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Alkaline rocks in the Kuboos-Bremen Igneous Province, southern Namibia: the Grootpenseiland and Marinkas Kwela Complexes

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The early Cambrian Kuboos-Bremen Igneous Province, of northwestern South Africa and southern Namibia, comprises a series of intrusive bodies that collectively encompass virtually the entire range of alkaline rock types. Two of these bodies, the Grootpenseiland and Marinkas Kwela Complexes, lie immediately north of the Orange River and are amongst the few that show this wide lithological range on a local scale. The rocks of both complexes are overwhelmingly felsic in composition. The oldest are nepheline-bearing syenites, which form the southwestern most intrusive phases. The sequence of intrusion in both complexes is to the northeast and to more siliceous rocks. Large granitic stocks form the youngest and most northeasterly intrusive phases. The same lithological range and intrusive sequence also occurs at Kanabeam, approximately 5 km to the northeast of Marinkas Kwela, indicating a close commonality in the origin and geological evolution of complexes in that region.

Introduction

First described by Söhnge and de Villiers (1948), the Kuboos-Bremen Igneous Province consists of a number of discrete intrusive complexes which are located with a remarkably high degree of linearity (Fig. 1). The province extends in a north-easterly direction for at least 270 km from the western Richtersveld region of South Africa to the Great Karas Mountains in southern Namibia. Equally remarkable is the range of igneous rock types that the province incorporates. Rocks of felsic composition predominate; mafic rocks comprise less than about 5% of the province and include medium- to coarse-grained gabbroic rocks found as xenoliths within later felsic rocks. Granites and Si-oversaturated syenites dominate to the southwest, forming the Swartbank, Kuboos and Tatasberg plutons. Si-undersaturated rocks, including nepheline-(sodalite) syenite and phonolite, become proportionally more important to the northeast. Carbonatite occurs approximately 20 km northeast of the Orange River, forming the Marinkas Kwela Carbonatite Complex. Radiometric age determinations show the province to be the result of Pan African magmatism, active in that region between at least 514 Ma and 529 Ma (Allsopp *et al.*, 1979; Smithies, 1992).

Intrusive phases of the Kuboos-Bremen Igneous Province were emplaced into a wide range of Precambrian crustal elements. From southwest to northeast these include the sediments of the Gariep Group and, respectively, calc-alkaline igneous rocks and gneisses of the Richtersveld and Gordonia Subprovinces of the Namaqua Metamorphic Province. Sporadically outcropping throughout the region, the Nama Group is a platform sequence that is partly complementary to the Gariep Group and lies unconformably on the rocks of the Namaqua Metamorphic Province.

Some aspects of the geology of the Kuboos-Bremen Igneous Province have been covered in regional studies by Söhnge and de Villiers (1948), Kröner (1975), Kröner and Blignault (1976) and Blignault (1977). Only two of the complexes, however, have so far received detailed attention in the literature - the Younger Bremen Complex (Middlemost, 1967) towards the northeastern end of the province, and the Kanabeam Complex (Reid, 1991). Reid (*pers. comm.*) recognized that, in the central portion of the province, the intrusive sequence, from Si-undersaturated in the southwest to Si-oversaturated in the northeast, is repeated along three loci of intrusion. One of these is at Kanabeam (Reid, 1991). The other two form one continuous outcrop between the Orange River and Kanabeam; northeast from the Orange River, the sequence from Si-undersaturated to Si-oversaturated is evident over the first 5 km and manifests itself again over the next 10 km. This repetition is the basis for recognizing the presence of two discrete intrusive complexes, called, respectively, the Grootpenseiland and Marinkas Kwela Complexes. We have completed a detailed geological study of both complexes. For logistical reasons, our study has been confined to the rocks on the north side of the Orange River. Alkali granite crops out to the south of the river. It apparently forms a continuation of the Grootpenseiland Complex, however, its relationship to the Si-undersaturated rocks to the north of the river could not be investigated. It is possible that the granite relates more to the large granitic bodies that comprise the southern portion of the Kuboos-Bremen Igneous Province. For the purpose of this study, the term 'Grootpenseiland Complex' refers only to the rocks to the north of the Orange River.

Field relationships and some detailed petrographic observations are presented here. This contribution will be followed by a more detailed discussion of the geochemistry and petrogenesis of the complexes (Smithies and Marsh, in prep.).

Geological Setting

All of the rocks of the Grootpenseiland Complex and most rocks of the Marinkas Kwela Complex intrude granitoids belonging to the Vioolsdrif Suite of the Richtersveld Subprovince. The far northern part of the Marinkas Kwela Complex also intrudes across the tec-

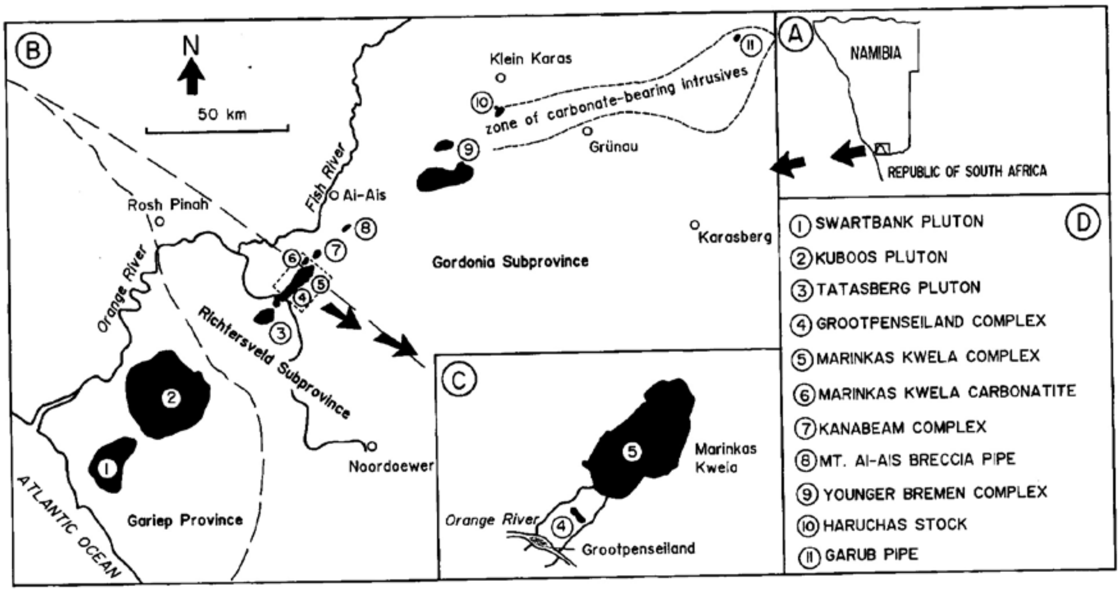

Figure 1: Regional locality map showing linear distribution of the intrusive complexes in the Kuboos-Bremen Igneous Province, with more detail (C) of the complexes that are the focus of this study. Modified after Reid (1991).

tonic transition zone separating the Richtersveld Subprovince from the quartzo-feldspathic gneisses of the Gordonia Subprovince. Intrusive contacts are commonly sharp and chilled margins are rare, although many contacts are obscured by scree.

In both complexes, field relations clearly show that the sequence of intrusion is from south to north. Rock types also trend to a more Si-oversaturated composition with decreasing intrusive age (Table 1). Thus, in each complex the sequence of intrusion is as follows:

1) Si-undersaturated rocks (nepheline syenites) crop out in the southwest;

2) outcrops of rocks that are critically saturated with respect to silica (syenite) are more or less centrally located;

3) Si-oversaturated rocks crop out in the northeast and include a large granite stock in each complex (the Grootpenseiland granite and the Marinkas Kwela granite respectively).

Inspection of figure 2 indicates that at present levels of outcrop the two complexes impinge on each other with the Grootpenseiland granite intruding the Si-undersaturated rocks of the Marinkas Kwela Complex. The intrusive age (Rb-Sr whole-rock) of the oldest phase of the Grootpenseiland Complex (529 ± 24 Ma) and the youngest phase of the Marinkas Kwela Complex (514 ± 26 Ma) are within error of each other (Smithies, 1992), and it seems likely that the two complexes developed synchronously.

A Note on Nomenclature

The rocks described here have been broadly subdivided into those having quartz as a minor or major mineral and that are generally *Q*-normative, those having only accessory, or no, quartz and that are only marginally *Q*- or *ne*-normative, and those having feldspathoids as a minor or major mineral and that are generally *ne*-normative. These will simply be referred to in general terms as granitoid (***G***), syenite (***S***) and *ne*-normative rocks (***NS***) respectively. More detailed classifications will be offered where appropriate. Within the classification 'nepheline syenite' (s.l.) fall two nepheline syenites (s.s.), one showing intergranular textures and the other showing hypidiomorphic granular textures. As a means of distinguishing clearly between them, the former is called 'foyaite' and the latter 'nepheline syenite'.

Where systematic variations in mineralogy and chemistry have been noted, the rocks are grouped into 'series'. Representative analyses and CIPW norms of the rock types found in the Grootpenseiland and Marinkas Kwela Complexes are in Table 2 while Table 3 presents average clinopyroxene and amphibole compositions.

Rock Types

ne-normative Rocks

This heading includes two rock series and a further two rock types ($NS_{1\text{-}4}$) whose distribution is shown in figure 2.

NS_1 (*monzodiorite*)

A medium-grained and melanocratic monzodiorite is found in the southwest of the Grootpenseiland Complex where it forms small contorted inclusions of about 0.5

TABLE 1 : Relative proportions, and sequence of intrusion, of components within the Grootpenseiland and Marinkas Kwela Complexes.

Rock Type	Code	Relative proportion and intrusive age in the Grootpenseiland complex *oldest (southwest)* — *youngest (northeast)*	Relative proportion and intrusive age in the Marinkas Kwela complex *oldest (southwest)* — *youngest (northeast)*
Si-undersaturated rocks	NS		
Monzodiorite	NS_1	xx	
nepheline-bearing syenite	NS_2	xxxxx	
Alkali-melasyenite - nepheline syenite	NS_3		xxx
Foyaite	NS_4		xxxxx
Syenites	S		
Alkali-syenite	S_1	xxxxxxxxx	xxx
Alkali-feldspar syenite	S_2	xxxxxxxx	
Granitoids	G		
Monzonite - granite	G_1	xxxxx	xxxxxxx
Alkali-granite	G_{2a}		xxxxxxxx
	G_{2b}	xx	xx

m in length within leucocratic nepheline syenites, and a discontinuous elongate body of about 700 m by 20 m within syenites. The monzodiorite shows no chilled margins and is probably xenolithic. Although up to 6 wt% *ne*-normative, the rock contains no modal feldspathoids. It consists essentially of subhedral to euhedral phenocrysts of plagioclase and diopside (clinopyroxene terminology after Morimoto *et al.*, 1988) in a groundmass of plagioclase, alkali-feldspar, diopside ($Wo_{47}En_{46}Fs_7$ to $Wo_{47}En_{25}Fs_{28}$), biotite, ferroan pargasite (amphibole terminology after Leake, 1978) and accessory sphene and apatite. Plagioclase phenocrysts are up to 1.2 cm in size and are distinctly more calcic (An_{80-58}) than groundmass plagioclase (An_{20-05}), Ferrokaersutite and biotite are rare phenocrystic phases.

***NS*$_2$** (*nepheline-bearing syenite series*)

Leucocratic rocks form a series that evolves from medium-grained and biotite-rich in the south, to coarse-grained and amphibole-rich in the north. The series forms a thin, irregular outcrop in the far southwest of the Grootpenseiland complex and is intruded by small dykes of the syenite that surrounds it.

Rocks in this series exhibit hypidiomorphic granular textures. The dominant felsic constituent is microperthite. Plagioclase (An_{56-10}) occurs only in the biotite-rich rocks, mostly as cores to microperthite. Nepheline occurs mainly in the amphibole-rich rocks where it lies interstitially between feldspar laths. Amphibole (ferroan pargasite to hastingsite) often rims biotite, particularly in the biotite-rich rocks, although both minerals also occur as discrete subhedral to euhedral grains. Clinopyroxene, mostly diopside but ranging to hedenbergite ($Wo_{45}En_{39}Fs_{16}$ to $Wo_{46}En_{16}Fs_{38}$), is commonly subhedral and sometimes rimmed by amphibole. Accessory phases include sphene, apatite, magnetite, zircon and fluorite.

***NS*$_3$** (*Alkali-melasyenite-nepheline syenite (s.s) series*)

This series occurs in the southwest of the Marinkas Kwela Complex, where it forms a northwest oriented band measuring about 2 km by 200 m, surrounded by foyaite (*NS*$_4$). The southern margin of the band is of fine-grained alkali-melasyenite.A mineralogical gradation occurs northwards into coarse-grained and leucocratic nepheline syenite (s.s.) and compositional planes more or less parallel the steeply dipping southern contact with the foyaite. Close to that contact, alkali-melasyenite xe-

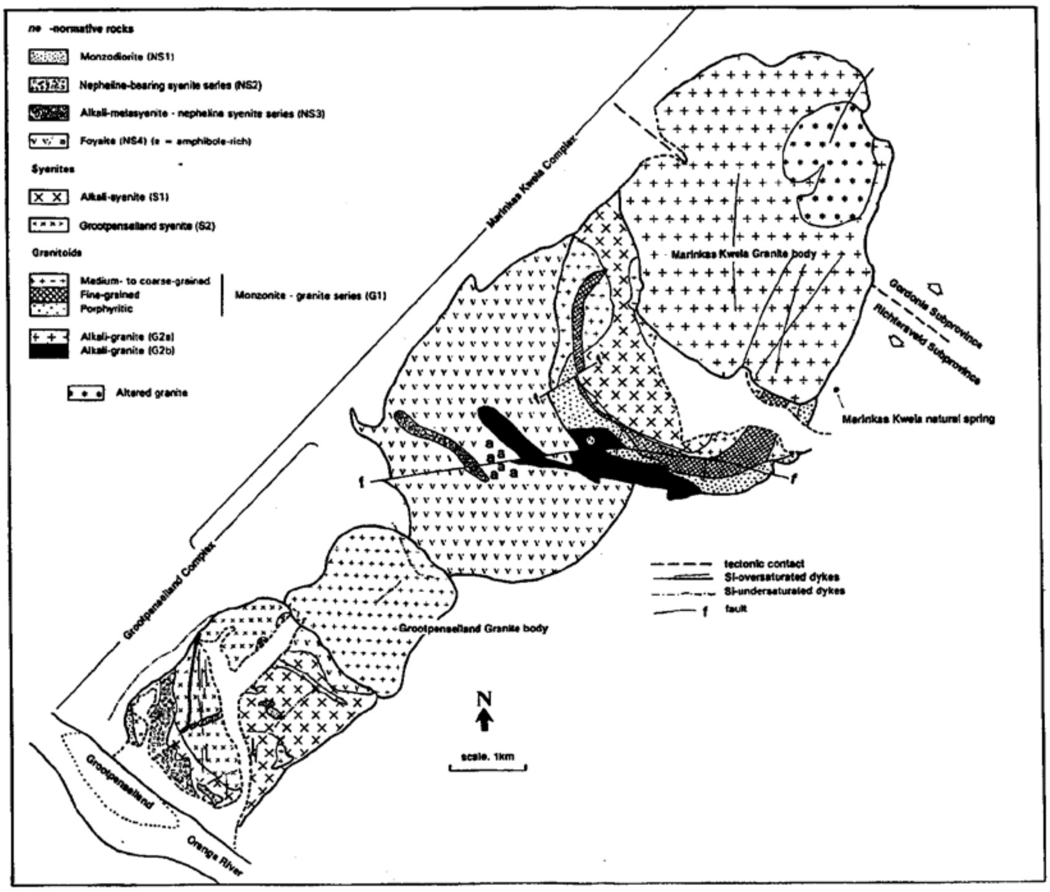

Figure 2: Geological map of the Grootpenseiland and Marinkas Kwela Complexes

noliths up to 1m in diameter lie in the foyaite.

The more mafic rocks have a mottled, intergranular appearance produced by mafic aggregates, poikilitically enclosed by large grains of intergranular nepheline, and together lying in a coarse-grained framework of coarsely perthitic alkali-feldspar. Plagioclase (An_{12-5}) is rare. Ferroan pargasite is the dominant mafic phase but in some cases has cores of diopside ($Wo_{48}En_{39}Fs_{13}$) to hedenbergite ($Wo_{47}En_{20}Fs_{33}$) or biotite, and contains inclusions of magnetite. Apatite, sphene and zircon are accessories associated with the mafic phases.

The nepheline syenite (s.s.) has a hypidiomorphic granular texture. In the most leucocratic samples, sodian hedenbergite (Ac_{35}) is abundant and commonly rims amphibole. The gradation from alkali-melasyenite to nepheline syenite is marked by an increase in the proportion of modal nepheline and a decrease in that of plagioclase and mafic phases.

NS*$_4$ *(Foyaite)

Foyaite crops out extensively in the southwestern third of the Marinkas Kwela Complex. It is predominantly coarse-grained and highly leucocratic and can be subdivided into clinopyroxene-rich and amphibole-rich varieties. The former are more common. They occur mainly to the northeast of the Grootpenseiland granite, but a small outlier also occurs to the southwest of that granite. The amphibole-rich variety is found only in the central part of the foyaite outcrop and in small, late-stage dykes which intrude that outcrop.

The foyaites show intergranular textures characterized by a network of tabular perthite grains that are randomly oriented or show slight preferential alignment, and in this way are distinct from the nepheline syenite (*NS*$_3$). In the clinopyroxene-rich variety, hedenbergite ($Wo_{46}En_{27}Fs_{27}$ to $Wo_{43}En_7Fs_{50}$) to sodian hedenbergite (Ac_{35}) is commonly the sole mafic phase, but is sometimes extensively rimmed by amphibole. In the amphibole-rich variety, hastingsite to taramite is commonly the sole mafic phase; biotite may occur as very minor inclusions in the amphibole or as late-stage reaction rims around magnetite. Late-stage aegirine-augite commonly rims amphibole in the amphibole-rich foyaite but is rare in the clinopyroxene-rich foyaite.

Braid-microperthite is the dominant felsic constituent of both varieties of foyaite. Nepheline ranges from minor to major modal proportions and lies interstitially to feldspar, except in some specimens of sodalite-bearing foyaite where subhedral to euhedral nepheline occurs. Where present, sodalite also lies interstitially to feldspar, and sometimes represents a reaction product of nephe-ine. Both feldspathoids may show partial to

TABLE 2: Representative major-element compositions and CIPW norms (wt%) for major rock types of the Grootpenseiland (GI) and Marinkas Kwela (MK) Complexes. All Fe is expressed as FeO. CIPW norms calculated assuming Fe^{2+}/Fe^{3+} = 2 (molecular)

Sample:	NS_1	NS_2 (biot)	NS_2 (amph)	NS_3 (mel)	NS_3 (ne-sy)	NS_4	S_1	S_2	G_1 (monz)	G_1 (gran)	G_{2a}	G_{2b}
Complex:	GI	GI	GI	MK	MK	MK	GI	GI	MK	GI	MK	GI
SiO_2	49.76	58.70	60.05	53.74	59.58	58.14	62.40	62.67	59.61	66.86	76.75	74.86
TiO_2	1.80	1.20	0.59	1.46	0.41	0.27	0.10	0.88	0.85	0.25	0.04	0.04
Al_2O_3	16.77	18.47	18.79	17.39	19.24	21.01	17.86	18.71	18.51	14.99	12.18	12.72
FeO	8.54	5.29	4.42	8.17	3.67	3.69	5.68	3.41	3.99	3.49	1.64	1.30
MnO	0.21	0.16	0.16	0.23	0.17	0.13	0.21	0.09	0.11	0.09	0.08	0.05
MgO	4.42	1.91	0.63	3.34	0.65	0.48	0.02	0.67	1.23	0.33	0.09	0.04
CaO	8.32	4.11	2.19	6.09	1.92	1.57	1.07	1.72	3.82	0.99	0.42	0.36
Na_2O	4.03	4.99	6.30	5.16	7.79	8.50	6.34	5.46	5.44	5.48	4.31	5.75
K_2O	2.84	4.19	4.96	3.25	4.86	6.13	5.33	5.30	4.84	5.10	4.39	4.41
P_2O_5	1.30	0.78	0.26	1.00	0.16	0.16	0.08	0.21	0.53	0.09	0.07	0.07
H_2O-	0.15	0.11	0.14	0.23	0.23	0.19	0.13	0.10	0.16	0.12	0.13	0.10
LOI	1.31	0.71	0.73	0.84	1.17	0.92	0.46	0.61	0.39	0.68	0.36	0.32
Total	99.45	100.62	99.22	100.90	99.85	101.19	99.68	99.83	99.48	98.47	100.46	100.02
q		2.74					0.60	5.70	0.60	12.43	33.48	27.37
c		0.12										
or	16.78	24.76	29.31	19.21	28.72	36.22	31.50	31.32	28.60	30.14	25.94	26.06
ab	30.29	42.22	51.82	39.92	47.17	32.34	53.65	46.20	46.03	46.37	36.47	40.88
an	19.28	15.29	8.34	14.69	3.18	1.07	4.53	7.16	11.79	1.24	0.92	
ne	2.06		0.81	2.03	10.16	21.45						1.39
ac												1.44
ns												
di	10.92		0.70	7.34	4.48	4.85	0.23		3.04	2.65	0.61	1.17
hy		7.94					5.38	3.51	4.03	2.40	1.48	1.11
ol	7.96		3.43	7.48	1.77	1.43						
mt	4.60	2.84	2.38	4.39	1.97	1.99	3.04	1.83	2.15	1.87	0.88	
il	3.42	2.28	1.12	2.77	0.78	0.51	0.19	1.67	1.61	0.47	0.08	0.08
ap	3.08	1.85	0.62	2.37	0.38	0.38	0.19	0.50	1.26	0.21	0.17	0.17

complete alteration to natrolite. Sphene, apatite and fluorite are accessory phases of both foyaites.

Syenites

S_1 *(Alkali-syenite)*

This rock type comprises a large portion of the Grootpenseiland Complex, also cropping out in a small, centrally located area of the Marinkas Kwela complex (Fig. 2). The highly leucocratic rock is inhomogeneous in texture, sometimes ranging from fine-grained to very coarse-grained across a single metre-scale outcrop. Very coarse-grained granular varieties occur in topographically higher parts of the central and northeastern portions of the Grootpenseiland Complex. The rock may demonstrate discontinuous and contorted banding on a scale of up to 30 cm. The bands alternate from highly felsic and coarse-grained to less felsic and fine-grained.

The rock contains up to 95% subhedral to euhedral microperthite. Amphibole (hasting site to katophorite) is the dominant mafic constituent, followed by biotite > aegirine-augite ($Di_6Hd_{68}Ac_{25}$)> magnetite, with accessory zircon, fluorite and allanite. It is the presence of alkali mafic minerals (katophorite and aegirine-augite) that distinguishes these rocks from other syenites (*S_2*).

S_2 *(Grootpenseiland syenite)*

This syenite is a medium- to coarse-grained and leucocratic rock forming poor outcrops in the central portion of the Grootpenseiland Complex. Turbid and commonly sericitized microperthite is the dominant phase. Biotite, commonly forming clusters of large radiating plates, is the main mafic mineral in rocks near the southwest margin of the complex, but in the central portion of the complex, amphibole is more abundant. Clinopyroxene (diopside to augite) ($Wo_{43}En_{32}Fs_{25}$ to $Wo_{45}En_{25}Fs_{28}$) is ubiquitous in minor proportions and quartz is an interstitial accessory phase in some rocks.

Sphene, apatite, fluorite and zircon form very rare accessories.

Granitoids

Granitoids comprise nearly half the outcrop of the Grootpenseiland Complex and an even greater portion of the Marinkas Kwela Complex (Fig. 2).

G_1 *(monzonite - granite series)*

The compositional range of granitoids of this series is wider in the Marinkas Kwela Complex than it is in the Grootpenseiland Complex. It extends from mesocratic monzonite through quartz syenite and granite to highly leucocratic alkali-feldspar granite. The rocks occur in a sequence of circular dykes that overlap to form a wide ringdyke in which the most evolved rock type - alkali-feldspar granite - forms a discontinuous outer envelope. The absence of chilled margins suggests only limited cooling in between successive intrusions.

The rocks are mostly medium- to coarse-grained and hypidiomorphic granular, but fine-grained and porphyritic varieties also occur. In the hypidiomorphic variety, microperthite occurs both as subhedral to euhedral grains, and as extensive rims around plagioclase. The latter exhibits compositional zoning from calcic cores (An_{40}) to sodic (An_8) rims. Quartz lies interstitially to feldspar and ranges from accessory proportions in the monzonite to 30% in the alkali-feldspar granite. Amphibole (ferro-tschermarkite to ferro-edenite) is usually the most abundant mafic phase. It is commonly subhedral and may contain cores of altered diopside. Biotite is common and occurs either as inclusions within amphibole, or as discrete subhedral to euhedral grains which are partially rimmed by magnetite. Sphene and apatite are abundant accessories only in the less evolved rocks whereas zircon and allanite are abundant accessories only in the more evolved rocks.

G_2 *(Alkali-granites)*

Leucocratic and medium- to coarse-grained alkali-granite makes up the remainder of both Complexes and can be subdivided into two types.

The Marinkas Kwela granite (***G_{2a}***) forms a stock in the far north of Marinkas Kwela Complex and shows

TABLE 3: Average clinopyroxene and amphibole analyses. Fe^{2+}/Fe^{3+} ratios calculated after Droop (1987)

Clinopyroxene	**NS1**	**NS2**	**NS3**	**NS4**	**S1**	**S22**	**G1**	**G2**
n=	**48**	**96**	**34**	**59**	**12**	**11**	**24**	**11**
SiO_2	**51.4**	**51.6**	**50.6**	**50.3**	**50.8**	**52.3**	**50.4**	**49.5**
TiO_2	**0.5**	**0.3**	**0.4**	**0.3**	**0.2**	**0.4**	**0.3**	**0.2**
Al_2O_3	**2.3**	**1.1**	**2.2**	**1.4**	**1.1**	**1.0**	**1.1**	**0.2**
Cr_2O_3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Fe_2O_3	**5.2**	**3.3**	**5.6**	**8.9**	**16.6**	**0.3**	**3.4**	**6.0**
FeO	**4.0**	**9.2**	**6.7**	**10.2**	**11.0**	**11.2**	**10.2**	**20.6**
MnO	**0.4**	**0.9**	**0.7**	**1.2**	**1.3**	**0.9**	**0.7**	**1.5**
MgO	**12.9**	**10.4**	**10.9**	**5.5**	**0.5**	**11.9**	**9.5**	**1.2**
CaO	**23.0**	**22.1**	**21.6**	**18.5**	**10.6**	**20.9**	**23.1**	**15.5**
Na_2O	**1.1**	**1.1**	**1.4**	**3.3**	**7.3**	**0.6**	**0.7**	**3.3**
Total	**100.7**	**100.0**	**100.0**	**99.6**	**99.5**	**99.5**	**99.3**	**97.6**

Amphibole	**NS1**	**NS2**	**NS3**	**NS4**	**S1**	**S22**	**G1**
n=	**28**	**58**	**83**	**90**	**30**	**4**	**107**
SiO_2	**39.4**	**39.0**	**38.8**	**39.1**	**39.6**	**43.4**	**40.9**
TiO_2	**3.4**	**3.0**	**2.7**	**1.9**	**1.1**	**1.8**	**2.2**
Al_2O_3	**11.8**	**10.6**	**10.6**	**9.3**	**7.7**	**6.8**	**8.3**
Cr_2O_3	**2.2**	**1.8**	**2.6**	**5.9**	**7.5**	**6.3**	**5.4**
Fe_2O_3	**18.2**	**22.7**	**20.9**	**21.9**	**26.4**	**18.3**	**21.0**
FeO	**0.4**	**0.9**	**0.9**	**1.3**	**1.4**	**0.9**	**0.7**
MnO	**8.0**	**5.1**	**5.6**	**3.8**	**0.5**	**7.1**	**5.4**
MgO	**10.4**	**10.6**	**10.2**	**8.8**	**7.5**	**10.4**	**10.4**
CaO	**2.8**	**3.0**	**3.2**	**3.8**	**4.3**	**2.0**	**2.3**
Na_2O	**2.0**	**1.5**	**1.4**	**1.5**	**1.4**	**0.8**	**1.1**
Total	**98.5**	**98.2**	**96.8**	**97.2**	**97.5**	**97.9**	**97.5**

sharp contacts with all the rocks it intrudes. It is made up mostly of hypidiomorphic granular aegirine-augite alkali-granite. Quartz-feldspar porphyries also occur, found in topographically higher parts of the granite body where they are virtually devoid of mafic minerals and associated with hypidiomorphic granular varieties that are similarly leucocratic. Additionally, in the north-east corner of the body an ovoid depression of about 2 km^2 marks a zone of intense alteration characterized by a pervasive assemblage of quartz-sericite-pyrite.

Aegirine-augite alkali-granite (***G_{2b}***) occurs in both Complexes. In the Grootpenseiland Complex it is found in plugs and northerly-trending dykes, which cross-cut earlier Si-undersaturated rocks, and is the youngest intrusive phase of that Complex. In the Marinkas Kwela Complex, G_{2b} crops out in the central part of the Complex and shows sharp intrusive contacts against the G_1 ring-dyke and the foyaites (NS_4).

Both types of alkali-granite have hypidiomorphic granular textures. They are hypersolvus granites; the microperthite being of the patch and braid variety in G_{2a} and G_{2b} respectively. Quartz forms clusters of subhedral to anhedral grains. Mafic phases crystallize interstitially to feldspar. Aegirine-augite is most common and is accompanied by arfvedsonite in G_{2a} and ferrowinchite in G_{2b}.

Comparison With the Kanabeam Complex

There appear numerous similarities, in rock type and relative spatial and temporal arrangement of rock types, between the Grootpenseiland and Marinkas Kwela Complexes and the Kanabeam Complex. According to Reid (1991), a series of ring-dykes comprising at least six varieties of nepheline syenite form a sub-complex that is the oldest, and most southerly, component at Kanabeam. Four of these rock types are recognized in either the Grootpenseiland Complex (north of the Orange River) and the Marinkas Kwela Complex (Table 4), like wise forming the first and most southerly intrusive phase of each complex.

Intruding the nepheline syenites at Kanabeam, is a central plug of quartz syenite with a swarm of microsyenite dykes and plugs to the north. The quartz syenite has no close analogy recognized in the two Complexes to the south, although it shows some similarities to the Grootpenseiland syenite (S_2). The micro syenite contains neither quartz nor nepheline, is critically saturated, and closely resembles syenites found in the central portions of the Grootpenseiland and Marinkas Kwela Complexes.

In the northeast of the Kanabeam Complex, Si-oversaturated rocks comprise the youngest intrusive phases, beginning with granite, granite porphyry and, finally, microgranite (Reid, 1991). The first two of these phases bear mineralogical similarities to rocks of the monzonite - granite series (G_1) of the Grootpenseiland and Marinkas Kwela Complexes, whereas the microgranite shows similarities to hydrothermally altered portions of alkali-granite at Marinkas Kwela (G_{2a}).

Consequently, a remarkable feature of the central portion of the Kuboos-Bremen igneous province is that within a distance of less than 30km there occur three discrete intrusive alkali complexes, including Kanabeam, that are almost identical in terms of their range of rock types, and in terms of the spatial and temporal sequence in which individual rock types were emplaced. These similarities suggest that all three complexes derived

TABLE 4: Correlation between major rock types at Kanabeam (Reid, 1991) and at Grootpenseiland-Marinkas Kwela. In lists A and B, the order of intrusion, and sequences of intrusion (from southwest to northeast), is from top to bottom. NF = no similar rock type found at Grootpenseiland-Marinkas Kwela.

A: Kanabeam complex				**B: Grootpenseiland and Marinkas Kwela complexes**	
		normative *Q* or *ne* (average wt%)			**normative *Q* or *ne* (average wt%)**
Nepheline syenite (ns)				**Si-undersaturated rocks**	
	ns1 -		**NF**	**NS_1**	**4% *ne***
	ns2 -			**NS_2**	**1% *ne***
(monzonite)	**ns3**	**6% *ne***		**NS_3**	**8% *ne***
	ns4	**6% *ne***		**NS_4**	**18% *ne***
(foyaite)	**ns5**	**18% *ne***			
(melasyenite)	**ns6**	**10% *ne***		**Syenite**	
				S_1	**1% *Q***
Quartz syenite		**15% *Q***	**NF?**	**S_2**	**3% *Q***
Microsyenite					
Granite		**20% *Q***		**Granitoids**	
Granite (porphyry)		**15% *Q***		**G_1**	**7% *Q***
Microgranite		**37% *Q***		**G_{2a}**	**32% *Q***
				G_{2b}	**16% *Q***

from parental magmas of similar compositions and underwent similar subsequent compositional evolution.

Evolution of the Complexes

In the Grootpenseiland and Marinkas Kwela Complexes, field relationships clearly show that intrusive ages decrease from south to north. An accompanying progression in rock type also occurs, trending to more Si-oversaturated composition with decreasing intrusive age; from nepheline syenites in the southwest, through rocks that are critically saturated with respect to silica (syenite) in the middle, to ring-dykes and stocks of granitoids in the northeast. The close spatial relationships observed between Si-undersaturated and Si-oversaturated rocks of these two Complexes are also features of many other alkaline complexes (Pankhurst *et al.*, 1976; Upton and Thomas, 1980; Fletcher and Beddoe-Stephens, 1987; Woolley and Jones, 1987; Henderson *et al*., 1988; Reid, 1991). It has been proposed - for example by Foland and Henderson (1976) and Eby (1987) - that in such situations the two magma types may be genetically related to each other. Reid (1991), tentatively put forward an alternative suggestion regarding the Kanabeam Complex, whereby the Si-undersaturated rocks relate to a basanitic parental magma, magmas parental to the Si-oversaturated rocks are anatectic melts of silicic crust, and the intermediate rock types form through the interaction of those two melt lineages.

Smithies (1991) and Smithies and Marsh (in prep.) found that the most primitive nepheline-bearing syenite (NS_2) at Grootpenseiland and the most primitive monzonite (G_1) at both Grootpenseiland and Marinkas Kwela are mineralogically and geochemically almost identical to each other, although they clearly relate to different rock series in the field. According to Smithies (1991), Si-undersaturated rocks and the rocks of the monzonite -granite series (G_1) have very similar Sr and Nd isotopic compositions (respectively, initial Sr ratio 0.7048 and 0.7047; epsilon Nd + 1.0 and +3.5) which reflect derivation primarily from a mantle source. Oxygen isotopes, however, suggest a greater crustal input within the monzonite granite series (Smithies, 1991). The close compositional similarity between the least fractionated Si-undersaturated and Si-oversaturated rocks, and the isotopic evidence, led Smithies (1991) and Smithies and Marsh (in prep.) to suggest that the two rock types may, in fact, be derived from a common Si-undersaturated parental melt, but that the diverging compositional trends shown by the respective rock series were caused through the interaction of this melt with crustal material. Where little interaction occurred, the melts fractionated towards successively more foyaitic or phonolitic residuals. Incorporation of a 'granitic' component, however, resulted in critically saturated or Si-oversaturated trends. In this way it is possible to relate all intrusive phases of each complex to a common parental melt.

Nevertheless, the rocks found in both complexes are overwhelmingly felsic and far removed from parental compositions, the nature of which can only be guessed at. The least evolved rock in either complex is the monzodiorite (NS_1) of the Grootpenseiland Complex (48.13 - 49.78 wt% SiO_2), which is up to 6.00 wt% *ne*-normative and contains feldspar phenocrysts with extremely calcic cores (An_{80}). In the Kanabeam Complex, Reid (1991) reports the occurrence, in phonolite breccia pipes, of rounded xenoliths of olivine (Fo_{78}) and calcic plagioclase (An_{76}) bearing gabbro. These rocks have lower silica (45.20 wt%) and are more *ne*-normative (15.69 wt%) than any rock found in the other two Complexes and have compositions that approximate basanite. They may closely approach the 'composition of mantle melts envisaged to be parental to all three complexes.

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