EXPLANATION: SHEETS 2520 AND 2620

NOSSOB AND TWEE RIVIEREN

GEOLOGICAL SURVEY

REPUBLIC
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Cover — Younger dunes in the Gordonia Formation; Kalahari Gemsbok National Park.

Photo: J. du P. Bothma

Republic of South Africa

Department of Mineral and Energy Affairs

GEOLOGICAL SURVEY

THE GEOLOGY OF THE NOSSOB AND TWEE RIVIEREN AREAS

by

R. J. THOMAS, Ph.D., M. A. THOMAS, M.Sc. and S. J. MALHERBE, M.Sc.

Explanation of Sheets 2520 and 2620

Scale 1:250 000

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THE GEOLOGY OF THE NOSSOB AND TWEE RIVIEREN AREAS

Abstract

The rocks which crop out in these areas range in age from Mokolian to Recent. The oldest rocks are exposed in the Molopo River Valley around Khuis and are interpreted as belonging to the Olifantshoek Sequence. A small outcrop of quartz-muscovite schists of the Groblershoop Formation, the uppermost unit in this sequence, occurs in the bed of the Kuruman River on Matlapanen 192.

Sandstone and flagstones, 150 m thick, of the Nama Group form a series of outcrops north-west of Rietfontein, and are part of a prominent north-easterly-plunging anticline. The eastern limb of this fold forms a range of hills.

In the south-western corner of the area are good exposures of rocks of the Karoo Sequence, encompassing both the Dwyka and overlying Prince Albert Formations. The Dwyka Formation re-appears in the valley of the Molopo River in the east. The Karoo rocks, along with those of the Nama Group, are intruded by sills and dykes of Karoo dolerite. Diamonds were recovered from a kimberlite pipe which has penetrated the Dwyka Formation one kilometre east of Rietfontein village. To the north and east of this area, the older rocks are covered unconformably by those of the Kalahari Group. These comprise the basal Wessels and Budin Formations, which do not outcrop, but of which the distribution was obtained from boreholes. The Budin formation is followed conformably by the Eden Formation. The calcrete of the Mokalanen Formation covers all the older rocks to some extent. Overlying these more or less consolidated beds is a large accumulation of aeolian red sand (the Gordonia Formation) which covers more than 90% of the area. Longitudinal dunes are common. The total thickness of the Kalahari Group exceeds 110 m in the deepest pre-Kalahari troughs.

1. INTRODUCTION

These maps and explanation are the culmination of field work and interpretation from aerial photographs by Thomas (1981) and Malherbe (1984). The information gathered was transferred from maps of scale 1:50 000 to produce final maps on scales 1:500 000 and 1:250 000 for sheets 2520 and 2620 respectively.

Previous studies are limited. Rogers (1908) completed the first major geological study, but there was a long interval before work of any consequence appeared. Meyer (1953) carried out geological and geophysical investigations along the Molopo and Kuruman Rivers. During the 1960's geohydrological reports covering the area were compiled by Smit (1962, 1964) and some years later this was followed by a report on the pre-Kalahari geology (Smit, 1972). Although concentrating on the uranium potential, Levin (1980) produced a geological map of the area east of 20°38′E.

2. OLIFANTSHOEK SEQUENCE

2.1 LUCKNOW FORMATION

The extensive outcrops of massive grey and white quartzites on the farm Kolonkwanen 183 in the extreme east of the area, are interpreted as belonging to the Lucknow Formation. The quartzites contain conglomeratic layers with a very high matrix to clast ratio. The clasts are well rounded and are composed of milky quartz and white quartzite about 30–50 mm in diameter. The conglomerates occur sporadically in discontinuous bands and lenses. A few thin layers of quartz-muscovite schist are present in places. Apparently about 700 m of the sequence is present, though the extent to which repetition due to folding occurs, is not known.

In the massive quartzite units on Bogogobo 182, the development of round blebs and discontinuous bands of black hematite is frequently seen. One prominent lens of coarse conglomerate is exposed in the south bank of the Molopo River on Bogogobo 182. It shows large rounded clasts of quartzite and quartzitic schist in a sparse quartz-rich matrix.

2.2 MATSAP FORMATION

These rocks are a monotonous sequence of massive, purple quartzite with some schistose intercalations and subordinate grey quartzite that crop out in the Molopo River Valley on Khuis 181 and in one isolated occurrence on Springbok 176.

2.3 GROBLERSHOOP FORMATION

One very small outcrop of quartz-muscovite schist of the Groblershoop formation occurs in the Kuruman River on Matlapanen 192. It is clearly related to the outcrops of similar rocks on nearby Lonely 174 and is the northward continuation of the floor rocks that run to the eastern side of Sheet 2720 (Noenieput).

3. NAMA GROUP

3.1 BRECKHORN FORMATION

A low, but prominent range of hills running north-east from the South-West African border, five kilometres north-west of Rietfontein, is formed by the eastern limb of a north-east-plunging anticline in the Nama Group. The range is cut by a series of south-east-trending valleys which are probably the expression of erosion along small faults. The sediments comprise about 150 m of red, brown and purplish sandstones, quartzites and flagstones with rare clay-pellet conglomerates and thin, micaceous shale horizons. They are extensively cross-bedded, showing both planar and trough cross-beds; ripple marks are commonly seen on bedding surfaces. Load structures are frequently present at the base of some of the micaceous beds.

The eastern limb of the anticline dips at between 25° and 35° to the east, with occasional steeper dips. In the north the closure of the fold appears to have been cut off by an east-trending fault which has had the effect of "dragging" the beds eastwards, markedly steepening the dips and, in some places, actually overturning them. Unfortunately the detailed relationships are obscured here as the Nama rocks are covered unconformably by those of the Kalahari Group.

The western limb is rather poorly exposed in isolated, westerly-dipping outcrops which lie beneath the prominent calcrete escarpment to the north. The core of the fold is quite well exposed in the low-lying area between the limbs where reddish flagstones and micaceous shales occur.

The rocks of the Breckhorn Formation were probably deposited in a high-energy shallow-marine or deltaic environment, with currents bringing in matetial from the north and north-east.

4. KAROO SEQUENCE

This sequence consists of the Dwyka and Prince Albert Formations which are extensively present beneath the cover of Kalahari rocks and crop out only in a few places.

4.1 DWYKA FORMATION

Rocks of the Dwyka Formation crop out in two areas: a large area around Rietfontein where they lie unconformably on the Nama Group, and in the valley of the Molopo River from Katakura 171 eastwards.

In the south-western area, around Rietfontein, extensive tracts of ground are underlain by the Dwyka Formation. The sediments show a wide range of lithologies; predominantly arenaceous rocks with tillite. Estimation of the thickness is rendered difficult by the flatness of the terrain and the isolated nature of the outcrops. Probably not less than 50 m are present, and the thickness increases eastwards away from the Nama basement. It is also difficult to construct a sequence as it appears that lateral facies variation is at least as important as vertical changes.

Northwards from Rietfontein are good outcrops of coarse, brown, immature conglomerates, cross-bedded grits and sandstones, flagstones, calcarenites and nodules of impure, brown, ferruginous limestone. These occur mainly on the higher ground between the incised, dry stream valleys where, obviously lower in the sequence, tillite and grey-green shales with occasional dropstones are exposed in addition to the arenaceous rocks. The tillite contains sub-rounded clasts up to 750 mm across. These frequently exhibit surface striations, and a large variety of exotic lithologies are found, which include vesicular basalt, granite, gneiss, dolomite, quartzite and red sandstones.

On the north-west side of Hakskeenpan there are extensive outcrops of ferruginous, brown and grey, flaggy sandstones, which are cross-bedded, ripple-marked and show extensive slumping. In these beds Meyer (1953) identified imprints of Glossopteris, though no fossils were found during the present study. It appears that these beds form the uppermost sediments of the Dwyka Formation as they are conformably overlain by those of the Prince Albert Formation on the southern margin of the pan. North-east of the main outcrops, extensive areas of hard, brown, grey and greenish, cross-bedded and slumped sandstones and grits, also presumably of Dwyka age, are exposed in the floor of Witpan.

In the flatter, lower grond south from Rietfontein, the outcrops become gradually poorer, to be replaced by areas covered by clasts derived from the erosion of the Dwyka tillite. Amongst these gravel-strewn areas, small outcrops do occur, often of sandy tillite and hard, grey limestones exhibiting well-developed cone-in-cone structures. These areas are indicated as sub-outcrops on the map.

At the southern end of Philandersbron Settlement, a prominent low escarpment is formed in buff-coloured, poorly indurated sandstone, showing magnificently developed slumped bedding and load structures. These sandstones are 2–4 m thick and overlie sandy tillite. It is estimated that at least 50 m of the Dwyka sediments are exposed in the vicinity. The lower portion consists of tillite, which becomes sandier higher in the sequence. Smit (1972) correlated these arenaceous rocks with the Nossob and Auob sandstones of South-West Africa.

Eastwards the Kalahari Group increases in thickness and covers the Karoo sediments, as is shown from borehole data. Dwyka tillite with a thickness of 122 m was recorded from a borehole on Dagarida 161, and the Dwyka Formation reappears on the banks of the Molopo River on Katakura 171. Here the succession is mainly sandy, and consists of brown-weathered, ferruginous sandstones and grits with well-developed cross-bedding, wave-ripple marks and soft sediment deformation and slump structures, such as load casts and striation marks. A well-developed fluvio-glacial channel is exposed on Vergenoeg 172. These rocks show a marked similarity with those in the vicinity of Hakskeenpan. Some of the ferruginous sediments appear to be dolomitised. Besides sandstone, discontinuous layers of poorly-sorted conglomerate and impure brown limestone area present. In many places the limestone forms large, compact masses which show a well-developed concentric Liesegang structure. Pink to grey fairly pure limestone with prominent internal dendrites of manganese oxide is present in continuous layers.

The Dwyka Formation is exposed almost continuously for some 30 km from Katakura 171 to Springbok 176, reaching a maximum thickness of 25 m on Vergenoeg 172 and Mokalanen 175. As ascertained from borehole information in the south-western area, these arenaceous and calcareous beds are underlain by tillite. Some shaley beds do in fact crop out, e.g. on the Botswana side of the Molopo River opposite Vergenoeg 172, where 10 m of grey-green shales without dropstones are associated with small pods of impure, brown limestone.

Identical arenaceous sediments reappear in the Molopo River on Police 180, west of Khuis, where 25 m of ferruginous sandstones are exposed, displaying a wide range of sedimentary structures. From Khuis eastwards, relatively small exposures of Dwyka Formation sporadically occur overlying the Mokolian quartzites. These are mainly composed of pinkish grey tillite, sandy tillite and poorly-sorted conglomerates.

The diamictite is interpreted as being of glacial-marine origin. Icebergs, bearing clasts and rock flour, were calved from glaciers and deposited dropstones and finer-grained material into muddy and sandy sediments of the sea-floor. The arenaceous rocks are clearly indicative of much nearer-shore, possibly deltaic, conditions. The spatial distribution of these two facies suggests the proximity of a landmass somewhere to the north, with deeper-sea conditions prevailing to the south.

4.2 PRINCE ALBERT FORMATION

Sedimentary rocks interpreted as belonging to the Prince Albert Formation, occur in a fairly large area south-east of the Rietfontein–Kalahari Gemsbok Park road. They are well represented with a thickness of 30–50 m in the impressive cliffs which tower above the western rim of the Koppieskraalpan.

At the end of Dwyka times, conditions favourable for the deposition of sandy material continued into the basal part of the Prince Albert Formation. Brown, ferruginous sandstones, which quickly give way to dark-grey and green, occasionally carbonaceous, thinly-bedded micaceous shales, are well exposed north and west of Koppieskraalpan. These shales are typically broken up into small, lenticular fragments a few centimetres across. Where they are in close contact with the many dolerite sills and dykes of this area, the shales show extreme hardening to a dark-grey, flinty hornfels, which often shows a prominent spotting close to the contact with the larger instrusions. The shales contain no dropstones and are virtually structureless except for infrequent slumps and occasional highly weathered ferruginous nodules. Areas covered with weathered fragments of the shales and small outcrops lying beneath the Prince Albert escarpment are shown on the map as sub-outcrop. The shales total 10–12 m in thickness and are overlain by 10–15 m of arenaceous sediments. These hard and compact rocks form the top of the escarpment west of Koppieskraalpan and are well developed on Oxford 123. The rocks are light-grey, rather pure sandstones and quartzitic sandstones, with darker ferruginous and micaceous bands and lenses. They show extensive load casting and have themselves slumped down into the underlying shales. Some of the arenaceous rocks are rich in clastic feldspar, giving rise to arkosic beds within the sequence. In common with the shales, these rocks have been extensively hardened by the ubiquitous dolerite intrusions. In fact the "prominent rock outcrop" shown on the 1:50 000 Topographic Sheet 2620 CC (Hakskeenpan) consists of two low parallel ridges of baked Prince Albert sediments on either side of a dolerite instrusion which has been almost completely weathered away in places.

Above the arenaceous beds are 10–20 m of mixed, arenaceous and argillaceous sediments which are well exposed on Oxford 123 and Eierdopkoppies. The shales are blue-grey and in places show slumping. The sandstones are grey and micaceous with some prominent arkosic sandstones and grits. One prominent arkosic grit is well developed below the dolerite sill which forms the prominent koppies of Eierdopkoppies. This bed is 2–4 m in thickness and comprises a hard, white, well-cemented rock with prominent rounded quartz and kaolinised clastic feldspars. The arkose contains occasional flat lenticular clasts of dark-grey, micaceous, ferruginous, sandy shale. The unit can be traced over an area of more than 50 km^2 and forms a capping to the prominent mesa 500 m north of the main road on Oxford.

The Prince Albert Formation appears to represent a marine environment with slow deposition of which was periodically interrupted by periods of rapid influx of coarser clastic material.

5. KALAHARI GROUP

5.1 WESSELS FORMATION

The Wessels Formation does not crop out and its subsurface distribution can only be inferred from borehole data. It consists of clayey gravel and forms the basal unit of the Kalahari Group, occupying some of the deeper pre-Kalahari channels in the south-eastern parts of the area, where it attains a maximum thickness of 20 m. It is probable that erratics from the Dwyke Formation supplied much of this material.

5.2 BUDIN FORMATION

Similarly, the Budin Formation is not exposed on surface, but boreholes show that it has quite a wide distribution in the pre-Kalahari channels. It is composed of red and brown clays and marls of probable lacustrine-fluvial origin. The formation is present in three main areas. In the south-east a maximum thickness of 43 m is on record. In the central area, on Rappells 149, 80 m of red clays are present, though the thickness in this important pre-Kalahari trough is extremely variable. The large north-west-trending trough in the west shows a patchy distribution of the red clays, but thicknesses up to 100 m have been measured.

5.3 EDEN FORMATION

The Eden Formation is widely distributed and crops out through the calcretes over most of the area, except in the extreme south-west. It consists predominantly of sandstones which are well exposed along the Auob, Nossob and Molopo Rivers, particularly in the eastern Molopo on De Brak 177 and Mulapo 179; a succession of 25 m is exposed in the cliffs forming the western edge of Koopan (on Koopan Noord 136).

The succession comprises red, brown, yellow, cream and green rather poorly-consolidated sandstones, grits and minor conglomerates. The greener grits and conglomerates tend, however, to be more strongly cemented. The sediments show a gradation downwards into the clay of the Budin Formation and upwards into sandy limestones. The sandstones are very fine-grained in places. Cross-bedding is rarely seen. The conglomerate consists of red, poorly-rounded sandstone pebbles in a red sandstone matrix.

In the less well-consolidated sandy beds, an irregular interlocking network of biotubes filled with sand are common. The material filling the tubes is identical to that of the surrounding matrix, though it is slightly better cemented, so that the tubes weather out as positive features on bedding surfaces (Fig. 1). Two types of hollow tubes are present. The one type shows a rim of limestone and was almost certainly formed by plants. The other may have been formed either by plant roots or burrowing organisms, possibly worms (Fig. 2). The tubes measure up to 300 mm in length and are usually oval in cross-section. They are well-developed in Inkbospan, Luitenantspan and in several places in the Kalahari Gemsbok National Park.

In Koopan and Mierhooppan high-angle cross-bedding is developed in the sandstones and grits. In Mierhooppan large channels filled in with coarse, reddish-brown conglomerate can be seen. The Eden Formation in the west tends to reddish-brown, whilst in the east greenish and lighter-coloured sandstones occur. Towards the east it is covered by thick limestone and it disappears at Rappells 149 to reappear on Dagarida 161, both on the Molopo River.

In the section from Dagarida 161 to Springbok 176 the sandstones tend to be green, often flaggy, with poorly developed biotubes, and containing some gritty and conglomeratic bands. On Mokalanen 175 the greenish Eden sandstones have been deformed into quite angular folds which are probably due to slumping.

To the east of Springbok, where the Kalahari Group re-thickens after thinning over the basement high, evidenced by the outcrop of purple Matsap quartzite, white calcareous sandstones up to 20 m thick are exposed. These rocks, and much of the sandy limestones in the vicinity, probably resulted from calcification of the sandstones by the overlying calcretes.

The Eden Formation was probably laid down under fluvial conditions by a braided-river system on a surface of low relief.

5.4 MOKALANEN FORMATION*

5.4.1 **Calcrete**

The calcrete of this formation has a wide distribution and straddles the boundary between the Tertiary and Quaternary rocks.

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* Not yet approved by SACS

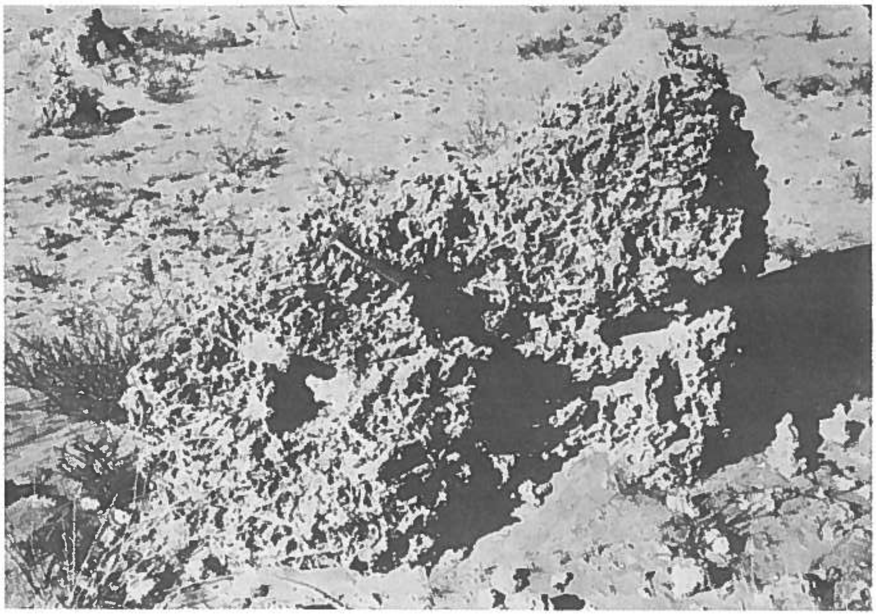

Fig. 1 — An interlocking network of sandfilled tubes in the Eden Formation; Kalahari Gemsbok National Park.

Photo: A. W. Keyser

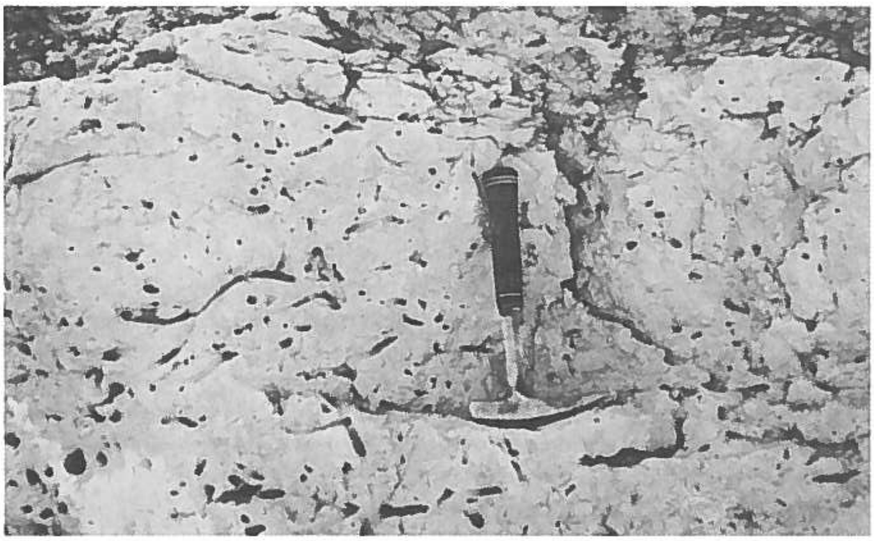

Fig. 2 — Hollow tubes in the Eden Formation probably formed by plants and burrowing organisms; Kalahari Gemsbok National Park.

Photo: A. W. Keyser

The calcareous rocks, overlying the Eden Formation, can conveniently be divided into two units (not differentiated on the map). Firstly, the lower sandy limestones grading downwards into the Eden Formation. An arbitrary boundary of 50:50 sand to limestone ratio was taken. Secondly, overlying the limestone is a calcrete which consists of calc-conglomerate with angular calcareous clasts up to 150 mm across, cemented by a calcareous matrix which often contains rounded quartz grains (Fig. 3). It seldom exceeds 3 m in thickness and usually becomes rubbly towards the base, where nodular calcrete is usually present (Fig. 4). It is thought that, while most of the limestone is Tertiary, part of the hardpan calcrete may be of Quaternary age. The total thickness of both units appears to reach a maximum of 80 m on Dreghorn 145, as ascertained from borehole data. The maximum exposed thickness is about 20 m on Police 180, Mokalanen 175 and Khuis 181. The calcrete can be seen in section along the Molopo, Kuruman, Auob and part of the Nossob Rivers. It is considered to be a duricrust.

Occasionally the sandy limestones shows some silicification, giving rise to discontinuous layers and lenses of hard, often opaline silcrete. The hardpan calcrete is an extremely weather-resistant rock which forms a prominent terrace which crops out over a wide area, particularly around Khuis, Klein Mier, Luitenantspan and along the Auob River, where extensive limestone flats are visible between the dunes (Fig. 5). There is evidence from some pans to suggest that it may still be forming in places today.

Calcrete occurs on the Dwyka Formation and to a lesser extent on the Prince Albert Formation and the Nama Group.

Whereas the underlying fluvial formations of the Kalahari Group represent more humid conditions, the Mokalanen Formation indicates a semi-arid environment.

5.4.2 Diatomaceous limestone

Diatomaceous limestones occur in the Kuruman River on Matlapanen 192 and is found in steps along the sides of and in pans such as Bayip and Sewepanne (Fig. 6). The rock is a white, poorly consolidated limestone with a very low relative density, and is usually bored. The borings are not filled in by sediment and are probably recent. Root channels of recent origin are also typical. The limestone contains minor quantities of rounded quartz grains and is markedly fossiliferous. The fauna was identified by Jutson (1980) and consists of the following:

Diatoms (Figs 7 and 8):

Cymbella gastroides	(Kutzing)
Cymbella lanceolata	(Ehrenburg)
Epithemia gibba	(Kutzing)
Epithemia argus	(Kutzing)
Melosira cf. roeseana	(Rabenhorst)

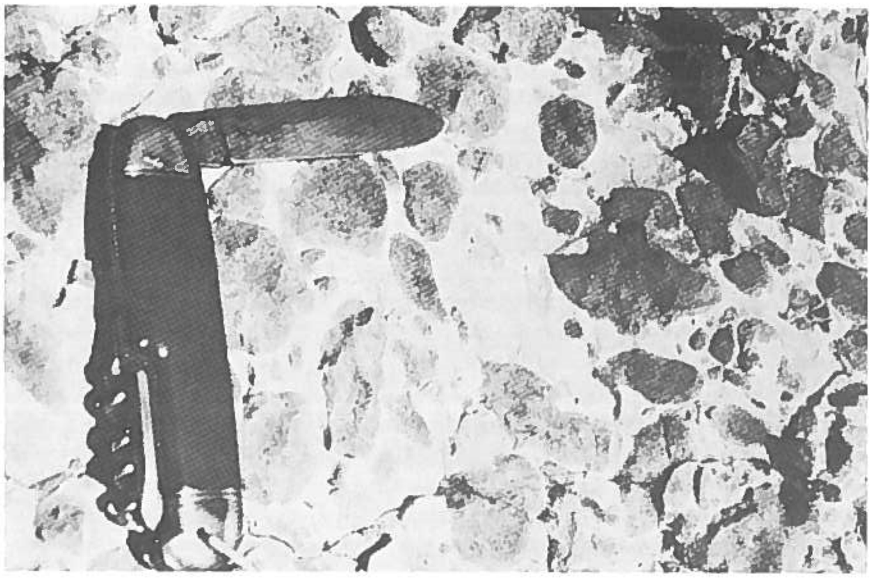

Fig. 3 — Fragments of the Eden Formation cemented by calcrete in the Mokalanen Formation; Kalahari Gemsbok National Park.

Photo: A. W. Keyser

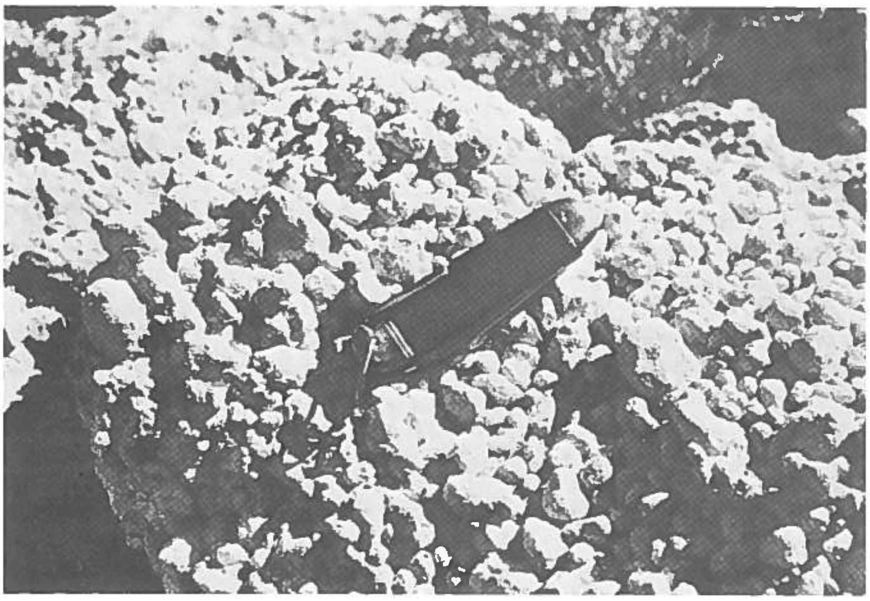

Fig. 4 — Nodular calcrete in the Mokalanen Formation; Kalahari Gemsbok National Park.

Photo: A. W. Keyser

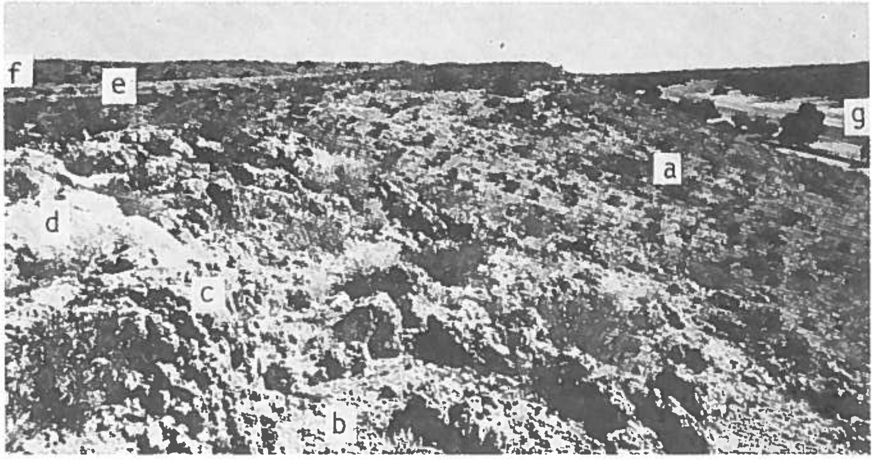

Fig. 5 — A number of features are visible in this picture:

(a) Reddish sandstone of the Eden Formation.
(b) Nodular calcrete.
(c) Hardpan calcrete.
(d) Surface rind of calcrete of the Mokalanen Formation.
(e) The flat surface on top of the Mokalanen Formation.
(f) A sand dune of the Gordonia Formation.
(g) River deposits.

The Auob river eroded a valley which is younger than the Mokalanen Formation but older than the Gordonia Formation; Kalahari Gemsbok National Park.

Photo: A. W. Keyser

Fig. 6 — Clayey diatomaceous limestone at Bayip; Kalahari Gemsbok National Park.

Photo: A. W. Keyser

Melosira distans	(Kutzing)
Diplonaeis sp.	
Fragillaria spp.	
Mastogloia sp.	
Stauroneus sp.	
Synedra sp.	

Ostracods:

Cypridopsis aculeata	(Costa)
Cypridopsis elizabethae	(Sars)
Gomphocythere expansa	(Sars)
Gomphocythere obtusata	(Sars)

Freshwater gastropod:

Xeroceratus damarensis

Freshwater bivalve:

Corbula africana

Charophyte stems and oogonia were liberated when the specimen was treated with hydrogen peroxide.

A good example of diatomaceous limestone is found around the rim of the Bayip Pan near the centre of the Kalahari Gemsbok National Park. It is approximately 2 m thick and highly fossiliferous, containing freshwater gastropods and bivalves of a Quaternary age. Fossiliferous limestones are found in many places along the rivers.

The environment suggested by the sediments and its fauna is one of a sluggish-flowing river or still freshwater lake.

5.5 GORDONIA FORMATION

This formation is the vast accumulation of unconsolidated, red aeolian sand, much of it as longitudinal dunes, which cover more than 90% of the area. Along river courses, around some pans and in some of the streets between dunes, the sand is white, while the dunes themselves consist of a bright reddish sand. Local variations in colour may occur, usually shades of yellow or brown. The average thickness of the sand is 10 to 20 m, reaching a maximum of more than 40 m in the north-west, where the dunes are 30 m in height.

The sand is made up of well-rounded quartz grains, uniformly about 0,5 mm in size, thus indicative of an aeolian origin. The red colouration is caused by a thin coat of

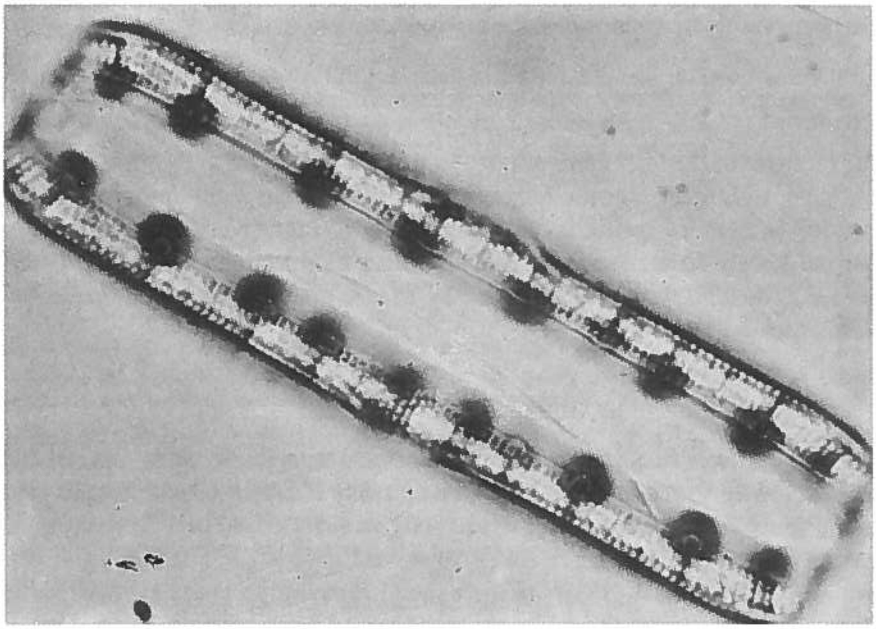

Fig. 7 — *Epithemia* × 1 000; Kalahari Gemsbok National Park.

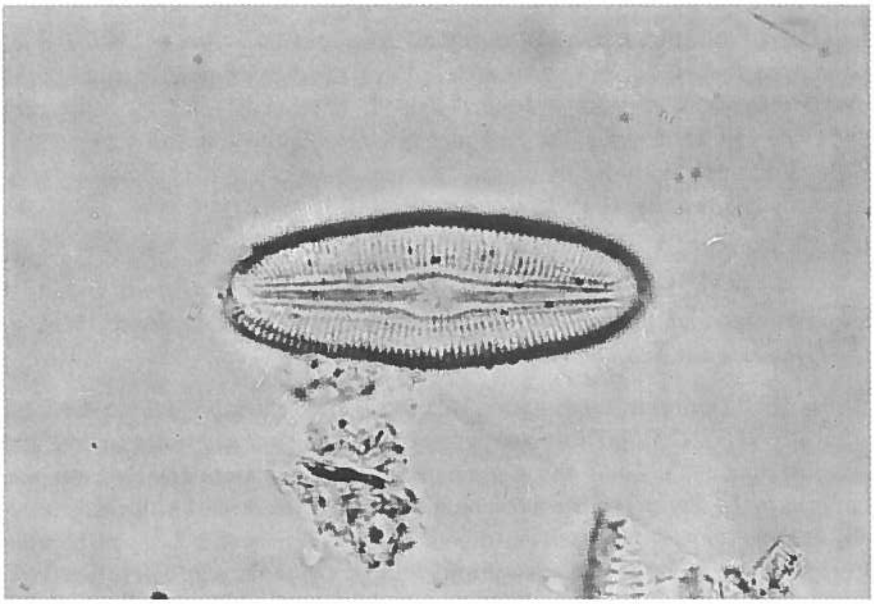

Fig. 8 — Frustules of diatoms at Bayip – *Diploneis* × 1 000; Kalahari Gemsbok National Park.

hematite. Heavy-mineral residues constitute less than 2% of the sand and include most commonly garnet, ilmenite and magnetite.

The longitudinal dunes generally trend to the south-east, though transverse dune piles do occur on the leeward sides of pans or in places along the rivers. Even though the sand is unconsolidated, it has been fixed by vegetation over most of the area. However, over-grazing has denuded the dunes to such an extent in some places that aeolian migration is taking place (for example along the Nossob River, south of Twee Rivieren).

5.6 PAN SEDIMENTS, WHITE SAND AND SOIL

The pan and river beds are practically horizontal and are covered by brown to white, fine-grained sandy sediment. These sediments have largely been derived from dune sand; the hematite having been removed through leaching by ground water. Pans in all stages of development can be observed, from small depressions between dunes where water has collected for short periods producing small quantities of white sand and soil, to the largest pan in the area, Hakskeenpan, which measures 20 by 10 km. There are also deep pans like Koopan of which the floor is 35 m below the general surface. Some pans have a white salt crust and during dry periods mud cracks and peels appear on the surface.

These sediments are relatively young and some are in fact forming at present. Quartz, calcite, montmorillonite and feldspar are the main components. In some of the river sediments, particularly those of the Molopo River, recent bivalves of the genus *Corbula* can be found.

6. KAROO DOLERITE

Dykes and sills of Karoo dolerite are present in the Nama Group and the Dwyka and Prince Albert Formations.

The dolerite in the Nama rocks was injected into the eastern limb of the anticline north-west of Rietfontein. It is a sill up to 100 m in thickness and, like the bedding of the sediments, dips eastwards at an average of 30°. The Nama sediments above the body are mildly bake and the dolerite itself has a 2- to 5-m-wide chilled margin. This and the baking are less well developed at the lower contact.

South-east of Rietfontein much dolerite was intruded into the Prince Albert Formation. Here there are two major sills which crop out over an area exceeding 200 km^2. The upper sill forms the very prominent Eierdopkoppies. Though a thickness of 100 m is exposed, the roof of the intrusion is not seen and this therefore represents a minimum thickness. The dolerite is generally fine-grained and fresh. The lower sill has a similar thickness and is markedly more weathered, giving rise to tracts of ground covered with dark, coarse sand consisting of pyroxene and plagioclase. In these areas poor outcrops of weathered, exfoliating dolerite are common, and they are indicated as sub-outcrops on the map. The lowermost body may correspond to the highly altered sill which is extensively intruded into the Dwyka Formation around Klein and Groot Mier, indicating that it may be mildly transgressive.

The magma for the two sills appears to have been injected along feeder-dykes. To the west is a 12-m-wide highly-weathered dyke, bound by two parallel ridges of hornfelsed Karoo country rocks. To the east, a large dyke is seen in the northwest corner of Koppieskraalpan which trends at 110° and bifurcates eastwards into two 10-m-wide dykes.

In the southern parts of the huge Hakskeenpan, small curved and en-echelon dykes were intruded into the uppermost sandy beds of the Dwyka Formation.

7. KIMBERLITE

There is one kimberlite pipe in the area, situated about one kilometre east of Rietfontein. It was intruded into greenish Dwyka tillite. Extensive flooded workings can be seen at the site where diamonds were mined from 1968 to 1970. Dumps of blue-ground show the kimberlite to contain olivine, chrome-diopside, garnet, phlogopite, lithic fragments and only minor amounts of ilmenite.

8. STRUCTURAL GEOLOGY

The area is structurally simple, only the Mokolian and Namibian rocks having been folded. The Mokolian quartzites have a marked foliation, dipping either steeply westwards or in a vertical orientation. The rocks of the Nama Group were folded into a northeastwards-plunging anticline.

Faulting also occurs on a minor scale. The northern part of the Nama anticline was displaced by an east-trending fault, possibly of the same generation as the small faults which form valleys, cutting across the eastern limb of the fold. Small, inconsequential normal and reverse faults with throws of less than 2 m can be observed in good sections in the Karoo Sequence.

9. GEOMORPHOLOGY

The area is cut by a peneplain of Tertiary age which has an average height of 900 m above sea level. The pre-Kalahari topography was, however, much more uneven, as shown by the isopach lines drawn on the map. This was deduced from data obtained from about 200 boreholes drilled since 1940 by the Department of Water Affairs. These show a deep trough, deeper than 110 m in the vicinity of 21°E, that extends north-west between the Kuruman and Molopo Rivers. A second trough is present in the south-eastern corner of the area. The outcrops of the Mokolian quartzite represent high points of the floor. Present-day drainage is dominated by the Auob, Nossob, Kuruman and Molopo Rivers. Their separate flows are all located in the area. Minor streams drain the area of Rietfontein and end in the larger pans.

Simple linear dunes are well-developed near the river beds, but further away they become at least partially transverse with a tendency to form barchanoid ridges in places. The spacing of the troughs (streets) decreases sharply away from the river beds. Some areas are virtually free from dunes or are only gently undulating (Bothma and De Graaff 1973a). In a number of localities Bothma reported irregular dunes. They are younger transverse dunes with barchanoid ridges formed in spots where older stabilised sands had become loose again, probably as a result of the loss of vegetation, or where younger sands with different grain sizes were blown over older sands.

Without the sand cover, the whole area can be considered to be a young plateau where vertical erosion by the rivers stopped as a result of the onset of desert conditions. The Nossob River received enough water at one stage to become a mature river; it formed meanders inter alia near Rooikop and Kwang and even some oxbow lakes near Grootbrak. Vertical erosion then resulted in the formation of terraces slightly above the present river level.

Many incipient pans can be recognised among the dunes. Some of the pans, e.g. at Langklaasdam and Kwang, formed when the flow of the Nossob River could not remove the sand load fast enough. The tributaries dammed against the higher base level of the Nossob River and formed pans. The pans away from the rivers have probably been formed by deflation (Lancaster 1979) and have deepened by wind action and to a smaller extent by the effect of animals on the pan floors, i.e. trampling of the pan floors to dust, to be blown away or carrying material away after a mud-bath.

10. ECONOMIC DEPOSITS

10.1 DIAMONDS

Diamonds were first mined from the Rietfontein pipe in 1916 when 18,75 carats to the value of £153.10/- were recovered. Work restarted in 1968 and continued until 1970, during which time 474,35 carats were recovered, to the value of R9 490,00.

10.2 DIATOMACEOUS LIMESTONE

Blocks can easily be formed from this type of limestone and it was used locally as building material.

10.3 COAL

A thin seam of low-quality coal is known from boreholes in the Kalahari Gemsbok National Park.

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