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Notes on the Permian to Recent Geology of the Kruger National Park

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Permian to Recent rocks form narrow, roughly north-south and east-south-east trending belts in the north-eastern Transvaal. The rocks consist of a thin succession of Karoo sediments, a thick overlying succession of mafic and felsic volcanics referred to as the Lebombo Group, isolated outcrops of Cretaceous sediments and fairly extensive Tertiary-Recent Gravels and sediments. These rocks are in general well exposed along the eastern margin of the Kruger National Park and also crop out in the extreme north. Emplacement of the Lebombo volcanics and subsequent deposition of the Cretaceous rocks was intimately associated with the fragmentation of Gondwanaland.

Key words: Mesozoic, Cenozoic, Karoo, Lebombo, nephelinite, picrite, basalt, rhyolite, granophyre, volcanology.

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Introduction

A summary of the Permian to Recent geology of the Kruger National Park (KNP) is presented in this paper. This geological period is represented by Karoo sediments, Lebombo volcanics, and overlying Cretaceous to Recent deposits. Note that reference may be made to the northern and central Lebombo (Figs 1 and 2) in this paper. This simply represents a convenient means of subdividing the region under consideration, particularly from the point of map compilations. Overall the region concerned stretches southwards from the Limpopo River to the Swaziland border, a distance of approximately 400 km, and has been subdivided into two sections by an imaginary line drawn at 24° 30′S. Karoo to Recent rocks which crop out in a series of east-north-east trending fault blocks between the Soutpansberg Mountains and the Limpopo River are incorporated in the northern Lebombo (Fig. 1).

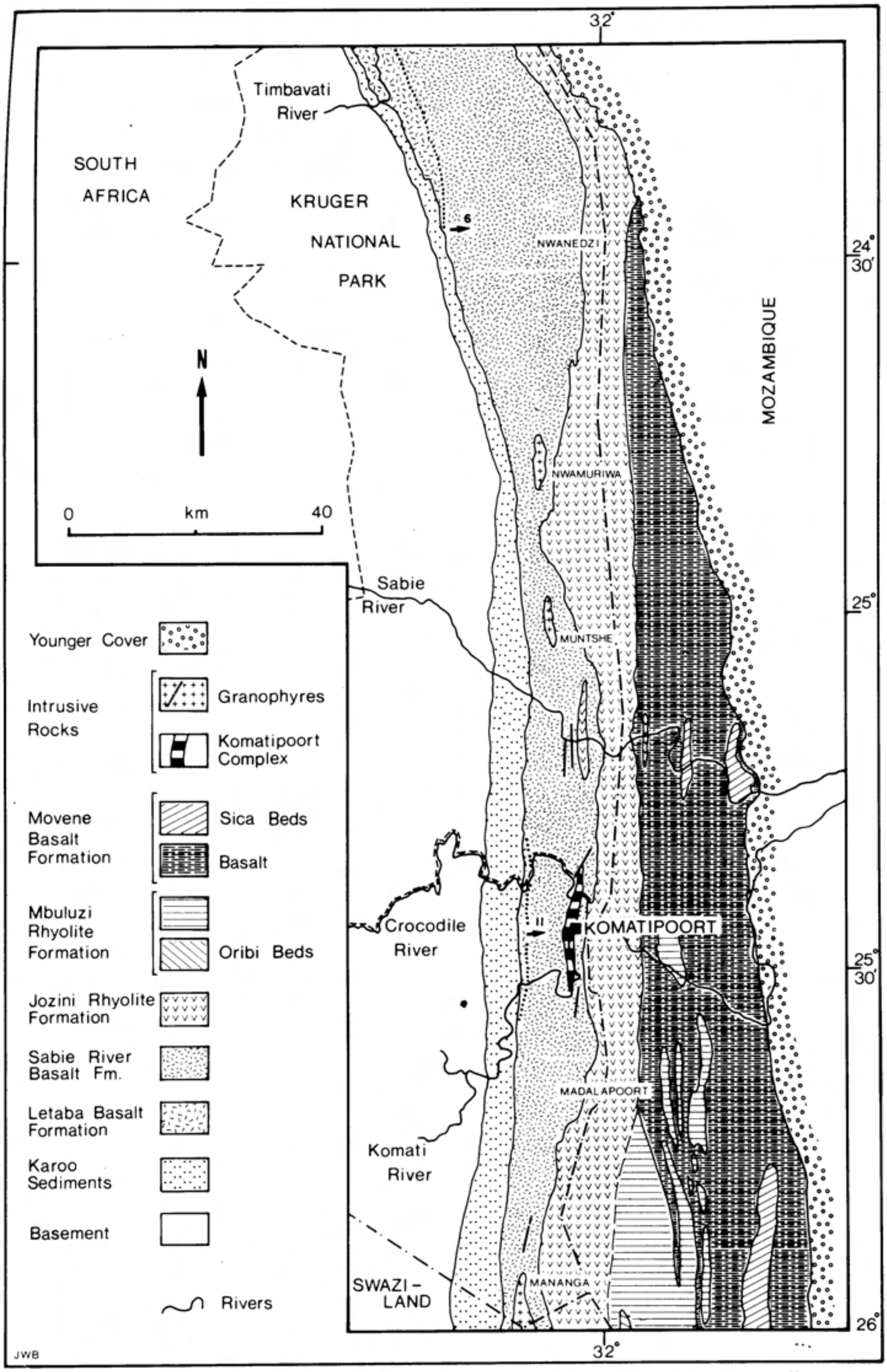

Fig. 2. Simplified geological map showing the distribution of Karoo sediments, Lebombo volcanics and Cretaceous-Recent deposits in the southern half of the Kruger National Park (from Bristow 1982).

The Lebombo volcanic succession is composed of a wide variety of rock types, the most important being nephelinites, olivine-rich basalts, olivine-poor basalts and rhyolites. These rock types occur in systematic sequence and can thus be mapped as individual lithologic units. The volcanostratigraphic nomenclature proposed by Cleverly & Bristow (1979) and Bristow & Cleverly (1983) is used throughout this paper (Table 1). Underlying Karoo sediments consist predominantly of sandstones, shales and mudstones, with minor siltstones and volcanoclastic material. New units have been recognised in the sedimentary sequence and are described in the text. Younger Cretaceous to Recent sedimentary deposits overlie the Lebombo volcanics.

Data presented here is based on detailed mapping of river sections, *viz.* the Komati, Sabie, Olifants, Shingwedzi and Luvuvhu rivers, coupled with reconnaissance work in intervening areas and air photo interpretation. The mafic lavas in particular are deeply weathered and generally covered by a layer of residual soil. This highly weathered zone is particularly thick (10 m - 15 m) between the Olifants River and Pafuri and this area also shows extensive calcrete development. Exposure in the Olifants and Shingwedzi rivers and the area to the west of Pafuri was found to be exceptionally good due to the strongly dissected nature of the topography.

General accounts of the geology of the northern and central Lebombo have been presented by Rogers (1925), Lombaard (1952), Van Eeden, Visser, Van Zyl, Coertze & Wessels (1955), Van der Schijff (1968) and Schutte (1974, 1982). Material presented in this paper represents new data collected during the course of the Karoo Geodynamics Project which was sponsored by the Council for Scientific and Industrial Research (South Africa)(see Erlank 1984).

Karoo Sedimentary and Volcanoclastic Rocks

A sequence of Karoo sedimentary rocks, occasionally superseded by reworked volcanoclastic deposits, overlies the Basement Complex along the entire length of the Lebombo. The Karoo sediments are disconformable on the basement rocks and form a narrow, belt-like outcrop to the west of the volcanics. They consist of rocks of the Tshidizi, Madzaringwe, Mikambeni, Fripp, Solitude, Bosbokpoort, and Clarens Formations. These formations have been described by Schutte (1986) and only the sandstones (Clarens Formation) underlying the Lebombo volcanics are discussed in this paper. These rocks are collectively shown as "Karoo Sediments" in Figs. 1 and 2. Recent work in Swaziland (Hawthorn, Carrington, Clement & Skinner 1978) and the southern, central and northern Lebombo (Bristow 1976, 1982) has also shown that there are occurrences of volcanoclastic sediments overlying and interbedded with the Clarens Sandstone Formation. They are incorporated in the Clarens Formation and are designated the Ehlane Beds.

Throughout much of the central Lebombo the Karoo sedimentary succession is relatively thin and consists of sedimentary strata dipping gently to the east (3°-10°). The Karoo sediments are very much thicker in the northern part of the region and the area between the Kloppersfontein Dam and the Limpopo River is characterised by numerous sandstone koppies and extensive, thick

Table 1

Summary of the Permian to Recent stratigraphy of the Kruger National Park (after Bristow 1982)

	FORMATION	BEDS	ROCK TYPES	AGE Ma	THICKNESS m	TYPE AREA
RECENT			Aluvium Sand, Salt			
CRETACEOUS	Malvernia		Fossiliferous conglomerates and sandstones			
	Movene basalt		Basaltic and alkaline lavas	~137	~2 000	Movene River Moçambique
		Sica	Rhyolites			
	Jozini Rhyolite		Plagioclase-phyric rhyolites	~175	~2 500	Jozini road, dam and canal section – S. Lebombo
LEBOMBO		Olifants	Plagioclase-phyric rhyolites			
	Sabie River Basalt		Tholeiitic andesites, basalts, shoshonites and absarokites	~190	~4 500	Sabie River
	Letaba Basalt		Picrite lavas	~200	~4 000	Letaba River
	Mashikiri Nephelinite		Nephelinite lavas	~200	~170	Mashikiri Windmill area N. Kruger Park
		Ehlane	Reworked volcanoclastic sediments			
KAROO	Clarens Sandstones		Massive sandstone, minor siltstones and shales	~200	~250	Luvuvhu River Gorge

(250 m) sandstone inliers. Off-white and rusty coloured sandstone koppies are particularly prevalent along the western flank of the volcanic belt between Kloppersfontein and the Luvuvhu River. The koppies consist of massive sandstone devoid of all structures except dune bedding and rough vertical or curvolinear exfoliation joints. Outcrops of nephelinite lavas of the Mashikiri Formation are often found encircling the koppies (Fig. 1), indicating that the basal Lebombo lavas covered an uneven sandy surface. Many of the koppies undoubtedly represent segments of original sand dunes.

Exposures of the Clarens sandstone-Lebombo lava contact are also found in the Shingwedzi, Tsende and Sabie rivers, and a well-exposed section of sandstones, reworked volcanoclastic and nephelinite lavas occurs along the Olifants River. The volcanoclastic-sediment/nephelinite lava contact is relatively sharp though vesiculation and disruption of the uppermost clastic sediment layers and the lower 10 cm - 50 cm of overlying lava flows was observed in several instances. These features are considered to reflect minor phreatic activity along the contact zone in response to heating of water in the volcanoclastic layers by the overlying high temperature lava flows.

1. The Clarens Sandstone Formation

The Clarens Formation consists of off-white, cream and occasionally red, *e.g.* at Gubyane Potholes and Red Rocks, sandstones. They are typically massive with dune bedding and appear to be largely of aeolian origin. The eastern portion of the Luvuvhu River Gorge, *i.e.* the area to the east of the confluence between the Mutale and Luvuvhu rivers, is proposed as the type area for these rocks. Minor siltstones and shales may be interbedded or overlie the Clarens sandstones along with the volcanoclastics of the Ehlane Beds.

In the Kumane-Marheya area gentle folding of the Karoo sediments has resulted in the formation of a plunging anticline which occurs to the east of the main Karoo sediment outcrop. The anticline measures about 28 km from north to south and about 8 km from east to west. The northern portion of the anticline consists of Clarens sandstone while progressively older sedimentary units crop out to the south, suggesting that the anticline plunges to the north. Numerous north-south trending dolerite dykes occur in the area giving rise to a complex soil pattern.

Exposures of the Ehlane volcanoclastics are localised and seldom very extensive. A well-exposed example of these rocks occurs at the top of the Clarens Formation in the Olifants River area and is proposed as the type area for the Ehlane Beds. In this locality the volcanoclastics are approximately 1,5 m thick and consist of finely bedded sandstones and siltstones which incorporate a high proportion of glassy material including fragments of glass shards.

Mashikiri Nephelinite Formation

The Mashikiri Formation (Cleverly & Bristow 1979) is slightly disconformable on the Clarens Formation and occurs as a thin succession of flows attaining a maximum thickness of about 170 metres. Due to poor exposure the thickness and extent of individual flows could not be ascertained.

The nepheline-bearing lavas are best exposed in the Kloppersfontein-Mashikiri area of the northern Lebombo and were traced to the south of Dzundwini. They were not found in the Shingwedzi River area but reappear as a series of thin flows at the base of the lavas in the Kaleka area and Olifants River section which represents their southern limit of outcrop. Inliers of nephelinite lavas also occur in the Pafuri-Luvuvhu River area and occurrences of nephelinite lavas have been reported from the Soutpansberg area (Rogers 1925).

The nephelinite lavas are a distinctive suite of rocks, easily recognised in the field. The most common type is distinguished by the presence of large discrete plate-like or stellate glomeroporphyritic aggregates of clinopyroxenes set in a fine-grained matrix. Many of the flows are also characterised by the presence of large (up to 10 mm) spherical amygdales. Other flows contain obvious nepheline phenocrysts and, occasionally, flakes of biotite. Small altered olivine crystals are also recognisable in some lavas, though the latter lava type is far less common than the pyroxene-phyric variety.

The petrography and geochemistry of these rocks have been described in detail by Bristow (1984a).

Letaba Basalt Formation

The Letaba Basalt Formation consists of an exceptionally thick (up to 4 km) succession of olivine-rich lava flows. Their proportion relative to the olivine-poor basalts typical of the central, Swaziland, and southern Lebombo increases in a northerly direction so that in the Pafuri-Limpopo River area the volcanic succession consists predominantly of olivine-rich lavas.

The lavas dip to the east at angles of between 5° - 15° and attain a thickness of approximately 4 km in the Babalala-Shingomene area of the northern Lebombo. They appear to be conformable on the Mashikiri Formation with possible interdigitation. In those areas where the olivine-rich lavas rest directly on strata of the Clarens Formation, the contact is slightly disconformable.

The lavas of the Letaba Basalt Formation are characterised by an abundance of olivine phenocrysts in a fine grained or glassy matrix. They typically show dark brown or reddish weathered surfaces; since the olivine weathers more readily than the groundmass, weathered surfaces are frequently pitted. Glassy rocks tend to be hackly in appearance. They are rarely amygdaloidal and were found to be devoid of flow structures. Because of the poor exposure throughout the area underlain by the Letaba Formation no accurate estimate could be made of flow thicknesses though somewhat equivocal field evidence suggests that the olivine-rich lavas are generally thicker than the olivine-poor flows of the Sabie River Basalt Formation.

The petrography and geochemistry of the Letaba picrite basalts have been discussed by Bristow (1984b) and Cox, Duncan, Bristow, Taylor & Erlank (1984).

Sabie River Basalt Formation

Olivine-poor lavas of the Sabie River Basalt Formation (Cleverly & Bristow 1979) constitute the major portion of the mafic succession in central Swaziland and the southern Lebombo but, as noted in the previous section, are almost totally excluded from the sequence in the northern Lebombo (Fig. 1). In the north, the olivine-poor rocks overlie the more basic lavas of the Letaba Formation, whereas to the south of the Timbavati River they overlap on to the sandstone and volcanoclastics of the Clarens Formation.

The lavas dip to the east at angles of between 5° and 20° (Fig. 3) and attain a maximum thickness of about 4,5 km in the Sabie River area which has been designated as the type section (Cleverly & Bristow 1979) in view of the good exposures found along the river. The average thickness of individual flows is probably in the range of 5 m - 10 m though very few measurements were made. In a gravel pit at the eastern edge of the Nwanedzi experimental burning plots three consecutive flows each measuring about 1,5 m were noted dipping to the east at about 28 degrees. The flows display different weathering patterns and contain different proportions of amygdales. It is apparent that older lava flows in this section were thicker and more homogenous than the younger and thinner flows mentioned above which also contained more amygdales thus making them more susceptible to weathering. This has resulted in a distinct boundary between soil patterns and plant communities found east and west of the Shishangane Windmill.

Fig. 3. Easterly dipping basalt flows of the Sabie River Formation. Locality: South bank of the Olifants River immediately to the east of the Olifants Rest Camp.

The basalts are commonly amygdaloidal and can be grouped into porphyritic and aphyric types. Aphyric lavas are generally fine- to medium-grained and have a granular appearance. Phenocrysts in the porphyritic rocks are generally less than 10 mm in length, with the exception of a series of macroporphyritic lava flows encountered in the Letaba River area. Phenocrysts in the macroporphyritic lavas are commonly up to 5 cm in length and are arranged in "birdsfoot" textures or else aligned parallel to the flow contacts. Particularly interesting 'swirl' and flow structures are also found in these lavas in exposures on the Letaba River. Autobrecciated flow tops and reddish bole surfaces (palaeo-soil horizons) were noted in some of the northern and central Lebombo exposures of the Sabie River Basalt Formation. Good examples of such features are found in outcrops on the Olifants River immediately below the Olifants Rest Camp.

In Swaziland (Urie & Hunter 1963) and the southern Lebombo (Bristow 1976) it was found that the basalt succession within the Sabie River Basalt Formation could be subdivided on the basis of textural and lithological differences, *e.g.* aphyric or porphyritic. In the central and northern Lebombo the generally poor exposure has prevented subdivision of the succession though it is notable that most of the lavas sampled to the north of the Komati River tended to be either aphyric or sparsely porphyritic.

The occurrence of volcanoclastics at the base of the Olifants section has already been noted and the occurrence of microscopic glass-shards in some bole surfaces within the Sabie River Formation suggest that localised explosive activity took place during the emplacement of the lava pile.

Two thick interbedded rhyolite units crop out in the lower half of the Sabie River Basalt Formation in the Olifants River area (Fig. 1). They have been designated as the Olifants Beds. The Olifants Rest Camp is located on the larger and more easterly of the two units. The rhyolites occur as prominent, north-south, strongly-elongated domes which are characterised by strongly contorted flow banding and some autobrecciation. Progressive overstepping rather than disruption and brecciation of basalt flows and the presence of a thin paleosol along the eastern contact of the Olifants Rest Camp rhyolite suggest that the domes represent exhumed extrusive features rather than being intrusive into the Sabie River Formation. Relatively steep westerly margins and more gently inclined easterly slopes, characteristics of present day outcrops, represent modifications. These rhyolites occur in a similar stratigraphic position to the Mkutshane Beds in Swaziland but are dissimilar in terms of geochemistry.

Composite flows characterised by a felsic matrix supporting mafic xenoliths were noted in a few instances in the Sabie River basalt succession. A good example of a composite flow is exposed on the north bank of the Olifants River below the Olifants Rest Camp (Fig. 4).

A detailed account of the petrography and geochemistry of the Sabie River basalts has been presented by Cox & Bristow (1984).

Jozini Rhyolite Formation

Eastward dipping rhyolitic flows, designated as the Jozini Formation

Fig. 4. Composite lava flow consisting of mafic xenoliths contained in a felsic (granophyric) matrix. The xenoliths show deformation structures suggesting that they were semi-solid when incorporated into the felsic magma. Locality: North bank of the Olifants River immediately east of the Olifants Rest Camp.

(Cleverly & Bristow 1979) overlie the Sabie River Basalt Formation with slight angular disconformity (Fig. 5). They are generally poorly exposed and crop out in a narrow belt, 3 km to 15 km wide straddling the Moçambique border, attaining a maximum thickness of approximately 2,5 km in the southernmost area. As noted elsewhere the rhyolites form the high ground of the Lebombo Mountain Range and extend as far north as Shingomeni, whereupon they deviate into Moçambique and become buried under recent Cretaceous sediments. To the south the rhyolites are continuous through Swaziland to the town of Hluhluwe in the southern Lebombo area.

The rhyolites of the Jozini Rhyolite Formation in the KNP are petrographically and geochemically similar to those found in Swaziland (with the exception of the Mbuluzi River Formation) and southern Lebombo (Cleverly, Betton & Bristow 1984). They are invariably porphyritic and consist of phenocrysts of plagioclase feldspar, ferro-augite, titanomagnetite and zircon set in a fine-grained, devitrified matrix; rare phenocrysts of quartz and K-feldspar occur in some rocks.

In the central Lebombo (southern half of the KNP) the rhyolite succession is constructed of a series of flow units characterised by volcanological relationships similar to those noted in Swaziland and the southern Lebombo. The flows of Swaziland and the southern Lebombo have been studied in much detail by Cleverly (1977) and Bristow (1976) respectively. Both authors have concluded that they represent the products of high temperature

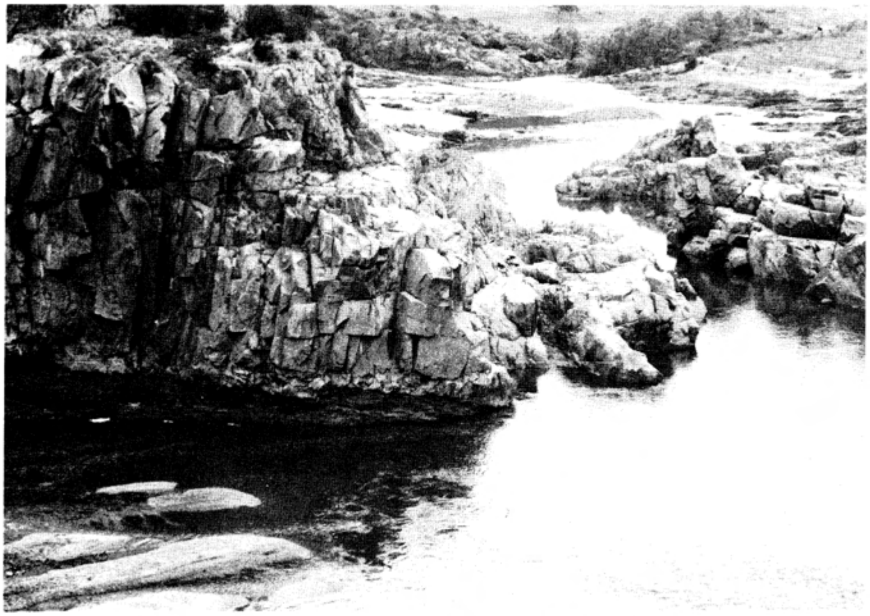

Fig. 5. Exposure of Jozini rhyolite at the confluence of the Letaba and Olifants rivers. The rhyolite flow is overlying basalts of the Sabie River Formation which can be seen in the lower left side of the figure. A sharp contact separates the basaltic and rhyolitic rocks.

pyroclastic-type eruptions. On the basis of the volcanological and compositional similarity shown by the central Lebombo rhyolite flows to those of Swaziland and the southern Lebombo it is concluded that a similar eruptive mechanism was operative during the emplacement of the rhyolites in all three of these areas.

The character of some northern Lebombo (northern part of the KNP) rhyolites appears to differ from those typical of the rhyolite flows farther south. The Olifants River provides the only suitable section for studying the volcanological aspects of the rhyolite succession in the northern Lebombo and data collected from the area suggest that some of the flows may represent lava flows *sensu stricto* fed by a system of rhyolite dykes. East of its confluence with the Letaba River, the Olifants River flows through a narrow, deeply incised gorge which cuts through a series of rhyolite dykes, rhyolite flows and thin, interbedded basalt lava flows. The dykes show well-developed intrusive contacts and are overturned to the west. In at least two cases dykes are seen to develop into remnants of flows which are characterised by steep westerly-facing scarps with well-developed columnar jointing.

The geology, petrography and geochemistry of the Lebombo rhyolites have been discussed by Cleverly *et al.* (1984).

Intrusive Rocks

1. Nepheline-bearing Intrusives

A series of coarse-grained nepheline-bearing intrusives crop out to the west and north-west of the Mashikiri Formation. The rocks are generally poorly exposed but appear to be in the form of plugs and irregular dyke-like bodies intruding the granitoid rocks of the Precambrian basement (*e.g.* ijolite-nephelinite plugs south-west of Kaleka) and Clarens sandstones. Probable remnants of plugs, represented as a distinct north-south line of koppies, are also present north of Shingwedzi in the vicinity of Bowkers Kop. The alkaline character of the intrusive rocks suggests that they represent feeders to the lavas of the Mashikiri Nephelinite Formation. Alkaline dykes appear to be rare within the lavas, though Saggerson (*pers. comm.*) noted a nepheline-bearing dyke intruding the base of the volcanic succession in the Olifants-Letaba River area.

2. Picrite Dykes

Several coarse-grained olivine-bearing dykes (hereafter referred to as picrite dykes) are intrusive into the Letaba Basalt Formation and crop out in the Shingwedzi River and Punda Milia-Pafuri areas of the northern Lebombo. In many cases they are poorly exposed and were generally recognised on the basis of north-south-trending lines of boulders protruding from the eroded basalts. Excellent examples of picrite dykes cross cutting easterly dipping basalt flows are present on the southern bank of the Letaba River just west of the high water bridge. Thicknesses estimated from a large number of boulder lines range from 1 m - 4 metres.

3. Dolerite Dykes

Dyke rocks characterised by low modal olivine contents (<9% by volume) are collectively referred to as dolerite dykes. They are found throughout the central and northern Lebombo areas and are densely concentrated in the Letaba and Sabie River Formations, whereas they are rarely found in the Jozini Rhyolite Formation. They show a predominantly north-south trend except in the Mashikiri-Pafuri area, where they strike approximately north-west/south-east.

On the basalt flats the dolerite dykes generally crop out as distinct ridges due to their superior resistance to erosion relative to the basalts. However, they tend to weather more rapidly than the acid volcanics so that dolerite dykes intrusive into the Jozini Rhyolite Formation and Olifants Beds are commonly located in narrow ravines or gulleys. The thickness of individual dykes varies considerably, ranging from a few centimetres up to 20 m and they dip steeply to the west at angles of 70° - 80°, though lower values are found. Dense swarms of dolerite dykes crop out in both the Olifants River area and the Pafuri area.

Numerous mafic dyke rocks are also found in the underlying Precambrian basement rocks. Many of these dykes are undoubtedly associated with the Lebombo volcanics. However, some of these dykes represent older intrusive rocks and as such are generally referred to as diabase dykes. Detailed studies are needed to fully unravel these different intrusive events.

4. Dolerite Sills

Two conformable dolerite sills occur in the Olifants River section. They are intrusive into the Sabie River Basalt Formation and are located at the base of each rhyolite of the Olifants Beds (Fig. 1), suggesting that the intruding magma occupied a zone of inherent weakness between the lavas and rhyolite flows. The sills vary in thickness between 250 m and 300 m and can be traced for about 7 km along a north-south strike.

5. Basaltic Dykes

A group of strongly altered and oxidized basaltic porphyritic dykes crop out in the area to the north-west of the Olifants Rest Camp. The dykes are generally 1 m - 3 m wide, show columnar jointing (Fig. 6), and are characterised by a red to brown appearance and the presence of small rounded amygdales. Large (up to 10 cm) calcite filled vesicles are also found in these rocks. They are distinct from the ubiquitous and typically fresh blue-grey dolerite dykes of the Lebombo. Field mapping and air-photo interpretation has shown that they have a curvolinear trend suggesting that

Fig. 6. "Basaltic" dyke showing well developed columnar jointing. Locality: Stream adjacent to dirt track north west of the Olifants Rest Camp.

they could represent the westernmost segment of a ring dyke complex. Thin section studies have shown that the dykes have suffered strong deuteric or hydrothermal alteration and this is reflected by the high levels of H_2O and CO_2 (up to 8,5 weight % total) obtained during chemical analysis of these rocks.

6. The Komatipoort Complex

The Komatipoort Complex is an elongated, layered gabbro body exposed in and around Komatipoort (Fig. 2). It is intrusive into the Sabie River Basalt Formation and has been described by Saggerson & Logan (1970), and Logan (1979). It is considered to be a composite body, comprising three separate intrusive phases.

7. Granophyres

Three major granophyre bodies and numerous smaller domes and dykes crop out in the central and northern Lebombo. Mananga Ridge in the south, Muntshe Ridge approximately 10 km north of the Sabie River, and the Nwamuriwa dome 4 km north-east of Tshokwane, represent the three main bodies, all of which form prominent topographical features. They all crop out as north-south elongated bodies, intruding the basalt very close to the base of the Jozini Formation.

The Mananga body stretches southwards into Swaziland and is the largest of the granophyres. At its highest point it stands 500 m above the Lowveld and stretches for some 10 km in a north-south direction with a maximum east-west width of 2 kilometres.

Other granophyre bodies are found in the rhyolite succession, particularly in the Olifants and Shingwedzi River sections. They include Klopperskop and Longwe east of Letaba and Shilowa north-east of Letaba. They rarely form prominent topographic features but can generally be recognised by the somewhat undulating appearance of the countryside they underlie, whereas areas underlain by the rhyolites are usually characterised by broken, often rugged, topography. Northwards from the Shingwedzi River granophyre bodies surpass the rhyolites in volume such that the northernmost section of the mountain range is constructed predominantly of coarse-grained granophyric rocks. The granophyre bodies form a series of narrow, parallel ridges with intervening wedges of rhyolite.

The granophyres are, in general, similar to the Jozini Formation rhyolites in terms of geochemistry but differ texturally in that they are all typically equigranular (medium- to coarse-grained) whereas the rhyolites are invariably porphyritic. Quartz, two feldspars, and clinopyroxene constitute the main constituents of the granophyres. Fine-grained margins indicative of chilled contacts were noted around the rims of some of the small bodies found intruding the rhyolites.

Granophyre dykes form prominent north-south trending ridges in the central Lebombo, in particular in the Komatipoort and Sabie River areas. They vary considerably in width ranging from a few metres up to a maximum of about 10 m and may extend over considerable distances. For example Logan (1979) has traced the Causeway dyke of the Komatipoort area for approximately 12 kilometres. A similar dyke (approximately 14 km in length) displaying impressive columnar and blocky jointing occurs in the rhyolites east of Nwanedzi. Smaller dykes are also common around the major granophyre bodies. They tend to radiate from the main bodies though generally retain a dominant north-south trend. The dykes are petrographically and chemically similar to the main intrusions but are usually finer-grained.

8. Rhyolite Dykes

Several prominent north-south trending rhyolite dykes crop out in the Olifants River area and Nwanedzi areas. A swarm of these dykes also occurs along the northern part of the Timbavati loop road. Unlike the equigranular granophyre intrusions, they are typically porphyritic with phenocrysts of plagioclase, clinopyroxene and titanomagnetite set in a very fine-grained rhyolite matrix.

Fig. 7. North-south trending granophyric (felsic) dyke cross-cutting basalts of the Sabi River Formation. Note dolerite dykes (also trending north-south) characterized by columnar jointing to the left and right of the granophyre dyke. In places the dyke contains mafic xenoliths suggesting that it could be a feeder to the composite flows. Locality: South bank of Olifants River immediately east of the Olifants Rest Camp.

9. Composite Dykes

Composite dykes have been noted in various parts of the Lebombo volcanics within the Kruger National Park. A felsite dyke cross-cutting the Olifants River east of the Olifants Rest Camp contains some mafic inclusions though cannot be truly termed a composite dyke (Fig. 7). A particularly good example of a composite dyke occurs immediately below the Engelhardt Dam wall on the Letaba River. This dyke is characterised by mafic margins and a felsic interior containing numerous mafic xenoliths. Sweeney (*pers. comm.*) has also noted composite dykes in the southern part of the Kruger National Park.

10. Xenolith Rich Dyke

An interesting dolerite dyke containing numerous granitoid xenoliths occurs on the north side of the Olifants River a few hundred metres east of the main road bridge across the river. Some of the xenoliths are particularly large and show interesting melt textures near the margins which were in contact with the host dolerite.

Lebombo Volcanics East of the Moçambique Border

Basaltic rocks and interdigitated rhyolite flows crop out east of the Jozini Formation in Moçambique (Fig. 2). The basaltic rocks have been designated as the Movene Formation (Cleverly & Bristow 1979) whereas the rhyolites, formerly referred to as the Little Lebombos (Wachendorf 1971, 1973) have been renamed the Sica Beds (Cleverly & Bristow 1979).

Little is known of the field relationships and detailed geochemistry, in particular trace element chemistry, of the Moçambique volcanics which is unfortunate since these rocks evidently represent an integral part of the Lebombo volcanic cycle. It is apparent from the accounts of Wachendorf (1971, 1973) that the Sica Beds are characterised by volcanological features generally similar to those described in flows from the Jozini Formation in Swaziland (Cleverly 1977) and the southern Lebombo (Bristow 1976). However, Wachendorf (1971, 1973) attributes the features of the Moçambique flows to a lava-type mode of origin whereas both Bristow and Cleverly have proposed a pyroclastic-type mode of emplacement for the Jozini Formation flows.

The major element chemistry of the Movene basalts has been discussed in some detail by De Assuncao, Pinto Coelho & Tavares Rocha (1962). Many of the rocks are similar to the Sabie River Basalt Formation though nepheline-normative types appear to be common, implying that the uppermost basalts of the Lebombo perhaps represent a final period of moderately alkaline volcanicity. However, the absence of trace element data for the Moçambique basalts seriously limits comparisons.

Cretaceous Group

1. Malvernia Formation

Deposition of Cretaceous sediments followed the emplacement of the Lebombo volcanics. Remnants of Cretaceous rocks are found in the northern part of the KNP at Mutale Hill and north of the Luvuvhu River where they crop out in valleys incised into the Nwambia Sandveld. Broadly similar rocks are also found north of the Limpopo River in the Malvernia area of south-east Zimbabwe.

The Cretaceous rocks of the KNP overlie the Lebombo volcanics with angular disconformity and in places appear to have been deposited in gulleys cut into the underlying volcanics. Cretaceous rocks are best preserved on a small plateau south of Pafuri. This plateau forms a capping on Letaba Basalts and has relatively prominent scarps on its north, west and southern sides. To the east it dips gently into Moçambique.

The Malvernia Formation consists of conglomerates, grits, sandstones, calcerous sandstones and shales. Approximately 110 m of the above alternating sediments are found in the section underlying the plateau south of Pafuri. Particularly good exposures are found in gulleys running off the plateau *e.g.* the Josias Stream course. Here the sediments appear to form cyclic units with conglomerates at the base followed by sandstones and red sandy-shales. In one outcrop the conglomerate was noted to be about 10 m thick with a much thinner (~2 m) zone of sandstone and sandy-shale. Similar rock types are also exposed in other gulleys *e.g.* the Malonga Spruit, and in sections to the north of Machayi Pan. Shale is sparser in some sections while in places the sandstone in strongly calcerous; with patches of calcrete developed in some exposures. Pebbles found in the conglomerates include rock types from the granite-gneiss basement, Waterberg quartzite, Soutpansberg dacites, various jaspers, cherts, banded ironstones and Clarens sandstone.

The nature of the sediments found in the Cretaceous Beds suggest that they are part of the lower Cretaceous Group. The lower Cretaceous Makatini Formation of Zululand in the south is typified by a similar sequence of conglomerates, sandstones and siltstones attributed to the progradation of braided fluvial deposits into a shallow sea. These older, relatively terrestrial basal Cretaceous sediments are probably related to late Jurassic – early Cretaceous rifting (see Flores 1973; Dingle & Scrutton 1974) which subsequently lead to complete dismemberment of eastern and western Gondwanaland and the opening of the Indian Ocean.

An outcrop of conglomerates, and coarse grits and sandstones is also found between the Luvuvhu and Limpopo rivers at Mutale Hill. These rocks are generally less compacted than the Cretaceous Beds found south of the Pafuri. However, on the basis of the broad lithological similarities between the two outcrops they have been tentatively correlated with the Malvernia Group. Subsequent work may however, show this to be incorrect and it is possible that they represent gravel and sand terraces associated with the Limpopo drainage.

Tertiary to Recent Deposits

In southern Africa the end of the Cretaceous period was marked by a general withdrawal of the sea, relative uplift of the land mass resulting in entrenched river drainages. Lying as it does some distance from the Indian Ocean, clear patterns of Tertiary sedimentation are not apparent in the KNP area though the manner in which all the major east flowing rivers have cut through compotent rock strata such as the Lebombo rhyolites suggests that Tertiary events played a part in the geological history of this area. Overall, however, it is difficult to recognise sedimentary units which could unequivocally be referred to as Tertiary material. Subsequent erosion and denudation through to recent times has undoubtedly resulted in thorough reworking of both

Cretaceous and Tertiary rocks, in addition to underlying strata. Consequently extensive areas of gravel and sand of probable Quaternary age mantle Cretaceous rocks.

Quaternary deposits are found adjacent to the park in Moçambique and extend into the park to form the Pumbe Sandveld north-east of Satara and the Nwambia Sandveld south of Pafuri. The terrain of these areas is flat or concave in aspect and is characterised by pans. The succession at Pumbe consists of unconsolidated conglomerates at the base overlain by medium grained red and white sands. The white and yellow sands are found in footslopes and depressions where they have been subjected to hydromorphism. The grain size and sorting of the covering sands at Pumbe and Nwambia suggest that they have not been transported over large distances by wind, but that they have only been subjected to local transportation, *i.e.* flattening of coastal dunes.

Younger alluvial deposits are found flanking most of the larger drainage lines in the KNP, and in a few exceptional cases are associated with old river beds, *e.g.* the Tsende-Kondlandyova area and north-east of Ratelpan Windmill along the Timbavati River. The largest alluvial deposits are typically found in the inside of river bends. These deposits have formed in response to recent and on-going processes such as flooding, alteration, erosion and wind-action. Thick sand fill characterises most river courses suggesting that they were probably deeply incised during the Tertiary period. The greatest development of alluvial cover occurs along the eastern part of the Luvuvhu River and along the Limpopo River.

The Luvuvhu River originates in the high rainfall area of Luvubu from where it flows through highly fertile land underlain by Soutpansberg lavas. In this area it becomes heavily laden with silt. West of Punda Maria Gate it enters a narrow gorge in the Clarens Formation sandstones which is probably superimposed on the present topography. Flow in the gorge is highly energetic and little sediment is deposited. East of the Lanner Gorge the Luvuvhu River encounters extensive areas of low-lying country towards Pafuri which causes rapid release of the silt load in much less energetic flow conditions. As a result this area has been covered by a thick veneer of red silt. In contrast the Limpopo and its tributaries flow through predominantly granitic areas. Consequently the alluvial cover flanking the Limpopo is mainly sandy and the floodplains along this river are fed by lateral percolation and not necessarily by flooding.

Stringers and concretions of calcrete and continuous calcrete banks are frequently found on the alluvial deposits along river banks and in the soil cover of some areas. Examples of calcrete formation can be seen in many road sections, notably along the Shingwedzi River and at the low-water bridge at Lower Sabie. Extensive calcrete formation is found in the residual soils which have developed on the Letaba Basalt Formation.

Tectonics

The Lebombo belt was originally described as a monocline (Du Toit 1929) and subsequently as a faulted monocline (Bristow 1976). For most of the central and northern Lebombo the belt retains the appearance of a faulted monocline though structural relationships are more complex in the extreme north and north-west of the belt. Brief details of faulting and flexuring in the Karoo sediments and volcanics north of Swaziland are presented in this section.

The most important faults affecting the Karoo rocks in the central and north Lebombo can be grouped, on the basis of distribution and trend, as follows:

(i) Faults with a north-south trend.
(ii) Faults with an east-south-east trend.
(iii) Faults with the Limpopo Belt trend.

The general structure of the belt between Swaziland and Dzundwini is that of slightly faulted, easterly dipping flexure. The sediments and volcanics dip at angles of between 5° - 15°E with steeper dips generally found in the most easterly outcrops. The relatively gentle dips observed to the south of Dzundwini suggest that much of the present-day outcrop represents the shallow dipping marginal zone of a faulted monocline in which the main zone of rifting, faulting and flexuring was located farther to the east. In the extreme north-east portion of the Lebombo the sediments and volcanics become more strongly inclined to the north-east in a series of east-south trending tilted fault blocks. This zone of intense structural deformation is continuous westwards into a zone of tilting and faulting which strikes east-north-east. The latter zone consists of a faulted monoclinal structure in which the northward-dipping Karoo rocks are repeated several times by faults with throw to the south. It maintains its identity for a distance of approximately 160 km and relative to the Limpopo Belt Basement structures occupies an analogous position to the Tuli syncline (Cox, Johnson, Monkman, Stillman, Vail & Wood 1965). The latter structure lies immediately to the north and parallel to the central, highly deformed zone of the Limpopo Orogenic Belt whereas the correlative faulted and flexured Lebombo sediments and volcanics described here occur on the southern side of the Central Zone.

Summary

The Permian to Recent geology of the KNP consists primarily of a major sequence of volcanic rocks underlain and overlain by relatively thin sedimentary units. These rocks, in particular the Lebombo volcanics and Cretaceous sediments were emplaced and deposited in response to the fragmentation of Gondwanaland and the forming of the Indian Ocean. Emplacement of the Lebombo volcanics as seen in the KNP occurred immediately prior to actual continental splitting and ocean formation.

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