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Rb-Sr AGES OF GRANITOIDS IN THE REHOBOTH-NAUCHAS AREA, SOUTH WEST AFRICA/NAMIBIA

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ABSTRACT

Rb-Sr ages have been obtained for several pre-Damaran granitoid suites that intrude various volcano-sedimentary sequences in the Rehoboth region of South West Africa/Namibia. Two major periods of granitoid emplacement are indicated by the results: (1) an older 1800-1600 Ma event so far only recognized in a small part of the region near Rehoboth, and (2) a younger 1 200-1 000 Ma event which is widespread throughout the region and represents a major magmatic episode, at least in terms of volume of products involved. The older granitoids include the Naub Diorite (1 725 ± 52 Ma) and the Swartmodder Granite (1639 ± 25 Ma), while the Biesiepoort Granite (1 222 ± 45 Ma), Piksteel Granodiorite (1170 ± 20 Ma) and Gamsberg Granite (1 079 ± 25 Ma) represent members of the voluminous younger granitoids. The Weener Quartz Diorite may also be part of the younger granitoid event (dated at 1 207 ± 170 Ma), but an older age of ~1 800 Ma cannot be ruled out. Agreement with published zircon U-Pb ages is variable, but detailed comparison is precluded by the incomplete nature of the published zircon data. Initial Sr isotope ratios indicate that the older granitoids may have been derived from pre-existing crust not much older than ~2 000 Ma, and that the younger granitoids showed increasing involvement of older continental crust with time.

1. INTRODUCTION

Attempts to elucidate the pre-Damaran geological history of South West Africa have often been based on unravelling the complex stratigraphic relations in the Rehoboth region. As a contribution to the timing of pre-Damaran igneous, sedimentary and metamorphic events in this important region, several granitoid suites have been investigated using the Rb-Sr method. Where possible the samples have been collected from localities showing the least equivocal field relations, which has often resulted in restricting the study to small areas. This has been especially so in the Nauchas area for example (Fig. 1).

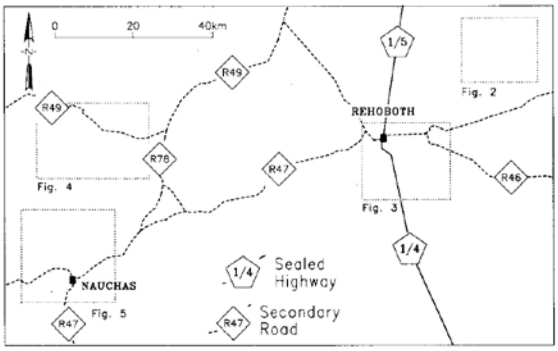

Fig. 1: General locality map of the Rehoboth region, showing major roads and the areas covered by the detailed locality maps.

The most recent stratigraphic analysis of the pre-Damaran in the Rehoboth region was published in SACS (1980), and has been followed in the compilation

TABLE 1: Pre-Damaran stratigraphy of the Rehoboth region. Based on SACS (1980), Borg and Maiden (1986) and Schalk (unpubl.)

VOLCANO-SEDIMENTARY UNITS		INTRUSIVE UNITS
Klein Aub Formation		
Doornpoort Formation	Sinclair Group	Gamsberg Granite Suite
Grauwater Formation		
Dordabis Formation		
Nükopf Formation		
	Piksteel Granodiorite Suite	
	Naub Diorite	
	Weener Quartz Diorite	
	Alberta Complex	
Gaub Valley Formation		
Billstein Formation	Rehoboth Group	
Marienhof Formation		
Elim Formation	Pre-Rehoboth	
Neuhof Formation	Sequences	
Mooirivier Formation		

of the 1: 250 000 geological sheet (Schalk, unpubl.). The stratigraphy presented in Table 1 contains units formally recognized and proposed, but not in the temporal order indicated by the age data presented in this paper.

2. RESULTS

Analytical data obtained during the whole rock Rb-Sr study appear in Table 2 and the general locality of samples collected is shown in Figs 1-5. Rb and Sr concentrations were determined by XRF at UCT using techniques similar to those described in Duncan *et al.* (1984). Sr isotope ratios were measured by mass spectrometry at the BPI using standard techniques (e.g. Allsopp *et al.*, 1979). A summary of Rb-Sr isochron ages appears in Table 3, together with details of regression procedures adopted. Rb-Sr isochrons have been distinguished from errorchrons using a cut-off value of 2,5 for the MSUM

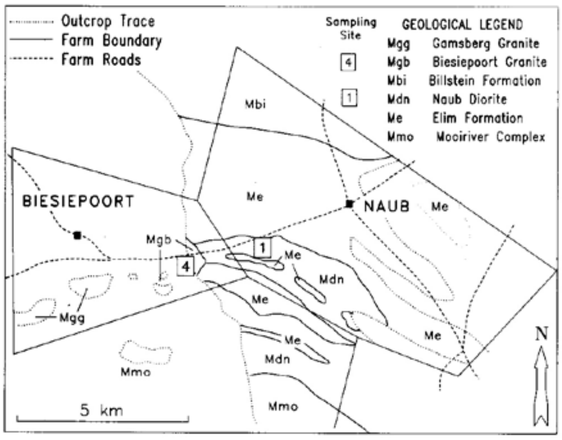

Fig. 2: Simplified geologic map of the Biesiepoort–Naub area, showing sample locations for the Naub Diorite (1) and Biesiepoort Granite (4). Geology on this map and on Figs 4 and 5 after Schalk (unpubl.).

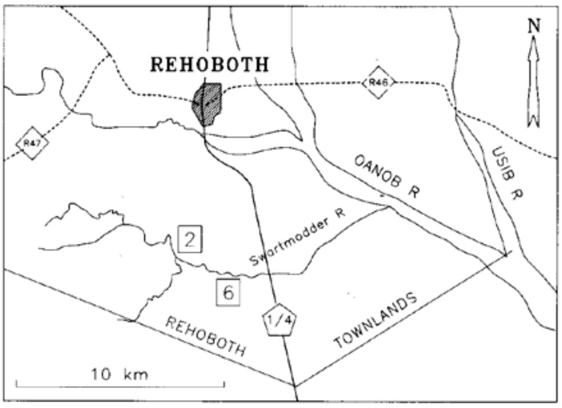

Fig. 3: Detailed locality map of the southern part of the Rehoboth townlands, showing sample locations of the Swartmodder Granite (2) and Piksteel Granodiorite (6).

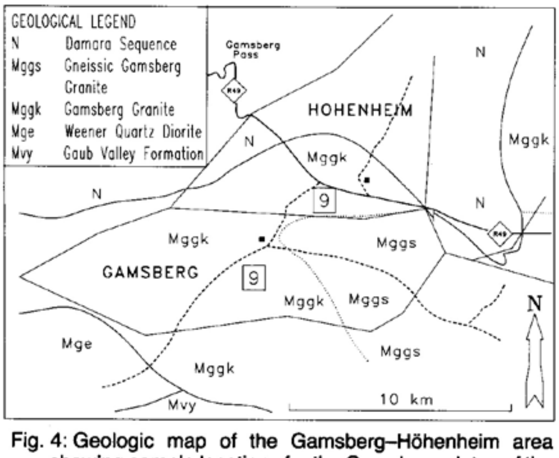

Fig. 4: Geologic map of the Gamsberg–Höhenheim area showing sample locations for the Gamsberg pluton of the Gamsberg Granite Suite.

TABLE 2: Rb and Sr data obtained during the present study

	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
NAUB DIORITE					
SM7630C	26,4	269	0,0981	0,283	0,71108
SM7630G	23,8	217	0,1098	0,317	0,71222
SM7630A	29,1	215	0,135	0,390	0,71364
SM7630	54,0	188	0,288	0,833	0,72500
NaDiBi	49,5	190	0,260	0,753	0,72261
SWARTMODDER GRANITE					
SM1236	115	186	0,618	1,793	0,75026
SM1172	58,3	118	0,494	1,43	0,74160
SM2193	81,1	143	0,566	1,642	0,74600
SM1083	98,3	547	0,19	0,521	0,72030
SM1135	99,2	107	0,925	2,689	0,77230
SM1050	120	116	1,037	3,011	0,77870
ALBERTA MAFIC COMPLEX					
SM7640C	34,7	271	0,128	0,370	0,70942
SM7642	192	632	0,304	0,879	0,72009
SM7642B	0,73	679	0,00108	0,003	0,70190
SM7642C	<0,2	634	—	—	0,70186
BIESIEPOORT GRANITE					
Bi-1	129	295	0,437	1,264	0,72720
Bi-2	158	242	0,654	1,893	0,73780
Bi-3	143	301	0,475	1,375	0,72846
SM76125	140	161	0,874	2,533	0,74910
SM76126	92,0	290	0,317	0,917	0,71996
SM76127	81,0	277	0,292	0,845	0,71923
SM76128	186	105	1,774	5,166	0,79303
WEENER QUARTZ DIORITE					
SM76146	47,9	781	0,060	0,176	0,70720
SM7651A	65,3	761	0,0858	0,247	0,70836
SM7651B	72,0	754	0,0955	0,280	0,70896
SM7651B2	72,7	729	0,0991	0,289	0,70920
SM7651D	69,5	739	0,094	0,275	0,70890
PIKSTEEL GRANODIORITE					
SM76–9	262	107	2,44	7,13	0,82740
SM76–8II	164	116	1,417	4,12	0,77918
SM76—8I	162	111	1,463	4,25	0,78180
SM76–5	202	451	0,449	1,30	0,73124
SM76154	162	134	1,21	3,49	0,76720
GAMSBERG GRANITE					
Nauchas Pluton					
SM064	285	26,9	10,59	32,05	1,19910
SMAG41	308	30,3	10,16	30,43	1,18430
SMAG42	289	34,1	8,476	25,4	1,09110
SM7641	208	279	0,745	2,16	0,74140
Namibgrens Pluton					
SM066	284	40,5	7,022	20,90	1,03000
SM7635	158	217	0,728	2,11	0,73960
SM7636	173	200	0,866	2,51	0,74690
SM76117	160	142	1,08	3,13	0,75800
SM76120	154	155	0,995	2,89	0,75350
Gamsberg Pluton					
SM76125G	126	149	1,18	3,42	0,76192
SM76123	327	16,1	20,34	64,23	1,66310
SM76124	310	11,6	26,63	86,31	1,89630
SM76125a	144	148	0,972	2,884	0,75194
SM76123A	299	12,9	23,29	73,50	1,70310
POST-GAMSBERG GRANITE MAFIC DYKES					
SM76130D2	8,93	360	0,0256	0,072	0,70750
AD21	10,6	191	0,0553	0,160	0,70868
AD22	21,3	342	0,962	0,180	0,70916
NAMD2	9,4	206	0,0457	0,132	0,70834
POST-GAMSBERG GRANITE ACID DYKES					
P2A	17,8	140	0,124	0,369	0,73641
P2B	30,0	123	0,245	0,709	0,74112
SRM16	146	106	1,378	4,005	0,77350
76118	69,1	43,9	1,574	4,595	0,79401
7639	181	220	0,824	2,390	0,77141

TABLE 3: Summary of Rb-Sr ages obtained during the present study

ROCK TYPE	AGE (Ma)	R_o	MSUM (N)
Post-Gamsberg Granite Mafic Dykes	1 030 ± 185	0,7064 ± 4	0,71 (4)
Gamsberg Granite (Gamsberg Pluton)	984 ± 55	0,7123 ± 39	21,04 (5)
Gamsberg Granite (Nauchas Pluton)	1 073 ± 25	0,7082 ± 16	3,48 (4)
Gamsberg Granite (Namibgrens Pluton)	1 096 ± 62	0,7075 ± 25	6,87 (5)
Gamsberg Granite (Combined Nauchas/ Namibgrens Plutons)	1 079 ± 25	0,7081 ± 12	4,39 (9)
Piksteel Granodiorite	1 170 ± 20	0,7095± 7	2,21 (5)
Weener Quartz Diorite	1 207 ± 170	0,7041± 6	0,16 (5)
Biesiepoort Granite	1 222 ± 45	0,7044 ± 9	3,82 (7)
Biesiepoort/Weener	1 238 ± 13	0,70406 ± 13	2,16 (7)
Alberta Mafic Complex	1 442 ± 32	0,70183 ± 14	0,23 (4)
SwartmodderGranite	1 639 ± 25	0,7080 ± 4	1,30 (6)
Naub Diorite	1 725 ± 52	0,7041 ± 3	2,03 (5)

Ages calculated using regression method of York (1969). Error assigned to $^{87}Rb/^{86}Sr$ = 1,0 %; to $^{87}Sr/^{86}Sr$ = 0,015 %. Regression errors are two sigma where the MSUM <2,5 and augmented by SQRT (MSUM) when MSUM >2,5. Decay constant and isotopic ratios after Steiger and Jäger (1977).

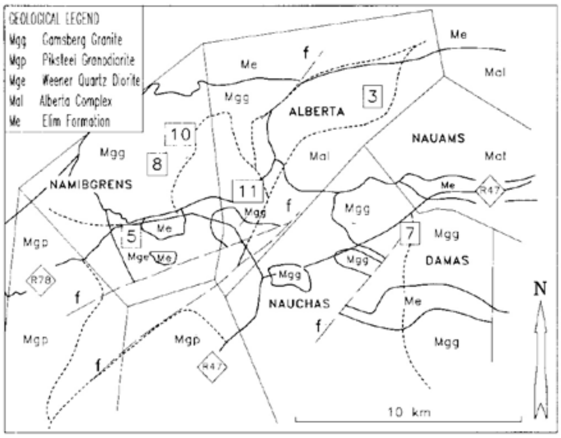

Fig. 5: Geologic map of the Nauchas area showing sample locations of the Alberta basic complex (3), Weener Quartz Diorite (5), Nauchas pluton (7) and the Namibgrens pluton of the Gamsberg Granite Suite (8), basic dykes (10) and acid quartz porphyry dykes (11) cutting the Gamsberg Granite. Major faults are labelled with 'f'.

value (York, 1969; Brooks *et al*., 1972).

2.1 Naub Diorite

The Naub Diorite was sampled where this rock type forms a body straddling the boundary between Naub 274 and Biesiepoort 275 (23°06'S, 17°04'E, Fig. 2). The rock is a mesocratic hornblende-biotite gneiss with an intense, near vertical foliation striking mainly south-east, but which swings nearly east-west, dipping steeply north where it is intruded by the younger Biesiepoort Granite (Schalk, unpubl.). The intense foliation in the Naub Diorite is shared by the Elim Formation metasediments and metavolcanics in this locality, and therefore suggests a pre- to early syntectonic intrusive relationship (Hoffmann, pers. comm., 1988). Contacts are diffuse but the diorite is full of rafts of Elim rocks. Inclusions of hornblendite and melagabbro also occur in the Naub Diorite, and may be derived from a large ultramafic body nearby, which has also intruded the Elim Formation. Five samples of the Naub Diorite define a Rb-Sr isochron (MSUM = 2,03, Fig. 6) with an age of 1 725 ± 52 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,7041 ±3.

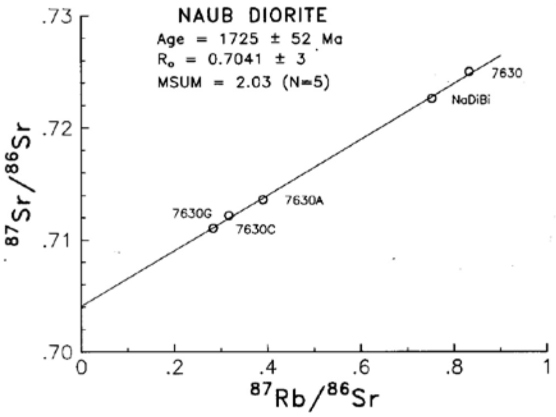

Fig. 6: Rb-Sr isochron diagram for the Naub Diorite (granodiorite gneiss). Labels on this and all subsequent Rb-Sr diagrams are abbreviated sample numbers.

2.2 Swartmodder Granite

The Swartmodder Granite does not feature in the stratigraphic column published in SACS (1980), and appears to have been included within the Piksteel Granodiorite (Schalk, unpubl.). The granite intrudes the Marienhof Formation in the southern portion of the Rehoboth town lands (23°28'S, 17°04'E, Fig. 3), just west of the main highway (N1/4). Petrographically the Swartmodder Granite is leucocratic and shows a

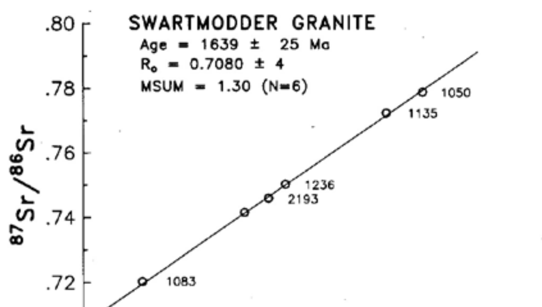

Fig. 7: Rb-Sr isochron diagram for the Swartmodder Granite.

variably developed foliation, which makes it difficult to distinguish from other similar granitoids that occur throughout the region. A pluton of the Piksteel Granodiorite Suite has intruded the Swartmodder Granite. Samples of Swartmodder Granite used in this study were obtained from Falconbridge Ltd., Windhoek, who provided fresh unweathered drill core. Six samples define a Rb-Sr isochron (MSUM = 1,30, Fig. 7), with an age of 1639 ± 25 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,7080 ± 4.

2.3 Alberta mafic complex

The mafic to ultramafic Alberta complex has intruded the Elim Formation, but has in turn been intruded by the Piksteel and Gamsberg granitoids. Fresh material suitable for Rb-Sr dating purposes is difficult to collect and the results reported here are only preliminary. Two anorthosites and two metagabbros sampled from the complex on Alberta (23°24'S, 16°20'E, Fig. 5) define a Rb-Sr isochron (MSUM 0,23, Fig. 8), with an age of 1 442 ± 32 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,70183 ± 14.

2.4 Biesiepoort Granite

The Biesiepoort Granite was sampled on Biesiepoort 275 (23°06'S, 17°21 'E) where it occurs as an adamellitic granite, weakly foliated in places, which has intruded the Naub Diorite (Fig. 2). Contacts are knife sharp and cut across the intense foliation in the Naub Diorite (Hoffmann, pers. comm., 1988). Seven samples define a Rb-Sr errorchron (MSUM = 3,82, Fig. 9), with an age of 1 222 ± 45 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,7044 ± 9.

2.5 Weener Quartz Diorite

The Weener Quartz Diorite was sampled from a pluton (consisting mainly of tonalite) on Namibgrens 154 (23°37'S, 16°14'W, Fig. 5) just south of an intrusive contact with a younger granitoid (Namibgrens pluton of the Gamsberg Granite Suite). Further south-west this Weener tonalite body is complexly intruded by the Piksteel Granodiorite. The locality on Namibgrens 154 is not the type locality of the Weener Quartz Diorite, which is further north on Weener 193, but the lack of pronounced foliation made the Namibgrens pluton a better candidate for the Rb-Sr study. Numerous and characteristic mafic xenoliths occur in the outcrops sampled and despite attempts to avoid them, some incorporation may have occurred. Five samples define a Rb-Sr isochron (MSUM = 0,16, Fig. 10), with an age of 1 207 ± 170 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,7041 ± 6. The samples all have low Rb/Sr ratios, and the range in Rb/Sr is small as well (note that the X-axis of the Rb-Sr diagram in Fig. 10 does not start at the origin), so the error in the age is very high, despite the low MSUM. Bearing in mind that this result is statistically within error of the Biesiepoort data, combination of the two rock types on a common Rb-Sr isochron (MSUM = 2,16) yields a more precise age of 1 283 ± 13 Ma and initial $^{87}Sr/^{86}Sr$ ratio of 0,70406 ± 13.

2.6 Piksteel granodiorite suite

A pluton mapped as part of this granitoid suite oc-

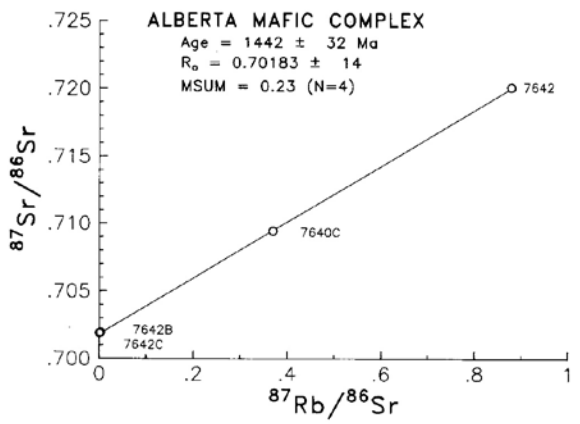

Fig. 8: Rb-Sr isochron diagram for the Alberta Complex.

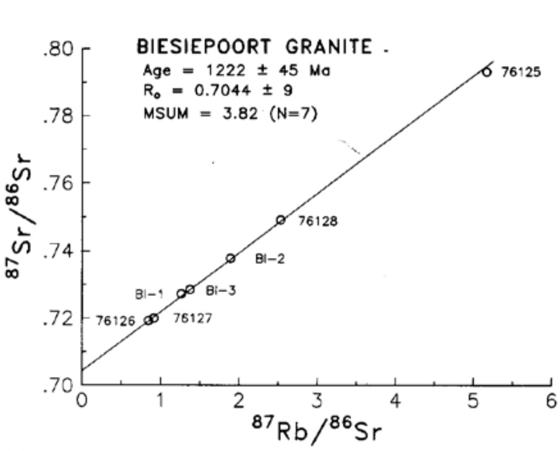

Fig. 9: Rb-Sr isochron diagram for the Biesiepoort Granite.

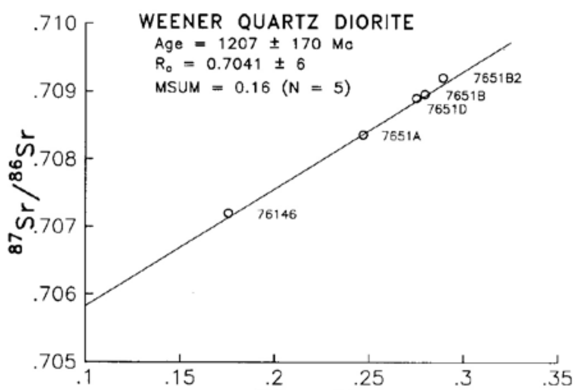

Fig. 10: Rb-Sr isochron diagram for the Weener Quartz Diorite (tonalite from Namibgrens). Note that the spread in data points has been accentuated by not starting the X-axis at the origin, which was necessitated by the very small spread in Rb/Sr ratios.

curs in the southern part of the Rehoboth townlands (23°25'S, 17°06'E, Fig. 3). The samples were collected on the Swartmodder River slightly downstream from the Swartmodder Granite locality described earlier. The Rehoboth locality was chosen in preference to the type locality on Piksteel 209 (some 100 km to the south-west) as the field relations were clearer in that a distinct pluton of the Piksteel Suite could be seen to have intruded both the Swartmodder Granite and the Marienhof Formation. Judging from previous descriptions (e.g. De Waal, 1966) the Piksteel granitoids contain a wide variety of rock types, largely migmatitic in character, and large relatively homogeneous plutons are rare. However, subsequent workers (e.g. Schalk, unpubl.) regard the "migmatitic Piksteel rocks" as part of a different unit, the Mooirivier Metamorphic Complex. The Piksteel Granodiorite has therefore been restricted to a recognizable suite of high-level plutons. Five samples from the Rehoboth locality define a Rb-Sr isochron (MSUM = 2,21, Fig. 11), with an age of 1 170 ± 20 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,7095 ± 7.

2.7 Gamsberg Granite Suite

The extensive development of the Gamsberg Granite Suite argued for the investigation of several separate plutons. The Gamsberg pluton was sampled near the highway between Windhoek and Walvis Bay (R49) on Höhenheim 25 (23°18'S, 16°24'E), and on the farm road to Gamsberg 24 (Fig. 4). Another pluton was sampled on Namibgrens 154 (23°36'S, 16°16'E, Fig. 5), while a third was sampled on Nauchas 14 (23°36'S, 16°24'E, Fig. 5). Several different Gamsberg suite granitoids occur on these latter two farms and in the case of Namibgrens, the sample locality was within the large pluton best exposed around the Drillingskuppen trigonometrical beacon. On Nauchas the sample locality was near the northern boundary with Nauams 177, just south of the road connecting the two farmhouses. The Gamsberg pluton defined a poor Rb-Sr errorchron (MSUM = 21,04, Fig. 12) and the calculated age (see

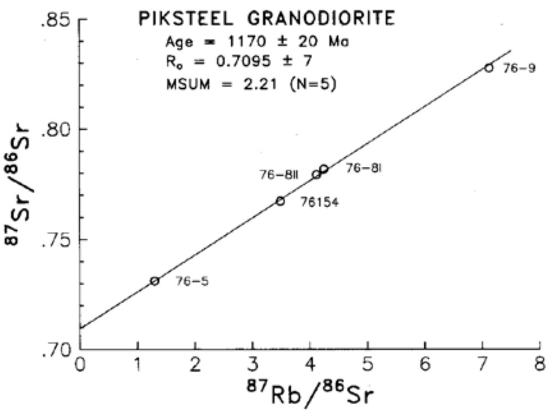

Fig. 11: Rb-Sr isochron diagram for the Piksteel Granodiorite.

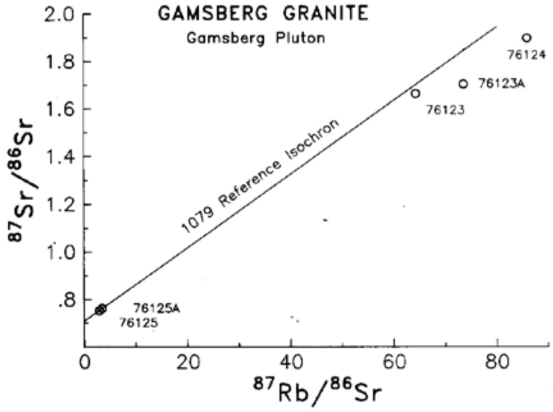

Fig. 12: Rb-Sr isochron diagram for the Gamsberg pluton of the Gamsberg Granite Suite. The data for this pluton shows considerable scatter, and the isochron obtained for the other two Gamsberg suite plutons (see Fig. 13) is plotted.

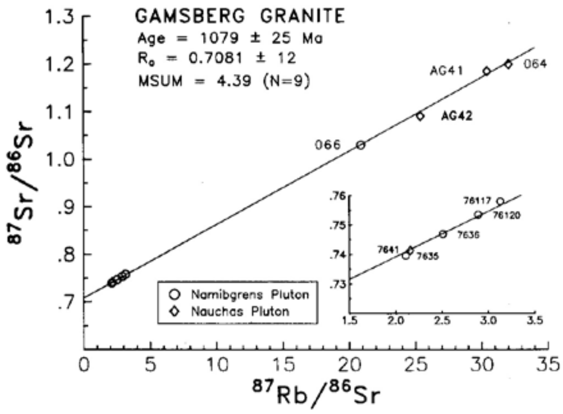

Fig. 13: Rb-Sr isochron diagram for the Namibgrens and Nauchas plutons of the Gamsberg Granite Suite.

Table 3) may have little significance. Better results were obtained for the other two plutons, with the Namibgrens data defining a Rb-Sr errorchron (MSUM = 6,87) with an age of 1 096 ± 62 Ma and initial $^{87}Sr/^{86}Sr$ ratio of 0,7075 ± 25. The Nauchas pluton yielded a Rb-Sr errorchron (MSUM = 3,48) with an age of 1 073 ± 25 Ma and initial $^{87}Sr/^{86}Sr$ ratio of 0,7082 ± 16. The Namibgrens and Nauchas results agree within error and their combination yields a Rb-Sr errorchron (MSUM = 4,39, Fig. 13) with an age of 1 079 ± 25 Ma and initial $^{87}Sr/^{86}Sr$ ratio of 0,7081 ± 12.

2.8 Post-Gamsberg granite dykes

Dykes cut the Gamsberg Granite Suite and therefore provide a minimum age for this important intrusive event. Basic dykes cutting the Namibgrens pluton (23°36'S, 16°16'E, Fig. 5), define a Rb-Sr isochron (MSUM = 0,71), but the very low Rb/Sr ratios preclude a precise age (1 030 ± 185 Ma, Fig. 14). The initial $^{87}Sr/^{86}Sr$ ratio is 0,7064 ± 4. Acid dykes (quartz porphyries) also cut the Namibgrens pluton (23°38'S, 16°18'E, Fig. 5), but Rb-Sr data for these intrusives do not define an isochron. Some plot close to a 1030 Ma isochron, but

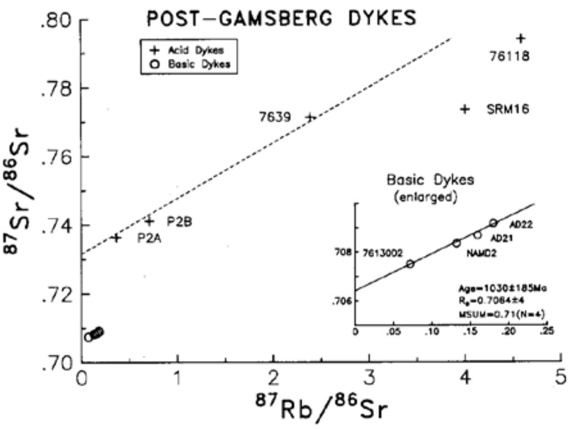

Fig. 14: Rb-Sr isochron diagram for post-Gamsberg mafic and acid dykes.

with a substantially higher initial $^{87}Sr/^{86}Sr$ ratio.

3. DISCUSSION

Each granitoid suite has been studied at a pluton scale, in the sense that sampling of a particular unit was confined to a relatively small area, rather than attempting to obtain a Rb-Sr isochron from apparently similar rock types from widely spaced localities. This approach may overcome problems such as incorrect correlation, variable initial $^{87}Sr/^{86}Sr$ ratios, differences in degree of deformation and metamorphism, and hence increase the likelihood of obtaining precise isochrons. However, there remains the uncertainty in the relationship between the use of these 'single pluton' results in the identification of major multi-pluton emplacement events on a regional scale. In addition, the complex tectonic and metamorphic history experienced by the Rehoboth region may have disturbed the various radiometric systems. The following discussion of the Rb-Sr results presented here, together with comparison between these new results and published age data, must be regarded in such a light. A summary of Rb-Sr ages obtained during this study is presented in Table 3, while a compilation of published zircon U-Pb ages is given in Table 4.

3.1 Older granitoids

Results obtained for the Naub Diorite and Swartmodder Granite indicate Rb-Sr closure about 1 800-1 640 Ma ago, which contrasts sharply with the majority of Rb-Sr ages obtained in this study, which cluster in the 1200-1 000 Ma range. Only the Swartmodder Granite has been investigated by another method, and one zircon U-Pb age obtained for this granitoid is similar to that obtained from the Rb-Sr system. A second sample has a zircon U-Pb age which is slightly older. Uncertainty in the nature and location of the second zircon sample, the problem of only having available the calculated $^{207}Pb/^{206}Pb$ age and the lack of analytical details all contribute to the difficulty of evaluating this discrepancy further. The results do, however, indicate the presence of older granitoids in the Rehoboth region which has hitherto been unrecognized. It is also likely

TABLE 4: Published zircon U-Pb ages from the Rehoboth-Nauchas region.

LITHOLOGIC UNIT	LOCALITY	SAMPLE	AGE (Ma)	REF
GAMSBERG GRANITE	Uitdraai Oos 296	PH8	932 ± 50	2, 3
SUITE	H6henheim 24	PH1	1 078 ± 30	2, 3
	Ganeib 61	PH6	1 150 ± 30	3
	Kanaus South 336	KES16	1 064 ± 20	3
	Kangas 371	KES2	1 104 ± 20	3
	Nauchas 14	KES15	1 178 ± 20	3
NOKOPF FORMATION	Auchas 347	KES138	1 770 ± 35	4
(Acid Lavas)	Lekkerwater Sta		1 130 ± 75	1
	Nauzerus 11	PH2	1 010 ± 30	2, 3
	Uitdraai Oos 296	PH7	1 083 ± 30	3
	Kartatsaus 293	PH5	1 090 ± 90	2, 3
PIKSTEEL	Piksteel 209	KES117	1 076 ± 25	4
GRANODIORITE	Rehoboth Townlands	KES1	1 476 ± 30	3
SUITE				
BIESIEPOORT GRANITE	Biesiepoort 275	KES179	1 110 ± 30	4
MARIENHOF FORMATION	Rehoboth Townlands	KES174	1 232 ± 30	4
(Acid Lava)				
KAM KAM GRANITE	Kam Kam 369	KES236	986 ± 20	5
	Swartskap 332	KES177	1 406 ± 35	4
SWARTMODDER GRANITE	Rehoboth Townlands	PH9	1 630 ± 50	3
	Rehoboth Townlands	KES238	1 784 ± 45	6
NEUHOF FORMATION	Neuras 330	KES235	1 784 ± 45	6
(Acid Lava)	Olifantsvloer 453	KES237	1 328 ± 25	5

Ages recalculated to decay constants in Steiger and Jäger (1978).
Sources: 1 Burger and Coertze (1973), 2 Hugo and Schalk (1972), 3 Burger and Coertze (1975), 4 Burger and Coertze (1977), 5 Burger and Walraven (1977), 6 Burger and Walraven (1979).

that gneissic granitoids of Swartmodder age may occur further afield, but have been mapped as part of younger suites (e.g. Piksteel).

Supracrustal sequences intruded by the Naub and Swartmodder granitoids (e.g. Elim Formation) must therefore be older than about 1 800 Ma. Direct evidence may be in the form of a zircon U-Pb age of 1784 ± 45 Ma obtained from an acid lava within the Neuhof Formation (see Table 4). The results therefore suggest that this particular pre-Damaran terrane does indeed contain an early-Proterozoic crustal component (>1800 Ma), as has been found in other regions, such as Fransfontein (Burger *et al.*, 1976), Abbabis (Jacob *et al.*, 1978) and Haib-Vioolsdrif (Reid, 1979a, b).

3.2 Weener Quartz Diorite

The Weener Quartz Diorite has been studied by Seifert (1986) at the type locality on Weener 193 and the results contrast quite sharply with those obtained in this study. The Weener locality did not produce a good Rb-Sr isochron, and Seifert (1986) suggested two possible interpretations of the data, which yielded ages of 1 871 ± 143 Ma and 1 560 ± 100 Ma, depending on which data points were considered aberrant. The two plutons of the Weener Quartz Diorite have significantly different compositions, as shown by their respective Rb and Sr contents (see Fig. 15). Moreover the Rb-Sr isotopic data cannot be combined in any reasonable fashion either. The Weener Quartz Diorite has intruded the Gaub Valley Formation and is itself intruded by the Piksteel and Gamsberg granitoids. While existing data on the latter granitoids provides a reasonable estimate of a minimum age for the Weener Quartz Diorite, no accurate estimate for the age of the Gaub Valley Formation currently exists.

The numerous mafic xenoliths found within the Weener Quartz Diorite may have introduced compositional effects, and possibly caused variations in initial $^{87}Sr/^{86}Sr$. As a result no Rb-Sr isochron relationship could be expected to occur amongst the samples collected. This is probably a feature of most granitoid suites, and contributes to the scatter usually found in Rb-Sr isochrons obtained for such rocks. However, the contrast shown between the Weener and Namibgrens localities looks too great to be a function only of inhomogeneous Sr isotope composition. The mafic xenoliths could be regarded as providing a maximum age for the Weener Quartz Diorite, if the source of these xenoliths were older mafic bodies like the Alberta Complex (cf. De Waal, 1966), and the Rb-Sr age for this latter complex was close to the true age. In this case the maximum age for the Weener Quartz Diorite would be ~1 490 Ma, thereby suggesting that the results reported by Seifert (1986) are anomalous.

Another possible explanation of the above discrepancy is the effect of deformation and metamorphism, since foliation is well developed at the Weener locality but nearly absent at Namibgrens. Both localities are situated very close to contacts with younger granitoids, and so contact metamorphism could have contributed to the contrasting results. However, the Rb-Sr patterns appear the reverse of those that would be predicted, in the sense that the Weener locality should have produced a younger age because of the greater degree of foliation. Contact metamorphic effects are common to both localities and therefore would not be expected to cause the difference.

A final possibility is that the Weener Quartz Diorite really was intruded 1700-1900 Ma ago, as indicated by Seifert (1986), and the result obtained in this study from Namibgrens argues against a correlation. The tonalite in this latter area rather forms a younger post-Weener intrusive, which may represent a mafic variant of either the Piksteel or Gamsberg suites. The implication that the Weener Quartz Diorite at the type locality may in fact represent an equivalent to the Naub Diorite, clearly requires a more detailed follow-up study.

3.3 Biesiepoort Granite

The Biesiepoort Granite at the type locality on Biesiepoort 275 is actually a foliated adamellite, which has intruded previously deformed gneissic Naub Diorite. The initial $^{87}Sr/^{86}Sr$ ratio for the Biesiepoort Granite of 0,7044 ± 9 is low and bearing in mind the average Rb/Sr ratio of the analysed samples (~0,7), a reasonable upper estimate assuming metamorphic resetting is barely outside the isochron error limits (~50 Ma). A zircon U-Pb age of 1110 ± 30 Ma has been obtained, which, while slightly lower than the Rb-Sr age (1 222 ± 45 Ma), suffers from the same problems of evaluation as recognized for the Swartmodder Granite.

3.4 Piksteel granodiorite suite

The granodiorite pluton included within the Piksteel suite which crops out on the Rehoboth town lands shows a marked discrepancy between the Rb-Sr and zircon U-Pb ages. The higher zircon age of 1 476 ± 30 Ma (cf. Rb-Sr of 1 170 ± 20 Ma) may be a function of inheritance, in the sense that the composite zircon sample analysed was in fact made up partly of xenocrystic material. Metamorphic resetting of the Rb-Sr system can also be ruled out in this case as the adjacent Swartmodder Granite has not been affected. Another zircon from the type area on Piksteel 209 yields an age significantly younger (1 076 ± 25 Ma), but perhaps more consistent with the Rb-Sr results, although the localities are very far apart. Also this younger zircon sample apparently suffered severe Pb loss, which implies high discordancy and renders the $^{207}Pb/^{206}Pb$ age difficult to interpret. Bearing in mind the geological complexity of the southern Rehoboth townlands, it is not impossible that the zircon sample may not have been derived from a Piksteel age granitoid, and the old U-Pb age may in fact reflect derivation from an unrecognized Swartmodder age granitoid.

3.5 Gamsberg Granite Suite

While there are several zircon U-Pb ages available from the Gamsberg Granite Suite, results by both methods exist only for the Gamsberg pluton. In contrast with the other granitoids, the Gamsberg pluton lacks any foliation where it has been sampled, although further to the east of Höhenheim the rocks become intensely gneissic (De Waal, 1966). Analytical results for the Höhenheim zircon sample were published by Hugo and Schalk (1972) and it can be seen that the degree of discordance is not marked, although the degree of Pb loss this represents is model dependent. In other words, if the discordancy is simply the result of geologically recent Pb loss, then the calculated $^{207}Pb/^{206}Pb$ age can be interpreted as recording magmatic crystallization. However, if the Gamsberg zircon had experienced some Pb loss during Damaran metamorphism (at about 500 Ma for example), then the degree of Pb loss is significantly greater (50 % instead of 20 %), and an upper intercept age of ~1 200 Ma is not impossible. The comparison is further hindered by the poor Rb-Sr isochron statistics exhibited by the Gamsberg pluton. Nevertheless, the results could indicate intrusion of the Gamsberg pluton somewhere between 1 000 and 1 100 Ma.

Although a zircon U-Pb age is available on a Gamsberg suite granitoid cropping out on Nauchas 14, it is most likely derived from a pluton exposed near the Nauchas village, which is distinct from the pluton sampled in this study. It is therefore not impossible that the Nauchas village pluton (as dated by the zircon age of 1 178 ± 20 Ma) was intruded before the northern Nauchas pluton (dated by Rb-Sr at 1 073 ± 25 Ma). Other explanations for the Nauchas village zircon age are possible, but their evaluation is not warranted until a strict comparison can be made.

Seifert (1986) also reported Rb-Sr data for the Gamsberg pluton of the Gamsberg Granite Suite. Again poor isochron relationships were obtained and two alternative interpretations were put forward, with suggested ages of 1 229 ± 29 Ma and 1 190 ± 23 Ma. Combination of the two sets of data for the Gamsberg pluton does not provide any better isochron statistics, although the very high Rb/Sr samples analysed in this study predictably lower the isochron age to a value within error of those obtained for the Namibgrens and Nauchas plutons of this suite. While confinement of the sampling to one single pluton may not always produce good Rb-Sr isochrons, this practice can, by reducing the likelihood of variable initial $^{87}Sr/^{86}Sr$, reveal the effects of other possible processes which may cause disturbances. In the case of the Gamsberg pluton, the poor Rb-Sr results may have been caused by subsolidus alteration, possibly due to Damaran metamorphism, as suggested by Seifert (1986).

3.6 Geochemistry

Rb and Sr concentrations of the various granitoids are plotted in Fig. 15, where separation on to three diagrams allows clearer comparison. The patterns displayed in Fig. 15 aid in both the evaluation of the Rb-Sr isochrons and the problem of lithostratigraphic correlation.

The Rb-Sr results obtained by Seifert (1986) for the Weener Quartz Diorite have raised the possibility that this rock type could be as old as the Naub Quartz Diorite. Such a correlation is possibly supported on compositional grounds, as inspection of Figs 15a and b shows the Naub and Weener of Seifert (1986) having similar Sr contents, although some of the Naub rocks are much lower in Rb. Neither of these two rock types closely resemble typical calc-alkaline diorites and tonalites, as typified in Fig. 15a using the Vioolsdrif batholith as an example (Reid, 1977). The nearest approach is provided by the Weener rocks from the Namibgrens locality, analysed in this study. Relating the rocks from the two Weener localities by some simple differentiation process (thereby demonstrating a possible correlation) is not easily accomplished, as the required trend diverges markedly from that defined by the Vioolsdrif fields.

Despite the unusual Rb-Sr trend displayed by Weener rocks from the two localities, the Biesiepoort Granite has compositions that plot in a very similar field. Furthermore, the Rb-Sr isotopic results show the. Biesiepoort and Weener rocks analysed in this study had practically identical initial $^{87}Sr/^{86}Sr$ ratios, a feature which would support a genetic relationship. It follows that if the trend displayed by the Weener and Biesiepoort granitoids analysed in this study was produced by some differentiation process, then a relationship between the two Weener localities can not be ruled out simply on compositional grounds. What is indicated is that processes other than that which produced the Vioolsdrif trend may have occurred in the Rehoboth-Nauchas region.

Apart from one exception, the Swartmodder Granite shares the relatively low Sr contents seen in the Naub Diorite, and this distinguishes the former from the Biesiepoort Granite. The Swartmodder Granite can further be distinguished from the less differentiated varieties of the Gamsberg Granite Suite by its lower Rb contents. The Rb-rich nature of the Piksteel rocks also serves to separate this younger granitoid suite from the Swartmodder. Bearing in mind the likelihood of mistaking Swartmodder-age granitoids (with similar petrography) for Piksteel and Gamsberg suite units, the Rb-Sr patterns displayed in Fig. 15 suggest that a regional geochemical study may aid lithostratigraphic mapping.

The Gamsberg granitoids are distinguished in Fig. 15 by their relatively low levels of Sr and enrichment in Rb. The tight field with Sr contents between 100-200 ppm constitutes the typical coarse-grained Gamsberg Granite that comprises most of the three plutons studied. The samples showing strong depletion in Sr are

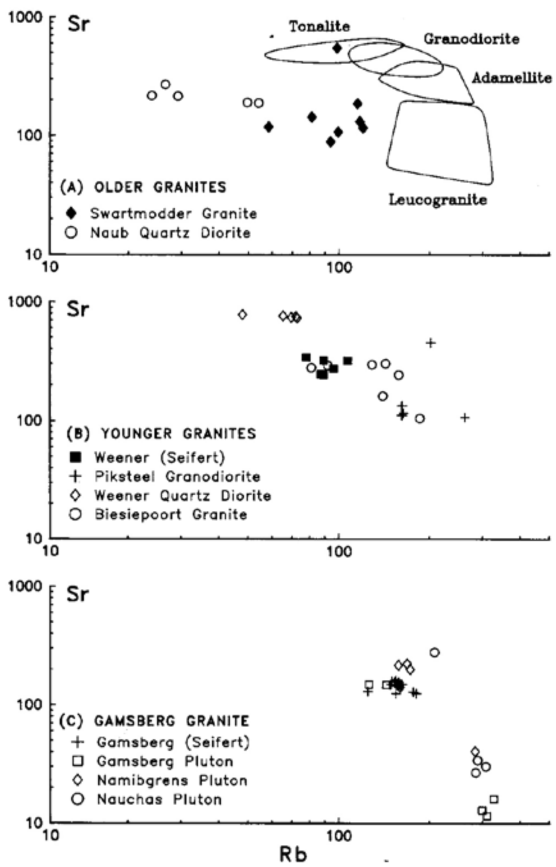

Fig. 15: Covariation of Rb and Sr for the granitoids analysed in this study. 15a: Granitoids with the oldest Rb-Sr ages, labelled fields enclose data for the Vioolsdrif granitoids (Reid, 1977); 15b: Younger granitoids, including data for the Weener Quartz Diorite from Seifert (1986); 15c: Gamsberg Granite Suite, including data for the Gamsberg pluton from Seifert (1986).

local variants that are very leucocratic and sometimes pegmatitic, and appear to be examples of extreme differentiation of the Gamsberg parent magma. The trend defined by the Gamsberg rocks is very similar to the corresponding part of the Vioolsdrif fields, where crystallization of adamellitic magmas produced leucogranites extremely depleted in Sr and moderately enriched in Rb. It follows that the Gamsberg trend may represent simple differentiation and therefore not argue against incorporation of the high Rb/Sr samples in the Rb-Sr isochrons.

If all the granitoids with Rb-Sr ages in the 1 200-1 000 Ma range are inspected in Figs 15b and c, the impression is one of a fairly continuous pattern of increasing Rb/Sr ratio with decreasing emplacement age. In other words, the earliest granitoids (Weener Quartz Diorite) are the least differentiated, with the Biesiepoort Granite and Piksteel Granodiorite forming intermediate members, while the Gamsberg Granite Suite represents the most evolved magmas emplaced at the end of what is a major magmatic episode. On the other hand, the older granitoids (Naub and Swartmodder) define a distinctly different trend in Fig. 15, thereby suggesting a separate system that could be regarded as having lithostratigraphic significance.

3.7 Proterozoic crustal evolution

Initial $^{87}Sr/^{86}Sr$ ratios for the various granitoids analysed in this study are plotted against Rb-Sr isochron age in Fig. 16. The younger granitoids clearly have a wide variation in initial ratios, with the Biesiepoort and Weener granitoids being derived from a much less radiogenic source than the later Piksteel and Gamsberg magmas. This difference rules out processes like simple crystal fractionation in the production of the compositional range of the granitoids, as represented by Rb and Sr contents discussed in the previous section. Rather the change in average Rb/Sr ratio with time appears to be related to initial $^{87}Sr/^{86}Sr$ ratio, so that the trends are controlled in some way by source region characteristics. In other words, the Biesiepoort/Weener granitoids represent products from the lower crust and upper mantle, while the slightly younger Piksteel and Gamsberg granitoids represent products from the upper crust. The trend therefore involved increasing contributions from older continental crust with time, a feature which has been already established for the nearby Damara Orogen (Miller, 1983) and the Namaqua Province (Reid and Barton, 1983), but is the reverse to that established for the Hercynian Orogen in Europe (Hamet and Allègre, 1975).

The older granitoids have emplacement ages similar to those already established for other mid-early Proterozoic terranes in South West Africa. Initial Sr isotopic ratios also vary, with the Swartmodder Granite having a relatively high value, suggesting a crustal source region already very radiogenic 1 600-1 700 Ma ago. The very high average Rb/Sr ratio of the Swartmodder Granite

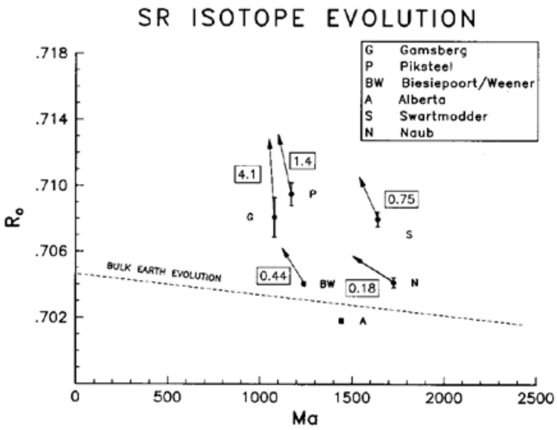

Fig. 16: Plot of initial $^{87}Sr/^{86}Sr$ ratios against Rb-Sr isochron age for granitoids analysed in this study. Error bars are two sigma estimates from the regression analyses. Arrows define the average rate of increase in $^{87}Sr/^{86}Sr$ with time for each rock type, and the figures in boxes represent the average Rb/Sr ratio calculated from the data in Table 2. Broken line represents the variation in $^{87}Sr/^{86}Sr$ with time for a model mantle having 'bulk earth' composition (O'Nions *et al.*, 1979).

may reflect derivation from a high Rb/Sr source, so that projection back on Fig. 16 to the mantle curve may not yield an age significantly in excess of that for the Naub Diorite. It follows that the maximum age of formation of the crustal protoliths may not exceed ~2 000 Ma, a result also reported by Hawkesworth and Marlow (1983) for the Damaran granitoids, although it would be useful to investigate the Sm-Nd systematics of these old Rehoboth rocks before proceeding further in the assessment.

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