown in Table 1. As noted by Zawada (1984) these geochemical differences coincide approximately with the established lithostratigraphic subdivision between the Ecca and Beaufort Groups.

The mudrock geochemistry has also shed important light on the palaeosalinity of the Tierberg Formation. Rb/K, V/Al and Cu/Al ratios and boron values have consistently shown that very little difference in palaeosalinity exists between the

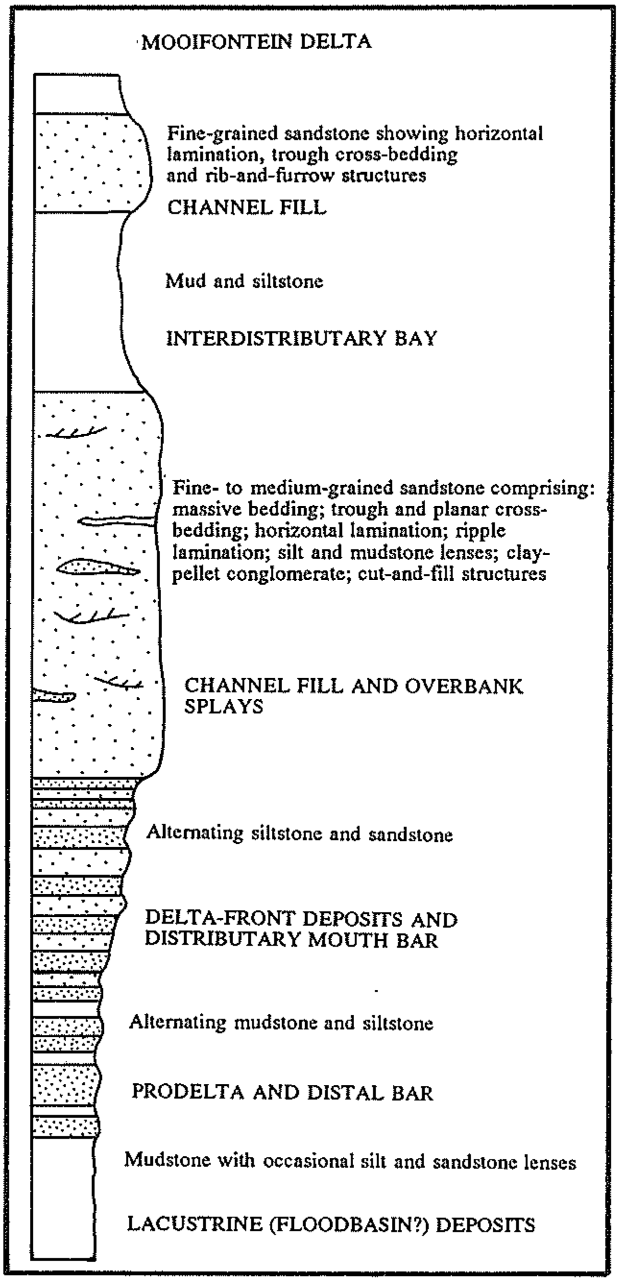

Fig. 9 — Lithological profile of the Mooifontein delta, Mooifontein uranium deposit (after Brynard *et al.* 1982).

Table 1 — Trace-element values (ppm) of mudrock samples from the Ecca Group (open water) and Beaufort (lower delta plain).

	MEAN		STANDARD DEVIATION	
	Open water Ecca Group	Lower delta plain Beaufort Group	Open water Ecca Group	Lower delta plain Beaufort Group
V	138	78	22	23
Ni	25	12	6	8
Cu	52	27	14	13
Zn	145	109	29	20
Sr	87	236	39	120
Rb	194	147	25	41
Pb	23	14	6	8
Zr	160	201	30	27
Ba	622	680	71	196

shales deposited under open-water conditions and the mudstones deposited in the lower delta-plain environment. It has also indicated that the salinity of the waters were brackish and/or fresh (Zawada, 1988). This interpretation agrees with Visser *et al.* (1977–78) who suggested that the Tierberg Formation was probably deposited under fresh-water conditions.

5. KAROO DOLERITE

Dolerite dykes, inclined sheets and sills intruded the sediments of the Karoo Sequence during the Jurassic period. The dykes are generally 1–10 m wide and several kilometres long.

The sills are generally discordant, often undulating and in some cases dipping to form ring structures. According to Cole (1978) all the sills are discordant and split or thin over domal structures. Cole (1978) and Potgieter (1974) noted that a dolerite sill has consistently intruded at the contact between the Whitehill and Prince Albert Formations.

According to Potgieter (1974) the dolerite consists primarily of subhedral labradorite ophitically intergrown with pigeonite and minor olivine whereas biotite, chlorite, amphibole and opaque minerals occur in small amounts. Potgieter tabulated the mineral composition of three dolerite samples (shown in Table 2).

Table 2 — Mineral composition of three dolerite samples (after Potgieter 1974).

MINERAL	LOCALITY		
	BANNOCK-BURN 138	BANNOCK-BURN 138	EGMONT 187
Pyroxene	39,63	41,50	39,01
Plagioclase	57,12	48,79	54,52
Olivine	0,00	5,08	4,39
Biotite + Chlorite	1,16	0,00	0,78
Amphibole	0,00	0,22	0,27
Opaques	2,09	4,41	1,03
TOTAL %	100,00	100,00	100,00

6. QUATERNARY SEDIMENTS

6.1 Calcrete

Large areas are underlain by calcrete, especially in the western part of the map area and in particular in areas comprising shales of the Ecca Group. According to Potgieter (1974), circulating ground water rich in calcium carbonate was introduced into the upper beds of the shales. Evaporation of the water close to the surface led to the precipitation of calcrete. This process was accompanied by lateral stress in the host rock due to carbonate crystal growth and was accommodated by acute folding in the uppermost shale beds. Potgieter (1974) stated that three types of calcrete, based on Netterbergs (1969) classification scheme, exist in the area:

1. First intermediate calcretes, mainly found in calcified alluvial gravels.
2. Second intermediate calcretes containing Middle Stone Age tools (the most common).
3. Recent hard-pan calcretes, found adjacent to pans.

6.2 Wind-blown sand

Aeolian sand occurs over large tracts of the map area, especially towards the west. Wind-blown sand may occur either as seif-like dunes with amplitudes of up to 40 cm (accounting for 10% of the total amount of wind-blown sand), or as a thin veneer of sand varying in thickness of between 0,02 and 1,50 m. The sand is reddish in colour and is composed principally of subrounded to rounded quartz grains with small amounts of feldspar. Sieve analyses of the sand by Potgieter (1974) suggested an aeolian origin with some degree of fluvial modification. Electron microscopy of sand grains by the same author showed that the grains possessed surface textures characteristic of both an aeolian and glacial environment.

The transport of wind-blown sand in the area was from the northwest. According to Potgieter (1974) the presence of certain unstable minerals like hornblende and tourmaline indicate that part of the sand was derived locally.

6.3 Alluvium

Alluvium of limited width occurs adjacent to river courses or is more widespread as sheet-wash deposits. The alluvium confined to river courses is mainly fine grained (silt and very fine-grained sand) whereas the sheet-wash deposits are generally coarser grained with many scattered rock fragments.

7. STRUCTURAL GEOLOGY

The map area may be divided into two structurally distinct regions namely gently folded Ventersdorp strata and horizontal or gently dipping strata of Karoo and younger.

Due to the paucity of outcrops it has not been possible to clearly identify key structural elements within the strata of the Ventersdorp Supergroup. Potgieter (1974) however, stated that the Ritchie Quartz Porphyry along the Riet River had been folded into a broad anticline with an east-northeast trend. In addition, local dips of up to 40° towards the west were noted. Potgieter also noted that the Ventersdorp lavas dip approximately 10° northwards in the Modder River area. According to McLaren (1974) the only structural feature in the Ventersdorp strata is an anticlinal structure trending northwest with no sign of large-scale tectonic activity in an area further south towards Hopetown. McLaren (1974) mentioned that local variations of dip occur with minor faulting and the development of lineaments and shear zones with an orientation of between 345 and 360°.

The Karoo strata of the area display a very low angle of dip (less than 5°) towards the south with only localised upturning of strata adjacent to dolerite dykes. Open folds were noted by Potgieter (1974) in the strata of the Ecca Group. These were not ascribed to tectonic movement but to differential compaction as a result of basement topography.

8. ECONOMIC GEOLOGY

8.1 Diamonds

Data obtained from the Catalogue of Kimberlites (Hine, in prep.) show that 41 occurrences of kimberlite-related intrusions occur in the map area. Eighteen of these are classified as pipes of which six have been profitably mined at some stage. Twenty-one occurrences of kimberlite intrusions related to fissures occur in the area, but only two have been of economic interest. The remaining two kimberlites are classified as blows. Details of kimberlite pipes and fissures that have been mined in the past are summarised in Table 3.

Table 3 — List of kimberlite occurrences that have been mined for diamonds in the past (Hine, in prep.).

FARM NAME AND NUMBER	DISTRICT NAME	KIMBERLITE	MORPHOLOGY
Panfontein 733	Koffiefontein	Panfontein	Pipe
Panfontein 733	Koffiefontein	Koffie Diamond Mine	Pipe
Panfontein 733	Koffiefontein	Ebenhaezer No. 1	Pipe
Panfontein 733	Koffiefontein	Ebenhaezer No. 2	Pipe
Saltpetre Pan 127	Herbert	Saltpetrepan W.1.	Fissure
Saltpetre Pan 127	Herbert	Saltpetrepan N.E.	Fissure
Jagersfontein 14	Jagersfontein	Bothas pipe	Pipe
Jagersfontein 14	Jagersfontein	Jagersfontein Mine	Pipe

The two most profitable diamond mines in the area are the Koffiefontein and Jagersfontein Mines.

Jagersfontein Mine:

Jagersfontein Mine comprises two kimberlite pipes that have produced diamonds of gem quality up to 1971 when the mine ceased production. Production figures show that in the Jagersfontein Mine 49 623 015 tons of ore were processed from which 5 927 701 carats at an average grade of 11,95 carats/100t were extracted.

Koffiefontein Mine:

Diamonds were first discovered in the Koffiefontein area in 1870 although it was not until 1879 that the area was declared a public digging. By 1911 De Beers had gained full control of the area through the cessation of leases. The next twenty years saw the extraction of 2 660 000 carats from surface mining of which 50% were of industrial quality. The depression of 1933 coupled with the low demand for industrial diamonds caused the mine to close and it had remained so for almost 40 years. In 1968, after renewed interest, the mine was reopened with the intention of bringing it into full production to eventually replace the old Jagersfontein Mine that was reaching the end of its economic life. The pit which has a circumference of 2 400 m at the surface reached a final depth of 244 m by the end of 1980. The Koffiefontein Mine closed around 1981 as a result of the low prices of gem-quality diamonds and reopened in 1987.

Production figures up to 1981 show that the Koffiefontein Mine processed 33 982 215 tons of ore from which 4 760 311 carats were recovered at an average grade of 14,01 carats/100t.

Saltpetre Pan 127:

Very little information is available on these kimberlite occurrences except that 8 404,9 tons of ore was processed of which 348,16 carats were recovered at an average grade of 4,14 carats/100t.

8.2 Uranium

In the map area 10 uranium occurrences have been identified based on data supplied by Rio Tinto Zinc and Cole *et al.* (1979). The Mooifontein deposit is regarded as the most viable economic deposit in the area. According to Rio Tinto these uranium occurrences show values of greater than 100 ppm U_3O_8. A brief description of some of these occurrences is presented below:

Locality: Sheet 2925 DB, Farm: Mooifontein 76.

Drilling operations by Rio Tinto Exploration between 1977 and 1980 outlined an F-shaped ore body at shallow depth having an average grade of 0,85 kg U_3O_8/ton. The Mooifontein deposit is located stratigraphically in the fluvial sandstones of the Adelaide Subgroup close to the contact of the *Aulacephalodon* and *Dicynodon lacerticeps* Assemblage Zones. The Mooifontein deposit comprises three major ore bodies each between 800 and 1 000 m long and 50–450 m in width. These bodies are isolated from each other by narrow barren strips. The mineralised interval is up to 7 m in thickness. Mineralisation by U_3O_8 has been aided by a mud-pebble conglomerate at the base of the ore body. Vegetation on the natural levees also helped to concentrate the uraniferous solutions by producing localised reducing conditions in the sediment.

Although the average grade of 0,85 kg U_3O_8/ton is slightly lower than the occurrences near Beaufort West of 1 kg/ton, Brynard *et al.* (1982) considered that the shallow depth of the ore body which allow open-cast mining would adequately compensate for the lower grade.

Locality: Sheet 2925 DC, Farm: Plaatjesfontein 143.

Scintillometer readings in excess of thirty times the background count are recorded from the base of a palaeochannel sandstone trending in a north-northwesterly direction for approximately 1 km. The mineralisation is patchy and is mostly confined to isolated outcrops of koffieklip (dark-brown calcareous concretion) that is found in the sandstone. According to Cole *et al.* (1979) the grade of the mineralisation is appreciable with a calculated value of 1 184 ppm of U_3O_8 occurring along the trend of the palaeochannel.

Locality: Sheet 2924 DD, Farm: Roodelaagte 131.

Scintillometer readings of between three and four times the background count were recorded from hornfels (baked Ecca Group shale). This is thought to be caused by ThO_2, which is probably related to the presence of zircon (Cole *et al.*, 1979).

Locality: Sheet 2925 DB, Farm: Vaalkraal 353.

Scintillometer readings of between two and six times the background count were recorded from a multistoreyed channel sandstone with occurrences of koffieklip. According to Cole *et al.* (1979) the grade of the mineralisation is low, due to the limited thickness of the sandstone.

Locality: Sheet 2925 DB, Farm: Mullersrust A 557.

Scintillometer readings of between four and six times the background count were recorded from a patchily developed mineralised sandstone, koffieklip and conglomerate (Cole *et al.*, 1979). According to Cole *et al.* the sandstone is coarse grained and the associated conglomerate is allochtonous.

Locality: Sheet 2925 DB, Farm: Springfontein 215.

Scintillometer readings of between four and five times the background count were recorded from a very fine to fine-grained buff sandstone. According to Cole *et al.* (1979) the grade of mineralisation is low and subsurface extensions of this mineralisation along the palaeochannel are unlikely.

According to Brabers (1976), quoting Richards (1975), most of the salt pans in the area show a higher level of radioactivity than the surrounding terrain. It was suggested that this radioactivity is caused by thorium and probably only slightly by uranium. None of these occurrences are, however, thought to be of economic importance.

8.3 Salt

Salt pans are widespread throughout much of the western part of the area. They are underlain by rocks of the Ecca Group and Dwyka Formation. According to Brabers (1976) very little data are available on the salt reserves of the pans but an indication of the resources may be obtained from the surface area of each pan on the assumption that the surface layers above bedrock contain 1 060 tons of salt per 3 m depth per hectare. The total production* of salt in the different districts is as follows:

Herbert — 16 278 tons

Fauresmith — 12 656 tons

Jacobsdal — 5 233 tons

Hopetown — 22 361 tons

8.4 Gypsum

Gypsum is known from several pans in the area. Brabers (1976) reported, however, that no production was taking place. A short description of the known localities of gypsum in the area is given below:

Wanda Pan 202:

Approximately 5 per cent of selenite crystals are found in clay and shale at the southeastern part of the pan. The deposit is not of economic interest.

Lilydale 228:

Two deposits of gypsum are known to occur on this farm. The northern deposit occupies an area of approximately 10 hectare with an average 65 per cent gypsum over a depth of about 70 cm. The reserves are estimated to be in the order of 65 000 tons. The southern deposit is of low grade and is of little economic interest.

Leinster 222–Langford 221:

An unknown quantity of gypsum is thought to be present on the common boundary of these two farms as well as further north.

8.5 Aggregate

The dolerites of the map area appear to be suitable for crushing for the production of aggregate. Crushed dolerite has been extensively used in the building of roads, bridges and irrigation canals in the area.

* Data supplied by the Minerals Bureau

8.6 Calcrete

Large regions of the map area are underlain by calcrete and it is used as a road-building material. According to Potgieter (1974) the calcrete contains between 70 and 79 per cent calcium carbonate and not more than 18 per cent magnesium carbonate and can possibly be used as a second-grade agricultural limestone.

8.7 Oil shale

An oil-shale occurrence was reported by Parkinson (1923) on the farm Elandsdraai situated on the south bank of the Orange River approximately 15 km east of Hopetown. Three boreholes were drilled and a seam of approximately 2,40 m was intersected at a depth of approximately 28 m probably in the Whitehill Formation. Analysis of the shale showed that its oil yield was too poor to be considered of economic interest. The amount of ammonia (0,085 per cent by mass) was considered high enough for the production of fertiliser.

The Geological Survey drilled a number of holes in 1977 between Strydenburg and Hertzogville to investigate the oil potential of the Whitehill Formation. The results were disappointing; the highest yield obtained was 60 ℓ/ton. The Whitehill was found to be detrimentally affected by the intrusion of dolerite.

REFERENCES

BRABERS, A. J. M., 1976. Mineral occurrences in the P. K. le Roux Dam irrigation area: Rep. geol. Surv. S. Afr., 1976–0001, 5p. (unpubl.).

BRYNARD, H. J., JAKOB, W. R. O. and LE ROUX, J. P., 1982. The sedimentology, mineralogy and geochemistry of the Mooifontein deposit, Orange Free State: Rep. Nuclear Development Corporation of South Africa, PER-67, 87p.

COLE, D. I., 1978. Preliminary report on the oil potential of the Whitehill Formation between Strydenburg (Cape Province) and Hertzogville (Orange Free State): Rep. geol. Surv. S. Afr., 87, 21p. (unpubl.).

COLE, D. I., LABUSCHAGNE, L. S., SCHUTTE, F. J. P. and HAYNES, L., 1979. Results of the ground follow-up of 40 airborne radiometric anomalies in block 9 of the Karoo survey: Rep. geol. Surv. S. Afr., 1979–0161, 19p. (unpubl.).

COLEMAN, J. M. and WRIGHT, L. D., 1973. Variability of modern river deltas: Trans. Gulf Coast Assoc. geol. Soc., 23, p. 33–36.

DU TOIT, A. L., 1907. Geological survey of portions of Hopetown, Britstown, Prieska and Hay: Twelth a. Rep. geol. Comm. Cape Good Hope, p. 159–192.

HINE, S. S., (in prep.). Catalogue of Kimberlites: Geol. Surv. S. Afr.

McLAREN, C. H., 1974. Die geologie van 'n gebied suid van Plooysburg, Noord-Kaapland: M.Sc. thesis, Univ. Orange Free State, 257p. (unpubl.).

NEL, L., 1977. Die geologie van 'n gebied suid van Hopetown: M.Sc. thesis, Univ. Orange Free State, 171p. (unpubl.).

NETTERBERG, F., 1969. Ages of calcrete in Southern Africa: Bull. S. Afr. Archeol., 24, p. 88–92.

PARKINSON, F. B., 1923. Report on the occurrence of oil shale on the farm Elandsdraai, adjoining Orange River Station, district Hopetown, Cape Province: Rep. geol. Surv. S. Afr., 1923–0003, 7p. (unpubl.).

POTGIETER, G. J. A., 1974. The geology of an area south of Kimberley: M.Sc. thesis, Univ. Orange Free State, 91p. (unpubl.).

POTGIETER, G. J. A. and LOCK, B. E., 1978. Correlation and lithology of the Ritchie Quartz Porphyry Formation along the Riet River, near Kimberley: Trans. geol. Soc. S. Afr., 81, p. 41–46.

POWERS, M. C., 1953. A new roundness scale for sedimentary particles: J. sedim. Petrol., 23, p. 117–119.

REINECK, H. E. and SINGH, I. B., 1975. Depositional sedimentary environments with reference to terrigenous clastics: Springer-Verlag, Berlin, 439p.

RICHARDS, D. J., 1975. Preliminary report on pan mineralisation from airborne radiometric surveys, N.W. Cape Province: Rep. geol. Surv. S. Afr., 1975–0267, 8p. (unpubl.).

THERON, J. N. and BLIGNAULT, H. J., 1973. A model for the sedimentation of the Dwyka glacials in the south-western Cape *in* I.U.G.S. 3rd Gondwana Symp. (K. S. W. Campbell, ed.), Canberra, p. 347–356.

VISSER, J. N. J., LOOCK, J. C., VAN DER MERWE, J., JOUBERT, C. W., POTGIETER, C. D., McLAREN, C. H., POTGIETER, G. J. A., VAN DER WESTHUIZEN, W. A., NEL, L. and LEMMER, W. M., 1977–78. The Dwyka Formation and Ecca Group, Karoo Sequence, in the northern Karoo basin, Kimberley–Britstown area: Ann. geol. Surv. S. Afr., 12, p. 143–176.

ZAWADA, P. K., 1984. A preliminary geochemical investigation of Ecca and Beaufort Group mudrocks in the Fauresmith area, Orange Free State: Ann. geol. Surv. S. Afr., 18, p. 53–65.

————, 1987. The stratigraphy and sedimentology of the Ecca and Beaufort Groups in the Fauresmith district: M.Sc. thesis, Univ. Witwatersrand, 198p. (unpubl.).

————, 1988. Trace elements as possible palaeosalinity indicators for the Ecca and Beaufort Group mudrocks in the southwestern Orange Free State: S. Afr. J. Geol., 91(1), p. 18–26.

ZAWADA, P. K. and CADLE, A. B., 1988. Position of the Ecca–Beaufort contact in the southwestern Orange Free State: an evaluation of four possible alternatives: S. Afr. J. Geol., 91(1), p. 49–56.