Alkaline rocks in the Kuboos-Bremen igneous province, southern Namibia: The Kanabeam multiple ring complex

David L. Reid

Department of Geochemistry, University of Cape Town, Rondebosch 7700, South Africa

The Kanabeam Complex forms one of many igneous centres that make up the early Cambrian (-520 Ma) Kuboos-Bremen igneous province. Situated about 12 km NE of the Orange River in southern Namibia, the complex measures only 3 km by 2 km, but contains within its modest dimensions practically every rock type encountered throughout the entire igneous province. The oldest intrusive phase recognised in the complex produced a series of concentric rings of nepheline syenite, which was subsequently intruded by a plug of quartz syenite. Later phases involved saturated microsyenites and a variety of granitic rock types differing in texture and quartz content. The intrusive axis shifted progressively from SW to NE, following the regional trend of the Kuboos-Bremen line, and was accompanied by a change from undersaturated to oversaturated rock types. Late phonolitic breccia pipes pierce the plutonic rocks along major contacts and contain, amongst other lithologies, several alkali gabbroic types which may have been derived from deeper unexposed parts of the complex.

Introduction

The remarkable line of igneous centres that constitutes the Kuboos-Bremen igneous province was first described by Söhnge & De Villiers (1948). Stretching some 270 km in a SW-NE direction across the lower Orange River (Fig. 1) and comprising over ten discrete central complexes, the province boasts an extreme range of igneous rock types, spanning the entire spectrum from granite to carbonatite (Kröner & Blignault, 1976). Another interesting feature of the province is that the linear trend cuts across several major Precambrian crustal boundaries. The Kuboos Complex intrudes sediments of the late Precambrian Gariep Province, while Tatasberg is emplaced within pre-Gariep basement rocks of the Richtersveld Subprovince. In Namibia, the igneous centres intrude gneisses and metasediments of the Namaqua Mobile Belt and the overlying Nama Group, the latter representing the youngest country rock cut by rocks of the igneous province. Radiomet-
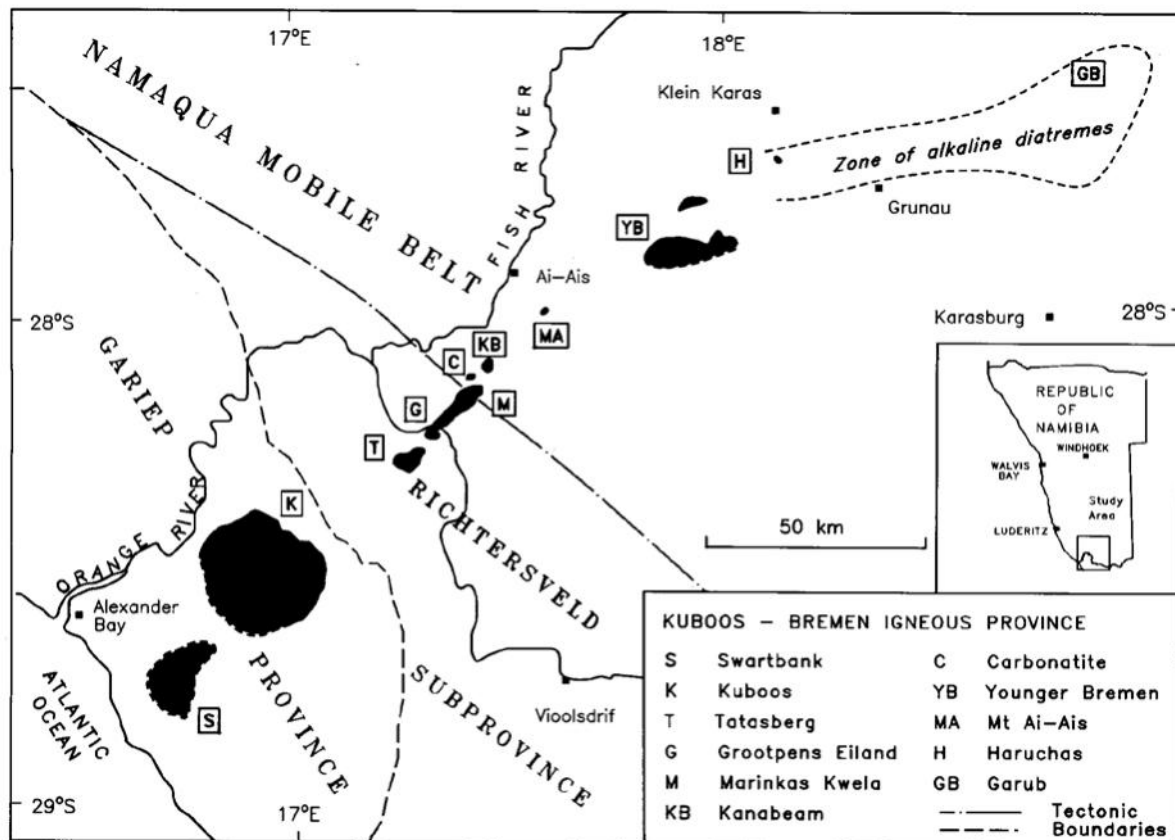

Fig. 1: Regional locality map showing the linear distribution of intrusive centres within the ~520 Ma old Kuboos-Bremen igneous province.

ric age determinations on Kuboos and Bremen indicate that they were intruded around 521 ± 12 Ma ago (Allsopp *et al.*, 1979).

Reconnaissance mapping in the lower Fish River region of southern Namibia by Blignault (1977) revealed several small igneous centres that formed part of the province between the Tatasberg granite and the Bremen Complex. Straddling the Orange River at Grootpens Eiland, these plutons were grouped within the so-called Tatasberg Complex of intrusions (Kröner & Blignault, 1976). Since the plutons around Grootpens Eiland are physically distinct from the Tatasberg granite and also consist of very different rock types, a modified classification is used in this study (Table 1). A discrete igneous centre situated to the NE of the Grootpens Eiland-Marinkas Kwela complex of plutons has been called the Kanabeam Complex, and is the subject of the current study. Apart from being described by Blignault (1977) as consisting of nepheline syenite and granite, no detailed work on the Kanabeam Complex has ever been carried out. It was found during the present study that the Kanabeam Complex contains within its relatively modest dimensions (3 km by 2 km) practically all the igneous rock types present in the entire Kuboos-Bremen province. As a result, the Kanabeam Complex was considered to be the prime candidate for the first in a series of detailed descriptions of all the complexes in the province.

Geological setting

The Kanabeam Complex is intruded into highly deformed granitoids and metasediments of the Namaqua Province. Blignault (1977) has described the area around Kanabeam and Marinkas Kwela as forming a transition zone between the Richtersveld Subprovince to the SW and the Namaqua Mobile Belt proper to the NE (Fig. 1). In a later paper, Blignault *et al.* (1983) interpreted the transition zone as forming the Fish River Thrust, comprising a northerly block overriding the Richtersveld Subprovince to the south. The timing of thrusting was placed during the Namaqua tectonism (1200-1000 Ma ago) and has produced a pronounced NW-trending structural grain.

The Kanabeam Complex owes its exposure to erosion of Karoo sediments eastwards from the Gamkab escarpment, a fault-controlled feature which has uplifted pre-Karoo basement that builds the mountain land surrounding the lower Fish River. Massive talus fans cover much of the dissected apron of the escarpment and extend over the western part of the Kanabeam Complex.

The Kanabeam Complex consists of a series of ring dykes and circular pIUGS which cross-cut each other, pointing to a multiple intrusion history. Where observed in the field, the outer margins of individual rings and pIUGS are near vertical to steeply outward dipping. Field relations between many of the individual intrusive phases indicate an age progression from south to north, although there are some cases where no relative age can be deduced. Individual intrusions can normally be distinguished petrographically, using either modal composition or texture. Secondary characterisation has utilised information obtained from thin section exami-

TABLE 1: Igneous centres making up the Kuboos-Bremen province.

Centre	Description
Swartbank	Granite
Kuboos	Granite, Syenite
Tatasberg	Granite
Grootpens Eiland	Granite, Nepheline Syenite Syenite
Marinkas Kwela	Granite, Nepheline Syenite Syenite
Marinkas Kwela North	Carbonatlte, Fenite
Kanabeam	Granite, Nepheline Syenite Syenite, Quartz Syenite Alkali Monzonite, Alkali Gabbro
Mt Ai-Ais	Alkaline Breccia Pipes
Bremen	Granite, Nepheline Syenite
Haruchas	Nepheline Syenite
Grunau	Parakimberlite-Carbonatite-Melilitite-Larnprophyre Swarm

TABLE 2: Intrusive components within the Kanabeam Complex. Oldest phase is placed at the top of the list, and the youngest at the bottom.

Main Lithology	Units	Description
Nepheline Syenite		
	nsl	White Alkali Syenite
	ns2	Grey Syenite
	ns3	Dark Alkali Monzonite
	ns4	Granular Alkali Syenite
	ns5	Foyaite
	ns6	Porphyritic Melasyenite
Quartz Syenite		
Microsyenite		
Granite		
Granite Porphyry		
Microgranite		
Hybrid Porphyry		Phonolitic breccia pipes
Late Dykes		Mafic to Felsic rock types
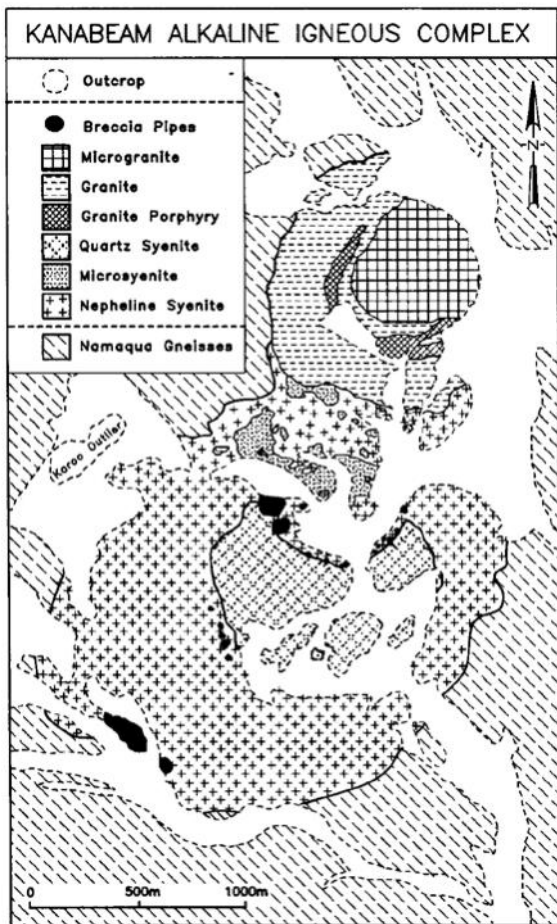
Fig. 2: Lithological map of the Kanabeam Complex. Cross-cutting dykes have been omitted to improve clarity.

Fig. 3: Detail of the multiple intrusive ring dykes within the nepheline syenite sub-complex. Labels ns1 to ns6 are described in Tables 2 and 3. Dashed lines within the sub-complex represent trends of prominent jointing observed within the syenites. Dry river beds and consequently the line of outcrop are shown with dotted lines.

nation and geochemistry. Subdivision and a summary description of each intrusive phase identified within the Kanabeam Complex are presented in Table 2.

Intrusive units

The separate intrusive phases listed in Table 2 are described in detail below. A geological map of the complex is shown in Fig. 2, while average modal data are listed in Table 3, and average major element compositions are presented in Table 4.

Nepheline Syenite

The southern most intrusive phase, which also represents the oldest component of the Kanabeam Complex, includes a series of nepheline syenites, that make up a sub-complex by themselves. At least six different varieties are distinguishable on the basis of modal composition, texture and field relations (units ns1 to ns6, Table 2). All the rings appear to have a common intrusive axis, although not all of them can be traced right around the sub-complex. Truncation of earlier rings by later rings, as well as later intrusive phases, all contribute to the complicated field relations within the sub-complex.
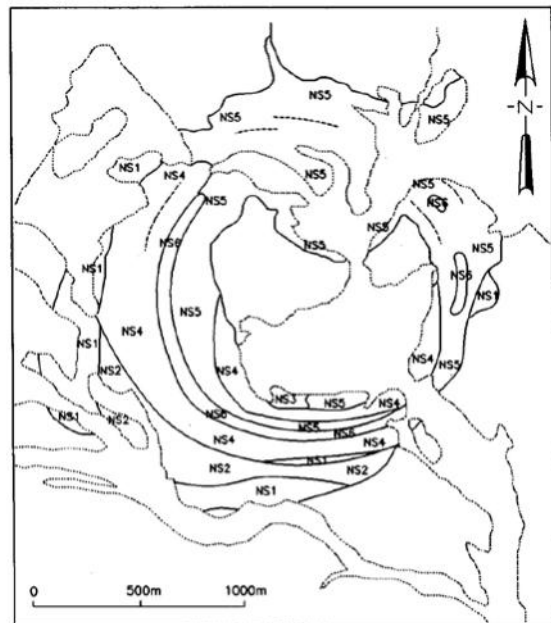
As a result, the detail within the nepheline syenite sub-complex has been omitted from the geological map in Fig. 2, and treated separately in Fig. 3, where the different units have been labelled ns1 to ns6.

White Syenite (ns1)

A cream-coloured white granular syenite with an average grain size of 4-6 mm crops out mainly along the southern outer contact of the complex, and it can be traced around to the southwestern side where it appears in narrow gullies cut into the extensive scree fans from the Gamkab escarpment. The rock can contain small amounts of either nepheline or quartz, and therefore appears to be close to silica saturation.

Certain zones along the outer contact feature country rock net veined with medium-grained quartz syenite, while highly feldspathised country-rock xenoliths are commonly distributed throughout the white syenite. The field evidence therefore suggests that extensive reaction has occurred between the syenite magma, which was probably originally undersaturated, and the quartzitic metasediments and granitoids that make up the country rock. Along the eastern margin of the sub-complex, the white syenite is truncated by granular syenite (ns4) and foyaite (ns5), although xenolithic blocks occur within these later rings.

The average mode is listed in Table 3. The predominant alkali feldspar is characterised by granular rather than prismatic habit. The white colour appears to be the result of turbid alteration of the feldspar, which shows very coarse vein and patch perthite (or anti-perthite)

TABLE 3: Average modes of the major lithologies in the Kanabeam Complex.

Phase	Lithology	Qtz	Neph	Sod	Alk Feld	Plag	Cpx	Biot	Amph	Mt
ns1	White Syenite	-	-	-	81	5	-	5	8	1
ns2	Grey Syenite	-	-	-	60	20	1	6	12	1
ns3	Monzonite		6	1	15	52	6	3	15	2
ns4	Granular Syenite	-	6	-	79	-	1	6	8	-
ns5	Foyaite	-	18	4	63	-	8	2	3	2
ns6	Porphyritic Melasyenite	-	10	2	56	-	10	8	12	2
QS	Quartz Syenite	15	-	-	62	12	-	4	6	1
MS	Microsyenite	-	-	-	63	20	-	6	10	1
G	Granite	20	-	-	57	15	-	3	4	1
GP	Granite Porphyry	15	-	-	57	22	3	3	1	-
MG	Microgranite	37	-	-	60	-	-	1	2	-

TABLE 4: Average major element composition and CIPW norms (wt %) for principle rock types in the Kanabeam Complex. Rock name abbreviations are after Table 3. The last two columns are single sample analyses: "Phon" is the phonolitic matrix of a breccia pipe, and the gabbro (sample DRK-72) is a xenolith from a breccia pipe. Data have been recalculated on a volatile-free basis with all Fe expressed as Fe_2O_3. CIPW norms calculated with $Fe_2O_3/FeO = 0.25$.

	ns1	ns2	ns3	ns4	ns5	ns6	QS	MS	GP	G	MG	Phon	Gabbro
SiO_2	61.69	56.89	54.71	60.86	58.55	55.31	66.56	60.66	68.07	68.21	76.48	54.48	45.20
TiO_2	.37	.90	1.16	.56	.28	.63	.50	.73	.52	.42	.08	.75	.50
Al_2O_3	19.30	18.52	21.20	19.09	20.45	18.01	15.91	18.54	15.06	15.35	12.06	18.80	17.88
Fe_2O_3	3.74	7.04	5.31	4.34	4.37	8.10	3.98	5.82	4.00	4.13	1.83	6.73	6.60
MnO	.11	.18	.13	.12	.14	.28	.09	.15	.04	.08	.01	.19	.10
MgO	.44	2.19	1.50	.63	.38	1.72	.55	.79	.69	.41	.00	2.33	12.02
CaO	1.80	4.19	5.59	1.57	1.31	3.75	1.57	2.06	1.70	1.22	.27	3.96	13.42
Na_2O	6.12	5.27	6.98	6.49	8.68	7.29	5.28	6.19	4.43	4.88	4.85	8.08	3.49
K_2O	6.33	4.40	2.97	6.16	5.75	4.54	5.41	4.86	5.29	5.18	4.49	4.31	.73
P_2O_5	.11	.42	.45	.17	.10	.39	.17	.22	.20	.13	.02	.37	.07
Qz							10.19		16.48	15.24	31.67		
Or	37.38	25.98	17.53	36.42	33.97	26.83	31.94	28.72	31.26	30.61	26.50	25.48	4.31
Ab	45.84	41.93	38.60	44.78	35.65	32.51	44.69	52.35	37.48	41.31	37.06	28.63	.58
An	6.54	13.88	17.75	4.79		3.01	3.74	8.47	5.57	4.67	2.31	30.97	
Ne	3.20	1.46	11.10	5.47	20.33	15.79						21.52	15.69
Ac				.25							.97		
Ns											.68		
Di	1.43	3.47	5.86	1.63	5.04	11.09	2.53	.26	1.29	.47	1.09	12.41	27.99
Hy							4.19	1.43	5.06	5.18	1.78		
Ol	3.35	8.14	4.07	3.95	2.60	5.86		4.86				5.02	17.08
Mt	1.00	1.87	1.41	1.16	1.04	2.15	1.06	1.55	1.06	1.10		1.79	1.76
Il	.70	1.71	2.19	1.07	.54	1.19	.94	1.38	1.00	.80	.16	1.42	.95
Ap	.26	1.00	1.07	.40	.25	.92	.39	.52	.49	.30	.04	.89	.17

reacted xenoliths or xenocrysts.

A significant feature of the dark syenite is the presence of small quantities of plagioclase, normally occurring in the cores of strongly zoned feldspar crystals. Green-brown

texture. Mafic minerals include colourless to very pale green clinopyroxene, green-brown amphibole, biotite and accessory magnetite. Amphibole predominates and invariably rims clinopyroxene. Quartz or zeolitised nepheline are confined to interstitial spaces between the feldspars.

Grey Syenite (ns2)

A dark-grey, granular, hornblende syenite cuts the white syenite and in turn forms the outermost intrusion along the southeastern contact. It appears to pinch out in the southwestern area and does not appear in the northern or eastern sectors. Although average grain size and mafic mineral content vary throughout, the unit has been mapped as a single lithology. In places, the rock is slightly porphyritic with larger feldspars set in a finer matrix. Mafic minerals commonly occur in large clots and some may represent reacted xenoliths or xenocrysts.

A significant feature of the dark syenite is the presence of small quantities of plagioclase, normally occurring in the cores of strongly zoned feldspar crystals. Green-brown hornblende is the dominant mafic mineral, and usually contains relict cores of pale green to colourless clinopyroxene. Biotite often mantles hornblende and magnetite. Altered nepheline occurs as a minor interstitial mineral, but a few samples carry accessory quartz instead of feldspathoid. The textural and mineralogical variability of the dark syenite suggests contamination and/or hybridisation.

Alkali Monzonite (ns3)

Part of an early intrusive ring of coarse-grained nepheline-bearing hornblende monzonite occurs in the south-central sector of the sub-complex, where it is truncated by a younger foyaite intrusion (Fig. 3). These two rock types together form a prominent and discrete annular ridge which defines the internal ring structure of the subcomplex (Fig. 4). The rock is mottled in hand specimen, being made up of dark hornblende and grey-

Fig. 4: Prominent annular ridge composed of alkali monzo (ns3) which forms the near end of the ridge (dark screes), a medium-grained foyaite (ns5) which cuts the monzonite makes up the far end of the ridge. Concentric syenite ring the right of the ridge can be made out in the surroun slopes. View looking ENE.

ish-white plagioclase. Under the microscope, the plagioclase can be seen to be mantled with alkali feldspar, while altered nepheline occurs interstitially between the large plagioclase laths. Hornblende is deep reddish brown with relict cores of diopside associated with coarse laminae of secondary magnetite. An extension of this ring, or the remnants of another, crops out as small indistinct zones within younger syenite units in the northwestern and northeastern sectors.

Granular Syenite (ns4)

Syenite characterised by a coarse granular texture makes up a significant part of the sub-complex, and forms the outer contact along the eastern side. Another feature of this lithology is the common development of very coarse pegmatoidal patches of syenite, where the interstitial feldspathoid has taken on a conspicuous red-brown colour, presumably through secondary alteration. Another distinguishing feature of the granular syenite is that hornblende is the dominant mafic mineral, whereas a sodic clinopyroxene predominates in the foyaite (ns5). Other mafic minerals include a pale green clinopyroxene usually restricted to small cores within hornblende, and small amounts of biotite and magnetite. On average the granular syenite contains less feldspathoid than the foyaite.

Foyaite (ns5)

The foyaite is a distinctive rock typically having prismatic alkali feldspars set in a divergent network, within which is included abundant nepheline. Average grain size varies from relatively fine-grained types to pegmatoidal patches with big feldspar tablets up to 20 cm across. A deep green sodic clinopyroxene is the dominant mafic mineral, while strongly pleochroic bluish-green alkali amphibole and a distinctly orange-brown biotite are confined to small mantles or intergrowths. Granular magnetite is also usually present and may predominate in some cases.

In addition to large pools of nepheline between the coarse alkali feldspar prisms, some foyaites contain sodalite. Minor intrusions of sodalite- or magnetite-microfoyaite occur locally, cutting across the various syenite rings. The proportion of nepheline to alkali feldspar varies, but seldom exceeds 50%, except in some pegmatoidal patches.

Porphyritic Melasyenite (ns6)

Perhaps the most distinctive rock type in the sub-complex is a porphyritic melasyenite which has intruded the granular syenite in a narrow ring that can be traced around three quadrants of the sub-complex (Fig. 3). The melasyenite has not been recognised in the northern part of the sub-complex where it is intensely intruded and altered by the later intrusive phases. Near vertical contacts of this particular ring against older syenites are well exposed (Fig. 5), and a pronounced vertical banding parallel to the contacts is a characteristic feature.

The banding is defined by preferred orientation of large tabular feldspar crystals (up to 15 mm long) and variation in mode (Fig. 6).

Between the large alkali feldspar prisms, finer grained subhedra of pale green clinopyroxene and green-brown hornblende are enclosed in large 'pools' of nepheline (Fig. 7). Another prominent mafic mineral is biotite, which occurs as intergrowths and mantles around hornblende.
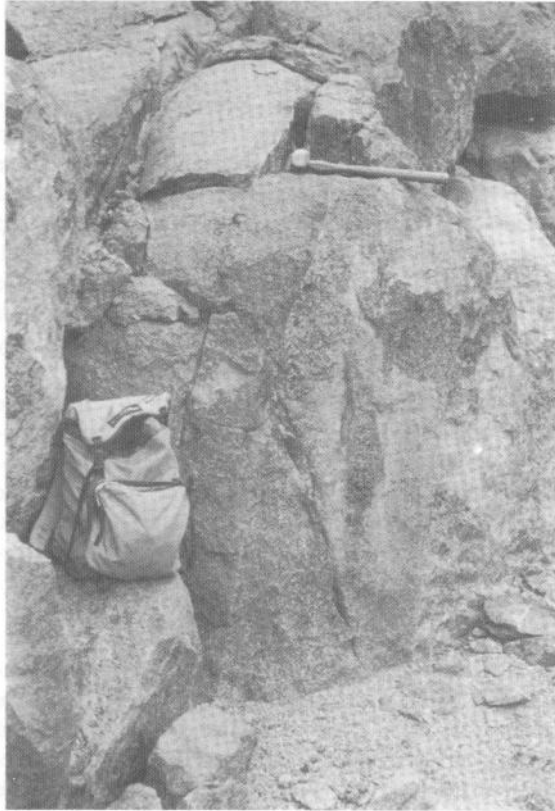

Fig. 5: Contact between porphyritic melasyenite (ns6) on left and foyaite (ns5) on right. Length of hammer handle is 45 cm.
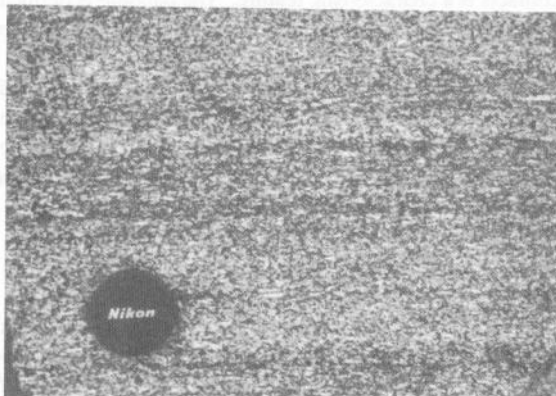
Fig. 6: Detail of banding in the porphyritic melasyenite (ns6), looking down on a horizontal surface. Tabular phenocrysts of alkali feldspar (white) show preferred orientation. Darker bands are richer in mafic minerals (clinopyroxene and amphibole) at the expense of the alkali feldspar phenocrysts. Width of lens cap is 5 cm.

Quartz Syenite

The centre of the nepheline syenite ring sub-complex has been intruded by a medium- to coarse-grained, equigranular to sub-porphyritic quartz syenite. While for most of its outer contact the quartz syenite appears to follow preexisting ring structures in the nepheline syenite, the northern contact is convex inwards, causing the pluton to resemble a kidney shape. The quartz syenite cross-cuts individual rings within the nepheline syenite in the northeast corner, while in detail the knife sharp contact can be seen to truncate large alkali feldspar crystals in the nepheline syenite, particularly where pegmatoidal patches are cross-cut. Reduction in grain size towards the contact with the nepheline syenite is seen in some places, but is not uniformly developed.

The proportion of quartz and plagioclase in the quartz syenite vary antipathetically, while the pluton as a whole is characterised by small, rounded, xenolithic patches of a fine-grained, slightly more mafic, rock type. These
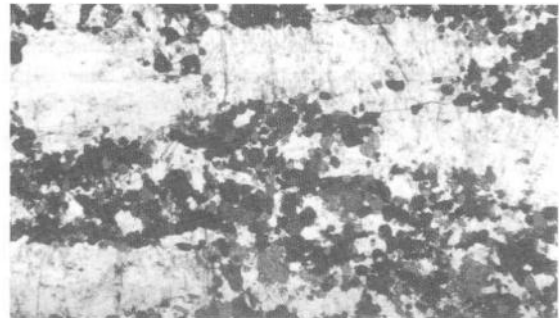

Fig. 7: Photomicrograph of porphyritic melasyenite (ns6) showing tabular alkali feldspar phenocrysts in preferred orientation. Finer grained subhedral crystals of dark hornblende and clinopyroxene are set in a matrix of nepheline (clear) and biotite. Width of photograph is 6.5 mm.
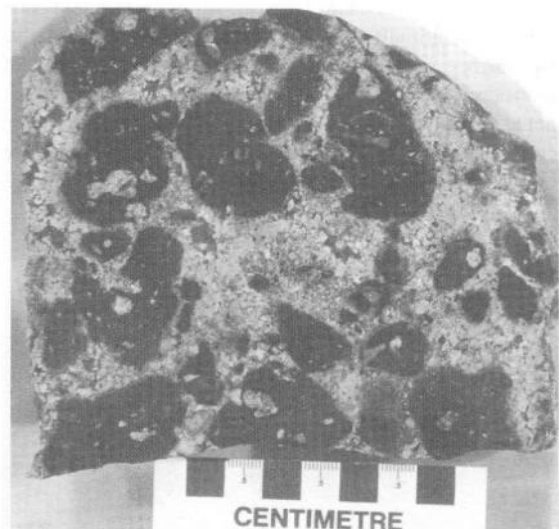

Fig. 8: Rounded xenoliths of dark, fine-grained porphyry set in a matrix of coarse quartz syenite. The rounded shapes of the xenoliths appear to be a product of liquid immiscibility.

xenoliths show variable degrees of digestion.

At one locality a remarkable texture has developed where small blebs of a porphyritic rock type are concentrated into a lensoid zone about 10m along strike and 3 m thick. The zone is situated close to the contact with the nepheline syenites and several hybrid porphyry pipes also occur nearby. The texture is illustrated in Fig. 8, which shows the blebs to have rounded amoeboid shapes suggestive of liquid immiscibility. The matrix is much coarser grained but typical of the quartz syenite host in the vicinity. Although some detailed petrological work needs to be done on this phenomenon, it is possible that the texture is a product of injection of a slightly more mafic magma into a cooler quartz syenite host magma. Chilling of the injected magma globules allowed their subsequent preservation during consolidation of the quartz syenite.

Microsyenite

In the northern portion of the nepheline syenite, a grey, fine-grained syenite (microsyenite) occurs as a swarm of small pIUGS and dykelets, covering a 1 km square area (Fig. 2). Only the larger bodies are shown on the map, the syenite in between being riddled with minor veins emanating from the larger parent bodies. This swarm of minor intrusions may represent offshoots from a larger, more coherent, body at depth. The micro syenite swarm is truncated by the granite plug forming the northern extension of the complex, and an intricate zone of contact migmatisation of the microsyenite and nepheline syenite has developed.

In thin section, the micro syenite has a sub-ophitic texture with a network of divergent feldspar laths, comprising both plagioclase and alkali feldspar. Prominent mafic minerals include hornblende and biotite, while magnetite is a widespread accessory. Neither quartz nor nepheline could be recognised, although the fine grain size makes positive identification difficult. Bulk chemical analyses indicate that the microsyenite is saturated, as indicated by the average normative composition listed in Table 4.

Granite

A plug of granite cuts both the micro syenite and nepheline syenite sub-complex along their northern borders, and forms the northern progression of the Kanabeam Complex. While predominantly composed of granite, the quartz content does vary in the samples examined, and the pluton in some places is transitional to quartz syenite. Porphyritic texture is developed locally, but the granite is more characteristically equigranular. Dark, fine-grained mafic xenoliths occur within the granite, but are far less frequent than observed in the quartz syenite found in the southern part of the complex.

Granite Porphyry

A discontinuous ring of granite porphyry occurs in the granite, and is best exposed to the west and south of the later micro granite plug. Field evidence for the relative age of the granite porphyry ring is conflicting, in that the granite contains both xenoliths and crosscutting veins of granite porphyry-type material. Contacts between the granite and granite porphyry are always covered by boulder screes, but the geometry of the granite porphyry outcrop tends to suggest that it has intruded the granite. Alkali feldspar is the most abundant and coarsest phenocryst mineral, while plagioclase, hornblende, biotite, quartz and magnetite occur as less common microphenocrysts in that order of relative abundance. The finer grained matrix is a hypidiomorphic intergrowth of all the above minerals, showing typical granitic proportions. Compared with other granite porphyries known from the Kuboos- Bremen province, the Kanabeam example has less prominent quartz phenocrysts, and appears, therefore, to be transitional to a quartz syenite.

Microgranite

The northernmost progression of the Kanabeam Complex consists of a small circular plug of fine- to medium-grained granite. The contact is knife sharp and the order of intrusion can only be determined by the observation that large alkali feldspar crystals in the surrounding granite have been truncated at the contact. Alteration is widespread, and the microgranite is commonly discoloured due to the advanced sericitisation and kaolinisation of the feldspars and the limonitisation of mafic minerals. Hence the microgranite is characterised by patchy development of zones where the granite is bleached white or stained red. Some of the latter zones yield a sulphurous odour when broken, suggesting the presence of pyrite and other sulphides. The nature and distribution of the secondary alteration is similar to that described by Killick & Odell (1980) in a similar fine- to medium-grained granite in the nearby Marinkas Kwela complex. Anomalous Cu, Mo, Pb and Zn concentrations appear to be associated with this alteration.

Phonolite breccia pipes

Several small pipes and associated minor intrusions of a dark porphyry are concentrated along the contact between the quartz syenite and nepheline syenite sub-complex. Some have also been found near the southern contact between the nepheline syenites and the metamorphic country rock (Fig. 2).

The most conspicuous feature of the pipes is their xenolith content, so much so that it is very difficult to recognise what constitutes the actual host matrix. It is, however, clear that the matrix is magmatic and not tuffaceous, in the sense that the pipes represent intrusion of xenolith-choked melt rather than a gas-charged, fluidised system. Although dark in hand specimen, the
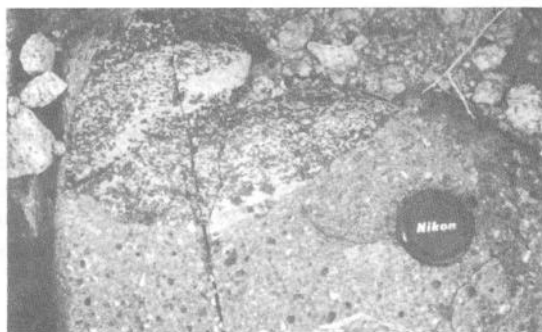
Fig. 9: Gabbro xenolith enclosed in hybrid porphyry pipe cutting the nepheline syenite sub-complex. Prominent minerals in the xenolith include clinopyroxene (dark) and plagioclase (pale grey). Grain size and mode vary across the xenolith giving rise to a crude layering.
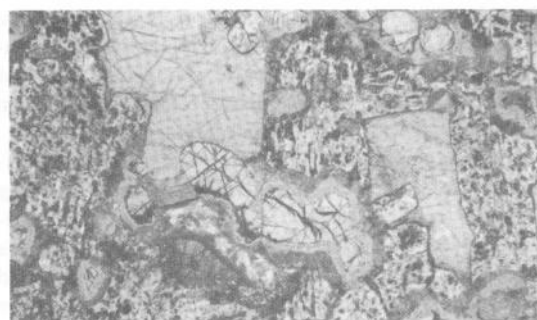

Fig. 10: Photomicrograph of gabbro xenolith sample DRK-72, showing primary igneous minerals clinopyroxene (clear), olivine (high relief with cracks accentuated by dusting of secondary magnetite), and plagioclase (showing patchy turbid alteration). Olivine in contact with plagioclase shows extensive reaction and the development of a multiple corona, while the grain in the centre of the photograph is unaffected where it is in contact with clinopyroxene. Width of photograph is 6.5 mm.
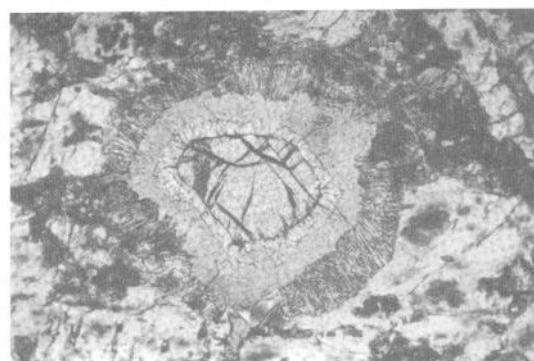

Fig 11: Photomicrograph of multiple corona texture developed around olivine enclosed in plagioclase. Unreacted olivine forms the centre, which is mantled first by clinopyroxene (rim 1), then amphibole (rim 2), and finally by a vermiform symplectite of amphibole and nepheline. Analyses of the various minerals are given in Table 5. Width of photograph is 2.25 mm.

matrix is actually quite felsic, being made up of a granular mosaic of feldspar and feldspathoids, but which is peppered with tiny granules of mafic minerals. On the basis of bulk chemistry, the matrix is a type of phonolite (Table 4). The hybrid nature of the matrix is suggested by the great variety of pheonocryst minerals seen in thin section, many of which are in varying states of replacement by minerals stable in the groundmass. Hence the use of the field term 'hybrid porphyry' during the mapping of these rocks.

Lithologies recorded as xenoliths in the various pipes include alkali gabbro, alkali syenite, trachyte porphyries, phonolite porphyries and other mesocratic porphyries containing plagioclase. Size and roundness vary considerably, with all the xenolith lithologies ranging down to microscopic fragments (disrupted xenocrysts). Gabbroic xenoliths tend to be more rounded, suggesting that they may have been transported further, although only few have significant reaction rims.

Nature and origin of gabbro xenoliths

The significance of the abundant gabbroic xenoliths is clear in that they might represent the link between the syenitic (phonolitic) magmas and their more basic parental magmas. These xenoliths have consequently received priority so far in the detailed description of these breccia pipes. Textures range from cumulate to coarse sub-ophitic and a few of the former show crude phase layering (Fig. 9). Proportions of plagioclase and clinopyroxene vary, and olivine is commonly present. In the least altered xenoliths, the clinopyroxene shows outward colour-zoning from colourless to pale mauve, suggestive of an increase in Ti content, which is typical of alkaline basic rocks. An analysis of a large homogeneous gabbro xenolith (DRK-72) is given in Table 4, which confirms its alkaline nature in the presence of significant normative nepheline. The major element data compare well with basanites.

Several xenoliths show extensive subsolidus reaction between olivine and plagioclase but not with any other mineral pair. The general texture and mineralogy of one

gabbro xenolith (sample DRK-72) is shown in Fig. 10. Plagioclase is patchily altered to finer grained aggregates of secondary products, distinguishable as turbid zones throughout the crystal. Clinopyroxene shows hardly any alteration, while original olivine-plagioclase grain boundaries have been replaced by multiple corona textures. Cores of relict olivine are surrounded successively by a narrow rim of granular clinopyroxene, a second continuous rim of granular pale green amphibole, and finally a third outer rim of amphibole-nepheline symplectite (Fig. 11).

The multiple corona around olivine reveals that the clinopyroxene and amphibole rims have grown at the expense of the olivine, while the amphibole-nepheline symplectite has developed into the plagioclase. Typical compositions of the various minerals in the multiple corona illustrated in Fig. 11 are listed in Table 5. What is noteworthy about the analytical data is the similarity between the clinopyroxene in the corona and that form-

ing the bulk of the rock, and the calcic nature of the nepheline. Furthermore, amphibole in the middle and outer rims of the corona also has the same composition.

The multiple corona texture is reminiscent of similar textures in gabbros found in metamorphic belts, where the slow cooling within an amphibolite (or granulite) facies environment has caused the olivine-plagioclase assemblage to break down. Characteristically, the corona consists of an inner rim of orthopyroxene, and outer rims containing amphibole and amphibole-spinel symplectite (Mongkoltip & Ashworth, 1983). Such coronas have been described from several gabbroic bodies within the Namaqua Province, particularly in Bushmanland, such as Nouzees (Reid *et al.*, 1979) and Tantalite

Valley (Moore, 1975). Many other bodies in the region are known to 'contain these coronites and appear to represent the product of intrusion of basic magma at depth in the Namaqua Mobile Belt.

A large gabbroic body occurs in the Namaqua gneisses only 10 km north of Kanabeam (Ai-Ais Complex of Blignault, 1977). Moore (1980) has suggested that the Ai-Ais gabbros may be part of an extensive swarm of mafic bodies developed in the Namaqua Province, which included those already mentioned in the Bushmanland region. It is therefore pertinent to assess whether the gabbro xenoliths in the phonolite breccia pipes at Kanabeam may have been derived from a subsurface extension of the Ai-Ais Complex. Very little is known about the Ai-Ais Complex, so comparison has

TABLE 5: Selected microprobe analyses from the multiple coronas between olivine and plagioclase developed in gabbro xenolith DRK-72 (illustrated in Fig. 11). The final column is typical core composition of magmatic clinopyroxene.

	Olivine	Rim-1/Cpx	Rim-2/Amph	Rim-3/Neph	Rim-3/Amph	Plagioclase	Clinopyroxene
SiO_2	38.83	53.99	39.93	43.66	40.57	50.19	50.31
TiO_2			.21		.16		.96
Al_2O_3	.50	19.30	33.33	19.53	31.46		5.10
Cr_2O_3						'	.11
FeO	20.48	3.32	9.50	.19	9.43		5.62
MnO	.35						
MgO	40.64	16.89	13.42		13.35		15.64
CaO	.17	25.67	12.86	3.58	12.82	15.40	22.71
Na_2O	.16	3.57	15.60	3.38	2.72		.41
K_2O			.30	3.93	.40		
Total	100.47	100.53	99.09	100.29	99.64	99.77	100.86
Oxygens	4	6	23	8	23	8	6
Si	.998	1.974	5.760	2.080	5.805	2.295	1.845
Ti			.023		.017		.026
Al		.021	3.282	1.872	3.294	1.695	.221
Cr							.003
Fe	.440	.100	1.146	.008	1.128		.172
Mn	.008						
Mg	1.556	.920	2.886		2.847		.855
Ca	.005	1.005	1.987	.183	1.965	.755	.892
Na		..011	.999	1.442	.938	.243	.029
K			.055	.239	.073		
Sum	3.007	4.031	16.138	5.824	16.067	4.988	4.043
Ab						24.38	
Or							
An						75.62	
Wo		49.63					46.48
En		45.41					44.55
Fs		4.96					8.97
Fo	77.66						
Fa	22.34						

been made using data from the Nouzees Complex (Reid *et al.*, 1979). Clearly the main difference is the presence of clinopyroxene, rather than orthopyroxene, mantling olivine at Kanabeam. In addition, the presence of the amphibole-nepheline symplectite serves to distinguish the Kanabeam corona. However, it must be remembered that the Kanabeam gabbro has been immersed in a highly reactive, undersaturated phonolite magma, which may have caused some metasomatic effects. Indeed, the nepheline-bearing symplectite may well be a product of such alkaline metasomatism, in which case the Kanabeam coronas can not necessarily rule out derivation from Ai-Ais-type gabbros at depth.

Clearly a detailed geochemical and isotopic investigation is warranted, but another petrographic feature already noted may provide a solution to the problem of the source of these gabbro xenoliths. Clinopyroxene that makes up a dominant component of the gabbro (as distinct from that developed in the coronas around olivine), shows compositional zonation to mauve titaniferous augite, a feature typical of and confined to alkaline mafic rocks. Reaction with a phonolitic magma would not be expected to produce such an effect, since the magma is normally very poor in titanium, as evidenced by the analysis of the phonolite matrix in Table 4. Evolution of clinopyroxenes in alkaline mafic magmas from diopsidic to titaniferous augites is a consequence of the high- Ti nature of the parent melt, which can be enhanced by fractionation of early-formed Ti-poor phases such as olivine and plagioclase. It is concluded therefore that the Kanabeam gabbros are probably not derived from old mafic bodies in the country rock at depth, but are more likely to represent deeper portions of the Kanabeam Complex, or a parental body near the base of the crust.

Dykes

Several dykes cut across the complex, varying widely in composition from mafic to felsic. A detailed description of the post-complex dykes is not attempted here, and their distribution has been omitted from the geological map (Fig. 3) in order to preserve clarity.

A feldspar porphyry dyke follows a prominent fracture that extends beyond the limits of the complex. This fracture coincides closely with the long axis of the complex and its significance is discussed later.

Several carbonatite dykes occur in the country rock between the Kanabeam Complex and Marinkas Kwela, and are probably related to the intrusion of carbonatite nearby (Fig. 1). No carbonatite dykes have been seen cutting the Kanabeam Complex.

Evolution of the Kanabeam Complex

A schematic reconstruction of the Kanabeam Complex illustrating the deduced order of emplacement of the six intrusive phases is given in Fig. 12. Progression

from SW to NE is clear and follows the general regional trend of the Kuboos-Bremen line. Shifting of the intrusive centre was accompanied by changes in magma composition, reflecting a passage from undersaturated to oversaturated rock types. The phonolite pipes were emplaced after Phase 3, as they intrude the microsyenites, but it is not possible to establish whether they post-dated the granitic intrusions (Phases 4 - 6) developed in the northern part of the complex.

The presence of a dyke following the long axis of the complex and cross-cutting all phases suggests continued control by a deep-seated fracture. Magmas rising up the fracture initially produced ring fractures and pIUGS, and, at a late stage after consolidation of the central complex, the fracture was propagated through the consolidated plutonic rocks.

The association of undersaturated syenites and alkaline granites is also observed in the intrusions at Grootpens Eiland and Marinkas Kwela. Judging from the lithologies recorded by Blignault (1977), it appears that two overlapping syenite-granite complexes occur, which argues for their distinction, both from each other and the Kanabeam Complex. These petrological features consequently suggest that the so-called Tatasberg Complex of Kröner and Blignault (1976) can be subdivided into four separate igneous centres as illustrated in Fig. 1 and listed in Table 1.

Although much of the undersaturated component of the Kanabeam Complex is felsic (syenites, foyaites),
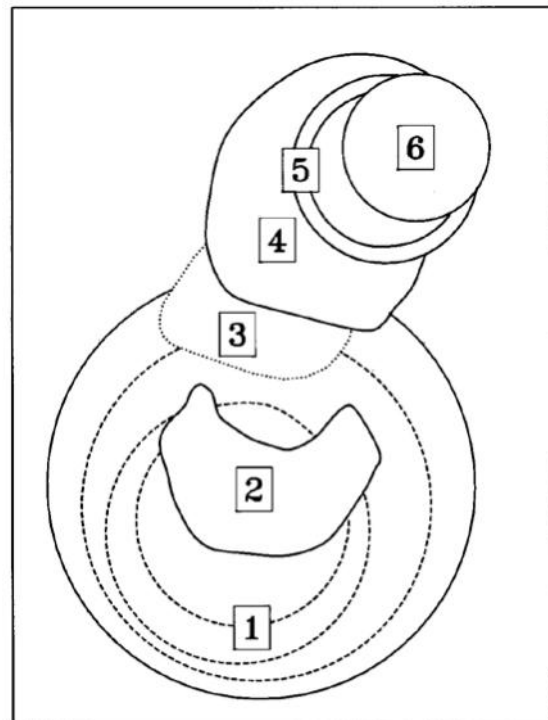

Fig. 12: Schematic reconstruction of the Kanabeam Complex showing the proposed order of intrusion of the separate centres. 1: nepheline syenite ring sub-complex, 2: quartz syenite plug, 3: microsyenite plug and dyke swarm, 4: granite plug, 5: granite porphyry ring, 6: microgranite plug.

the presence of plagioclase-bearing monzonites and alkali gabbros (the latter occurring as xenoliths in late breccia pipes) suggests a magmatic lineage involving a basanitic parental magma, which evolved to a phonolitic derivative. On the other hand, the oversaturated rock types may represent a separate magma type which was derived by crustal anatexis, perhaps caused by passage of the basaltic magmas. Interaction between the granitic magma and the basanite-phonolite suite may have been responsible for the intermediate rock types in the complex, but these petrogenetic aspects await detailed investigation.

Acknowledgements

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