Communs geol. Surv. Namibia, **10** *(1995), 51-56*

Granites and their mineralisation in the Swakop River area around Goanikontes, Namibia

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The Goanikontes area lies within the Central Zone of the northwest -trending branch of the Damara Orogen. The cover succession of the area is in tectonic contact with older pre-Damaran basement rocks. Sheeted granitoid intrusions are extremely well exposed and these leucogranite sheets, locally termed alaskites, intrude both basement and the Damaran cover sequence. The area is characterised by a northeast-plunging anticline which is truncated by a high strain zone to the east. Red and grey granite emplacement was followed by sheeted leucogranite intrusions which are preferentially located within the high strain zone. These sheets can be classified into six different types and ages on the basis of field characteristics. Major element data on the leucogranites, recalculated into cation normative compositions, show a compositional range from granodiorite to alkali feldspar granite, whereas modal proportions indicate a range from monzogranite to alkali feldspar granite. There is, however, an overall compositional trend, with increasing content of alkali feldspar with younger age. Primary uranium mineralisation is restricted to a single leucogranite type and is confined to the upper Khan and Rössing Formations within the high strain zone. Secondary hydrothermal mineralisation is widespread and is not restricted to either the high strain zone or any lithological unit.

Introduction

The Goanikontes area is situated along the Swakop River, west of the confluence with the Khan River and approximately 35 km inland from the town of Swakopmund (Fig. 1). The area lies within the Central Zone of the northwest-trending branch of the Damara Orogen which is characterised by a large number of igneous bodies that are dominantly granitic (Miller, 1983).

Sheeted granitoid intrusions are extremely well exposed in the Khan and Swakop Rivers. These leucogranite sheets, locally termed alaskites, are mineralogically and texturally variable and are emplaced into both basement rocks and younger Etusis, Khan, Rössing and Chuos Formations of the Damaran cover sequence. Different types of alaskite sheets can be distinguished in the field although there is probably a continuum between some of these alaskite types.

Late-stage sheeted granite intrusions are locally of economic interest on account of the associated uranium mineralisation. The Rössing Mine has produced uranium since the late 1970s and an uranium anomaly in the Goanikontes area has been investigated for its economic potential although it has never been developed. Detailed fieldwork has been carried out in the area of the Goanikontes uranium anomaly to make comparisons and contrasts with the Rössing deposit as part of a project to understand controls on mineralisation. The work in this paper is a preliminary report based largely on fieldwork.

Stratigraphy and structure

The Damaran stratigraphy as defined by SACS

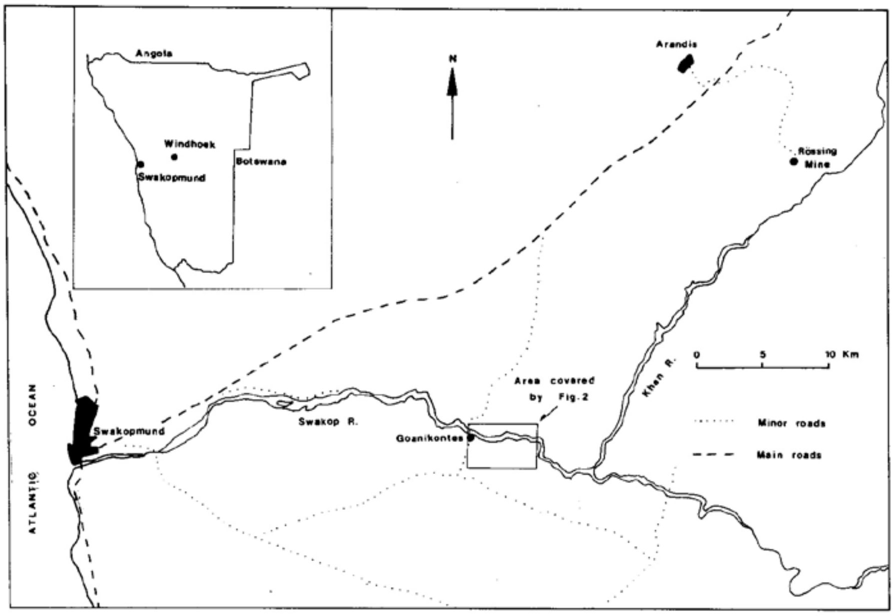

Figure 1: Location map of the Goanikontes area in western Namibia, showing the Khan and the Swakop rivers.

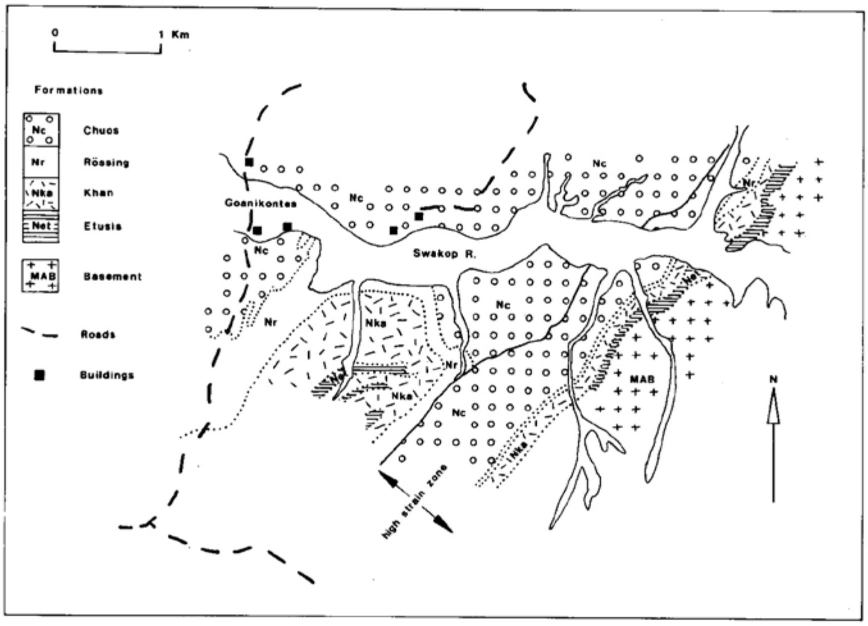

Figure 2: Simplified map of the Goanikontes area showing the northeast plunging anticline truncated by a high strain zone to the east.

(1980) comprises a lower arenaceous, arkosic, psammitic Nosib Group (Etusis and Khan Formations) and an upper calcareous-pelitic Swakop Group which includes the Rössing and Chuos Formations. This succession according to Oliver (1995) is in tectonic contact with older Pre-Damaran basement rocks.

A simplified geological map of the Goanikontes area (Fig. 2) shows that immediately to the east of Goanikontes there is an anticline with a northeast-trending axial trace. This provides a well exposed sequence of the succession, from Etusis to Chuos Formations. These lithologies are easily correlated with previous work carried out in the Rössing area, 35 km to the northeast (Berning, 1986) and, although there are variations in both the lithologies and thicknesses of the Formations between the two areas, the sedimentation history of both the Rössing and Goanikontes regions must have been similar.

East of the anticline, recent detailed fieldwork shows that the lithological sequence as mapped by Valois and Walgenwitz (1979), Marlow (1981) and Mouillac *et al.* (1986) requires some modification. The anticline is truncated by a high strain zone to the east which exhibits an attenuated sequence of the same cover succession. The lithostratigraphy of the thinned succession can be correlated with the main structure although the increase in deformation precludes the possibility of correlating the succession on anything more than a formation basis. The most obvious result of the deformation within the high strain zone is the preponderance of *L*-tectonites. These are easily seen where the country rocks are conglomeratic and clasts form prolate spheroids.

Thus the stratigraphy of the high strain zone comprises an attenuated succession of Etusis, Khan, Rössing and Chuos Formations rather than solely Etusis and Khan Formations as defined by previous work.

The high strain zone is a focus for leucogranite intrusions and 90% of the intrusions within the Goanikontes mapping area occur within this zone forming up to 40-50% of the exposed rocks. Marlow (1981) recognised this preferential emplacement of the leucogranites and considered the high strain zone to be the limb of another antiform.

Field classification of the granitic intrusions

The granite intrusions of the Goanikontes area can be divided into two main types:-

(1) Early equigranular homogeneous fine- to medium-grained red or grey granites which may form irregular intrusive bodies within the shear zone, but which may also occur in sheeted form, both within the shear zone and the cover sequence.

(2) Later sheeted leucogranites which are frequently pegmatitic and often inhomogeneous.

This categorisation is consistent with two of the five major groups of granitic intrusions of the Damara Orogen in the classification scheme of Brandt (1985).

The sheeted leucogranites have been examined in detail in the field and it has been possible to subdivide them broadly into six different types. The classification scheme is based wholly on observable field characteristics of structural setting, colour, grain size and texture. Cross-cutting and structural relationships, not discussed here, have been used to create a chronological sequence from type A which is the earliest to type F, which is the latest. Early type A sheets are narrow, <0.75 m wide, whereas B, C, D and E are generally between 0.5 m and 8 m in width. Sheets of types B, C, D, E and F can be followed along strike for distances of up to 1.5 km whereas type A sheets are less persistent.

Sample	Type	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total	Nb	Zr	Y	Sr	U	Rb	Th	Pb	Ga	Zn	Ni	Ce	Se	V	Ba	La
NG13A	Red Granite	72.70	0.33	13.8	2.34	0.03	0.53	1.2	2.4	6.4	0.18	1	99.91	18	227	65	77	8	355	100	44	17	19	8.5	200	3	17	464	92
NG13B	Red Granite	72.30	0.34	13.8	2.46	0.04	0.47	1.2	2.3	6.3	0.17	1	99.38	20	235	66	73	4.5	358	105	43	16	19	8.5	223	3	15	453	101
NG13C	Red Granite	71.60	0.32	13.7	2.43	0.04	0.5	1.2	2.3	6.2	0.16	1.2	98.45	19	244	71	70	7.5	365	105	45	17	19	7	223	4.5	15	447	103
NG30A	Red Granite	70.70	0.4	13.7	2.75	0.03	0.52	1.3	2.4	6.8	0.21	1.3	98.81	25	244	40	74	1	348	95	35	17	30	7.5	184	4.5	18	516	80
NG30B	Red Granite	71.40	0.42	13.9	2.84	0.04	0.53	1.3	2.3	6.7	0.21	0.8	99.64	21	272	43	75	0.5	344	100	31	16	33	6	202	5	18	525	93
NG30C	Red Granite	71.00	0.39	13.8	2.56	0.03	0.48	1.2	2.3	6.8	0.19	0.8	98.75	26	247	39	76	1	351	95	36	15	30	6.5	201	4	16	527	93
NG34A	Red Granite	76.80	0.31	7.46	3.41	0.04	0.17	3.5	0.9	5	0.11	1.9	97.7	9	200	42	36	7	203	83	4	4.5	3	9	86	5	42	824	52
NG34B	Red Granite	83.50	0.21	7.18	2.01	0.01	0.08	0.4	0.6	5.2	0.09	0.9	99.28	6	105	16	29	0.5	194	30	4.5	0.5	2	9	134	0	19	786	85
NG34C	Red Granite	82.10	0.25	5.44	3.42	0.06	0.12	3.3	0.3	4	0.07	1.3	99.06	8	139	38	27	7.5	163	120	8.5	0	3.5	9.5	136	3	55	548	81
NG29A	Grey Granite	71.10	0.4	13.8	2.83	0.04	0.55	1.2	2.4	6.6	0.2	1.3	99.12	22	259	41	76	0.5	343	103	35	16	34	8	223	4	20	527	103
NG29B	Grey Granite	71.90	0.36	13.8	2.05	0.03	0.49	1.2	2.4	6.6	0.17	0.8	99	28	217	29	87	2	343	82	31	17	20	5.5	202	3	12	583	96
NG29C	Grey Granite	71.50	0.39	13.8	2.61	0.03	0.54	1.2	2.2	6.8	0.19	0.7	99.26	22	249	40	76	0	343	98	35	16	34	7	203	3	18	531	91
NG19A	B	73.50	0.15	14.1	1.04	0.03	0.44	0.9	3	5.7	0.09	1.2	98.95	25	109	47	77	15	194	54	93	17	17	7.5	112	4.5	6.5	392	51
NG19B	B	75.30	0.1	13.8	1.02	0.03	0.29	0.9	3.1	5.4	0.11	0.9	100.1	14	77	42	77	7.5	185	35	81	15	11	8.5	69	3.5	5.5	363	34
NG19C	B	77.60	0.09	12.8	1.06	0.05	0.35	1.6	3.8	2	0.08	1.1	99.43	9	111	27	86	6	80	33	52	13	14	8.5	75	4	5	138	37
NG19D	B	75.50	0.09	13.7	0.88	0.03	0.32	1.4	3.7	3.5	0.08	1.4	99.2	10	106	22	91	5.5	127	28	69	14	12	8.5	63	2.5	8	236	30
NG25A	B	73.00	0.09	14.7	0.54	0.02	0.25	1.6	2.4	6.5	0.04	1.1	99.14	14	62	13	344	17	283	10	28	19	7	8	0.5	1.5	5.5	1249	6
NG25B	B	74.40	0.08	14.1	0.48	0.02	0.23	1.5	2.1	6.5	0.07	0.8	99.48	6	56	14	320	5	282	14	26	20	7.5	6	0	0.5	4	1167	5
NG25C	B	75.00	0.07	14.1	0.4	0.02	0.16	1.4	2.3	6.3	0.05	0.8	99.8	10	72	13	327	7	268	12	23	18	6	6.5	0.5	0.5	4	1125	7
NG32A	B	73.40	0.05	14	1.03	0.07	0.16	0.7	2.2	7.6	0.11	1.3	99.32	5.5	26	26	73	0.5	199	5.5	91	16	8	6	9	7.5	3	428	6
NG32B	B	72.20	0.04	14.8	0.75	0.06	0.16	0.7	2.4	8	0.13	0.6	99.24	8.5	43	28	93	2.5	247	12	91	17	5	6.5	13	4	0	602	9
NG32C	B	73.80	0.05	14.3	0.96	0.09	0.25	1.1	2.7	5.8	0.1	0.8	99.15	3.5	49	21	130	3	180	11	76	14	8	6.5	15	6.5	0.5	805	12
NG36A	B	74.20	0.06	14.6	0.38	0.02	0.15	1.2	2.9	6.2	0.14	0.4	99.85	0.5	31	11	130	0	236	1	51	13	3	9	0.5	0.5	2.5	459	6
NG36B	B	72.90	0.05	14.4	0.49	0.04	0.15	0.4	2.4	8.1	0.25	0.7	99.18	3	5	12	45	0	287	1.5	65	15	6	5.5	0.5	2	0.5	165	2
NG36C	B	71.70	0.04	15.2	0.56	0.05	0.11	0.6	2.5	8.3	0.19	0.4	99.25	2.5	7.5	14	66	0	315	1	73	17	6.5	6.5	3.5	1	1	316	3
NG31A	D	71.10	0.08	15.6	0.45	0.03	0.2	0.8	2.2	9.6	0.06	0.8	100.1	0	6.5	36	114	372	443	35	45	16	9	7	8	0.5	3.5	509	7
NG31B	D	73.80	0.06	14.2	0.36	0.02	0.13	0.7	1.9	8.6	0.09	1	99.86	0	14	36	106	45	399	41	48	14	6	6.5	20	0	4.5	471	13
NG31C	D	72.30	0.1	15.1	0.64	0.03	0.34	1.4	2.6	7.1	0.08	1	99.69	0	13	46	109	557	343	68	66	17	13	6.5	17	1.5	9.5	388	11
NG26A	F	69.20	0.29	14.7	1.65	0.03	0.84	0.5	1.6	10	0.08	1.2	98.89	18	323	67	112	150	500	192	67	16	18	10	258	2.5	6.5	821	130
NG26B	F	71.30	0.12	14	1.6	0.02	0.19	0.4	1.8	9.6	0.06	1	99.09	2.5	41	34	112	11	445	93	51	14	12	6.5	134	0	12	721	72
NG26C	F	77.50	0.08	11.6	0.46	0.02	0.22	0.3	1.4	8	0.06	1	99.64	4	6.5	22	97	2	395	30	35	7	5.5	6	43	0	4.5	743	26

Table 1: Chemical analytical data for red granites and three leucogranite types. Analysis by XRF calibrated against international standards

Type A. Narrow (<0.75 m wide), infrequent leucogranites, fine-medium grained, saccharoidal texture, weak foliation, boudinaged and folded (probably F_3) and only occurring within the high strain zone.

Type B. Dominantly white with variable grain size from fine to pegmatitic, some of the finer grain size material is foliated, frequently boudinaged and occasionally folded (probably by F_4 folds), accessory minerals include garnet where the leucogranite is emplaced within garnet-bearing country rocks, and some individual sheets contain substantial amounts of tourmaline. Common outside the high strain zone

Type C. The typical leucogranite of the area, variable in grain size, containing two populations of feldspar, with interstitial quartz and accessory magnetite, ilmenite and tourmaline. These are occasionally boudinaged although they are preferentially emplaced in flexures of possible F_3 age. Dominant in the relatively undeformed cover sequence, however, also occurring within the high strain zone.

Type D. Host-rock to primary uranium mineralisation, white in colour extremely irregular in form, granular texture and more variable grain size than other types of leucogranite apart from Type E. Comprises white feldspar and characteristic smoky quartz, occasional visible betauranophane, betafite crystals and accessory blue apatite. Scintillometer counts per second (cps) average 100 with maximum 300-400 compared with an average background count of 8-15 cps in the Swakop River. Analyses for 3 samples of this type showing uranium enrichment are given in Table 1. These leucogranites are restricted to the high strain zone close to the Khan/Rössing Formation boundary.

Type E. The most variable leucogranite, containing characteristic reddened "oxidation haloes" as described by Corner and Henthorn (1978). Grain size is extremely variable from fine-grained to coarse pegmatitic and also very variable colour, cps average 30 with maximum 300 typically in the centre of the red haloes where the rock is either similar to a type D leucogranite (white cores) or solely comprising smoky/black quartz and pink feldspar (red cores). White cores are only infrequently mineralised whereas red cores are less common and always show high radioactivity (max 250 cps). This type is dominant within the high strain zone and also occurs within basement rocks.

Type F. These are the youngest leucogranites, notably red in colour which are coarse-grained, tabular with parallel sides and are characterised by pink coarse feldspar, milky quartz and accessory biotite and magnetite/ilmenite. These range in size from 0.5 m to 3 m in width.

Cross-cutting and structural valiation show that these types constitute a viable chronological sequence of leucogranite intrusion. As cross-cutting relationships only reflect relative ages it is possible that different types may have been intruded at a geologically similar time.

With regard to type E leucogranite, the recognition of a particular type of sheet based on features which can be ascribed to alteration presents a problem when attempting to define a chronological sequence. The alteration may well be a much more recent event (Corner, 1982) in which case the original leucogranite sheet may well have been of type A, B, C or D.

On field evidence, the sheeted leucogranites cross-cut and are clearly younger than the red and grey granites. This is consistent with available age data for the area. U/Pb dating of zircons from a red granite by Briqueu *et al.* (1980) yield an age of 525 ± 25 Ma whilst an age date for an 'alaskite' sheet was given as 508 ± 2 Ma. Unfortunately, no description of the type of leucogranite (alaskite) was given. This makes it impossible to place within the chronological sequence of the above classification.

Mineralogical and chemical classification

The sheeted leucogranites which are host to the main mineralisation at both Rössing and Goanikontes are locally referred to as alaskites. The term was introduced by Spurr (1906) for a holocrystalline granular plutonic rock characterised by essential alkali feldspar and quartz and little or no dark component. According to the Commission of the Petrographic Committee of the USSR (1969), cited in Bates and Jackson (1980), the term alaskite is used to designate granitoid rocks in which quartz constitutes 20-60% of the felsic minerals and in which the ratio of alkali feldspar to total felspar is greater than 90%. However, as previous workers have noted (Kröner and Hawkesworth ,1977; Jacob, 1978; Mouillac *et al.*, 1986), the alaskites vary in composition and do not necessarily comply with the above definition. Therefore, in order to classify the leucogranites according to conventional nomenclature, preliminary normative and modal analyses have been undertaken.

Geochemical samples in excess of ten kilos were collected for analysis. The chemical data is given in Table 1. The major elements have been used to recalculate cation normative analyses and are plotted on the Streckeisen diagram in Fig. 3. They span the range from granodiorite to alkali feldspar granite (alaskite in composition).

Modal proportions of 19 samples have been produced by point counting 1000 points on thin sections. The modal data derived by this method are presented in Table 2 and are plotted in Fig. 4. Clearly, there is considerable discrepancy between the plotting positions of some samples in Figs. 3 and 4. Both techniques have considerable drawbacks and illustrate the problems involved in attempting to classify inhomogeneous pegmatitic intrusions.

In the case of the modal analysis technique, since the samples are commonly very coarse-grained and inhomogeneous and the area point-counted is small, it is therefore not representative of the body as a whole. There are also problems due to late-stage modification of the original mineralogy, particularly because the plagioclase is often so extensively sericitised as to make any distinction between albite and the rest of the plagioclase series difficult or impossible. Wrong identification would clearly affect the plotting position in the Streckeisen diagram since albite is added to alkali feldspars at the A pole whilst the rest of the plagioclase series constitutes the P component. In addition many of the plagioclases have been microclinised or silicified either partially or completely and the modal analyses therefore reflect the mineralogy after modification rather than the original mineralogy.

With regard to geochemical samples, these are large and may be inhomogeneous in texture and may represent a composite sample from different sheets within a multiple injection system rather than an individual sheet. Also the use of chemical data converted to cation normative compositions takes no account of alteration of the minerals or of the distribution of Ca in minerals other than plagioclase and apatite. Some samples contain several percent of calcite, and in particular many show varying degrees of epidote alteration which may also be severe in some specimens. For example, sample 34B plots considerably away from the Q-A tie line in Fig. 3, but only contains 2% plagioclase in the modal analysis. Its position is shifted in Fig. 3 due to 5% calcite with epidote. In contrast, sample 32B plots in a similar position in both Figs. 3 and 4 despite extensive

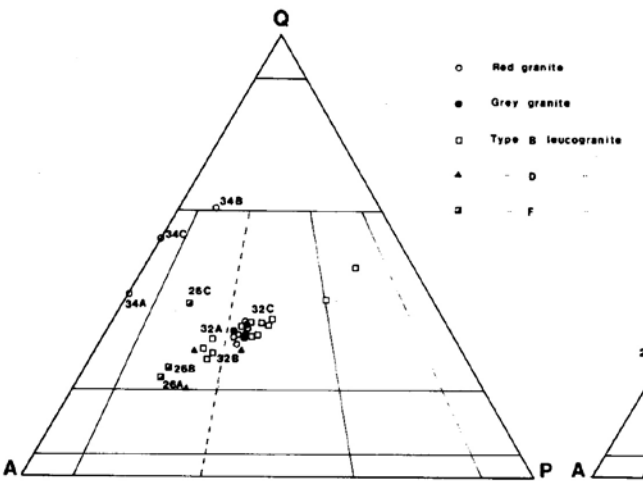

Figure 3: Cation normative compositions of 12 early granites and 19 leucogranites of types B, D and F. Numbered samples discussed in the text.

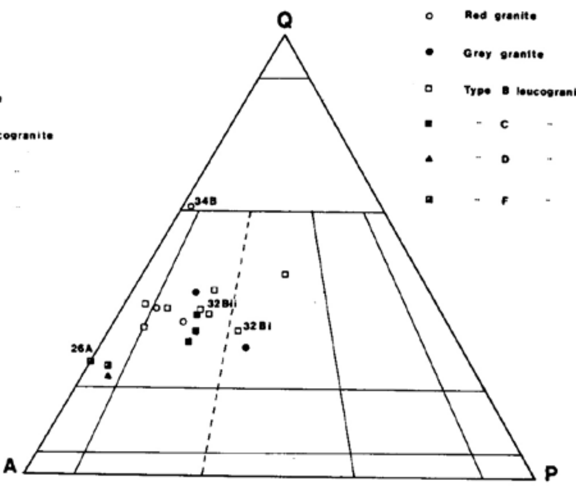

Figure 4: Modal analyses of 5 early granites and 14 leucogranites of types B, C, D and F. numbered samples discussed in the text. Two thin sections of the heavily altered sample, 32B have been included.

Sample	Type	Q	A	P	biot/chlor	muscov	zircon	garnet	tourmal	epidote	calcite	opaque	Total Q+A+P	Q%	A%	P%
NG03A	Red Granite	329	486	129	32	16	1					7	944	34.9	51.5	13.7
NG30A	Red Granite	345	513	65	71		2					2	923	37.4	55.6	7.0
NG34B	Red Granite	574	352	16	2	1	2			3	38	8	942	60.9	37.4	1.7
NG29A	Grey Granite	386	434	113	63		1			1			933	41.4	46.5	12.1
NG104B	Grey Granite	254	384	260	74					8		20	898	28.3	42.8	29.0
NG16A	B	336	504	41		2		1		3		2	881	38.1	57.2	4.7
NG18A	B	362	521	83	32		1						966	37.5	53.9	8.6
NG19A(i)	B	405	400	157		11		18		1			962	42.1	41.6	16.3
NG19A(ii)	B	332	597	59		7	1	4					988	33.6	60.4	6.0
NG25A	B	368	460	147	4	17		4		2			975	37.7	47.2	15.1
NG32B(i)	B	266	336	211	32	7		106	1	16		2	813	32.7	41.3	26.0
NG32B(ii)	B	309	392	153	56	12		67		11			854	36.2	45.9	17.9
NG37A	B	401	245	260	66	3				12		8	906	44.3	27.0	28.7
NG12A	C	346	468	148	24	11	1			1		1	962	36.0	48.6	15.4
NG27A	C	319	492	169	11	5				2		2	980	32.6	50.2	17.2
NG28A	C	302	521	165	11	1							988	30.6	52.7	16.7
NG31A	D	228	729	38						5			995	22.9	73.3	3.8
NG15A	F	253	712	25	4	2	1			1		2	990	25.6	71.9	2.5
NG26A	F	278	720	0		1				1			998	27.9	72.1	0.0

Table 2: Modal data for selected samples. Only the major accessory minerals are shown. Others include apatite, pyrochlore, betafite, monazite, beryl and sphene

alteration of plagioclase to sericite and epidote and the silicification of plagioclase. The problem is further emphasised when considering sheet 26, geochemical samples of which classify the leucogranite as syenogranite in composition. However, the thin section of the sheet contained 58.5% perthite, 13.5% microcline and 28% quartz, with no albite and no plagioclase in the mode.

Comparison of field classification with laboratory techniques

With regard to the data in Fig. 3 derived from chemical analyses, the early red granites plot in the range from monzogranite to alkali-feldspar granite, whereas the later grey granites plot as monzogranites. This compositional variation is also supported by the limited modal data. Such a variation rather contrasts with field evidence which suggests that the red and grey granites are the most homogeneous of all the intrusions. The limited modal data of the leucogranites indicates a possible evolutionary pattern according to leucogranite-type, whereas chemical analyses indicate that there is an overall coherent pattern of a compositional trend from right to left on Fig. 3, from granodiorite through monzogranite and syenogranite for early type B to more alkali feldspar-rich syenogranite for types D and F.

Further work will indicate whether chemical or modal analyses are reliable for leucogranite classification. Many more modal analyses will be undertaken to give a better representative view of the composition and in particular, emphasis will be placed on the proportion of perthite and microcline in the different types.

Obviously neither method of classification is reliable on its own and any nomenclature must take into account the chemical, normative and field data. The importance of field observations cannot be over-emphasised.

Mineralisation

Some late-stage sheeted leucogranite intrusions are host to primary uranium mineralisation with uraninite and/or betafite. In the Rössing Mine the proportions of U minerals have been given as 55% uraninite, 5% betafite and 40% secondary beta-uranophane (Berning, 1986). At Rössing the uraniferous granite sheets are most numerous close to the boundary between the Khan and Rössing Formations. However, in the Goanikontes area, uraniferous granite sheets are preferentially emplaced into the ductile high strain zone formed by an attenuated sequence of Damaran cover rocks adjacent to the basement/cover contact. The alaskites which contain primary uranium mineralisation have so far only been found in the upper Khan Formation within the high strain zone. Secondary mineralisation is more widespread and occurs throughout the high strain zone and in relatively undeformed cover where it is associated with north-south post Karoo faulting.

Conclusions

Red and grey granite emplacement was followed by leucogranite intrusions which can be classified into six different types on field evidence. Whilst chemical and normative data provide some evidence for chemical and mineralogical evolution with time of emplacement of the leucogranite type, field evidence is crucial to the understanding of the history of sheet emplacement.

The localisation of large volumes of leucogranites within a high strain zone and the apparent restriction of primary uranium mineralisation to this zone at Goanikontes is important and has not previously been recognised. Thus the primary uranium mineralisation at Goanikontes in the Swakop River is of a slightly different style to that of the deposit at Rössing in the Khan River and also the secondary mineralisation is not restricted to the Khan/Rössing Formation boundary.

Acknowledgements

The authors would like to thank Rössing Uranium Ltd. for logistical support including use of rock crushing facilities. Grahame Oliver and Tuomo Manninen for useful discussion during fieldwork. University College Cork provided financial support. Drs D. Hunter and R. Jacob are thanked for their comments which greatly improved the paper.

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