Communs geol. Surv. Namibia, **8** *(1992/93), 5-14*

New Rb-Sr data from the Central Zone of the Damara Orogen, Namibia

N.M. Steven[1], R.A. Armstrong[2] and J.M. Moore[3]

[1]*Department of Geology, University of Cape Town, Rondebosch 7700, RSA*
[2]*Department of Geochemistry, University of Cape Town, Rondebosch 7700, RSA*
[3]*Department of Geology, Rhodes University, Grahamstown 6140, RSA*

Pan-African Rb-Sr whole-rock and mineral ages have been determined for three granitoids and three pegmatites in the low-pressure/high-temperature Central Zone (CZ) of the Damara Orogen. There is a trend towards more evolved granite types and an increase in $(^{87}Sr/^{86}Sr)_I$ ratios with time. This can probably be ascribed to the partial melting of crustal material at progressively higher structural levels as the orogeny progressed. In common with the granitoid- and alaskite-hosted uraninite deposits, tin (cassiterite), tungsten (scheelite) skarn, and gold skarn or vein-type mineralisation in the CZ is either hosted by or associated with the younger, late-/post-tectonic intrusions. The Rb-Sr whole-rock dates do not support recent suggestions that Damaran stanniferous pegmatites have been modified by Jurassic-Cretaceous or post-Karoo greisenising fluids.

Introduction

The Central Zone (CZ) of the intracontinental branch of the Pan-African Damara Orogen is characterised by multiple deformation, low-pressure/high-temperature metamorphism and numerous granitoid plutons (Miller, 1983). It is divided into a northern (NCZ) and a southern portion (SCZ) by the magnetically defined Omaruru Lineament (Corner, 1983; Fig. 1). Most geochronological studies in the CZ have concentrated on Rb-Sr whole-rock determinations of the numerous granitic and pegmatitic intrusions. The geochronological data base for the Usakos-Karibib-Omaruru area largely rests on a detailed structural analysis of the planar fabrics within six granitoids and an accompanying Rb-Sr investigation (Haack *et al.*, 1980). A summary of the latest geochronological information available at the time was given by Miller (1983) and, more recently, Haack and Gohn (1988) have dated mineralised pegmatites from the Uis Tin Mine and the Rubicon Lithium Mine (Fig. 1).

Because the isotopic nature of the mineralised intrusions of the SCZ is known in some detail (Marlow, 1983; Haack and Gohn, 1988), this paper focusses on the syn- to late-tectonic granitoids and pegmatites of the NCZ. Early tectonic granitoids and red granites have not been analysed. The Rb-Sr whole-rock ages of six Damaran granitoids and pegmatites that, firstly, are considered to be representative of the NCZ and, secondly, either host tin mineralisation or crop out in the immediate vicinity of epigenetic gold and tungsten mineralisation, have been determined. Mineral ages from one intrusion have also been obtained.

Rb-Sr whole rock results

Whole-rock Sr isotope analyses were performed on 100-150 mg splits of powdered samples. Following dissolution in $HF/HN0_3$, Sr was separated and concentrated for mass spectrometric analysis using standard ion-exchange procedures. Samples were loaded on single Ta filaments with phosphoric acid and Sr isotope ratios were measured using triple-collector or quadruple-collector configurations (for isotope dilution analyses) in dynamic mode. The isotopic fractionation correction factor $^{87}Sr/^{86}Sr=0.1194$ was used. During the course of this study, a mean $^{87}Sr/^{86}Sr$ value of 0.71026 ± 2 (2s) was obtained for the NBS standard SRM-987 (n=30). Rb and Sr elemental concentrations were determined by x-ray fluorescence spectrometry (XRF). For checking purposes, Rb and Sr concentrations were determined by isotope dilution on one sample (NST12-2): concentrations of 963 ppm Sr (968 ppm by XRF) and 1791 ppm Rb (1766 ppm by XRF) were recorded. This results in a difference of only 1.9% in the Rb/Sr ratio.

Isotope ratios were measured on a VG Sector multi-collector mass spectrometer in the Department of Geochemistry, VCT. Dates were calculated using the statistical package GEODATE (Version 2.2; Eglington and Hanner, 1991). Results are listed and discussed in order of decreasing Rb-Sr age (Tables 1 and 2). Analytical errors of 1.5% and 0.005% were applied to the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values respectively. Errors in dates and $(^{87}Sr/^{86}Sr)_I$ ratios are reported at the 95% confidence level (Table 2). The Rb decay constant value of 1.42 x $10^{-11}y^{-1}$ was used. The MSWD value was in all but one case, with isochron/errorchron definition based on F parameters assuming 20 replicates.

Ohere Oos Salem granitoid

This intrusion has a granite core (samples NS233, NS234, NS234A) and a granodiorite marginal phase (samples NS232, NS235); both phases are considered to belong to the same pluton (Steven, 1992). If the Sr-isotope results (Tables 1 and 2) from the two phases are placed on the same isochron (Fig. 2, the pluton has a Rb-Sr whole-rock age of 542 ± 11 Ma ($(^{87}Sr/^{86}Sr)_I$=0.7062). This is considered to be the age of crystallisation and is almost identical to the emplacement age for the compositionally similar Otjozondjou pluton (Fig. 1), one of the best documented Salem granitoids in the CZ (Miller,

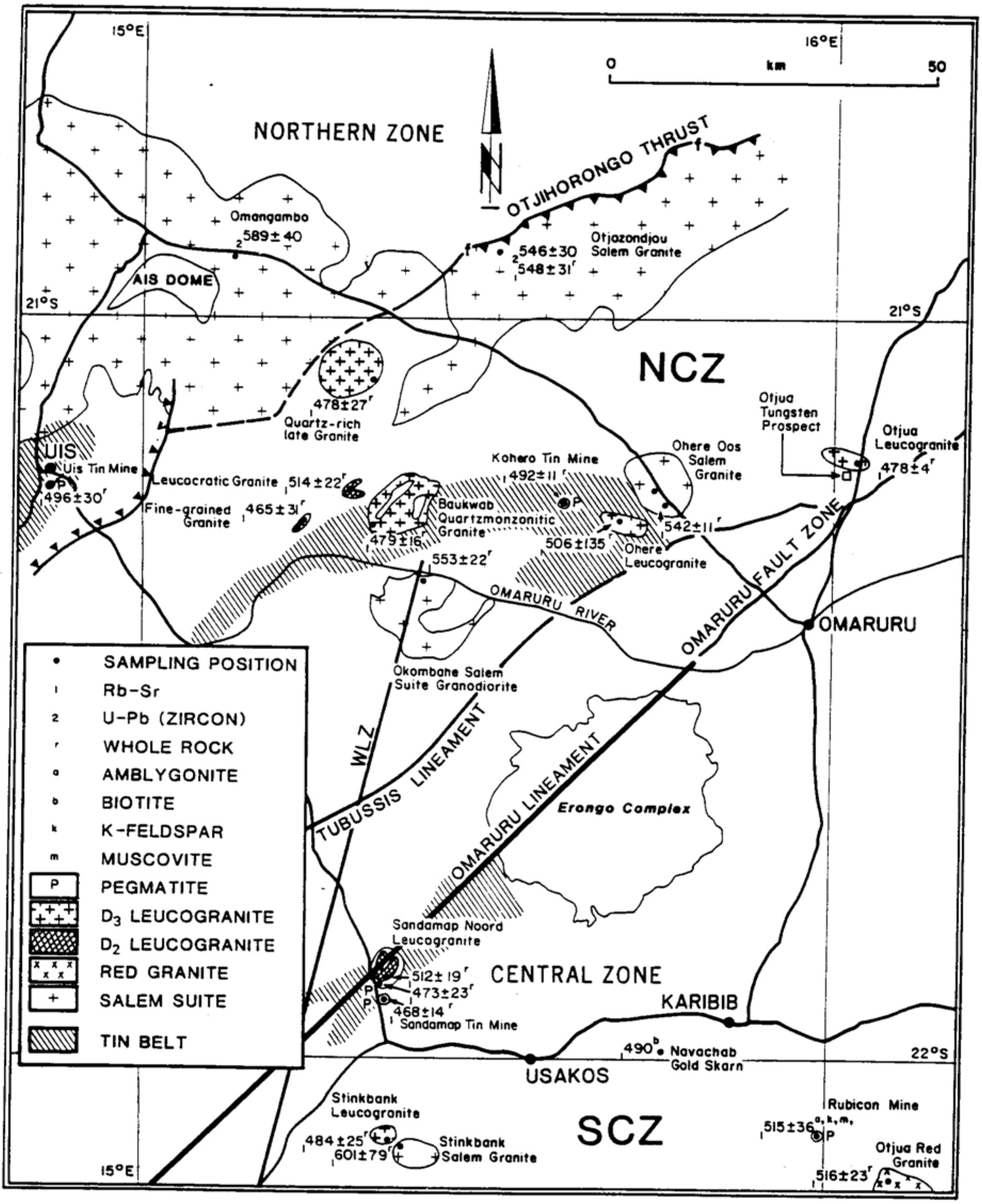

Figure 1: Whole-rock and mineral emplacement ages from central Namibia (modified after Miller and Grote, 1988)

1980). The Otozondjou intrusion is also composite with a one-kilometre-wide marginal phase of quartz monzodiorite and diorite. The pluton has a U-Pb zircon date of 546 ± 30 (Miller and Burger, 1983), a Rb-Sr whole-rock date of 548 ± 31 Ma (Hawkesworth *et al.*, 1983) and a low $(^{87}Sr/^{86}Sr)_I$ ratio of 0.7054. The only other Salem Suite granitoid that has been dated in the NCZ is the pre-F_2 Okombahe intrusion (Fig. 1) which has a Rb-Sr whole-rock age of 553 ± 22 Ma ($(^{87}Sr/^{86}Sr)_I$ Of 0.7056; Haack *et al.*, 1980).

Sandamap Noord leucogranite

The folded peraluminous leucogranite phacolith on Sandamap Noord (Fig. 1) has a Rb-Sr whole-rock date of 512 ± 19 Ma ($(^{87}Sr/^{86}Sr)_I$=0.7153; Table 2) which is taken to be the age of crystallisation of the intrusion (Fig. 3). This date coincides with the F_2 folding in NCZ

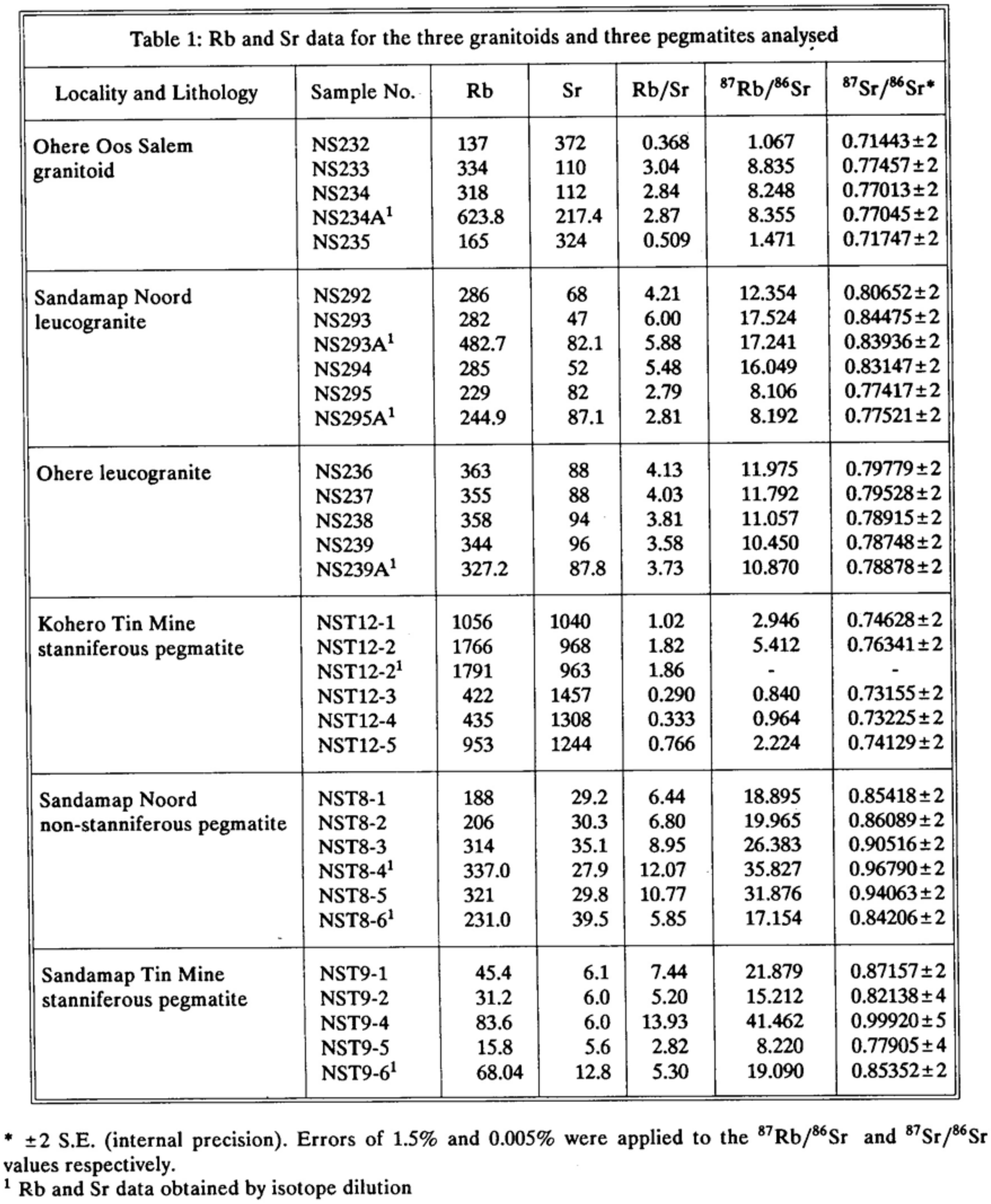

Table 1: Rb and Sr data for the three granitoids and three pegmatites analysed

Locality and Lithology	Sample No.	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$*
Ohere Oos Salem granitoid	NS232	137	372	0.368	1.067	0.71443±2
	NS233	334	110	3.04	8.835	0.77457±2
	NS234	318	112	2.84	8.248	0.77013±2
	NS234A[1]	623.8	217.4	2.87	8.355	0.77045±2
	NS235	165	324	0.509	1.471	0.71747±2
Sandamap Noord leucogranite	NS292	286	68	4.21	12.354	0.80652±2
	NS293	282	47	6.00	17.524	0.84475±2
	NS293A[1]	482.7	82.1	5.88	17.241	0.83936±2
	NS294	285	52	5.48	16.049	0.83147±2
	NS295	229	82	2.79	8.106	0.77417±2
	NS295A[1]	244.9	87.1	2.81	8.192	0.77521±2
Ohere leucogranite	NS236	363	88	4.13	11.975	0.79779±2
	NS237	355	88	4.03	11.792	0.79528±2
	NS238	358	94	3.81	11.057	0.78915±2
	NS239	344	96	3.58	10.450	0.78748±2
	NS239A[1]	327.2	87.8	3.73	10.870	0.78878±2
Kohero Tin Mine stanniferous pegmatite	NST12-1	1056	1040	1.02	2.946	0.74628±2
	NST12-2	1766	968	1.82	5.412	0.76341±2
	NST12-2[1]	1791	963	1.86	-	-
	NST12-3	422	1457	0.290	0.840	0.73155±2
	NST12-4	435	1308	0.333	0.964	0.73225±2
	NST12-5	953	1244	0.766	2.224	0.74129±2
Sandamap Noord non-stanniferous pegmatite	NST8-1	188	29.2	6.44	18.895	0.85418±2
	NST8-2	206	30.3	6.80	19.965	0.86089±2
	NST8-3	314	35.1	8.95	26.383	0.90516±2
	NST8-4[1]	337.0	27.9	12.07	35.827	0.96790±2
	NST8-5	321	29.8	10.77	31.876	0.94063±2
	NST8-6[1]	231.0	39.5	5.85	17.154	0.84206±2
Sandamap Tin Mine stanniferous pegmatite	NST9-1	45.4	6.1	7.44	21.879	0.87157±2
	NST9-2	31.2	6.0	5.20	15.212	0.82138±4
	NST9-4	83.6	6.0	13.93	41.462	0.99920±5
	NST9-5	15.8	5.6	2.82	8.220	0.77905±4
	NST9-6[1]	68.04	12.8	5.30	19.090	0.85352±2

*** ±2 S.E. (internal precision). Errors of 1.5% and 0.005% were applied to the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values respectively.**

[1] Rb and Sr data obtained by isotope dilution

and the regional metamorphic peak (Haack *et al.*, 1980). This is supported by the fact that the leucogranite has a banding rather than a true foliation, indicating a post-D_1 age. The result supports the contentions of Watson (1982) that the intrusion lies in the core of a domal structure which has deformed and been partly formed by the granite. The date for the Sandamap Noord intrusion is indistinguishable from the syn-F_2 "leucocratic granite" in the Omaruru River valley (Fig. 1; Haack *et al.*, 1980) which has a Rb-Sr whole-rock age of 514± 22 Ma (($^{87}Sr/^{86}Sr)_I$=0.7123). One of the few other granites in the orogen to contain magmatic muscovite is the Donkerhuk granite for which Blaxland *et al.* (1979) determined Rb-Sr whole-rock ages of 523 ± 8 Ma (($^{87}Sr/^{86}Sr)_I$=0.7074) and 521 ± 15 Ma (($^{87}Sr/^{86}Sr)_I$=0.7117). Contemporaneous intrusion of peraluminous granites in the vicinity of major structural breaks such as the Omaruru and Okahandja Lineaments is therefore indicated.

Ohere leucogranite

The Ohere leucogranite (Fig. 1) has a Rb-Sr whole-rock date of 506 ± 135 Ma (Table 2 and Fig. 4) which is interpreted as a crystallisation event. The very homogenous nature of this intrusion, and hence poorly constrained isochron, accounts for the large uncertainty on the date. In general, unfoliated CZ leucogranites with an oval to circular outcrop pattern such as the Ohere, Otjua and Stinkbank plutons (Fig. 1) have a late- to post-tectonic (post-D_2) age.

Pegmatites hosted by greenschist-facies rocks at the Kohero Tin Mine, west of Omaruru

The stanniferous pegmatite at the Kohero Tin Mine (Fig. 1), which does not contain any biotite, has a Rb-Sr wholerock date of 492 ± 11 Ma and a high $(^{87}sr/^{86}sr)_I$ ratio of 0.7256 (Table 2 and Fig. 5). This date is indistinguishable from that determined for the morphologically similar, essentially unzoned, dyke-like pegmatite at the Uis Tin Mine (496 ± 30 Ma, Haack and Gohn, 1988; Fig. 1) and the nearby Ohere leucogranite.

Pegmatites hosted by amphibolite-facies rocks on Sandamap Noord, west of Usakos

Non-stanniferous pegmatite (with traces of biotite) from the margin of the Sandamap Noord dome and stanniferous pegmatite (with no biotite) from the San-

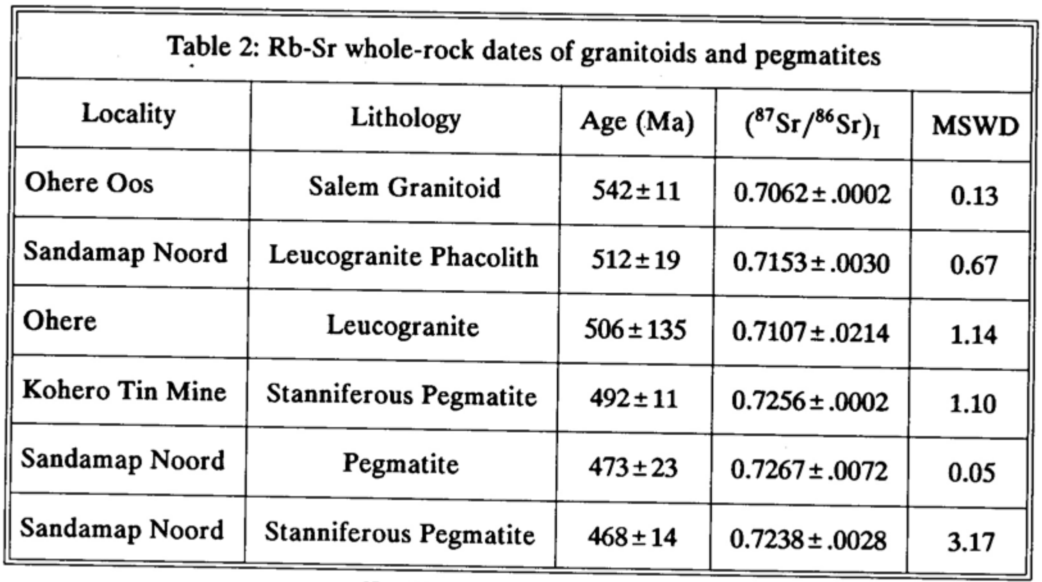

Table 2: Rb-Sr whole-rock dates of granitoids and pegmatites

Locality	Lithology	Age (Ma)	$(^{87}Sr/^{86}Sr)_I$	MSWD
Ohere Oos	Salem Granitoid	542±11	0.7062±.0002	0.13
Sandamap Noord	Leucogranite Phacolith	512±19	0.7153±.0030	0.67
Ohere	Leucogranite	506±135	0.7107±.0214	1.14
Kohero Tin Mine	Stanniferous Pegmatite	492±11	0.7256±.0002	1.10
Sandamap Noord	Pegmatite	473±23	0.7267±.0072	0.05
Sandamap Noord	Stanniferous Pegmatite	468±14	0.7238±.0028	3.17

Errors in dates and $(^{87}Sr/^{86}Sr)_I$ ratios reported at 95% confidence level

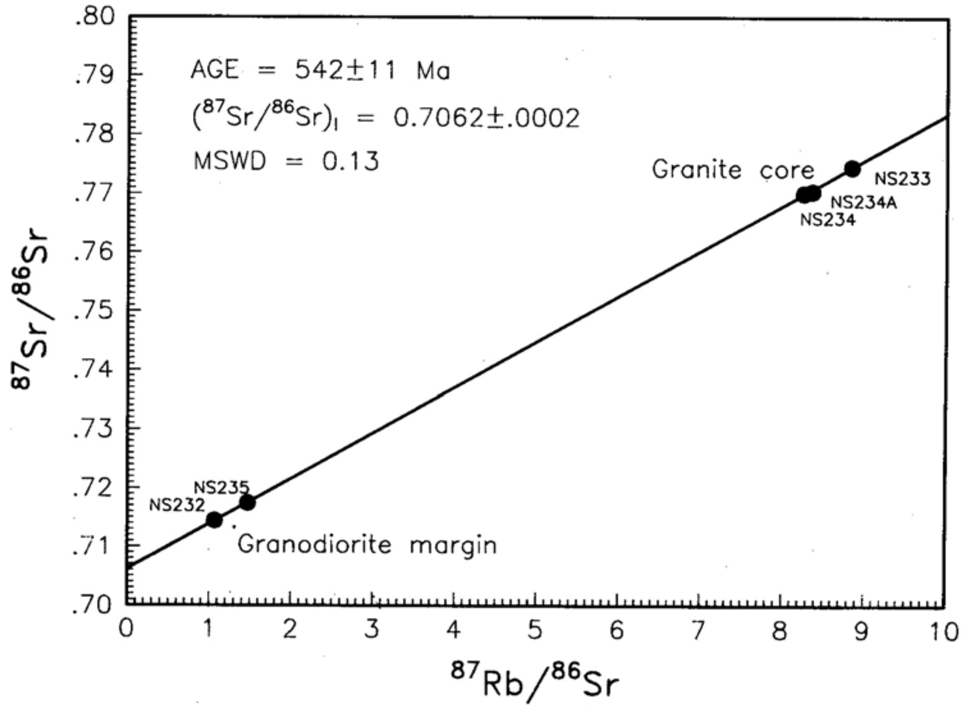

Figure 2: Rb-Sr wholr-rock isichron for the Ohere Oos Salem granitoid

damap Tin Mine (Fig. 1) have been investigated. Both pegmatites, which are essentially undeformed except for strained quartz, have late- to post-tectonic dates of 473 ± 23 and 468 ± 14 respectively (Table 2, Figs. 6 and 7).

These pegmatite dates are younger than the examined granitoids, but their significance is unclear because of the well-documented sampling problems and the discordance of ages in zoned rare-element pegmatites (Clark, 1982). Open-system behaviour of the Rb-Sr isotopic system has been documented by Clark (1982) in whole-rock samples even in cases where there has been no subsequent metamorphism. Thus age differences may not necessarily reflect different crystallisation times. Because of the generally high concentration of Rb in these lithologies and subsequent (post-crystallisation?) migration of ^{87}Sr, whole-rock and mineral dates are commonly anomalously low. This would appear to be the case at Sandamap Noord where the rare-element (more volatile-enriched) pegmatite has a slightly younger date. The pegmatites on Sandamap Noord have the high $(^{87}Sr/^{86}Sr)_I$ ratios so characteristic of this type of intrusion. The tin-bearing pegmatite on Sandamap Noord has an age which cannot be distinguished from the late-tectonic alaskite at the Rössing Uranium Mine (458 ± 8 Ma; Kröner and Hawkesworth, 1977; Hawkesworth *et al.*, 1983).

Summary of Rb-Sr whole-rock results

One of the most notable features of the results is the close agreement of the emplacement ages for specific granite and pegmatite types with those obtained by other workers in the SCZ (Fig. 1; Marlow, 1983), in the vicinity of the Rössing Uranium Mine (Kröner and Hawkesworth, 1977), in the lower Omaruru River (Haack *et al.*,1980) and on the northern margin of the CZ (Hawkesworth *et al.*, 1983; Miller and Burger, 1983). The second feature of note is the consistency of ages and $(^{87}Sr/^{86}Sr)_I$ ratios for specific types of intrusion in the CZ over an area of approximately 12 500 km^2 (Fig. 1). Four types of intrusion can be isotopically distinguished in the field area. There were several phases of intrusion of Salem Suite granitoids in the early stages of the orogeny. The younger, relatively undeformed post-D_1 Salem granitoids with low $(^{87}Sr/^{86}Sr)_I$ ratios intruded at 560-540 Ma. Sheet-like peraluminous leucogranites intruded along major structural breaks during F_2 at the peak of regional metamorphism (~520 Ma). The third type of intrusion is the oval-shaped ~500-475 Ma (approximately syn-D_3) leucogranites which are responsible for the northeast-trending elliptical outcrop pattern of the CZ. Finally, there are a number of late-/post-tectonic pegmatites concentrated in the vicinity of deep-seated crustal fractures such as the Welwitschia lineament zone (WLZ; Fig. 1) or found in the tin belts.

Intrusions hosted by greenschist-facies rocks on the northern side of the Tubussis Lineament-Kornpaneno Fault (Fig. 1), such as the Ohere leucogranite and the Kohero pegmatite, have slightly older radiometric dates than leucogranites and pegmatites hosted by amphibolite-facies rocks. This suggests that, in general, Rb-Sr whole-rock dates in the CZ represent cooling events, not the exact time of crystallisation. The data support the

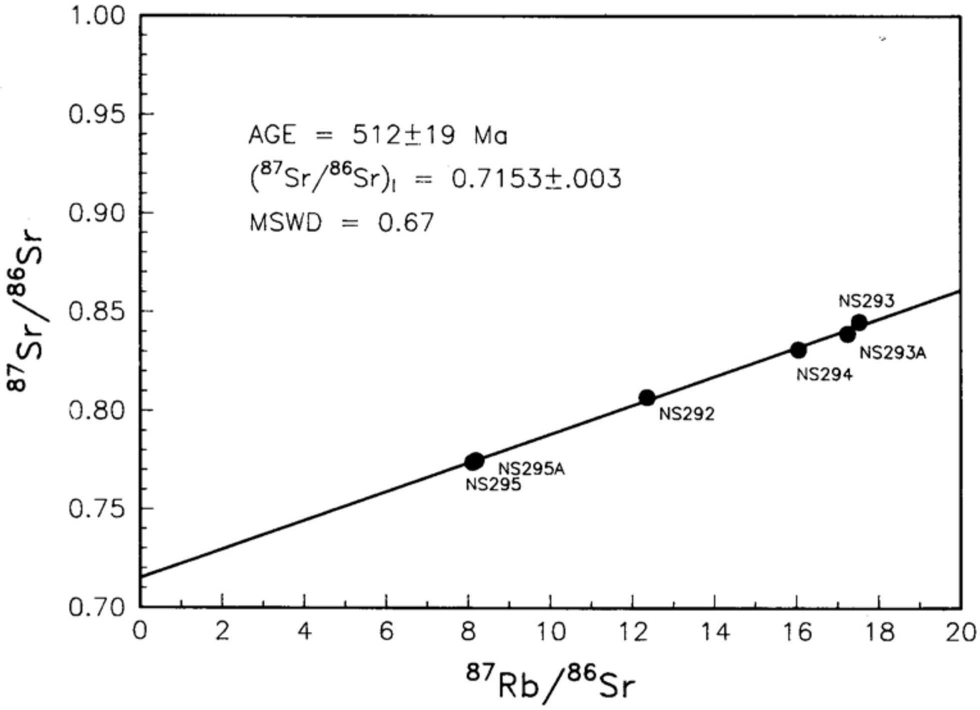

Figure 3: Rb-Sr whole-rock isochron for the Sandamap Noord leucogranite

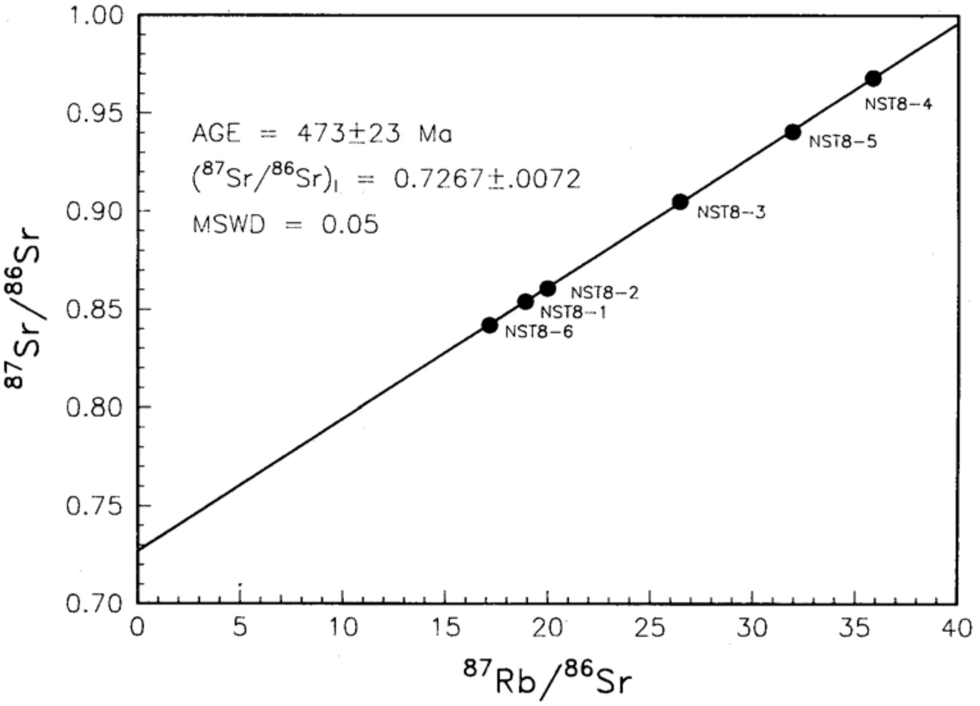

Figure 6: Rb-Sr isochron for non-stanniferous pegmatite from Sandamap Noord

assertions made by Steven (1992) that the Tubussis Lineament represents a terrane boundary, possibly a major thrust. Similarly, on the northern boundary of the CZ, late-/post-tectonic intrusions such as the Uis pegmatites on the northern side of the Autseib Fault-Otjihorongo Thrust are older than essentially undeformed intrusions hosted by relatively higher grade metamorphic rocks to the south (Fig. 1).

Table 3: Ages of late- to post-tectonic mineralised intrusions and mineralisation in the CZ

Locality	Style of Mineralisation	Lithology Dated	Method	Age (Ma)	(^{87}Sr/^{86}Sr)$_I$	Ref.
Rössing Mine	Uraniferous alaskite	Early alaskite	Rb-Sr (WR)	510	N.A.	1
Rössing Mine	Uraniferous alaskite	Late alaskite	Rb-Sr (WR)	458±8	0.759	2
Stinkbank	Uraniferous leucogranite and scheelite skarn	Leucogranite	Rb-Sr (WR)	484±25	0.739	3,4
Otjua Prospect	Scheelite skarn	Leucogranite	Rb-Sr (WR)	478±4	0.7196	4, 5
Gamigab Prosp.	Cassiterite veins	Muscovite	Rb-Sr (Ms)	510	-	6,7
Uis Mine	Stanniferous pegmatite	Pegmatite	Rb-Sr (WR)	496±30	0.734	8
Kohero Mine	Stanniferous pegmatite	Pegmatite	Rb-Sr (WR)	492±11	0.7256	9
Sandamap Mine	Stanniferous pegmatite	Pegmatite	Rb-Sr (WR)	468±14	0.7231	9
Rubicon Mine	Petalite (Li) pegmatite	Pegmatite	Rb-Sr (Amb, Kfs, Ms)	515±36	0.736	8
Navachab Mine	Gold skarn	Biotite	Rb-Sr (Bt)	490	-	10

Amb - Amblygonite; Bt - Biotite; Kfs - K-feldspar; Ms - Muscovite; WR - Whole rock; N.A. - Not available
References: 1 = Hawkesworth *et al.*, 1983; 2 = Kröner and Hawkesworth, 1977; 3 = Marlow, 1983; 4 = Steven, 1987; 5 = Haack *et al.*, 1983; 6 = Jacob, 1990, pers. comm.; 7 = Walraven, 1988; 8 = Haack and Gohn, 1988; 9 = Steven, 1993; 10 = Navachab Gold Mine Field Guide, 1989

Rb-Sr mineral results

Biotites from the two phases of the Ohere Dos Salem granite were analysed. The two analyses define an isochron with an age of 435 Ma (Fig. 8). This is interpreted as the time when the intrusion cooled through the blocking temperature for biotite of 300°C (Jäger *et al.*, 1967). This compares with biotite ages of 475-442 Ma determined by Hawkesworth *et al.* (1983) for central Namibia.

The relationship between leucogranite and stanniferous pegmatites on Sandamap Noord.

On Sandamap Noord, unzoned quartz-feldspar pegmatites, zoned rare-element pegmatites (defined as pegmatites enriched in Li, Rb, Cs, Be, Ta, Sn, Nb; Cerny, 1982a) and arsenic mineralisation are concentrically and successively arranged around a leucogranite-cored domal structure, while galena and auriferous quartz veins and hydrothermal alteration are confined to the northwestern side (Steven, 1991). This spatial relationship between leucogranites and stanniferous pegmatites has been recorded elsewhere in the Sandamap-Davib Ost tin belt (Watson, 1982) and similar processes may have produced other rare-element pegmatites in the orogen, notably the lithium pegmatites of the SCZ. The question as to whether the tin pegmatites are the products of the anatexis of Kuiseb Formation schist or late differentiates of the Sandamap Noord leucogranite may be addressed. The situation on Sandamap Noord invites comparison with other rare-element pegmatites (REP) which are spatially associated with leucogranites in andalusite-sillimanite terrains (Cerny, 1982b). The REP “provide the most convincing evidence for a genetic link [between pegmatites and] granites” (Cerny, 1982a), being generated from the fractionation of differentiated, allochthonous intrusions.

On Sandamap Noord, in contrast the relationship between the leucogranite and the pegmatites is not clear. The homogenous leucogranite phacolith has a banding, rather than a foliation, and rounded, partially recrystallised grains; the pegmatites possess neither of these. If the banding is interpreted as a fabric resulting from tectonism (D_2 deformation), then the leucogranite significantly predated pegmatite intrusion and the latter are unlikely to be differentiates of the leucogranite. If, however, the banding is interpreted as a fabric that developed during the diapiric development of the dome, then the leucogranite may not be so different in age from the pegmatite.

Moreover, the meaning of the Rb-Sr whole-rock dates of the pegmatites is equivocal. The leucogranite has a Rb-Sr whole-rock date of 512 ± 19 Ma which is interpreted to be the age of crystallisation. The pegmatites have significantly younger dates (473 ± 23 Ma and 468 ± 14 Ma), but their ages of emplacement may be considerably older. The large difference in $(^{87}Sr/^{86}Sr)_I$ ratio between the leucogranite (0.75 and the pegmatites (0.7267 and 0.7238) seems to preclude the possibility that either of the pegmatite types are differentiates of the phacolith, but the significance of this can only be discussed once the ages of crystallisation are more

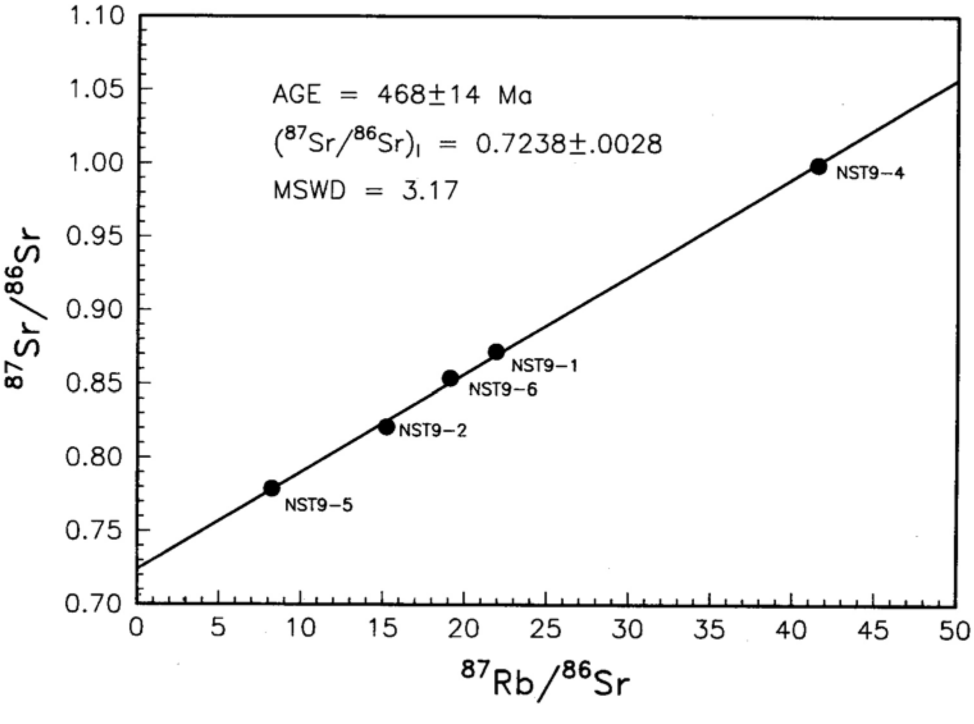

Figure 7: Rb-Sr whole-rock isochron for stanniferous pegmatite from Sandamap Tin Mine

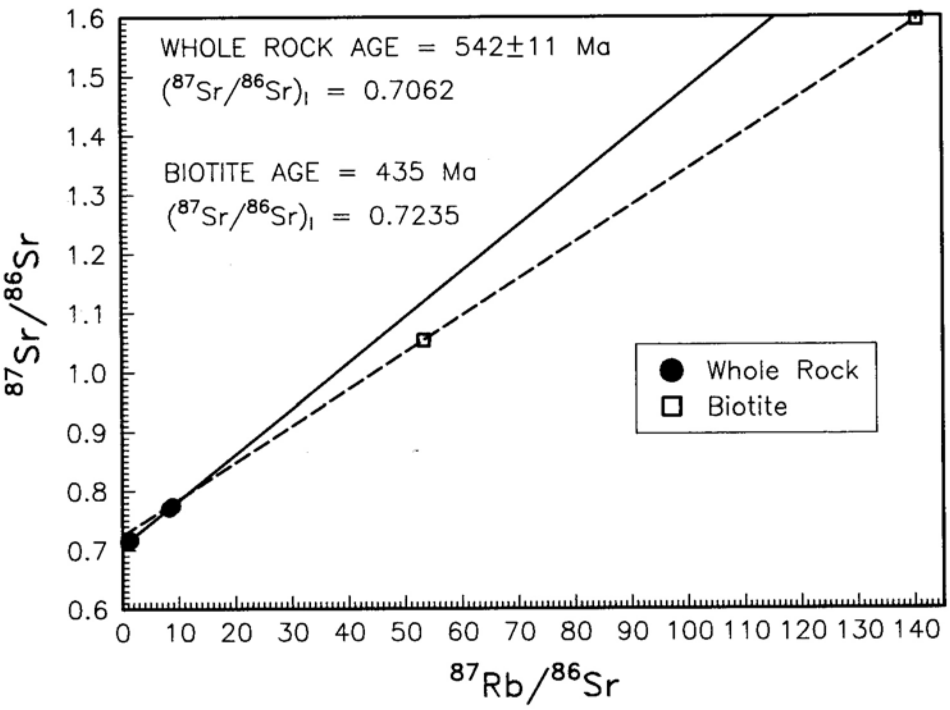

Figure 8: Rb-Sr isochrons (WR and minerals) for the Ohere Oos Salem granite

accurately known. Anomalous, and particularly high, $(^{87}Sr/^{86}Sr)_I$ values are a feature of pegmatites worldwide (Clark, 1982).

Haack and Gohn (1988) argued that the stanniferous pegmatites of central Namibia were derived from the disequilibrium melting of biotite and/or muscovite in metasediments during and slightly after the peak of regional metamorphism. This process is believed to have been enhanced by the Buchan-style metamorphism associated with the large number of syn-/late-tectonic granitic intrusions. It would seem unlikely that this happened at the present-day erosional level because peak metamorphic conditions (~3 kbar, 650°C) were not high enough for partial melting to have occurred (Steven, 1992). In general, REP are not formed by regional metamorphic processes, but are thought to have been generated at intermediate depths (3.5-7 km, i.e. 0.9-2.2 kbar) from the differentiation of granites (Cerny, 1982a, 1982b). Cerny distinguished between the “sterile” granitoids, which comprise the bulk of a batholithic assemblage, and the rarer, predominantly S-type “fertile” granites which are the parents to REP (Cerny and Meintzer, 1988). These fertile granites occur in compressional regimes of orogenic chains, in low-pressure terrains, are hosted by lower-amphibolite facies rocks above the zone of anatexis and commonly posta ate the peak of regional metamorphism and batholithic granitoids (Cerny and Meintzer, 1988).

The flat topography and poor exposure on Sandamap Noord precludes an examination of the leucogranite to determine whether the intrusion is as compositionally inhomogenous as most REP-generating granites. The three pieces of evidence that indicate that it is a fertile granite, at least in Damaran terms, are the presence of magmatic muscovite, the rare stringers of apatite and the high $(^{87}Sr/^{86}Sr)_I$ ratio. Whether the pegmatites and hydrothermal alteration are derived from residual fluids in the leucogranite or from the large-scale anatexis of Kuiseb Formation metasediments below the present-day erosional level cannot be determined because of the depth of erosion, poor exposure and ambiguous isotopic data. However, the strong stratigraphic control on the types of pegmatite in the CZ (Steven, 1993) and in particular the restriction of certain types of REP to specific stratigraphic levels (especially the tin pegmatites in the Kuiseb Formation), indicate that, even if the REP of the CZ are the products of igneous fractionation of granitic melts and not the products of anatexis, there has been considerable interaction with fluids in the country rock.

Mineralisation and the younger intrusions

Throughout the CZ, mineralisation is either hosted by, or spatially associated with, the younger intrusions. Granitoids of the Salem Suite and the older, deformed (D_1 and D_2) leucogranites are generally not of economic interest. The only two examples of CZ Salem Suite intrusions known to be partly responsible for epigenetic mineralisation are the Omangambo and Ohere Oos plutons (Fig. 1), in the aureoles of which massive skarns at the Ais Dome (Miller, 1980) and the scheelite skarnoid rocks on Ohere (Steven, 1992) are respectively developed. Uranium mineralisation in central Namibia is hosted by leucogranites and alaskites that are 510 Ma old or younger (Table 3). Tungsten skarn mineralisation on Stinkbank and at the Otjua Prospect (Steven, 1987; Fig. 1) is spatially associated with syn-D_3 leucogranites. Whole-rock Rb-Sr dates for stanniferous pegmatites are now available for the Sandamap-Davib Ost (CZ), Nainais-Kohero (CZ) and Strathmore-Uis (NZ) tin belts (Table 3 and Fig. 1): all the tin pegmatites have late-tectonic Damaran emplacement ages. In the NZ, the stanniferous pegmatite at Uis and muscovite from cassiterite veins at the Gamigab tin prospect to the northwest of Uis (Walraven, 1988) have Rb-Sr ages slightly older than the tin pegmatites hosted by amphibolite-facies rocks in the CZ (muscovite ages are identical to whole-rock ages elsewhere in the Damara, for example the Donkerhuk granite; Blaxland *et al.*, 1979). There is no evidence from the results presented above and other recently reported data on stanniferous pegmatites (Haack and Gohn, 1988) for the modification of Damaran stanniferous pegmatites by post-Karoo “greisenising fluids” as suggested by Pirajno *et al.* (1988). Lithium-bearing pegmatite at the Rubicon Mine also has a late-tectonic Damaran age (Haack and Gohn, 1988).

Granite and pegmatite petrogenesis and the isotopic evolution of the CZ

The isotopic evolution of the orogen has already been addressed by Hawkseworth and Marlow (1983), but the small data set presented here emphasises some important points about the intrusions of the CZ. There is a general trend towards more evolved granite types and an increase in $(^{87}Sr/^{86}Sr)_I$ ratios with time, a fact Hawkesworth *et al.* (1983) attributed to the partial melting of crustal material at higher structural levels as the orogeny progressed. The new data confirm Hawkesworth *et al.*’s (1983) contention that the younger ages are concentrated in the centre of the orogen, that is the CZ. Prograde metamorphism continued in the CZ 40-50 Ma after the margins of the orogen had started to cool (Hawkesworth *et al.*, 1983). Buchan-style metamorphism was responsible for the partial melting of basement and Nosib Group metaquartzites in the SCZ to form the uraniferous intrusions. Partial melting of Kuiseb Formation schists in the NCZ may have played a role in the formation of stanniferous pegmatites.

All granitic intrusions in the CZ, with the exception of the D_2 leucogranite on Sandamap Noord, have the trace element characteristics of intraplate or intracratonic intrusions (Steven, 1992), but the early tectonic Salem Suite granitoids have $(^{87}Sr/^{86}Sr)_I$ ratios similar to the magmas generated along destructive plate margins such as the Andes (Hawkesworth, 1982). The Salem Suite granitoids are the only intrusions in the CZ that could have been derived from the mantle or the lower crust. The post-collision (530-460 Ma) intrusions of the CZ are nearly all S-type granites, if not leucogranites, have a restricted compositional range (Steven, 1992) and generally have high $(^{87}Sr/^{86}Sr)_I$ and $\delta^{18}O$ values (Haack *et al.*, 1983). Only the synmetamorphic peak D_2 leucogranites contain substantial magmatic muscovite. The pressure limitations on the ascent of peraluminous granite are well documented (Zen, 1988): pressures of 3-4 kbars were only attained during the regional metamorphic peak. The isotopic characteristics of the CZ intrusions indicate that the major portion of the magmatic zone of the orogen developed as the result of high-grade thermal metamorphism of metasediments and underlying granitic crust in an intracratonic setting, not as the result of subduction and subsequent partial melting of oceanic crust. This is reflected in the ensialic nature of the CZ mineral deposits.

Acknowledgements

This research was supported by Gold Fields South Africa and Gold Fields Namibia. Nick Steven also acknowledges receipt of a CSIR bursary. Chandra Harris and Move Steven are thanked for help in the laboratory and draughting room respectively.

References

Blaxland, A., Gohn, E., Haack, U. and Hoffer, E. 1979. Rb/Sr ages of late-tectonic granites in the Damara Orogen, South West Africa/Namibia. *Neues Jahrb. Mineral. Monatsh*., **11**, 498-508.

Cerny, P. 1982a. Anatomy and classification of granitic pegmatites, 1-39. *In*: Cerny, P., Ed., *Granitic pegmatites in science and industry*. Mineralog. Assoc. Can. Short Course Handb. vol. **8**, Winnipeg, 555 pp.

Cerny, P. 1982b. Petrogenesis of granitic pegmatites, 405-461. *In*: Cerny, P., Ed., *Granitic pegmatites in science and industry*. Mineralog. Assoc. Can. Short Course Handb. vol. **8**, Winnipeg, 555 pp.

Cerny, P. and Meintzer, R.E. 1988. Pertile granites in the Archean and Proterozoic fields of rare-element pegmatites: crustal environment, geochemistry and petrogenetic relationships. *In*: Taylor, R.P. and Strong, D.P., Eds, *Recent advances in the geology of granite-related mineral deposits*. Can. Inst. Min. Metall., Spec. vol. **39**, 170-207.

Clark, G.S. 1982. Rubidium-strontium isotope systematics of complex granite pegmatites, 347-371. *In*: Cerny, P., Ed, *Granitic pegmatites in science and industry*. Mineralog. Assoc. Can. short Course handb. vol. **8**, Winnipeg, 555 pp.

Corner, B. 1983. An interpretation of the aeromagnetic data covering the western portion of the Damara Orogen in S.W.A./Namibia. *Special Publn, geol. Soc. S.Afr*., **11**, 339-354.

Eglington, B.E. and Harmer, J.E. 1991. GEODATE (Version 2.2): a program for the processing and regression of isotope data using IBM-compatible microcomputers. *CSIR Manual EMA-H9101*, 57 pp.

Haack, U. and Gohn, E. 1988. Rb-Sr Data on some pegmatites in the Damara Orogen. *Communs geol. Surv. Namibia*, **4**, 13-18.

Haack, U, Gohn, E., Klein, J.A. 1980. Rb/Sr ages of granitic rocks along the middle reaches of the Omaruru River and the timing of orogenic events in the Damara belt (Namibia). *Contrib. Mineral. Petrol.*, **74**, 349-360.

Haack, U., Hoefs, J. and Gohn, E. 1983. Genesis of Damaran granites in the light of Rb/Sr and $\delta^{18}0$ data, 847-872. *In*: Martin, H. and Eder, P.W., Eds, *Intracontinental Fold Belts*. Springer Verlag, Berlin, Heidelberg, 945 pp.

Hawkesworth, C.J. 1982. Isotopic characteristics of magmas erupted along destructive plate margins, 549-571. In: Thorpe, R.S., Ed., *Orogenic andesites*. Wiley Intersciences, New York, 724 pp.

Hawkesworth, C.J. and Marlow, A.G. 1983. Isotope evolution of the Damara Orogenic Belt. *Special Publn geol. Soc. S.Afr.*, **11**, 397-408.

Hawkesworth, C.J., Gledhill, A.R., Roddick, J.C., Miller, R. McG. and Kröner, A. 1983. Rb-Sr and ^{40}Ar/^{39}Ar studies on models for the thermal evolution of the Damara belt, Namibia. *Special Publn geol. Soc. S. Afr.*, **11**, 323-338.

Jäger, E., Niggli, E. and Wenk, E. 1967. Rb-Sr Alterbestimmungenan Glimmern der Zentralalpen. *Beit. zur geol. karte, Schweiz*, **NF134**, Bern, 1-67.

Kröner, A and Hawkesworth, C. 1977. Late Pan-African emplacement ages for Rössing alaskitic granite (Damara belt) and Rooi Lepel bostonite (Gariep belt) in Namibia and their significance for the timing of metamorphic events. *Twentieth Annual Report of the Research institute for African Geology, University of Leeds*, 14-17.

Marlow, A.G. 1983. Geology and Rb-Sr Geochronology of mineralised and radioactive granites and alaskites, Namibia. *Special Publn geol. Soc. S.Afr.*, **11**, 289-298.

Miller, R.McG. 1980. Geology of a portion of Central Damaraland. *Mem. geol. Surv. S.A., S.W.A. Series*, **6**, 78 pp.

Miller, R.McG. 1983. The Pan-African Damara Orogen of S.W.A/Namibia. *Special Publn geol. Soc. S.Afr.*, **11**, 431-515.

Miller, R.McG. and Burger, A.J. 1983. U-Pb zircon ages of members of the Salem granitic suite along the northern edge of the central Damaran granite belt. *Special Publn geol. Soc. S.Afr.*, **11**, 273-280.

Miller, R.McG. and Grote, W. 1988. *Geological Map of the Damara Orogen, 1:500,000*. Map accompanying 'Evolution of the Damara Orogen of S.W.A./Namibia, Special Publication of the geological Society of South Africa, Number 11. Geological Society of South Africa, Johannesburg, 515 pp.

Navachab Gold Mine Field Guide, 1989. Prepared for the Geological Society of Namibia by Erongo Mining and Exploration Company.

Pirajno, F., Petzel, V.PW. and Jacob, R.E. 1988. Geology and alteration-mineralisation of the Brandberg West Sn-W deposit, Damara Orogen. *S. Afr. Jour. Geol.*, **90**(3), 256-269.

Steven, N.M. 1987. *Tungsten mineralisation at the Otjua Prospect: A geological and geochemical investigation*. Unpubl. M.Sc. thesis, University of Cape Town, 152 pp.

Steven, N.M. 1991. Turbidite-hosted gold mineralisation at the Sandamap Noord prospect, central Namibia, 567-574. In: Ladeira, E.A., Ed., *Proceedings of Brazil Gold '91, An International Symposium on the Geology of Gold: Belo Horizonte, 1991*. Balkema, Rotterdam, Holland 823 pp.

Steven, N.M. 1992. *A study of epigenetic mineralisation in the Central Zone of the Damara Orogen, Namibia with special reference to gold, tungsten, tin and rare earth elements*. Unpubl. Ph.D. thesis, University of Cape Town, 221 pp.

Walraven, F.C. 1988. Geology and alteration-mineralisation in the Gamigab area, north of Brandberg. *Communs geol. Surv., Namibia*, **4**, 83-88.

Watson, N.I. 1982. *Unpublished report on the geology of area 211SC*. Geological Survey of S.W.A.

Zen, E-an. 1988. Phase relations of peraluminous granitic rocks and their petrogenetic implications. *Ann. Review Earth Planet. Sci.*, **16**, 21-51.