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Geology of the Sabie River Basalt Formation in the Southern Kruger National Park

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The Sabie River Basalt Formation (SRBF) in the central Lebombo is a virtually continuous sequence of basaltic lavas some 2 500 m thick that was erupted 200 – 179 Ma ago. Flows are dominantly pahoehoe in character and vary from 2 m to 20 m in thickness. Dolerite dykes cross-cutting the basalt sequence probably represent feeders to this considerable volcanic event. Volcanological features observed within the SRBF are described. Two chemically distinct basaltic magma types are recognised, the simultaneous eruption of which presents an intriguing geochemical problem as to their origins.

Key words: Jurassic, igneous, basalt, doleritic, lava, dyke, geochemistry, volcanology, volcano-stratigraphy, Karoo, Lebombo.

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Introduction

The Sabie River Basalt Formation (SRBF) is part of a stratigraphically continuous sequence of volcanic rocks which were erupted between about 200±5 Ma to 179±3 Ma ago. The 200 Ma age was obtained (Allsopp & Roddick 1984) for a kimberlite pipe in Swaziland which cross-cuts Karoo sediments underlying the mafic volcanics, whereas the upper age limit is provided by Rb-Sr dating (Allsopp, Manton, Bristow & Erlank 1984) of the Jozini Rhyolites which overlie the Sabie River Basalt Formation.

This paper is concerned primarily with the descriptive geology of the SRBF in an area between the Sabie and Komati rivers (the central Lebombo – Fig. 1). Chemical characteristics of the basalts and intrusive rocks are discussed briefly. The geological sequence found in the area consists of Precambrian granitoid rocks overlain by thin Karoo sediments, in turn followed by basaltic lavas (SRBF) and rhyolites of the Jozini Formation. The Karoo sediments and Lebombo volcanics dip at varying degrees (basalts 10° – 30°), with some progressive steepening of the dip up-section to the east (Fig. 2).

In the area under discussion the SRBF has a stratigraphic thickness of about 2 500 m – a voluminous outpouring of basaltic material by any standards. The sediments immediately underlying the SRBF consist of massive light brown sandstones which are particularly well exposed at the Lubyelubye Stream bridge adjacent to the Sabie River and at the Hippo Pool viewsite on the Crocodile River (Fig. 1). The contact with the overlying basalts is not exposed in the area. The upper lavas of the basalt sequence are interbedded with rhyolites of the Jozini Formation. The resistant nature of these rhyolites has resulted in their forming the prominent Lebombo range of hills almost co-incident with the eastern boundary of the Kruger National Park (KNP).

Descriptive Distinction Between Volcanic Rock Types

1. Basalts

Subaerial basaltic lava flows can be separated into three types: pahoehoe, blocky and aa lavas. These distinctions were formulated from observations of Hawaiian lava flows made in the last century.

Pahoehoe lava is characterised by a smooth undulating or hummocky surface in contrast to the rough jagged aa surface and the irregular blocky surface of block lava. The distinction is dependent upon the physical properties of the magma – the most important of which appears to be the viscosity and the degree of turbulence in the flow (MacDonald 1968). The less turbulent, hotter and therefore less viscous a magma, the greater is the tendency for pahoehoe lava to develop. It is important to stress, however, that there is a complete gradation from pahoehoe to aa to block lava with an increase in viscosity and turbulence.

Only one lava flow which appeared to have a blocky character was observed in the area. The characteristic angular and massive nature of block lava was found preserved in a flow cropping out near the base of the stratigraphic section on the Crocodile River. The fact that no amygdaloidal phase (consisting of predominantly minerals of a hydrous character) was observed in this rock, testifies to its low volatile content and therefore higher viscosity. This particular flow was found to be at least 20 m thick. The remainder of basaltic flows in the area have characteristics typical of pahoehoe lava.

Lavas of the SRBF were extruded as a series of flows of apparently highly variable thickness (2 m-20 m). Typically these flows have a massive lower portion grading upwards into an amygdaloidal flow top. The definition of flow boundaries is largely a problem of semantics. It is difficult to decide on how considerable a time break must be in the volcanic record to permit the definition of another flow unit. Where the time interval between two flows is large enough to permit the development of a sediment horizon this decision is straightforward. This decision is less categorical when a boundary is represented by oxidation of the underlying flow top and pipe amygdales in the base of the overlying flow. A series of apparently thin (1 m - 3 m thick) lava flows may just be lava lobes representing pulses of the same eruption.

A petrographic distinction between magma types may be made on the

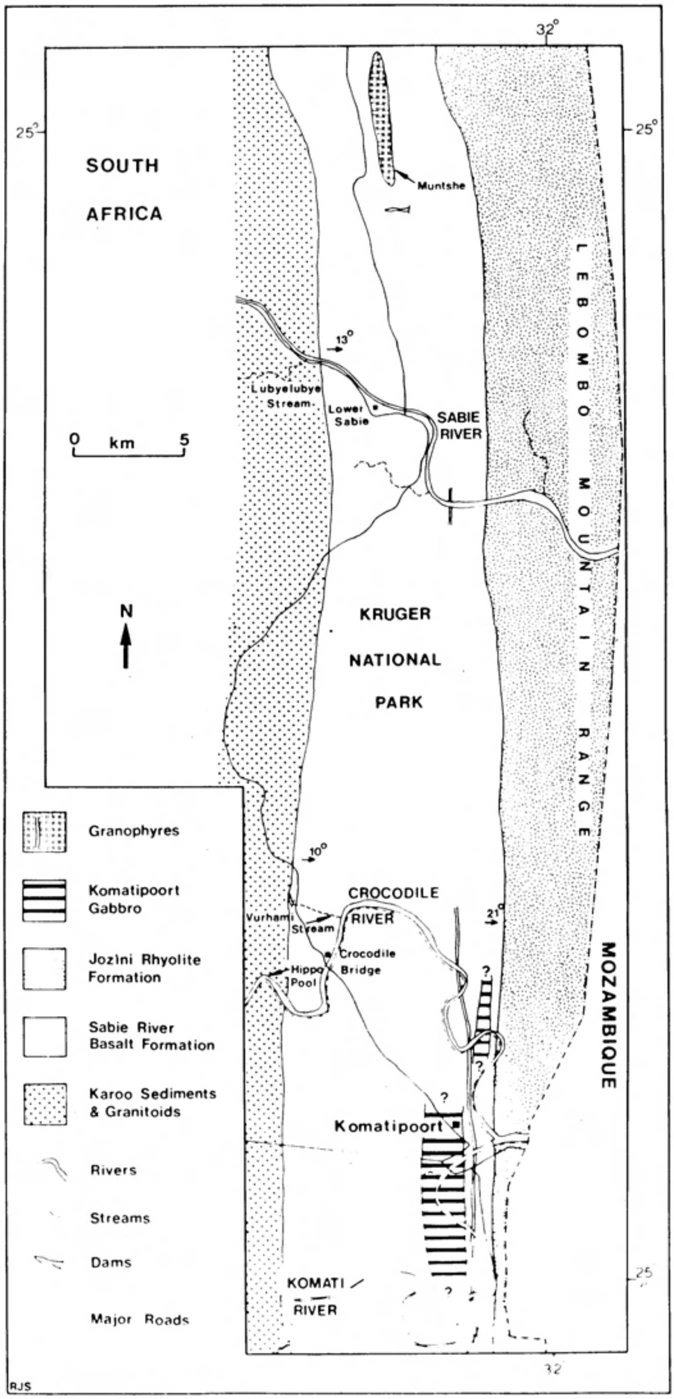

Fig. 1. Geological map of the Sabie River Basalt Formation in the central Lebombo.

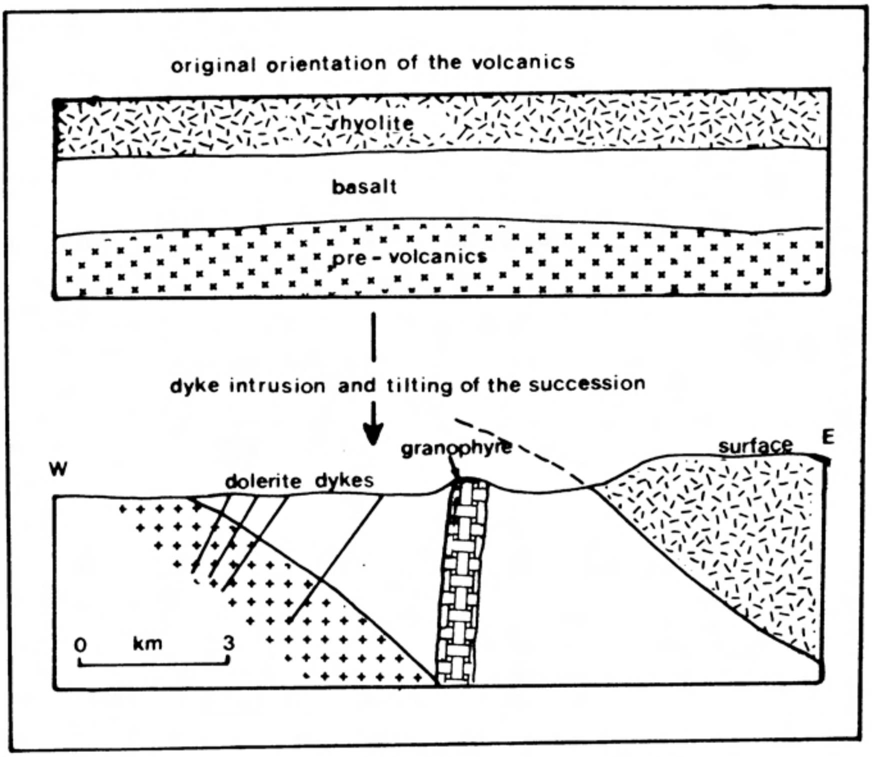

Fig. 2. Schematic cross-section of the central Lebombo volcanics.

presence (phyric) or absence (aphyric) of phenocrysts. The only phenocryst phase visible in basalt hand specimens is plagioclase feldspar. Porphyritic textures are ascribed to a period of slow cooling during which the phenocrysts grew, followed by a period of rapid cooling (quenching) during which the groundmass crystallised. In the case of basaltic lavas slow cooling may take place in a magma chamber whereas rapid extrusion of this magma onto a cold land surface as a lava causes rapid cooling or quenching. The aphyric/phyric character of a magma is not reflected in the chemistry (with the possible exception of Sr which has an affinity for plagioclase), nor is it dependent on the intrusive (dolerites) or extrusive (lavas) nature of the magma.

2. Intrusive Rocks

Three types of rock have intruded the Sabie River Basalt Formation. Dolerite dykes are the most common and are estimated to comprise 15% – 20% of the river sections considered. Dolerite may be considered as the intrusive phase of a basaltic eruption and in this area they cross-cut the lavas perpendicularly. The appearance of dolerite in outcrop is characterised by fine grained chilled margins and frequently columnar jointing which develops perpendicularly to the chilled margins. Dolerite dykes are typically intruded where a tensional tectonic regime exists, therefore their N-S linearity implies the existence of a tensional stress operating in an E-W direction. It has been established by many authors (Du Toit 1929; Cox 1978; Norton & Slater 1979;

Scrutton, Du Plessis, Barnaby & Simpson 1979) that the breakup of Gondwanaland represents the large scale manifestation of such stress. The absence of a volcanic centre from which the lavas may have erupted suggests their eruption from a fissure system, the conduits of which are represented by these dykes.

The Komatipoort Gabbro is a basaltic intrusive rock of a much larger scale (Fig. 1). It is spectacularly exposed below the road bridge over the Komati River south of Komatipoort and has been examined in detail by Saggerson & Logan (1970) and Logan (1979). Acid rocks ($Si0_2 > 65\%$) intrusive into the SRBF are present as felsic dykes (10 m-40 m wide) or much larger granophyre bodies. The Muntshe granophyre intrusion forms a spectacular hill rising above the basalt plain north of the Sabie River. The Molondozi Dam lookout is sited on the southern edge of this granophyre.

Fig. 3. Pipe amygdales at the base of a lava flow.

Volcanological Features of Basaltic Lava Flows

1. Amygdales

Amygdales are mineral fillings in vescicles (spaces) in a lava flow. Two possible origins for the amygdale phase in a lava exist. These low temperature minerals may form *during* the extrusion event by the migration of the volatile component in a lava into interstices or they may be deposited in vescicles due to the *later* circulation of groundwater in the lava pile. Indications are that both types are present. The presence of crystalline epidote in some vescicles indicates a crystallisation temperature of above 400 °C, while minerals such as calcite and halite present in vesicles may well be the product of circulating groundwaters.

Aside from the typically spherical shape of most amygdales a variety of shapes exist.

i) *Pipe amygdales.* Where present these amygdales are restricted to the lower 20 cm of a flow (Fig. 3). Typically 2 cm - 6 cm in length, pipe amygdales are the result of the volatilisation of moisture on the surface over which the lava flows. Differential lava flow rates at the base of flows causes these amygdales to assume an inclination, the azimuth of which indicates the direction of flow movement.

ii) *Cone amygdales.* Although not ubiquitous these amygdales typically occur at the top of the massive amygdale-free lower portion of a lava. They are the result of the expansion of volatiles as they rise upwards creating a vesicular cone about 30 cm in length.

iii) *Sheared and cuspate amygdales.* These are usually observed in the upper reaches of a flow. Shearing is a result of flow movement and the cuspate (dome) nature reflects the tendency of volatiles to migrate upwards.

2. Pillows

Pillows are accumulations of pillow-shaped pods formed when basaltic lava flows into a body of water. Fingers of successive lava flows ooze out over the crests of their predecessors and sink into the spaces between the underlying pillows. The similarity of pillow lava structures to pahoehoe toes (discussed below) has often led to confusion. The most obvious morphological differences are the downward pointing apex of a pillow and the presence of interstitial material filling in spaces between pillows. The only definite example of a pillow lava in the area was observed just below the Gazantombi Dam wall on the Vurhami Stream virtually at the base of the succession (Fig. 1). Their presence implies that the initial lava erupted into an aqueous environment at this locality. The presence of pillow lavas higher in the succession and infrequently at the base of the SRBF suggests that water was present in ephemeral pans or lakes on the underlying sediments.

3. Flow-Within-Flow

Flow-within-flow is the small-scale movement of lava within a flow and results in the development of alternating amygdaloidal and amygdaloidal-free bands on a 5 cm-10 cm scale. This often gives the weathered surface of a lava a “ropy” appearance (Fig. 4).

4. Pahoehoe Toes

These frequently observed features are lava “fingers” which project from the edge of a lava flow. The oxidised material which delineates the margins of these toes may be either palaeo-oxidation or preferential oxidation of a chilled glassy skin by later circulating waters.

5. Basaltic Dykes

Flow tops often have a preponderance of cross-cutting basaltic dykes (Fig. 5a,

Fig. 4. Alternating amygdaloidal and amygdaloidal-free bands results in the lava outcrop having a "ropy" appearance.

b). These dykes are distinct from dolerites in that they have a very irregular development in the lavas and their margins are commonly amygdaloidal with no obvious chilling, thereby implying emplacement when the host lava was still hot. MacDonald (1968) has described auto-intrusive dykes in Hawaiian lavas. Fluid lava from the central part of a flow is injected into fractures in the solidifying crust and bulges up through the cracks, sometimes spreading out on the former flow surface as pahoehoe toes. This is an attractive explanation for the many cross-cutting basaltic features observed in the SRBF and explains their preponderance on/in the amygdaloidal upper reaches of a flow. Furthermore the similarity in chemistry between an auto-intrusion and its host lava supports this explanation (Table 1).

A number of the features discussed may be illustrated by an idealised cross-section of a flow as represented in Fig. 6.

Chemical Distinction Between Magma Types

From perusal of Table 1 the chemical differences between rhyolite and basalt

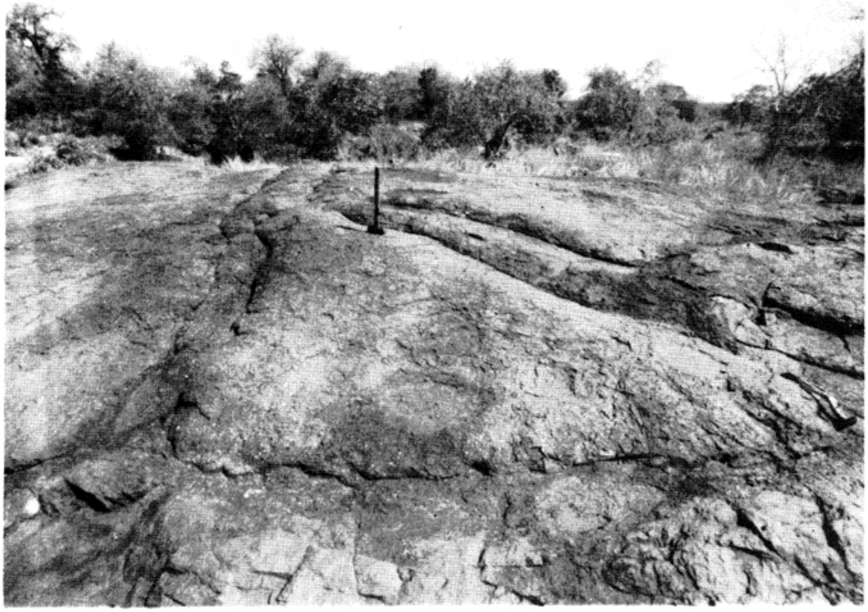

Fig. 5a. Typical distribution of basaltic auto-intrusive dykes in a flow top.

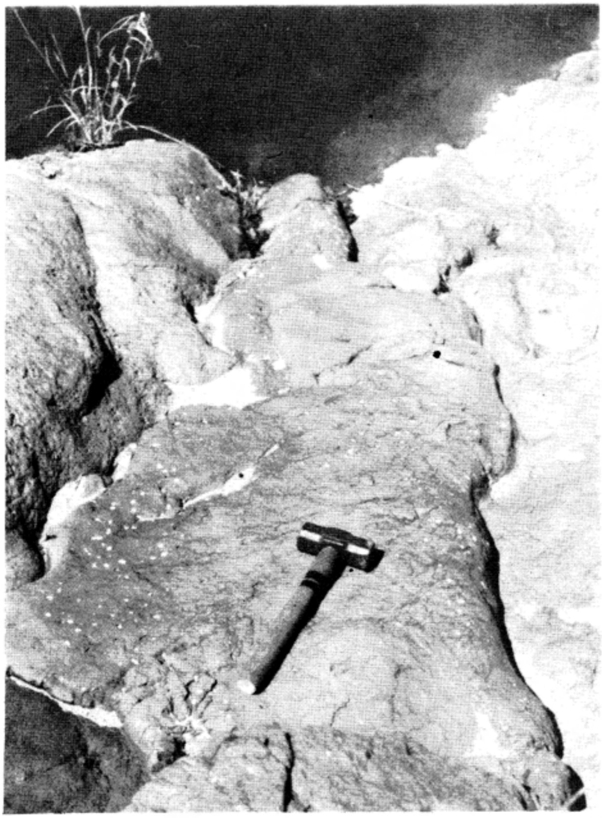

Fig. 5b. An auto-intrusive dyke. Note the development of amygdales in the margins.

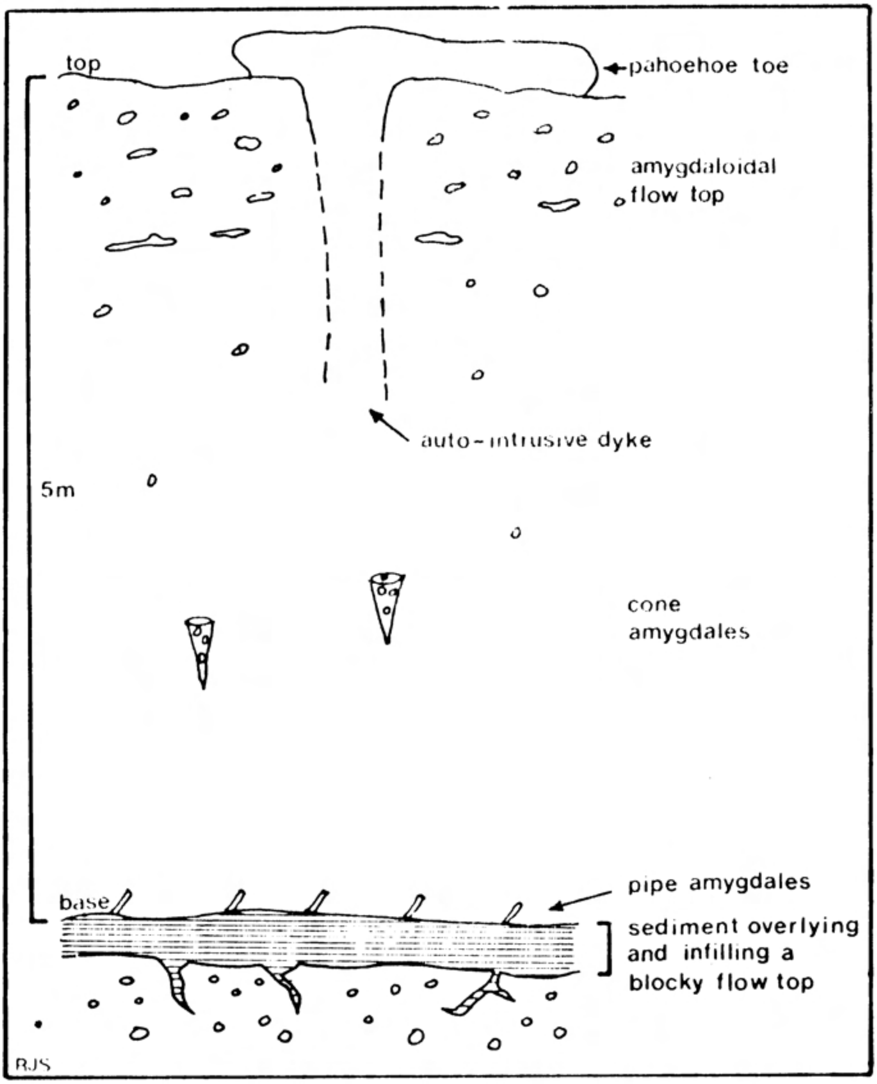

Fig. 6. An idealised cross-section of a basaltic lava flow.

are obvious. The differences in chemistry between the two basalt types are, however, more subtle and are shown by the following elements: TiO_2, P_2O_5, Zr, Nb, Y, La, Ce and Nd.

"Enriched" lavas have greater concentrations of these elements than "depleted" lavas. This bimodal distribution of chemical types is demonstrated by plotting Zr *vs.* TiO_2 (Fig. 7) for 156 central Lebombo basaltic lavas. It is this simultaneous eruption (interbedded nature) of two lava types in the same area which presents an intriguing geochemical problem as to their respective origins. The investigation of this problem is one of the prime motivations for the detailed study currently being conducted by the

Table 1

Typical chemistries of the volcanic rock types

	"Enriched" Basalt	"Depleted" Basalt	Jozini Rhyolite*	Basaltic Auto-intrusion	Basalt "Host"
weight %					
SiO_2	49.18	49.13	68.45	51.54	50.73
TiO_2	3.35	1.84	.53	2.89	2.84
Al_2O_3	11.31	14.23	12.58	13.29	12.96
Fe_2O_3	12.42	11.93	6.60	11.81	12.11
MnO	.15	.17	.14	,15	.14
MgO	6.94	6.86	.46	5.29	5.67
CaO	8.66	8.96	2.18	9.63	7.20
Na_2O	1.91	3.28	3.17	1.78	2.75
K_2O	1.88	1.33	4.19	1.96	2.41
P_2O_5	.51	.21	.15	.47	.46
H_2O^-	.63	.32	.72	.66	.64
LOI	2.35	2.05	.27	0.88	1.77
Total	99.30	100.32	99.44	100.36	99.68
parts per million					
Zr	374	119	1193	346	331
Y	35	24	124	37	36
Nb	20	7.4	91	17	16
La	43	9.6	–	40	38
Ce	98	21	–	84	83
Nd	73	15	–	58	61
Ba	627	267	1283	653	879
Sr	667	569	208	794	1040
Rb	43	46	122	34	54
Cr	267	273	10.5	119	117
V	276	272	4.3	238	215
Sc	28	27	10.7	24	22
Ni	101	126	–	121	119
Co	53	50	–	51	50
Zn	121	101	143	119	121
Cu	106	223	11	50	51

All Fe reported as Fe_2O_3, H_2O^- is adsorbed water, LOI is the weight lost upon ignition of the sample (950 °C for basalts and 450 °C for rhyolites), * a central Lebombo rhyolite (CL209) from Bristow (1980). The analyses were obtained by X-ray fluorescence spectroscopic techniques currently in use at the Department of Geochemistry, University of Cape Town.

author, previous studies having suggested that the Lebombo basalts showed important geochemical changes in the vicinity of the Sabie River (see Duncan, Erlank & Marsh 1984).

The possibility of the dykes representing feeders to the lavas may be explored by matching their chemistries and indeed dolerite dykes having "enriched" and "depleted" chemistries are present in the area.

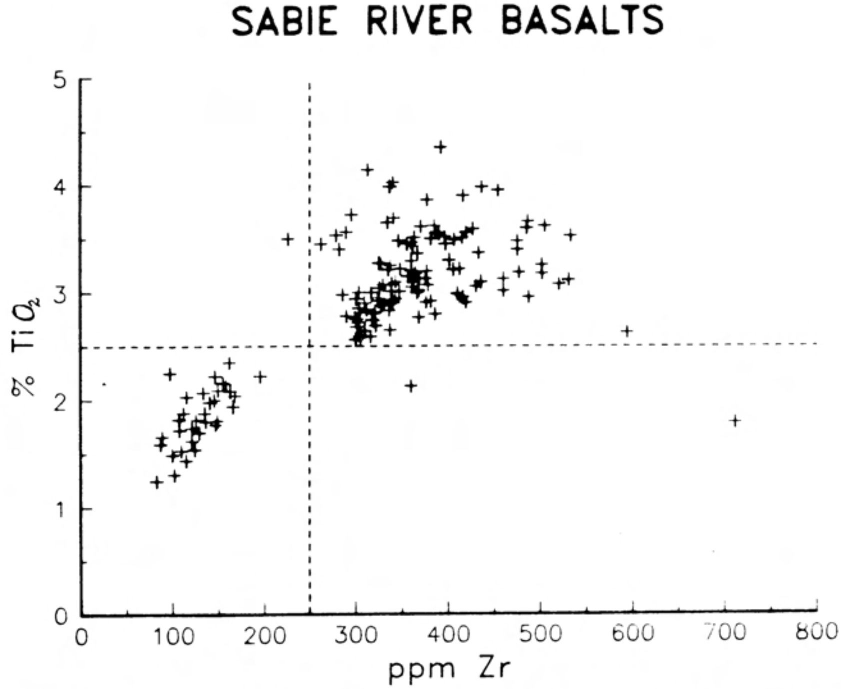

Fig. 7. Zr (parts per million) *vs.* TiO_2 (weight % of the oxide) for 156 SRBF lavas. (These analyses were generated using a semi-quantitative X-ray fluorescence spectroscopic technique at the Department of Geochemistry, University of Cape Town).

Summary and Conclusions

The Sabie River provides an ideal section for the study of tholeiitic basalts of the Lebombo Group and has been designated the type section of the SRBF (Cleverly & Bristow 1979). Approximately 2 500 m of basalt representing over 200 flows, of which over 100 have been sampled, are found in the section. On the basis of geochemical studies at least two groups of basaltic rocks have been recognised in this section. Petrographic and geochemical details of these rocks have been published by Cox & Bristow (1984) and Duncan *et al.* (1984). Detailed follow-up studies of this area are presently being conducted by the author.

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