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CHEMICAL VARIATION IN THE INSIZWA COMPLEX, TRANSKEI, AND THE NATURE OF THE PARENT MAGMA

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ABSTRACT

The Insizwa Complex, located in Transkei, southern Africa, consists of four layered intrusive bodies. Whole-rock geochemical and mineral compositional data for the marginal gabbro and picrite units are consistent with a low-Mg parentage. The modal mineralogy, petrography and geochemistry of the marginal gabbro unit point to olivine enrichment of a low-Mg magma by the settling of olivine crystals toward the contact and reaction of these crystals with the host liquid.

Keywords: Insizwa Complex, marginal gabbro, picrite, olivine, compositional data, parent magma, Transkei, South Africa.

SOMMAIRE

Le complexe intrusif d'Insizwa (Transkeï, Afrique du Sud) comporte quatre massifs stratiformes. La composition chimique des roches et celle des minéraux montrent que le gabbro de bordure et la picrite dérivent d'un magma à faible teneur en magnésium. La composition modale, la pétrographie et la géochimie du gabbro de bordure indiqueraient l'enrichissement d'un tel magma en olivine, dont les cristaux se sont entassés en direction du contact et ont réagi avec le bain fondu.

(Traduit par la Rédaction)

Mots-clés: complexe intrusif d'Insizwa, gabbro de bordure, picrite, olivine, chimisme, magma parental, Transkeï, Afrique du Sud.

INTRODUCTION

Whether basaltic rocks in continental flood-basalt provinces represent a primary magma or whether they are derived from a picritic parent-magma is a fundamental question in igneous geology (Cox 1980). The question is pertinent in the Central Karoo Province of southern Africa, a carapace of basalt located in Lesotho. The basalt flows are the surface manifestation of magma that formed a complex subsurface network of feeder dykes, sills and larger irregular intrusive bodies (Walker & Poldervaart 1949). Marsh & Eales (*in prep.*) have shown that the magmas of the Karoo Province are predominantly of the Lesotho type, *i.e.*, low in Mg and emplaced during the final phase of volcanism as a sequence of basalts (the Stormberg sequence) and their intrusive equivalents, the Karoo dolerites. Furthermore, they have shown that this sequence is remarkably uniform in chemical composition; though there are several distinctive earlier magma-types (mostly andesitic, dacitic and tholeiitic), the predominant magma of the Central Karoo Province belongs to the Lesotho type.

The larger intrusive bodies of Karoo age, such as the Insizwa and Elephant's Head complexes (Eales & Marsh 1979, Eales 1980), contain a very narrow chill-zone adjacent to the country rock, and a wide zone of gabbros consisting of a chilled groundmass hosting olivine phenocrysts. In the case of Insizwa, the chilled margin is only 5–10 cm wide, and the zone of gabbros with chilled groundmass, 10–15 m wide. Geochemical data are available for the marginal-zone rocks at Insizwa (Scholtz 1937, Bruynzeel 1957) and have been interpreted by Cawthorn (1980) and Tischler *et al.* (1981) as evidence for a high-Mg parent to the Insizwa Complex.

New petrographic and geochemical data are presented in this paper to demonstrate that the observed variations in the Basal Zone of the Insizwa Complex are consistent with olivine enrichment of a low-Mg parent magma and can in no way be interpreted as the products of a high-Mg parent magma.

GENERAL GEOLOGY OF THE INSIZWA COMPLEX

The Insizwa Complex is a group of four intrusive bodies (Tabankulu, Tonti, Insizwa and Ingeli) located in northern Transkei and centred on the village of Mount Ayliff (Fig. 1). Each intrusive body is up to 1 km wide and is composed predominantly of picrite and gabbro that occupy a basinal depression in the Jurassic sediments of the Ecca Series (Maske 1966).

This investigation uses data collected from the northern end of the Tabankulu body and the Waterfall Gorge sections of the Insizwa Complex. The se-

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quence of rock types exposed at Tabankulu and in the Waterfall Gorge section of Insizwa are shown in Figure 2. The petrographic variation through the sequence differs at the two localities. The section at Tabankulu is taken at the axis of the basin, whereas that at Waterfall Gorge appears to be peripheral to the main body of the complex. Both sections have a marginal olivine gabbro, and in many other

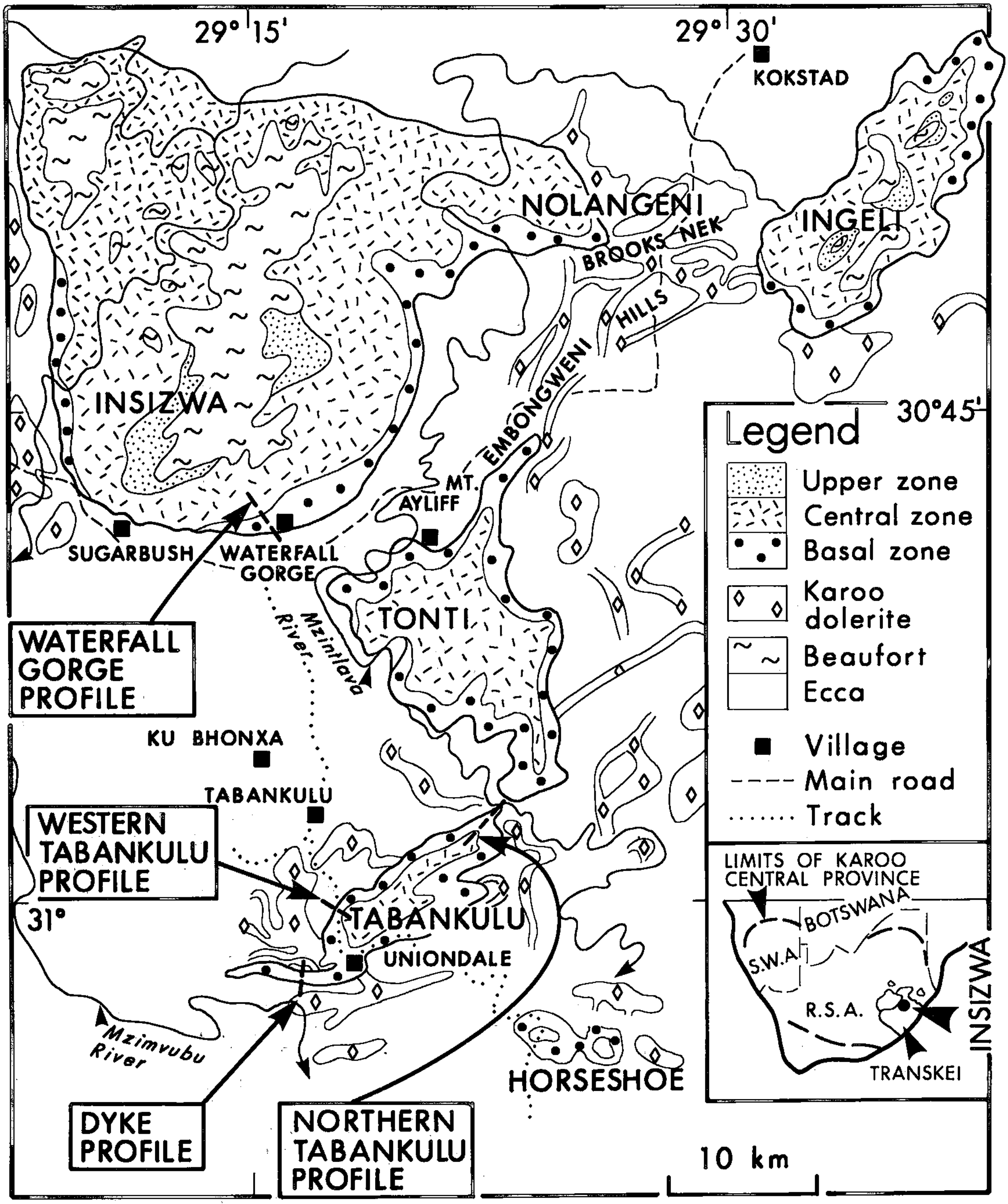

FIG. 1. General geology of the Insizwa Complex, showing the location of the Tabankulu and Insizwa sections and the profiles sampled through the intrusive body.

respects their petrographies are quite similar. However, certain major differences also exist. The olivine gabbro at Insizwa hosts a small showing of nickel sulfide (Goodchild 1916, Scholtz 1937), and is overlain by a thin unit of picrite and a thick sequence of gabbros. At Tabankulu, the marginal gabbro is overlain by a thick sequence of picrite and troctolite, and is capped by a sequence of gabbros. Drilling at Insizwa (Dowsett & Reid 1967) suggests that the picrite thickens toward the centre of the intrusive complex.

Petrology and Petrography of the Lower Basal Zone

Analytical techniques

Olivine compositions were determined by energy dispersion using an ARL–EMX electron microprobe operated at an accelerating voltage of 25 kV and a specimen current of 3 μA and an ETEC electron microprobe operated at 1 μA. On-line reduction of spectra was performed on a PDP11 computer using a modified version of PESTRIPS (Statham 1975). The wavelength-dispersion system on the ARL–EMX instrument was used where detection of elements present in concentrations of less than 0.5% was required. A series of nickel-bearing olivine standards was used to produce a calibration curve, and these standards were analyzed with each group of samples. Three 100-second counts (real time) were collected from each grain at peak and two background positions.

Whole-rock compositions of a selection of samples from Waterfall Gorge were obtained by combined X-ray-fluorescence spectroscopy and neutron-activation analysis (Table 1). XRF data were collected on an energy-dispersion instrument using a selection of standards. Data for Rb, Sr, Y and Zr were collected on a Siemens automated XRF unit, and the data were reduced on-line using a PDP11

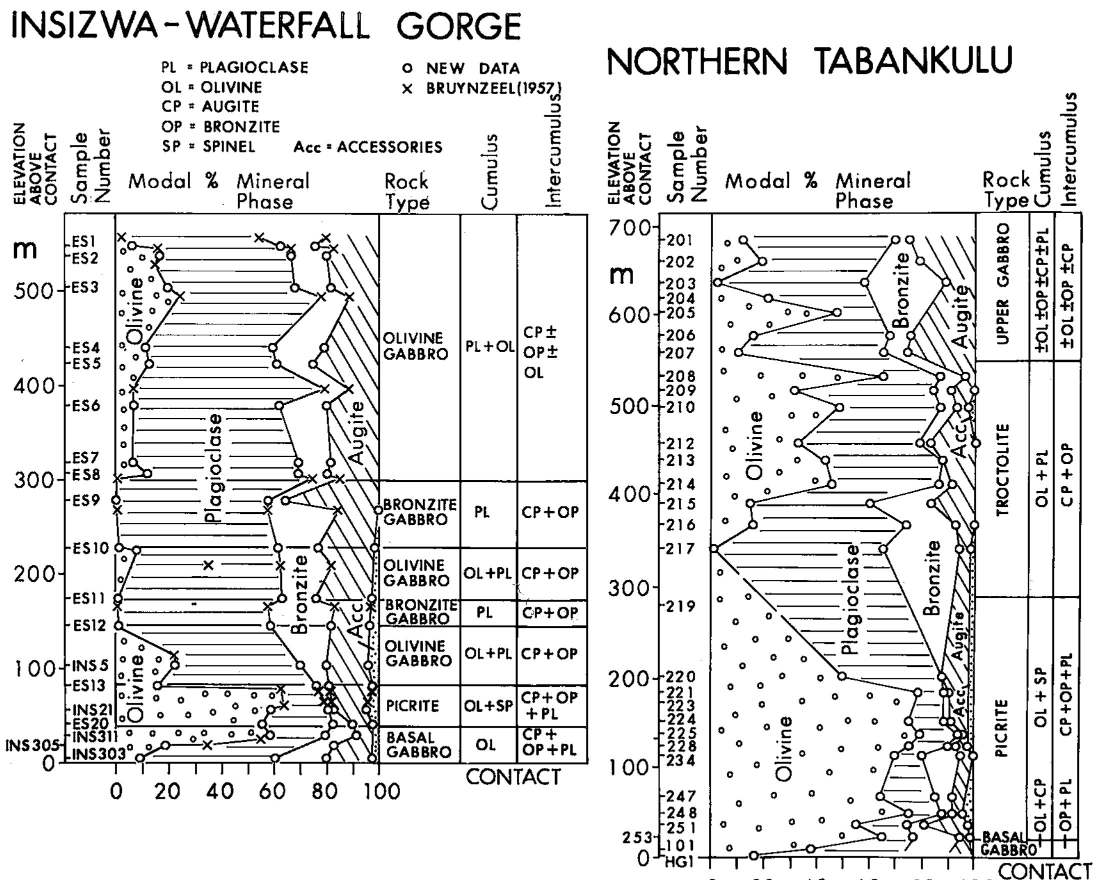

FIG. 2. Variation in petrography and modal mineralogy, showing the entry and exit of cumulus and intercumulus phases for samples collected from the northern Tabankulu and Waterfall Gorge sections of the Insizwa Complex.

TABLE 1. WHOLE-ROCK GEOCHEMISTRY OF THE LOWER BASAL ZONE AT WATERFALL GORGE

	INS 301	INS 302	INS 303	INS 304	INS 305	INS 306	INS 307	INS 308	INS 309	INS 310	INS 311	ES 20
SiO_2	68.46	53.72	49.16	48.15	48.14	47.52	47.12	48.97	47.45	46.31	45.36	43.91
TiO_2	0.47	0.96	0.68	0.68	0.62	0.65	0.63	0.66	0.59	0.55	0.46	0.34
Al_2O_3	12.23	13.36	14.07	14.01	13.15	12.68	12.47	13.73	11.66	10.85	10.73	8.39
FeO	7.91	11.77	13.21	13.21	13.27	13.30	13.67	13.11	13.08	13.83	13.94	15.45
MnO	0.10	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19
MgO	1.46	7.07	11.88	13.02	14.90	16.43	16.73	12.94	18.52	20.86	21.74	26.98
CaO	2.47	9.01	8.42	8.09	7.49	7.38	6.98	7.89	6.74	6.15	5.83	4.09
Na_2O	2.72	1.88	1.61	1.78	1.75	1.43	1.15	1.58	1.42	1.05	1.54	0.72
K_2O	3.60	0.75	0.46	0.47	0.40	0.41	0.39	0.49	0.29	0.25	0.16	0.01
P_2O_5	0.00	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.13	0.11	0.08	0.07
L.O.I.	1.78	1.17	0.42	0.49	0.50	0.46	0.43	0.89	0.72	0.89	0.60	0.29
TOTAL	101.20	100.05	100.25	100.23	100.55	100.59	99.90	100.59	100.78	101.03	100.62	100.44
Rb	153	29.5	21.5	18	17	16	17.5	21.5	13.5	12.5	11	9
Sr	266	188	153	140	131	131	136	147	118	101	96	76
Y	21.5	24.6	20.9	19.4	18.1	17.5	18.1	19.6	15.7	14.6	13.2	9.3
Zr	201	90	78	70	65	64	66	72	57	51	46	33
Nb	10	8	6	5	6	6	5	6	5	5	5	4
Cu	3703	597	1525	1108	1081	602	1063	1300	243	360	602	301
Ni	2640	705	1972	1439	1551	1034	1566	1798	882	1093	1367	1010
La	27.3	14.4	10.8	10.1	9	9.2	9.3	10.8	8.3	6.8	7.2	n.d.
Ce	n.d.	28.9	22	21.2	19.2	19.9	19.1	32.1	17.4	13.9	13.9	n.d.
Nd	n.d.	13.5	12.3	10.7	9.8	9.9	10.5	11.9	8.4	8	6.5	n.d.
Sm	5.2	3.7	2.9	2.8	2.5	2.5	2.5	2.9	2.2	1.9	1.9	n.d.
Eu	n.d.	1.2	1.1	0.8	0.9	0.8	0.8	0.9	0.8	n.d.	n.d.	n.d.
Tb	n.d.	0.2	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.1	0.4	n.d.
Ho	1.6	1.0	n.d.	n.d.	n.d.	0.6	0.7	0.8	0.8	n.d.	n.d.	n.d.
Yb	2	2.5	2	2	1.8	1.8	1.7	2	1.7	1.2	1.3	n.d.
Lu	0.3	0.4	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.2	n.d.

n.d. not determined. L.O.I. Loss On Ignition at 1100 °C.

computer. Rare-earth elements were determined by neutron-activation analysis using the University of Toronto SLOWPOKE reactor facility and counters.

Petrology and petrography

The exact position of the intrusive contact at Tabankulu and Waterfall Gorge is difficult to recognize owing to poor degree of exposure and intense recrystallization of the country rock below the contact. The contact in the field is, therefore, best described as a zone between 0.25 and 1 m wide.

Thin sections prepared from samples collected from the contact of the intrusive complex with a vein of footwall-derived granophyre show radiating clusters of plagioclase crystals set in a groundmass of fine-grained orthopyroxene, apatite, potassium feldspar, biotite, ilmenite, spinel and quartz. Olivine is absent within 5 cm of the contact, but enters as small anhedral crystals at 5 cm from the contact (Fig. 3). Petrographic evidence suggests that interaction of the chilled magma and the granophyre has occurred close to the contact: grains of quartz and potassium feldspar have been incorporated into the chilled margin. The geochemical data available for the chilled margin may reflect this mixing process and the possible incorporation of xenolithic fragments of granophyre or cumulus olivine phenocrysts.

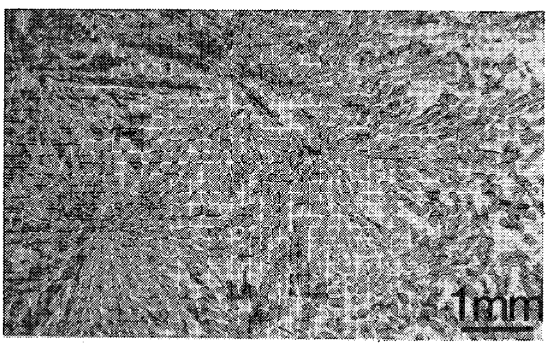

FIG. 3. Photomicrograph showing the chilled margin of the Insizwa intrusive complex developed within 10 cm of a vein of granophyre cutting the marginal gabbro. Note the radiating clusters of plagioclase enclosed in a matrix of bronzite.

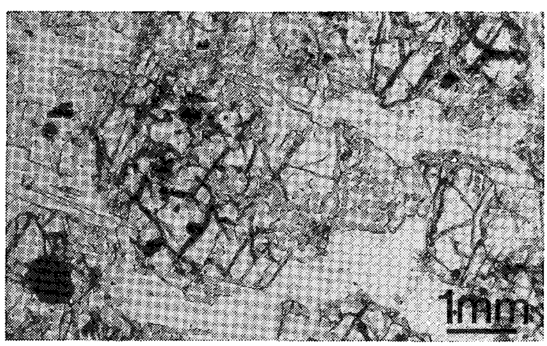

FIG. 4. Photomicrograph of the marginal gabbro showing subhedral phenocrysts of olivine partly surrounded by bronzite. The grains of olivine have embayed margins where in contact with bronzite.

Olivine increases rapidly in modal proportion and grain size away from the contact and through the marginal gabbro; the grains change from resorbed crystals surrounded by bronzite at the base of the unit to equant crystals close to the contact with the picrite. The grains of olivine are set in a groundmass of plagioclase, bronzite, ilmenite, sulfide and biotite that shows an increase in grain size away from the contact (Fig. 4).

The transition to the overlying picrite is gradational over 20 m, and is defined by the appearance of large crystals of intercumulus plagioclase, augite and bronzite, and a leveling-off in the proportion of olivine at 60–65 modal percent.

Compositional Data on Olivine

Data for the Tabankulu and Waterfall Gorge profiles are presented in Figures 5, 6 and 7. Figure 8 shows the variation in forsterite with nickel content of the olivine.

The following features are evident from the Tabankulu data:
(1) There is a reversal in the forsterite and nickel contents of the olivine 20 m above the base that correlates with an abrupt change in the trend of increasing modal olivine. (2) The olivine from the picrite unit is the most forsterite-rich, but has, in some cases, a lower content of Ni than the olivine from the marginal gabbro. (3) There is a gradual increase in nickel through the upper part of the picrite unit, and (4) the olivine from the rest of the intrusive complex (*i.e.*, the troctolite and the upper gabbro) shows a gradual decrease in forsterite and nickel contents from the top of the picrite upward.

At Waterfall Gorge, the olivine data exhibit the following features: (1) There is a well-defined downward decrease in the forsterite and nickel con-

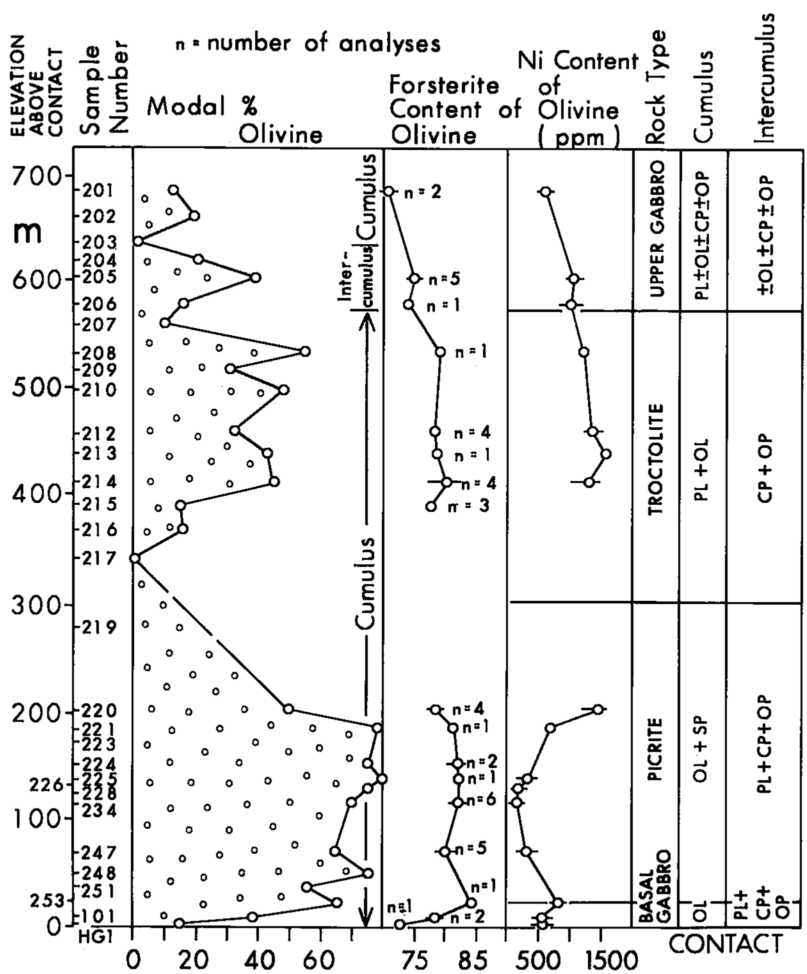

FIG. 5. Modal and compositional data for olivine from northern Tabankulu.

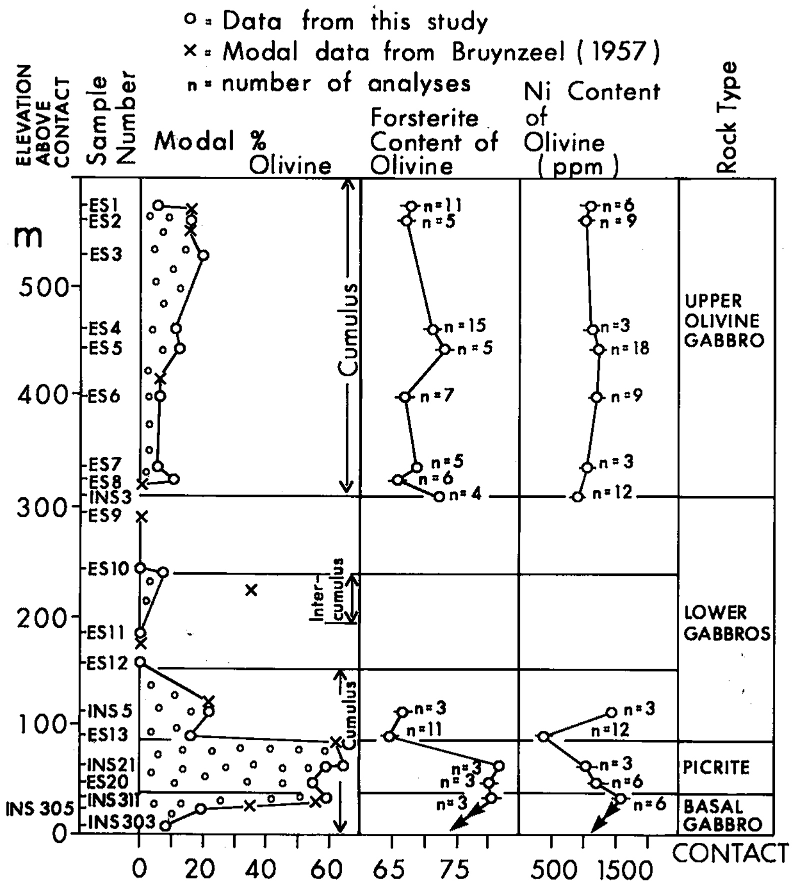

FIG. 6. Modal and compositional data for olivine from Waterfall Gorge.

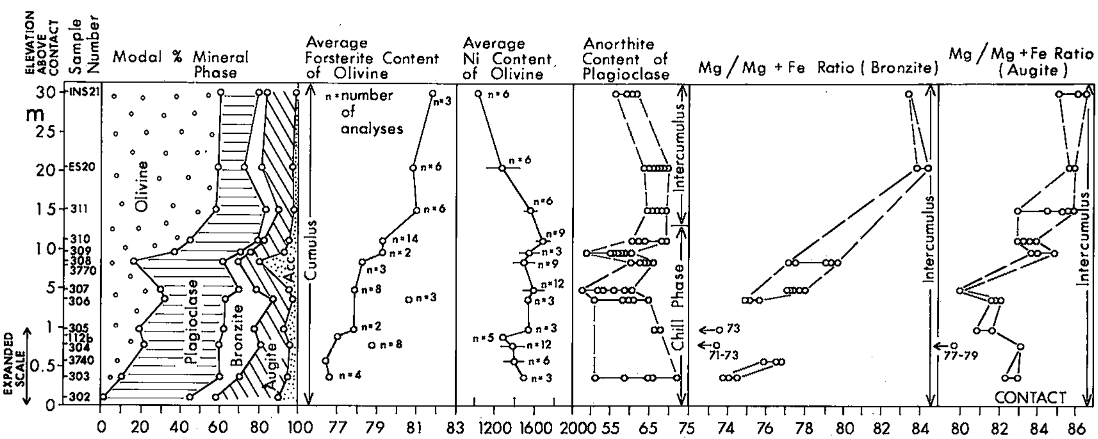

FIG. 7. Data on mineral and modal compositions for the lower part of the Basal Zone at Waterfall Gorge. The region between 0 and 1 from the contact is plotted on an expanded scale (n number of analyses).

tents of olivine below the 30 m level (Figs. 6, 7) that correlates with a downward decrease in the proportion of modal olivine. These reversed trends are similar to those observed in the basal gabbro at Tabankulu, but more clearly defined by the better coverage of samples. (2) The olivine from the picrite unit has the highest forsterite content and is low in nickel compared to the marginal gabbro, although not as low in nickel as that seen at Tabankulu. (3) There is a rapid decline in the forsterite and nickel contents of the olivine above the picrite. Olivine disappears at the top of the hypersthene gabbro unit, but reappears higher in the intrusive sequence. (4) Olivine re-enters 300 m above the contact and exhibits a fairly constant content of forsterite and nickel.

NATURE OF THE PARENT MAGMA

The geochemical data presented in Table 1 may be used to place broad constraints on the nature of the parent magma. The approach presented here is to first outline the nature of the possible parents (Table 2) and then to test these proposed parents using the available mineral and whole-rock geochemical data.

The predominant magma involved in the Central Province is of the Lesotho type. Geochemical work by Marsh & Eales (*in prep.*) has shown that these rocks have a uniformly low concentration of magnesium. Marsh & Eales also showed that there also exists a sequence of dacites, andesites and tholeiites in the Central Province of earlier age than the Lesotho-type rocks. Their limited volume and evolved compositions render them unsuitable parents for the Insizwa Complex.

High-Mg rocks are absent from the Central Province, though Cox & Jamieson (1974) have described high-Mg ultramafic rocks from Nuanetsi and Lebombo. Cawthorn (1980) and Tischler *et al.* (1981) argued that the Insizwa Complex is derived from such magmas on the basis of so-called chilled-margin compositions from Insizwa. The petrographic data presented here suggest that olivine enrichment has occurred throughout the Basal Zone; at the contact, only a 5-cm-thick unit exists that is free of olivine. The use of the gabbro to typify the composition of the parent magma is thus complicated by the additional component of cumulus olivine that has enriched the rock in Mg.

CONSTRAINTS ON THE NATURE OF THE PARENT MAGMA

Mg–Fe–Ni geochemistry

It is possible to place some broad constraints on our understanding of the composition of the liquid

TABLE 2. COMPOSITIONAL DATA FOR CENTRAL PROVINCE MAGMA-TYPES

	LESOTHO TYPE[a]		INSIZWA MARGINAL GABBROS[b]		
	DOLERITE	BASALT	(1)	(2)	(3)
SiO_2	51.76	51.51	52.00	52.16	53.72
TiO_2	1.00	0.95	0.60	0.90	0.96
Al_2O_3	15.23	15.69	12.81	13.55	13.36
FeO	10.90	10.95	8.88	10.01	11.77
MnO	0.20	0.16	0.28	0.18	0.18
MgO	6.86	7.02	13.24	9.94	7.07
CaO	10.57	10.69	7.65	9.74	9.01
Na_2O	2.28	2.17	n.d.	1.42	1.88
K_2O	0.56	0.70	n.d.	0.58	0.75
P_2O_5	0.17	0.16	n.d.	0.17	0.18
L.O.I.	n.d.	n.d.	n.d.	1.83	1.17
Ba	213	175			n.d.
Sr	208	191			188
Rb	12.5	12			29.5
Zr	97	94			90
Nb	6.3	4.8			8
Zn	87	86			111
Co	46	48			
V	246	241			
Ni	87	94			705
Y	25.7	24.4			24.6
n	22	48	1	1	1

n.d. not determined, n number of analyses. a Data from Marsh & Eales (in prep.). b (1) Scholtz (1937), (2) Bruynzeel (1957), (3) contact gabbro (1% modal olivine), this study, INS 302.

with which the most Mg-rich olivine from the Tabankulu and Waterfall Gorge profiles is in equilibrium. Given the olivine composition, we can derive the MgO/FeO ratio of the melt with which the olivine phenocrysts were in equilibrium, using the distribution coefficient

$$K_D = \frac{W(\mathrm{FeO})^{\mathrm{ol}} \bullet W(\mathrm{MgO})^{\mathrm{liq}}}{W(\mathrm{MgO})^{\mathrm{ol}} \bullet W(\mathrm{FeO})^{\mathrm{liq}}}$$

which has a mean of 0.30 and a standard deviation of 0.03, as derived by Roeder & Emslie (1970) in their experiments. Here, W is the concentration of an oxide in weight %.

TABLE 3. MgO-FeO GEOCHEMISTRY OF THE INSIZWA COMPLEX

	Fe^{3+}/Fe^{2+}	FeO	MgO	$(MgO/FeO)^{Obs.}_{Liq.}$	$(MgO/FeO)^{Calc.}_{Ol.}$		
K_D[a]					0.27	0.30	0.33
Karoo[b] Dolerite	0.10	9.81	6.86	0.70	2.59	2.33	2.12
	0.15	9.27	6.86	0.74	2.74	2.47	2.24
	0.20	8.72	6.86	0.79	2.91	2.62	2.38
Insizwa[c] Contact Gabbro	0.10	10.59	7.07	0.67	2.47	2.23	2.02
	0.15	9.98	7.07	0.71	2.62	2.36	2.15
	0.20	9.40	7.07	0.75	2.79	2.51	2.28

a $(MgO/FeO)_{Ol.}$ is calculated for three values of Kd and Fe^{3+}/Fe^{2+}.
b The Karoo dolerite composition is the average chilled margin composition of Central Province dolerites (Marsh and Eales, in prep.).
c The Insizwa contact gabbro was sampled adjacent to the contact of the intrusion with a vein of footwall-derived granophyre. The MgO/FeO ratio is not significantly changed by small degrees of local assimilation.

	FeO[a]	MgO[a]	$(MgO/FeO)^{Obs.}_{Liq.}$	$(Fo)_{Ol.}$
Tabankulu[b]	16	42	2.63	82.5
Insizwa[b]	17	44	2.59	82.5

a Oxides are given in weight percent.
b Olivine compositional data for the picrite units of both intrusions and are representative of the most forsterite-rich compositions found.

The MgO, FeO and forsterite contents of olivine from the Tabankulu and Waterfall Gorge sections of the Insizwa Complex are shown in Table 3, together with the MgO/FeO value of the equilibrium liquid calculated for three different values of K_D. The compositional data for putative parents are also shown in Table 3 for Fe^{3+}/Fe^{2+} ratios of 0.1, 0.15 and 0.2 (Brooks 1976). This comparison shows that the most Mg-rich olivine from Tabankulu and Waterfall Gorge is in equilibrium with a Lesotho-type parent magma and close to the value derived for the chilled margin sampled at Insizwa.

An alternate explanation for the observed compositional data requires the olivine to have crystallized from a high-Mg parent liquid and then equilibrated to a less forsteritic composition. Subtraction of olivine from the marginal gabbro produces a composition approaching that of a Lesotho-type parent magma; thus this model would require removal of a large part of the trapped liquid to produce a low-Mg host liquid.

Leeman & Lindstrom (1978) have determined the distribution coefficient for nickel between olivine and a liquid of a given content of magnesium; their data

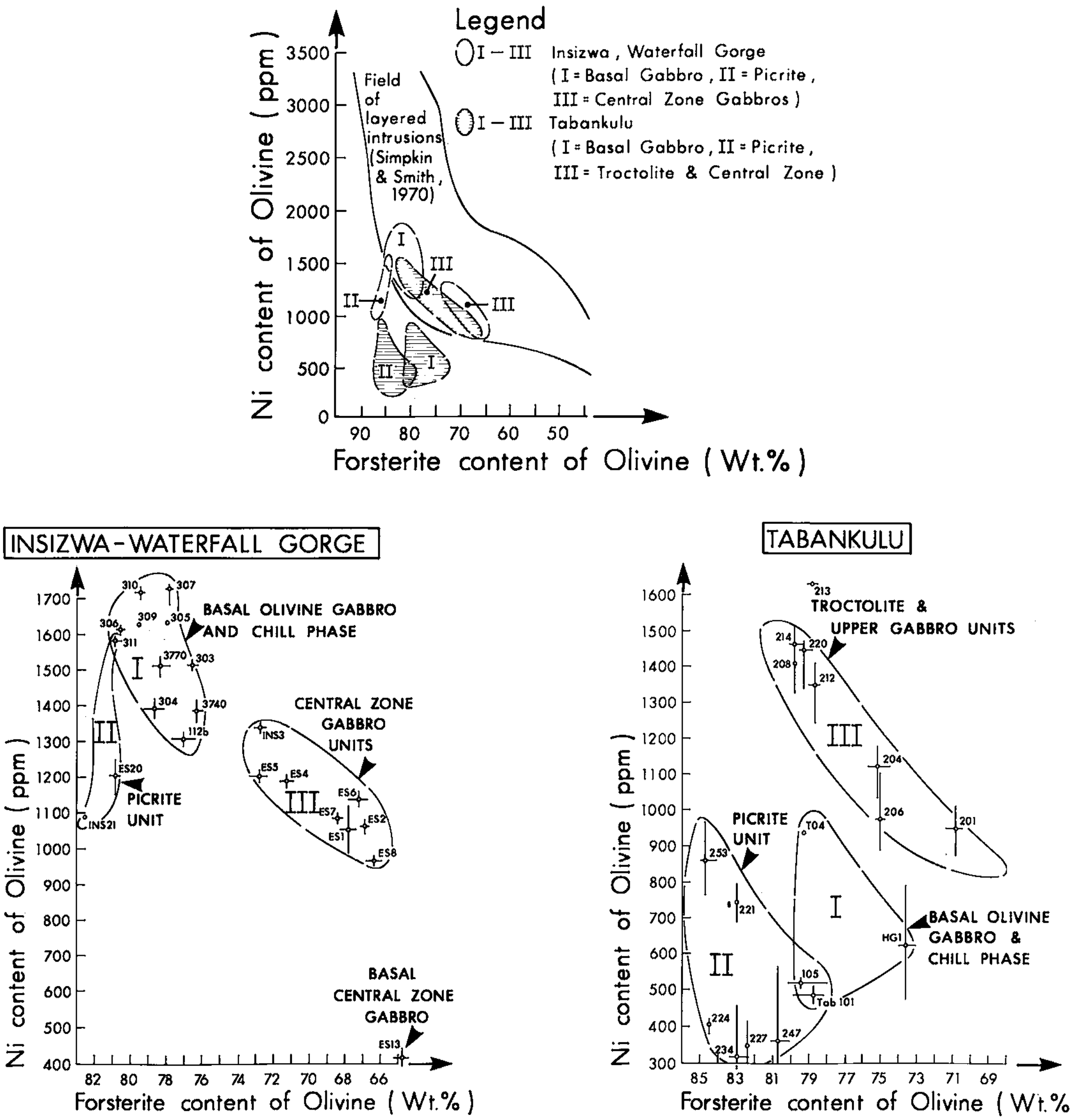

FIG. 8. Plot of Ni concentration *versus* forsterite content for olivine from Waterfall Gorge and Tabankulu. Inset shows the fields occupied by these data compared to the data collected from world-wide localities by Simpkin & Smith (1970).

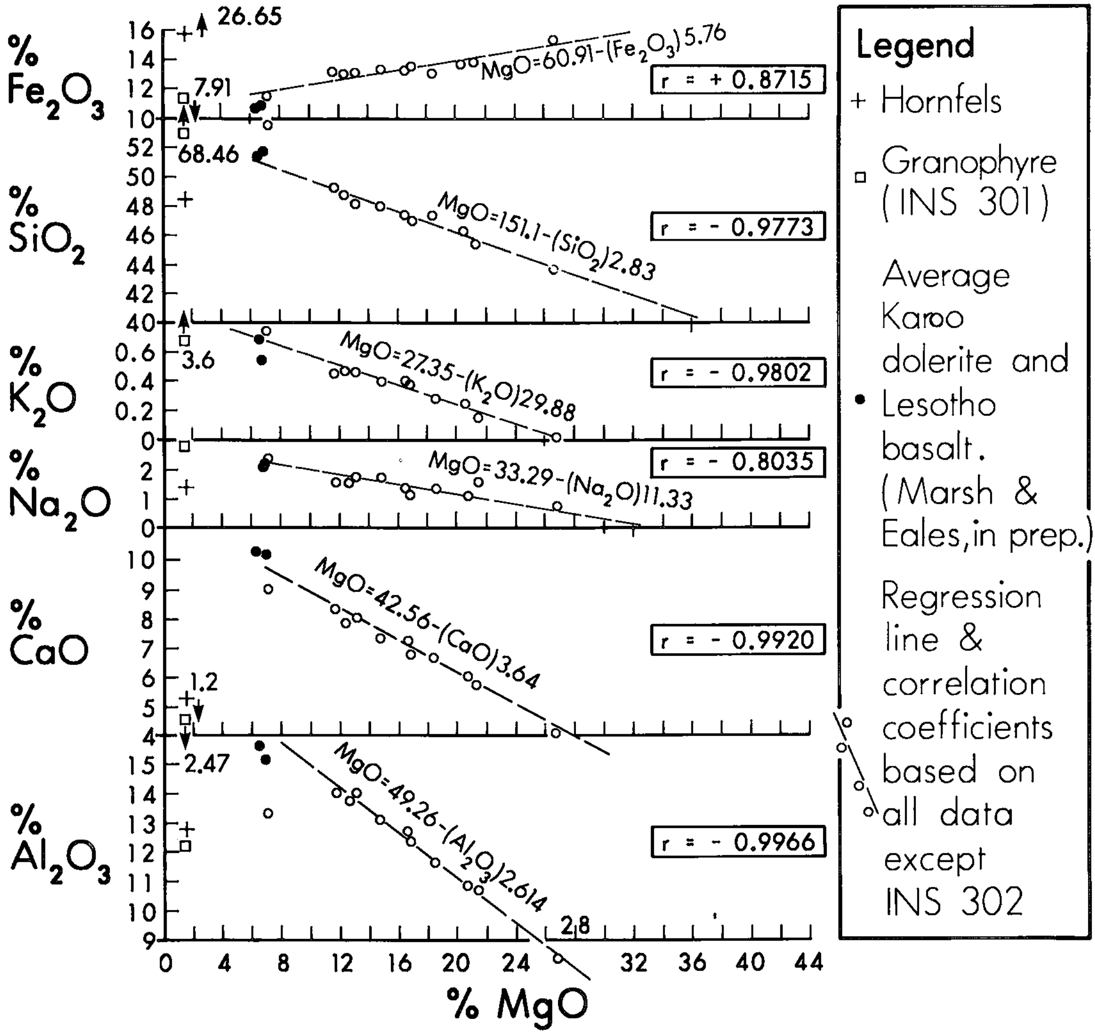

FIG. 9. Major-element geochemistry of the lower Basal Zone plotted against MgO content. Regression lines and correlation coefficients are for all data for rocks of the Basal Zone except for samples INS302, which is considered to contain xenolithic granophyre of footwall origin.

can then be used to compute the nickel content of the magma that would be in equilibrium with any given composition of olivine.

The variation in forsterite and nickel contents of olivine from Tabankulu and Waterfall Gorge is summarized in Figure 8. The most Mg-rich olivine from the picrite has a lower content of nickel than olivine from the rest of the intrusive complex. Lightfoot, Naldrett & Hawkesworth (*in prep.*) discuss this variation of nickel with forsterite and conclude that the data reflect equilibration of the olivine with sulfide. This precludes the direct use of the Leeman & Lindstrom relationship to further constrain the nature of the parent magma, though it is worth noting that the most forsteritic (Fo_{80}) and Ni-rich (1600 ppm) olivine from the troctolite unit is in equilibrium with a low-Mg parent magma.

Major, trace and rare-earth-element geochemistry

Major-element data are presented in Table 1 and in Figure 9, where the data are plotted against MgO, an index of the olivine content. The data include those for the chill, the marginal gabbro unit and the picrite. Also shown are the compositions of the granophyric vein and hornfels (Lightfoot, Naldrett & Hawkesworth, in prep.), and the Lesotho parent-magma type (Marsh & Eales, *in prep.*).

In calculating the correlation coefficients and

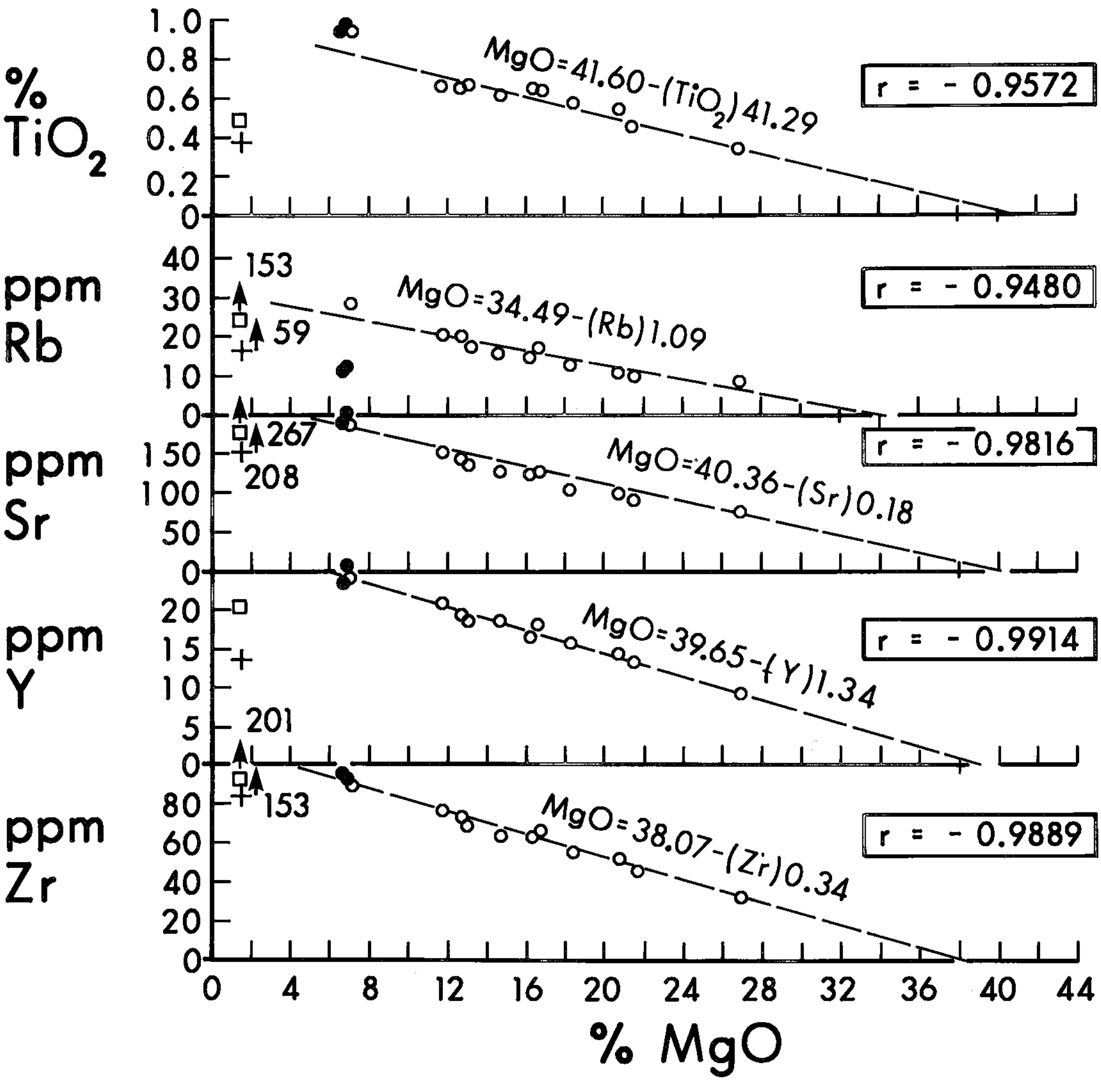

FIG. 10. Minor- and trace-element geochemistry of the lower Basal Zone plotted against MgO content. Regression lines and correlation coefficients are calculated for all samples of the Basal Zone except INS302, which contains xenoliths of footwall-derived granophyre. Symbols as Figure 9.

regression lines, sample INS302, collected adjacent to a vein of granophyre, was omitted, since it probably contains xenoliths of granophyre, which significantly influences the concentrations of incompatible elements.

In the case of the major-element oxides, the regression lines intersect the MgO axis, indicating a component of olivine control. As would be expected in the case of olivine control, the oxides such as FeO (expressed in Figure 9 as Fe_2O_3) and SiO_2, which reflect components of olivine, define trends that do not intercept the MgO axis between these limits. The data for Na_2O, determined by energy-dispersion X-ray fluorescence, are not of high quality. The low value of the intercept on the MgO axis given by K_2O is attributed to the very low concentration of potassium in the picrite and the scatter in the data. It can be seen that the trends defined by the Insizwa rocks pass through or near the composition of the Lesotho-type parent magma, suggesting that the rocks are a mixture of this magma and olivine.

The trace-element data (Table 1) further support this contention. Data for Sr, Y and Zr, plotted in Figure 10 against MgO, define similar regression lines that intersect the MgO axis between 38 and 40% MgO and pass through, or close to, the composition of the Lesotho-type parent. The data for Rb do not intersect the point, though they do suggest olivine control. Normal continental flood-basalts contain between 30 and 40 ppm Rb, which is much higher than the values quoted by Marsh & Eales (*in prep.*).

Thus, the major- and trace-element data appear compatible with the concept that the rocks of the Basal Zone at Insizwa are enriched in olivine containing 39 % MgO. These data strongly suggest a low-Mg parent to the rock and enrichment of the parent liquid in olivine to produce the rocks of the Basal Zone.

Data for the rare-earth elements are presented in Table 1, and chondrite-normalized patterns are plotted in Figure 11A. The range shown by the Karoo dolerites is shown in Figure 11B [which includes results of four new analyses and data from Marsh & Eales (*in prep.*)]. The data, as presented in Table 1, illustrate a progressive decline in overall rare-earth-element content with distance from the contact (increasing sample numbers from 302 to 311).

The major- and trace-element data suggest a control by olivine rather than contamination as the reason for the range in compositions; consequently, the rare-earth-element data have been corrected for olivine addition such that the data in Table 4 represent the concentration of rare-earth elements in the trapped liquid, including the normative olivine component. These results have been calculated assuming that the Zr content of a parent Lesotho-type magma is 97 ppm and that the Zr does not partition into olivine. The systematic decrease in rare-eearth concentrations with increasing distance from the contact is no longer visible in this data-set. It can be seen from the right-hand diagram in Figure 11 that the average of the corrected data corresponds closely to the upper part of the field occupied by Karoo dolerite, sample INS302 being the exception for reasons outlined above. Thus, the rare-earth-element data suggest a Lesotho-type magma parentage, with olivine control accounting for the range of observed values.

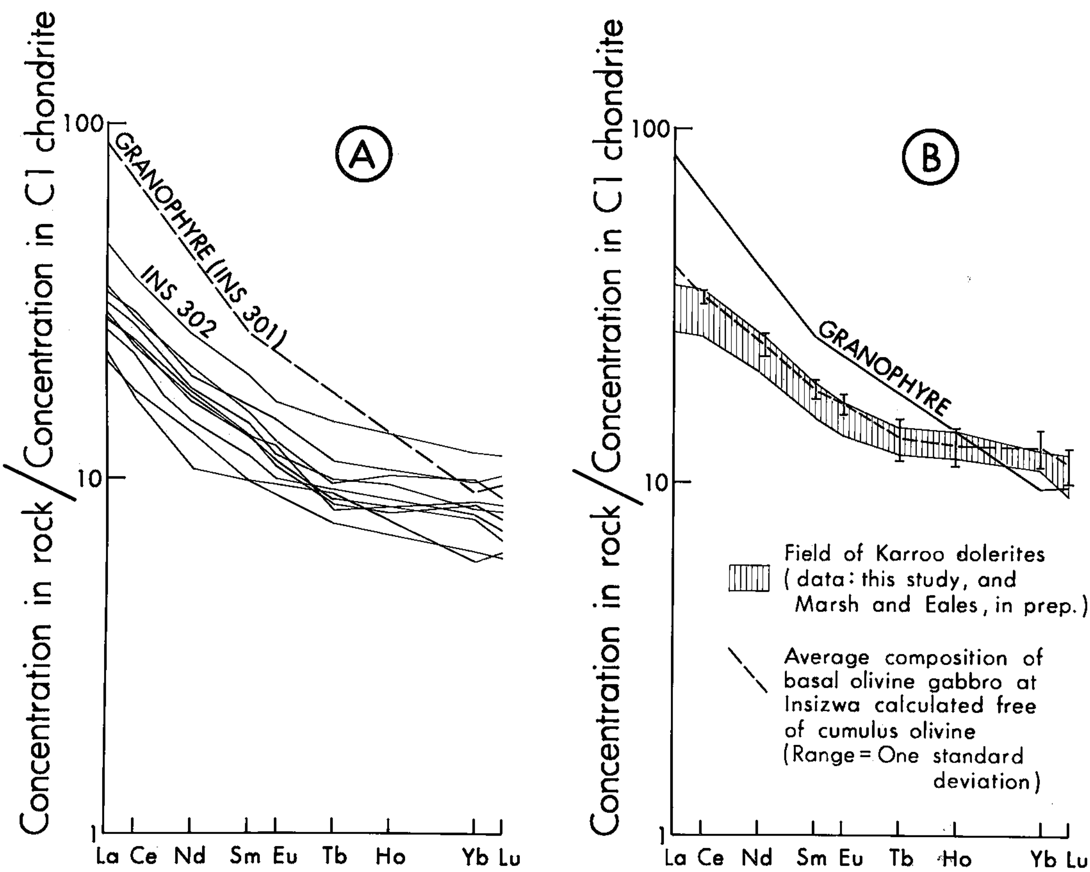

FIG. 11. Rare-earth-element data for the lower Basal Zone, showing chondrite-normalized data (A) and average composition of trapped liquid, compared to the field for Karoo dolerites (B) of Marsh & Eales (*in prep.*).

TABLE 4. CONCENTRATIONS OF RARE-EARTH ELEMENTS IN TRAPPED LIQUID

	INS 302	INS 303	INS 304	INS 305	INS 306	INS 307	INS 308	INS 309	INS 310	INS 311	MEAN[a]	ONE S.D.[a]	RANGE OF KAROO DOLERITE
La	49.3	42.2	44.0	42.9	43.9	43.6	45.9	44.9	40.8	47.8	44.0	2.05	26-36
Ce	38.5	33.3	36.0	35.5	37.0	34.8	38.0	36.5	32.6	35.8	35.5	1.71	25-34
Nd	24.4	25.3	24.8	24.7	24.9	26.0	26.8	24.0	25.6	22.7	25.0	1.19	19-24
Sm	20.9	18.6	20.1	19.1	19.9	19.0	20.4	19.6	18.6	20.6	19.5	0.76	15-19
Eu	17.5	18.3	16.4	18.7	17.2	16.8	17.5	17.0	n.d.	n.d.	17.4	0.82	13-16
Tb	15.7	13.7	13.6	12.3	12.1	13.1	12.9	16.2	17.2	16.0	14.1	1.86	12-14
Ho	14.6	n.d.	n.d.	n.d.	12.1	14.6	14.0	n.d.	n.d.	n.d.	13.6	1.31	12-14
Yb	12.8	11.9	13.5	13.1	12.8	12.5	13.3	13.9	11.0	13.0	12.8	0.88	11-12
Lu	12.9	12.3	12.4	12.5	11.6	12.0	12.1	12.4	12.1	12.8	12.2	0.34	9-11

a Mean and standard deviation of samples INS 303 to INS 311 recalculated to reflect concentrations in trapped liquid relative to C1 chondrite (5% normative olivine is included so that direct comparison with olivine-normative Karoo dolerites is possible).

Petrogenesis of the Lower Basal Zone

A low-Mg parent magma for the marginal rocks of the Insizwa Complex is suggested by the compositional data for olivine and the major- and trace-element geochemistry. The petrographic and geochemical data also permit a model to be proposed for the petrogenesis of the lower Basal Zone. It will be recalled that the marginal gabbro is marked by: (1) A downward decrease in modal olivine from 60% at the picrite contact to 15% at the base in the case of Tabankulu, and less than 1 modal % in the case of Insizwa, (2) a downward decrease in the forsterite content of the olivine from 82 to 74 at Tabankulu, and 81 to 76 at Insizwa, and (3) an increase in the degree of resorption exhibited by the olivine toward the contact and a decrease in the grain size.

Our explanation for these observations is that both intrusive complexes were formed from an initial influx of Lesotho-type magma which became supercooled at the base. The olivine nucleating higher in the intrusion settled gravitationally toward the base until the more viscous supercooled magma was encountered. This effectively prevented further motion. Cooling in the marginal gabbro closest to the contact was most rapid, and therefore very little olivine could be incorporated. However, further into the complex, cooling was much slower, thus permitting a larger number of phenocrysts to settle into this region. The fact that the Tabankulu contact contains more olivine than that from Insizwa is due to the poor exposure at the former locality, which prevented location of the basal contact with the same degree of precision as in the underground mine-workings at Insizwa. The Tabankulu sample, therefore, was probably taken farther away from the contact than the Insizwa sample.

The Tabankulu marginal gabbro contains 15% modal olivine, with a composition of Fo_{78} and 38 wt.% MgO. Subtracting this olivine from the bulk composition of the marginal gabbro gives a value of 10.4 for the MgO content of the chilled groundmass. This is still over 3% MgO higher than the Lesotho-type magma. In the same way, the Insizwa chilled margin (INS302) can be shown to contain 1–2% more MgO than the Lesotho parent. We suggest that resorption of the settled grains of olivine, indicated by their appearance in thin section, accounts for the increase in MgO of the groundmass. This resorption would have occurred as the magma cooled below the stability field of olivine into that of bronzite, accounting for the extensive mantling and replacement of the olivine that is seen in thin section.

Summary

The main objective of this paper was to discuss the nature of the parent magma giving rise to the larger layered intrusive complexes of the Central Karoo Province. Cawthorn (1980) and Tischler *et al.* (1981) suggested a high-Mg parent, similar in composition to the chilled margins. We disagree with this conclusion for the following reasons:

1. The forsterite content of the most Mg-rich olivine is in equilibrium with a low-Mg parent, with an MgO/FeO ratio identical to a Lesotho-type parent magma.
2. The major, trace, and rare-earth-element data suggest that olivine control on a low-Mg parent magma is primarily responsible for the observed geochemistry of the lower Basal Zone.

Admixture of olivine phenocrysts with Lesotho-type magma, coupled with reaction between the magma and the phenocrysts, and the resorption of olivine to produce haloes of bronzite, can account for the Mg-rich nature of the marginal olivine gabbro.

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