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The Sinclair Sequence: U-Pb age constraints from the Awasib Mountain area

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The Mid-Proterozoic Sinclair Sequence in southern Namibia is made up of volcano-sedimentary successions and associated high-level intrusions in a mainly extensional tectonic environment. Granitoids from the marginal Awasib Mountain area have been investigated using precise U-Pb determinations on zircons. Regression of three zircon fractions from the pre-Sinclair Aunis Tonalite Gneiss yields an upper intercept, or emplacement, age of 1376.5+ 1.7/-1.6 Ma. A previous Rb-Sr whole-rock age determination of 1271 ± 62 Ma for the Aunis Tonalite Gneiss may be attributed to resetting at that time during an early tectonothermal event in the Grenville-age Namaqua Orogeny. Within the Sinclair Sequence, three zircon fractions from the Haisib Quartz Syenite produce an emplacement age of 1216.2 + 1.8/-1.5 Ma. Two zircon fractions from each of the Awasib and Chowachasib Granites yield emplacement ages of 1216.4 ± 1.2 Ma and 1216.7 + 4.7/-3.5 Ma, respectively. A composite regression treatment of all seven zircon fractions indicates that the emplacement ages for these three units are indistinguishable with an upper intercept age of 1216.4 + 1.3/-1.2 Ma (2 sigma). This places a minimum age constraint on the mafic flows of the Haiber Flats Formation and is significantly older than the 1086 ± 44 Ma Rb-Sr whole-rock age reported previously. Tectonothermal activity at ca. 1100 Ma in the Namaqua Province could account for the greenschist facies metamorphism of much of the marginal part of the Sinclair Sequence and related disturbance of the Rb-Sr system.

Introduction

Regional setting

The Sinclair Sequence comprises a volcano-sedimentary succession with associated high-level granitoids which is situated adjacent to the Grenville-age Namaqualand Metamorphic Complex in the southern part of Namibia (Fig. 1). It forms part of a curvilinear outcrop of Mid-Proterozoic rocks that extends along the southwestern and northwestern margins of the Namibia Province (terminology of Tankard *et al.*, 1982). The geotectonic setting of this association has been interpreted as an ancient active continental margin (Watters, 1974; Hoal, 1987), an aulacogen (Kröner, 1977), an intracontinental rift (Mason, 1981; Borg, 1988) and a collision-related rift (Hoal, 1987).

Within the type area of the Sinclair Sequence, volcanic and sedimentary rocks are typically hosted within northwest-trending fault-bounded troughs that parallel the structural grain in the underlying metamorphic basement and much of the adjacent Namaqualand Metamorphic Complex. The relationship between the latter and the basement to the Sinclair Sequence (grouped variously into the Naisib River Suite, Neuhof Formation and Mooirivier Complex - South African Committee for Stratigraphy, 1980) remains unclear although these have been correlated with one another by Jackson (1975), Kröner (1977) and Hoal (1989). Other workers such as Von Brunn (1967) and Blignault *et al.* (1974) considered the basement to have a stronger affinity with the Kheis Group in South Africa. The Airborne Magnetic Anomaly Map of Namibia (1993) indicates a magnetic pattern which is common to the Sinclair basement and the Namaqualand Metamorphic Complex, hence inferring that the Sinclair Sequence is located within the Namaqua Province.

There is a progressive increase in deformation and metamorphism of the Sinclair Sequence towards an inferred palaeomargin in the west. The Awasib Mountain area is located close to this margin where rocks of Sinclair age are characterised by both shearing and greenschist facies metamorphism. The subsolvus appearance of granitoids has been attributed to the introduction of water via shear zones, whereas relatively low TiO_2 contents of biotites suggest a metamorphic origin in part (Hoal, 1990). Such metamorphic effects are also recorded in the pre-Sinclair schists and gneissic granitoids which show retrogression of amphibolite facies assemblages. This episode of greenschist facies metamorphism and deformation predates the Pan-African Damaran orogeny and may be related to tectonothermal activity in the Namaqua Orogeny at ca. 1100 Ma.

Previous work

A number of radiometric studies have been conducted on both the Sinclair Sequence and similar lithotypes in the Rehoboth Sequence since the late nineteen sixties. Mainly Rb-Sr whole-rock and V -Pb zircon age determinations have been reviewed in Caben and Snelling (1985), Reid *et al.* (1988) and this study. Earlier U-Pb zircon dating yielded ages in the range 1360 Ma to 900 Ma for granitic units of the Sinclair Sequence. However, subsequent whole-rock Rb-Sr dating by Hoal *et al.* (1989) suggested that magmatism occurred from ca. 1100 Ma to 950 Ma along the western margin of the sequence in the Awasib Mountain area. There is a poorly defined relationship between these magmatic events and tectonothermal activity associated with the Namaqua event in the period 1.3-1.0 Ga.

Some of the relatively old U-Pb zircon ages obtained for granitoids in the Sinclair Sequence have been attributed to inherited zircons (Hoal *et al.*, 1989). More

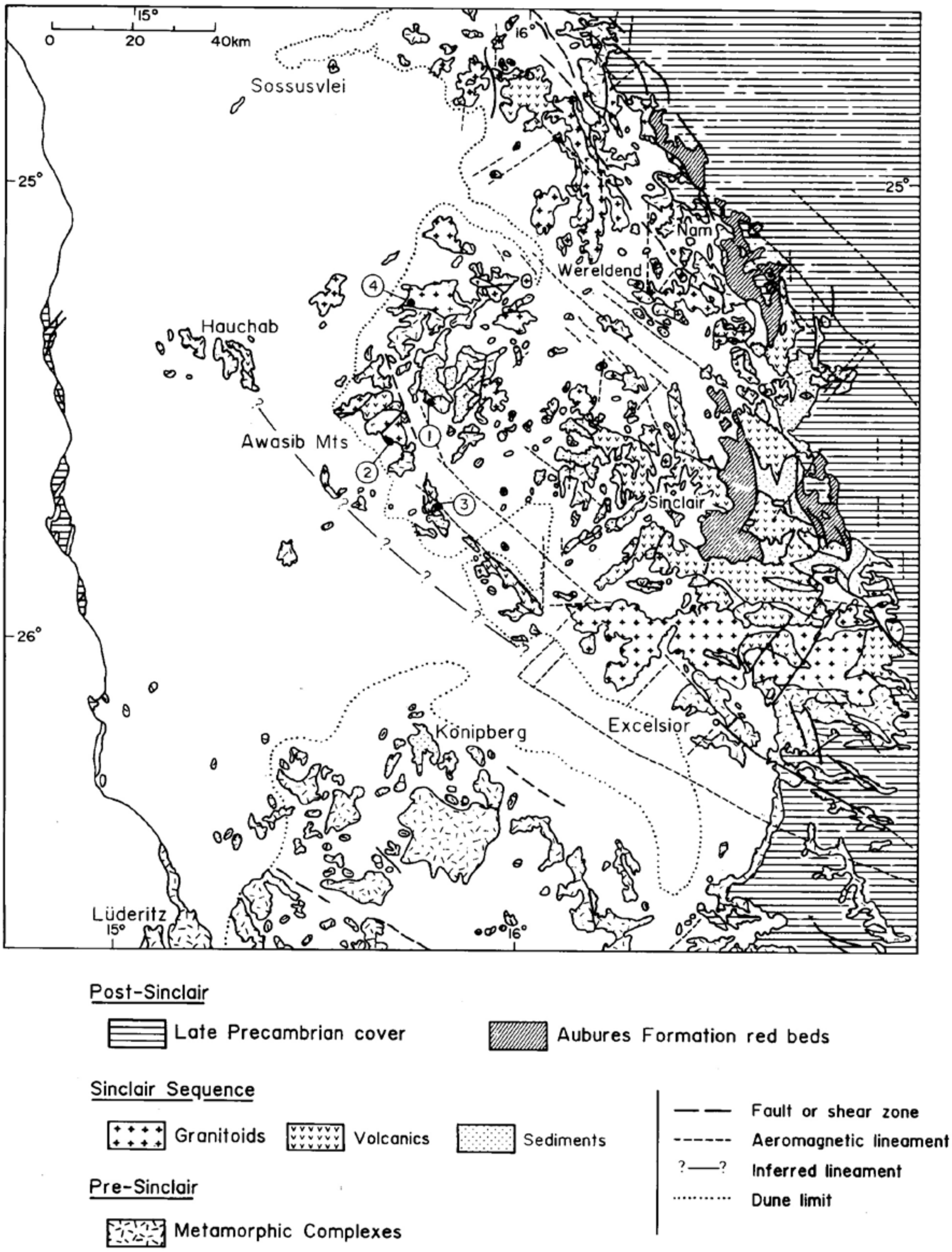

Figure 1: Regional geological map of the Sinclair Sequence type area showing the location of samples selected for this U-Pb study. ① = BH942, ② = BH658, ③ = BH943, ④ = BH760.

recently, however, it has become clear that several whole-rock Rb-Sr ages for Sinclair Sequence and related rocks appear to record events more recent than magmatic episodes. Ziegler and Stoessel (1991), for example, attribute partial resetting of the Rb-Sr system in the Weener Intrusive Suite, Rehoboth area, to the intrusion of younger magma. Whereas such disturbances of the Rb-Sr system typically result in ages younger than emplacement, anomalously older ages have been recorded in cases where isotopic mixing has taken place (e.g. Heaman and Smalley, 1994). The recognition of anomalously old Rb-Sr ages as well as anomalously young Rb-Sr ages in granitoid rocks makes it difficult to evaluate the geological significance of Rb-Sr whole rock ages.

Recent U-Pb zircon dating carried out in the Rehoboth area by Stoessel and Ziegler (1989) and Pfurr *et al.* (1991) indicate ages of close to 1200 Ma for rocks of the Gamsberg Granite Suite and associated rhyolite dykes. As illustrated in Table 1, this should represent the final stage of magmatism in the Sinclair-Rehoboth area. However, U-Pb zircon ages of 1102 7 Ma and 1094 +18/-20 Ma have been recorded for porphyritic metavolcanic rocks in the Rehoboth and Gobabis areas by Pfurr *et al.* (1991) and Hegenberger and Burger (1985), respectively. This largely felsic volcanism overlaps in time with the likely age of extrusion for the Nückopf Formation (mean of 1078 Ma for four U-Pb zircon determinations; Hugo and Schalk, 1972; Burger and Coertze, 1973, 1975), the latter being correlated with the Guperas Formation in the Sinclair area (Table 1). Coeval emplacement of the Gamsberg Granite Suite with the accumulation of volcanic rocks of the Nückopf Formation (South African Committee for Stratigraphy, 1980) suggests a closing period of felsic magmatism in excess of 100 Ma for the Rehoboth area.

	Sinclair Sequence Type Area		Awasib Mountain Area
Upper	Gamsberg/Sonntag Granite and dyke swarms		Chowachasib Granite and dyke swarms
	Guperas Formation	rhyolitic extrusives basic lava	
		sandstone, conglomerate	
Middle	Nubib/Rooikam/Haremub Granite		Awasib Granite
	Saffier Intrusive Suite	gabbro, norite, monzonite, diorite, syenite	Saffier Intrusive Suite, Haisib Intrusive Suite, Bushman Hill Quartz Diorite
	Barby Formation	basic lava and rhyolitic extrusives	Barby Formation and Haiber Flats Formation
	Kunjas Formation	arkose, grit shale	Urusib Formation
Lower	Tumuab/Kotzerus Granite		
	Nagatis Formation	rhyolitic extrusives and minor basic lava arkose, grit, shale	
	Naisib River Suite Neuhof Formation Mooirivier Complex		Khorasib Granite Gneiss Aunis Tonalite Gneiss Kairab Complex

Table 1: Simplified lithostratigraphy of the Sinclair Sequence in the type area and the adjacent Awasib Mountain area. Underlined units are those investigated in this study.

This study

Recognition of the basement to the Sinclair Sequence as part of the Namaqualand Metamorphic Complex, as indicated by aeromagnetic data, requires that precision dating be used in an attempt to resolve the problem of unclear age relationships between basement and cover. Furthermore, regional correlations between the Sinclair and Rehoboth areas have frequently been made on the basis of Rb-Sr whole-rock data, some of which have recently been shown to yield anomalously young ages. Accordingly, the aim of this study is to apply precise U-Pb zircon dating to a number of Sinclair Sequence granitoids in the Awasib Mountain area (Table 1, Fig. 1). Where possible we have used samples for which Rb-Sr whole-rock age determinations have been made, in an attempt to provide a comparative basis for the two techniques; In reviewing other geochronological work, we restrict our comments to U-Pb zircon studies that have been conducted on similar granitoids in other parts of the Sinclair-Rehoboth domain.

The Sinclair Sequence is of importance with regard to its close temporal and spatial relationship to the Namaqua Province. Constraining the timing of magmatism within the Sinclair Sequence will allow a better understanding of crustal processes along the southwest margin of the enigmatic Namibia Province.

Analytical Techniques

The four granitoid samples were prepared by standard crushing (jaw crusher, disk mill) at the Geological Survey of Namibia and mineral separation (Wilfley Table, heavy liquids, Frantz magnetic separator) techniques at the National Physical Research Laboratory in South Africa by E. Retief. The zircon concentrates were processed at the Royal Ontario Museum and grains devoid of fractures, mineral inclusions or turbidity were generally selected for analysis. Many of the fractions were given an abrasion treatment (Krogh, 1982) prior to dissolution that significantly reduced discordance. The selected multi-grain fractions were washed in warm 4N HNO_3 (15:1) mixture. Uranium and lead were purified by anion exchange chromatography (Krogh, 1973; Heaman and Machado, 1992) and were loaded together onto single Re filaments using a Si-gel technique (Cameron *et al.*, 1969). The isotopic compositions of U and Pb were determined with two separate VG354 thermal ionization mass spectrometers (referred to as VG354 and VGM354, respectively) in single collector mode using either a Faraday cup or Daly photomulti-

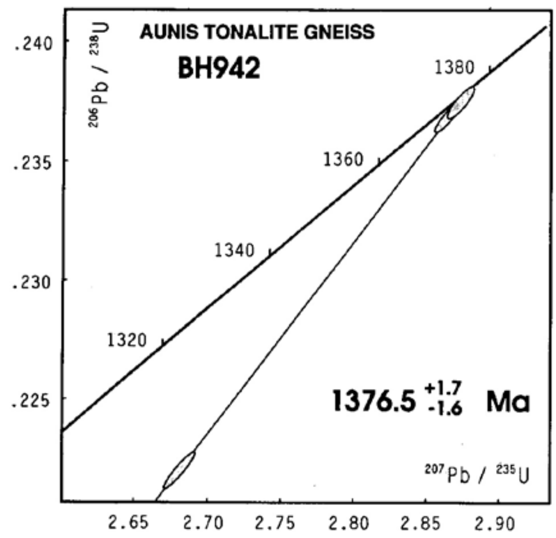

Figure 2: U-Pb concordia diagram showing three zircon analyses from the Aunis Tonalite Gneiss. The zircons of the two nearly concordant analyses were given an air abrasion treatment. Error ellipses on all concordia diagrams are shown at the 2 sigma level.

plier detector system. All isotopic data were corrected for mass discrimination of 0.1 %/amu based on repeat measurements of the NBS981 and U500 standards on both mass spectrometers. An additional correction of 0.3%/amu for both U and Pb (VG354) and 0.15%/amu and 0.13%/amu for U and Pb, respectively (VGM354) was applied to all data obtained using the Daly detector. All ages were calculated using the two-error linear regression program of Davis (1982) and all associated errors are quoted at 2 sigma. The decay constants for ^{238}U (1.55125 x 10^{-10} yr.$^{-1}$) and ^{235}U (9.8485 10^{-10} yr.$^{-1}$) 137.88) used in this study are the values determined by Jaffey *et al.* (1971) and recommended by Steiger and Jäger (1977).

Results

Preliminary V - Pb results for ten multi-grain zircon fractions (Table 2), weighing between 4 and 238 micrograms, from four granitoid units indicate pre-Sinclair magmatism at 1377 Ma and Sinclair-age magmatism at 1216 Ma. The Aunis Tonalite Gneiss (BH942) is the oldest unit investigated so far. The zircon grains recovered from this sample consist of a single population of euhedral, colourless to pale pink, stubby to equant multi-faceted crystals. A regression treatment of three multi-grain zircon fractions from this sample (Fig. 2) yields an upper intercept age of 1376.5 + 1.7/-1.6 Ma (53% probability of fit), that is considered a very accurate estimate of the tonalite emplacement age, with a lower intercept age of 70 Ma. Two of these fractions were given an abrasion treatment and are concordant to nearly concordant (0.3 and 0.4% discordant) with ^{207}Pb/^{206}Pb model ages of 1377 and 1376 Ma, respectively while a third unabraded fraction is 6.5% discordant.

Sinclair-age magmatism at 1216 Ma is represented by the Haisib Quartz Syenite (1216.2 Ma), Awasib Granite (1216.5 Ma) and Chowachasib Granite (1216.7 Ma). These results are consistent despite the differences in zircon populations recovered from each sample. Although all three populations have ubiquitous mineral inclusions, the Awasib and Chowachasib Granite samples contain smaller (30-150 µm) euhedral, equant to stubby prisms that range in colour from colourless to a dark brown while the Haisib Quartz Syenite sample contains larger (150-250 µm), anhedral, subspheroidal dark pink grains. Three zircon fractions from the Haisib Quartz Syenite (Fig. 3) yield an upper intercept age of 1216.2 + 1.8/-1.5 Ma (79% probability of fit) which is interpreted as an accurate estimate of the emplacement age for this quartz syenite. The U-Pb results for two zircon fractions each from the Awasib and Chowachasib Granites are shown in Figs 4 and 5, respectively. The nearly concordant data for the Awasib Granite are difficult to treat by linear regression in order to calculate any error for the age of 1216 Ma. Instead, we can use the error calculated from the average ^{207}Pb/^{206}Pb age to calculate an age of 1216.4 ± 1.2 Ma (2σ) or 1216 ± 1 Ma.

By excluding one unabraded zircon fraction that is 3.5% discordant, six zircon analyses from these three granitoid units have ^{207}Pb/^{206}Pb model ages that cluster between 1215 and 1217 Ma and a composite regression treatment of all seven zircon fractions (Fig. 6) indicates that the emplacement ages for these three units are indistinguishable with an upper intercept age of 1216.4 + 1.3/-1.2 Ma (2σ).

Discussion

Aunis Tonalite Gneiss

The U-Pb zircon age of 1376.5 Ma determined for this unit is approximately 100 Ma older than the Rb-Sr wholerock determination of 1271 ± 62 Ma (Table 3). Whereas the age of 1376.5 Ma constitutes a maximum for the earliest magmatism in the Sinclair Sequence, it also predates the granulite facies metamorphism considered to have taken place at ca. 1200 Ma in the adjacent Namaqualand Metamorphic Complex (Clifford *et al.*, 1981; Joubert, 1986). These conclusions are valid even if Cahen and Snelling's (1984) maximum age of 1300 Ma for the D_2 Namaqua event is adopted. It therefore appears likely that the resetting of the Rb-Sr system at 1271 Ma reflects tectonothermal activity related to the Namaqua event. The age of 1376.5 Ma for the Aunis Tonalite Gneiss is further consistent with its emplacement into ca. 1460 Myoid metabasalts of the Kairab Complex (Hoal, 1990; Rb-Sr, Pb-Pb whole-rock ages).

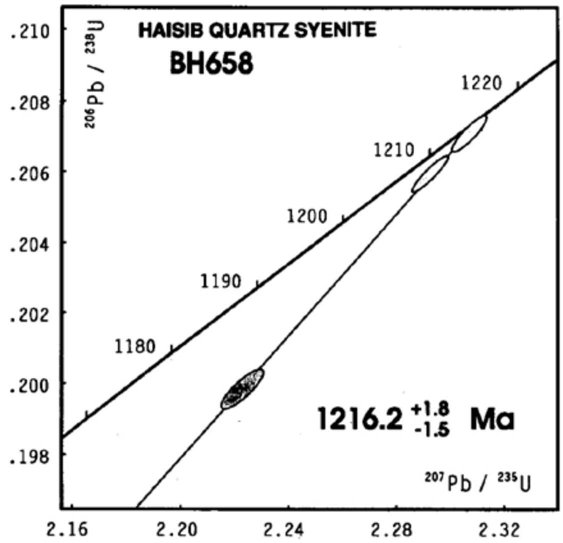

Figure 3: U-Pb concordia diagram showing three zircon analyses from the Haisib Quartz Syenite. The zircons of the two concordant to nearly concordant analyses were given an air abrasion treatment.

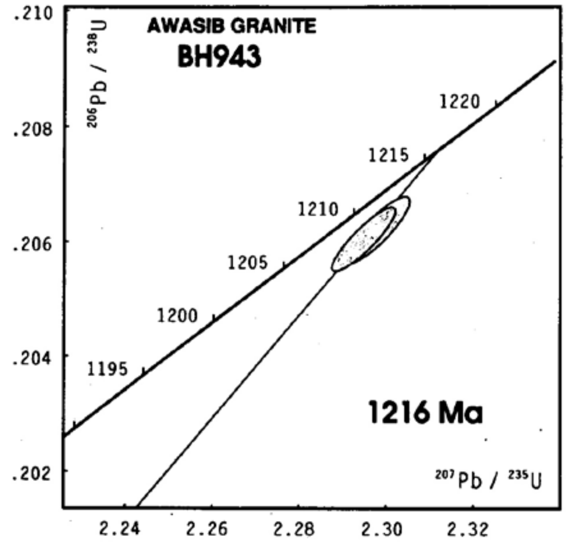

Figure 4: U-Pb concordia diagram showing two zircon analyses from the Awasib Granite.

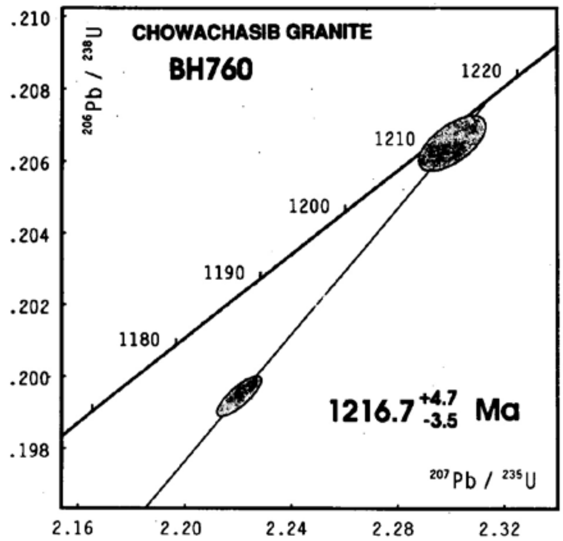

Figure 5: U-Pb concordia diagram showing two zircon analyses from the Chowachasib Granite.

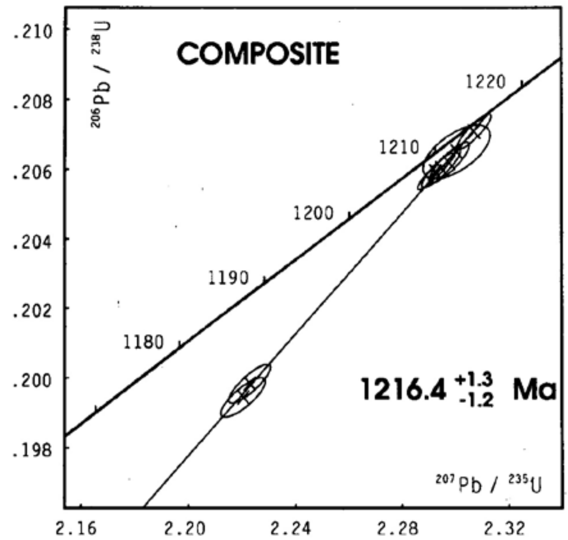

Figure 6: U-Pb concordia diagram showing a composite regression treatment of all seven zircon fractions from the Sinclair-age granitoids.

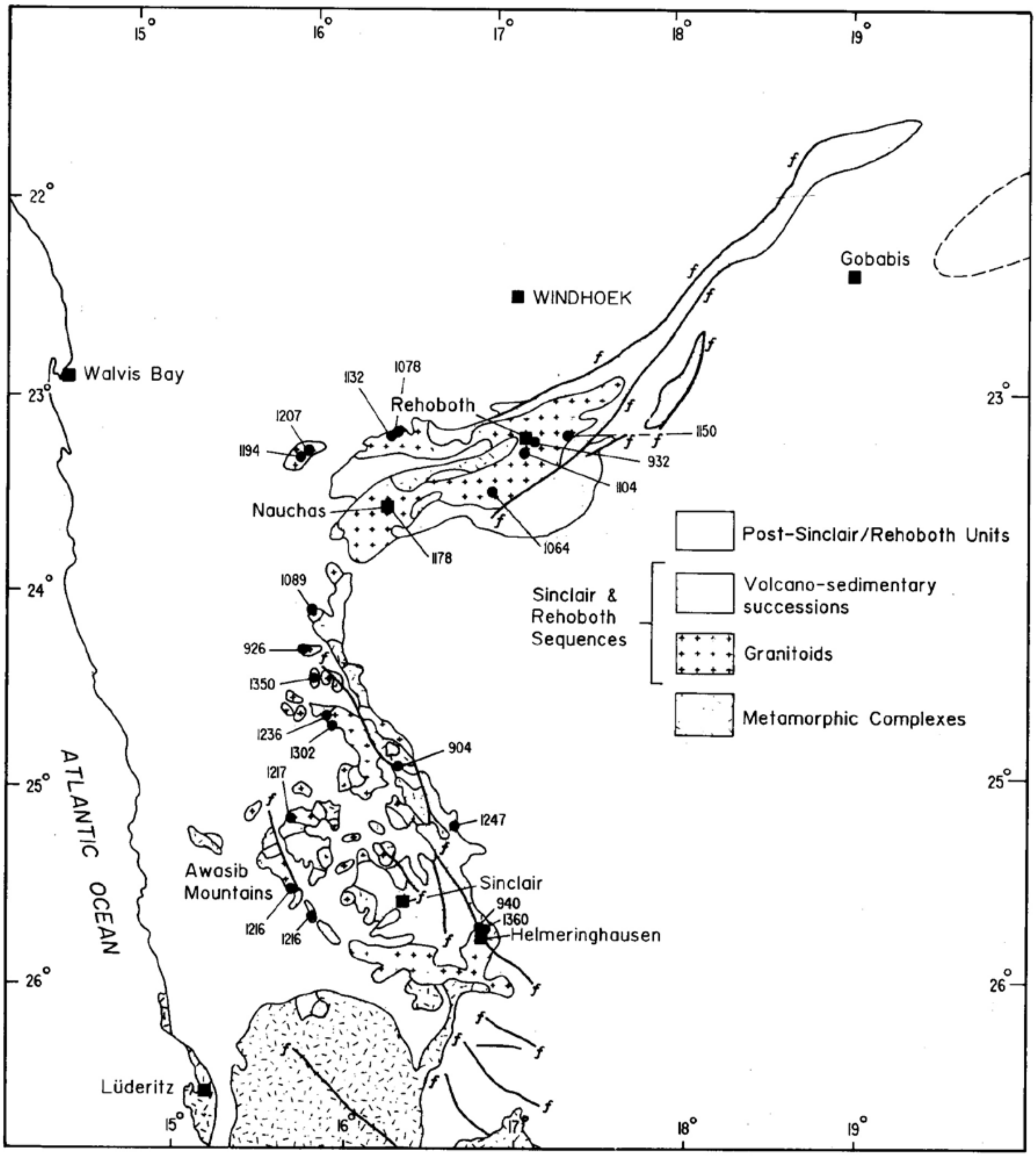

Figure 7: Regional distribution of the Rehoboth and Sinclair Sequences showing the U/Pb age determinations on Gamsberg- and Nubib-type granitoids as illustrated in Table 4.

		Concentration (ppm)						Atomic Ratios			Apparent Age (Ma)				
Fraction No	Description	Weight (μg)	U	Pb	Th	Common Pb (pg)	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}Pb$	$^{207}Pb/^{206}Pb$	1σ (Ma)	Dis-cord.
Aunis Tonalite Gneiss															
1	cl, (10)	132	184	43	66	97	3477	0.22198 ± 31	2.68080 ± 43	0.08759 ± 5	1292	1323	1373	1.1	6.5
2	cl, Abr, (7)	31	102	25	35	11	4336	0.23746 ± 27	2.87301 ± 38	0.08775 ± 6	1373	1375	1377	1.2	0.3
3	cl, Abr, (7)	21	158	38	54	4	13410	0.23686 ± 26	2.86404 ± 36	0.08770 ± 5	1370	1373	1376	1.1	0.4
Awasib Granite															
4	cl, Abr, (18)	12	256	57	138	7	5907	0.20605 ± 23	2.29477 ± 30	0.08077 ± 5	1208	1211	1216	1.2	0.7
5	cl, Abr, (16)	10	267	59	129	7	4834	0.20620 ± 24	2.29776 ± 31	0.08082 ± 6	1209	1212	1217	1.3	0.8
Haisib Quartz Syenite															
6	pk, (8)	238	280	65	217	451	1866	0.19985 ± 23	2.22302 ± 32	0.08067 ± 6	1175	1188	1213	1.5	3.5
7	pk, Abr, (3)	61	204	48	166	3	46724	0.20709 ± 21	2.30718 ± 27	0.08080 ± 4	1213	1214	1217	1.0	0.3
8	pk, Abr, (12)	168	307	75	287	12	55145	0.20595 ± 21	2.29260 ± 27	0.08074 ± 4	1207	1210	1215	0.9	0.7
Chowachasib Granite															
9	cl, Abr, (16)	12	216	49	138	18	1771	0.19945 ± 23	2.22046 ± 34	0.08074 ± 7	1172	1188	1215	1.8	3.9
10	cl, Abr, (3)	4	207	48	122	10	1077	0.20651 ± 31	2.30060 ± 52	0.08080 ± 14	1210	1212	1217	3.4	0.6

Notes:
Fraction Description: Colour - cl = colourless, pk = pink; Abr = given an abrasion treatment. Numbers in parentheses correspond to the total number of grains analyzed.
Atomic ratios corrected for 2 pg Pb and 0.5pg U blanks, and an initial common Pb (Stacey and Kramers, 1975).
Discordance refers to percent displacement of an analysis from the concordia curve measured along a line to zero age.

Table 2: U-Pb zircon results from the Awasib Mountain area.

	Rb-Sr (Hoal et al., 1989)			U-Pb zircon (This study)
	Age (Ma)	$(^{87}Sr/^{86}Sr)_0$	MSUM (n)	Age (Ma)
Chowachasib Granite				1216.7 +4.7/-3.5
Awasib Granite	957 ± 50	0.717 ± 8	15 (10)	1216.4 ± 1.2
Haisib Quartz Syenite				1216.2 +1.8/-1.5
Haiber Flats Fm. basaltic andesite	1086 ± 44	0.70305 ± 17	0.82 (8)	
Aunis Tonalite Gneiss	1271 ± 62	0.70269 ± 12	2.48 (10)	1376.5 +1.7/-1.6

Table 3: Comparative table of Rb-Sr whole-rock and U-Pb zircon data for the Awasib Mountain area.

Haisib Quartz Syenite

The age determination of 1216.2 Ma for the Haisib Quartz Syenite cannot be compared directly with any Rb-Sr determination carried out on the same unit. However, the Haisib Quartz Syenite forms part of the more widespread Haisib Intrusive Suite which has intruded basaltic andesites of the Haiber Flats Formation at a number of localities. This basaltic andesite member was dated, using the Rb-Sr wholerock method, at -1086 ± 44 Ma (Table 3), thereby setting a Rb-Sr whole-rock maximum age for the Haisib Quartz Syenite. The age difference of at least 130 Ma is difficult to explain unless the Rb-Sr system is considered to have been disturbed or reset by a later event. Greenschist facies metamorphism in the basaltic andesite may be related to late-tectonic plutonism and shearing in the Namaqua Province which took place around 1.1 Ga (Hartnady *et al.*, 1985).

Awasib Granite

The age of 1216.5 Ma for the Awasib Granite is within error of the Haisib Quartz Syenite and approximately 260 Ma older than the Rb-Sr errorchron age of 957 ± 50 Ma (Table 3). The latter is a poorly constrained age although it is consistent with the other Rb-Sr determinations in the Awasib Mountain area. This disturbance appears to coincide with the regional thermal event recorded in the Namaqualand Metamorphic Complex at around 900 Ma (Joubert, 1986). The similarity in age to the Haisib Quartz Syenite supports geochemical evidence that the Haisib Intrusive Suite and Awasib Granite belong to a single intrusive suite (Hoal, 1990).

Chowachasib Granite

The age of 1216.7 Ma for the Chowachasib Granite is again within error of the age determinations for both the Haisib Quartz Syenite and Awasib Granite. While there is as yet insufficient evidence for the inclusion of this granite in a Haisib-Awasib intrusive suite, it is clear that the Chowachasib Granite cannot be separated stratigraphically as indicated in Table 1. Although the age for the Chowachasib Granite is in good agreement with that recorded for the Gamsberg Granite (1207 ± 15, U-Pb zircon, Pfurr *et al.*, 1991), it is considerably

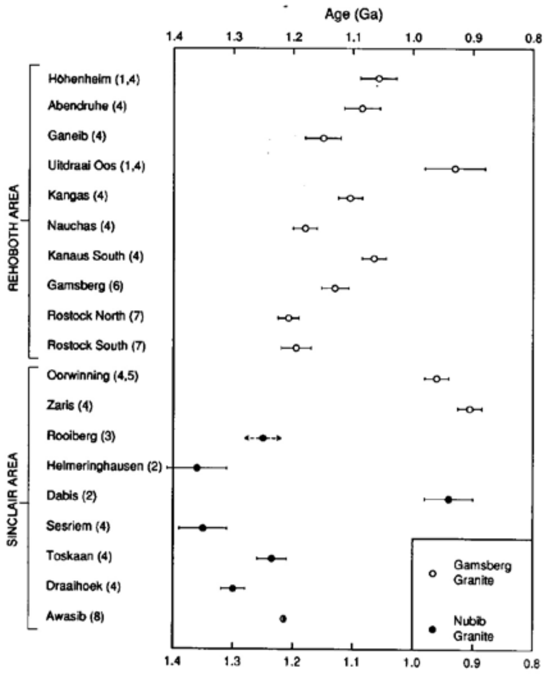

Table 4: U-Pb zircon age determinations from the Sinclair and Rehoboth areas. Error bars at the 1 σ level. Sources: (1) Hugo and Schalk (1972); (2) Burger and Coertze (1973); (3) Watters (1974); (4) Burger and Coertze (1975); (5) Burger and Coertze (1977); (6) Ziegler and Stoessel (1991); Pfurr *et al.* (1991); (8) this study.

older than expected for the youngest magmatism in the Sinclair Sequence.

Regional considerations

The data from Sinclair-age granitoids are compared with other U-Pb zircon age determinations from the Sinclair-Rehoboth domain in Table 4 and Fig. 7. The differentiation between granitoids of Nubib- and Gamsberg-type in Table 4 indicates the tremendous spread of ages for these granitoids as well as large uncertainties for most determinations. Whereas U-Pb zircon data more recent than 1990 indicate a definite event at ca. 1.2 Ga, the geological significance of ages both older and younger than this is unclear. With regard to the Sinclair Sequence, 1.2 Ga is the age of the youngest undeformed granites but also coincides with the age of granulite facies metamorphism and syn-tectonic plutonism in the adjacent Namaqualand Metamorphic Complex. Crustal melting has been attributed to the Namaqua event, resulting in syn- to late-tectonic granites such as the Little Namaqualand and Spektakel Suites in South Africa (Joubert, 1986). The peak of the Namaqua event at 1.2 Ga is related to granulite facies metamorphism and chamockite emplacement adjacent to the Sinclair Sequence (Tankard *et al.*, 1982). Waters (1990) has further shown that low-pressure Namaqualand granulites record an anticlockwise P-T path which can be attributed to major magmatic advection as a result of basaltic underplating. Although in need of further precision dating, it is likely that the regional emplacement of granitoids of batholithic dimensions in the Sinclair-Rehoboth domain (Fig. 7) was related to this major heat transfer during the Namaqua event.

Concluding Remarks

Earlier indications from both Rb-Sr whole-rock and U-Pb zircon age determinations that the Sinclair Sequence was built up over a protracted period of around 500 Ma are in need of revision. Precise U-Pb determinations on zircons from the Awasib Mountain area suggest that this period of magmatism was significantly shorter. Pre-Sinclair Aunis Tonalite Gneiss dated at 1377 Ma places a maximum age on such magmatism, while the young Gamsberg-type Chowachasib Granite yields a near-minimum age of 1216 Ma. Duration of magmatism is hence thought to be no more than 200 Ma for the entire succession and may be considerably less.

Rb-Sr whole-rock ages significantly younger than the U-Pb zircon determinations are considered to reflect disturbances of the Rb-Sr system. Tectonothermal activity in the adjacent Namaqualand Metamorphic Complex may be partly responsible for several such disturbances in the period 1.2-0.9 Ga. The resetting of the Rb-Sr system by hydrothermal activity at higher crustal levels could be attributed to granulite facies metamorphism in the deeper crust. The age of ca. 1.2 Ga records a major tectonothermal event which took place across much of the southwestern part of Africa. This was the time when high-grade metamorphism reached its peak in the Namaqualand Metamorphic Complex and widespread basaltic underplating and crustal melting resulted in the emplacement of granitoid suites of batholithic dimensions throughout the Namaqua Province and the Sinclair-Rehoboth domain.

Acknowledgements

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References

Airborne Magnetic Anomaly Map of Namibia. 1993. Scale 1:1000 000. Geol. Surv. Namibia.

Blignault, H.J., Jackson, M.P.A., Beukes, G.J. and Toogood, D.J. (1974). The Namaqua tectonic province in South West Africa, 15-29. *In*: A. Kröner (Ed.), *Contributions to the Precambrian Geology of southern Africa*. Bull. Precambr. Res. Unit, Univ. Cape Town, **15**.

Borg, G. 1988. The Koras-Sinclair-Ghanzi Rift in southem Africa. Volcanism, sedimentation, age relationships and geophysical signature of a late middle Proterozoic rift system. *Precambr. Res*., **38**, 75-90.

Burger, A.J. and Coertze, F.J. 1973. Radiometric age measurements on rocks from Southern Africa to the end of 1971. *Bull. geol. Surv. S. Afr*., **58**, 46 pp.

Burger, A.J. and Coertze, F.J. 1975. Age determinations - April 1972 to March 1974. *Ann. geol. Surv. S. Afr*., **10**, 135-142.

Burger, A.J. and Coertze, F.J. 1977. Summary of age determinations carried out during the period April 1974 to March 1975. *Ann. geol. Surv. S. Afr*., **11**, 317-322.

Cahen, L. and Snelling, N.J. 1984. *The Geochronology and Evolution of Africa*. Clarendon Press, Oxford, 512 pp.

Cameron, A.E., Smith, D.E. and Walker, R.L. 1969. Mass spectrometry of nanogram size samples of lead. *Anal. Chem*., **41**, 525-526.

Clifford, T.N., Stumpfl, E.F., Burger, A.J., McCarthy, T.S. and Rex, D.C. 1981. Mineral chemical and isotopic studies of Namaqualand granulites, South Africa: a Grenville analogue. *Contrib. Mineral. Petrol*., **77**, 225-250.

Davis, D.W. 1982. Optimum linear regression and error estimation applied to U-Pb data. *Can. J. Earth Sci*., **19**, 2141-2149.

Hartnady, C., Joubert, P. and Stowe, C. (1985). Proterozoic crustal evolution in southwestern Africa. *Episodes*, **8**, 236-244.

Heaman, L.M. and Smalley, P.C. 1994. A U-Pb study of the Morkheia Complex and associated gneisses, southern Norway: Implications for disturbed Rb-Sr systems and for the temporal evolution of Mesoproterozoic magmatism in Laurentia. *Geochim. cosmochim. Acta*, **58**, 1899-1911.

Heaman, L.M. and Machado, N. 1992. Timing and origin of midcontinent rift alkaline magmatism, North America: evidence from the Goldwell Complex. *Contrib. Mineral. Petrol*., **110**, 289-303.

Hegenberger, W. and Burger, A.J. 1985. The Oorlogsende Porphyry Member, South West Africa/Namibia: its age and regional setting. *Communs geol. Surv. S.W. Afr./Namibia*, **1**, 23-29.

Hoal, B.G. 1987. Terrane significance of the boundary between the Rehoboth and Gordonia subprovinces in southern Namibia, 42-45. *In*: Hartnady, C.J.H. (Ed.) *Proceedings and Abstracts of the Alex L. du Toit Golden Jubilee Conference on Tectonostratigraphic Terrane Analysis.* Precam. Res. Unit, Univ. Cape Town, 69 pp.

Hoal, B.G. 1990. The geology and geochemistry of the Proterozoic Awasib Mountain terrain, southern Namibia. *Mem. geol. Surv. Namibia*, **11**, 163 pp.

Hoal, B.G., Harmer, R.E. and Eglington, B.M. 1989. Isotopic evolution of the Middle to Late Proterozoic Awasib Mountain terrain in southern Namibia. *Precambr. Res*., **45**, 175-189.

Hugo, P.J. and Schalk, K.E.L. 1972. The isotopic ages of certain granites and acid lavas in the Rehoboth and Maltahöhe districts, South West Africa. *Ann. geol. Surv. S. Afr.*, **9**, 103-105.

Jackson, M.P.A 1975. Field relations between key lithological units of the Namaqualand Metamorphic Complex and the Naisib River Complex in the eastern Lüderitz district. *12th Ann. Rep. Precambr. Res. Unit, Univ. Cape Town*, 33-40.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C. and Essling, A.M. 1971. Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U. *Phys. Rev.*, **4**, 1889-1906.

Joubert, P. 1986. Namaqualand - a model of Proterozoic accretion? *Trans. geol. Soc. S. Afr*., **89**, 79-96.

Kröner, A 1977. The Sinclair aulacogen a late Proterozoic volcano-sedimentary association along the Namib Desert of southern Namibia (SWA). *Abstr. 9th Colloquium Afr. Geol*., Göttingen, 82-83.

Krogh, T.E., 1973. A low-contamination method for hydrothermal decomposition of zircon and the extraction of U and Pb for isotopic age determinations. *Geochim. cosmochim. Acta*, **37**, 485-494.

Krogh, T.E. 1982. Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique. *Geochim. cosmochim. Acta*, **46**, 637-649.

Mason, R. 1981. The Damara Mobile Belt in South West Africa/Namibia, 754-802. *In*: Hunter, D.R. (Ed.) *Precambrian of the Southern Hemisphere. Developments in Precambrian Geology*, **2**. Elsevier, Amsterdam, 882 pp.

Pfurr, N., Ahrendt, H., Hansen, B.T. and Weber, K. 1991. U-Pb and Rb-Sr isotopic study of granitic gneisses and associated metavolcanic rocks from the Rostock massifs, southern margin of the Damara Orogen: implications for lithostratigraphy of this crustal segment. *Communs geol. Surv. Namibia*, **7**, 35-48.

Reid, DL, Mailing, S. and Allsopp, H.L. 1988. Rb-Sr ages of granitoids in the Rehoboth-Nauchas area, South West Africa/Namibia. *Communs geol. Surv. S.W. Afr./Namibia*, **4**, 19-27.

South African Committee for Stratigraphy. 1980. Comp. Kent, L.E. *Stratigraphy of South Africa. Part 1 Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia and the Republics of Bophutatswana, Transkei and Venda*. Handb. geol. Surv. S. Afr., **8**, 690 pp.

Stacey, J.C. and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by two-stage model. *Earth Planet. Sci. Lett*., **26**, 207-221.

Steiger, R.H. and Jäger, E. 1977. Subcommission on geochronology: convention of the use of decay constants in geo- and cosmochronology. *Earth Plant. Sci. Lett*., **36**, 359-362.

Stoessel, G.F.U. and Ziegler, U.R.F. 1989. Report: Geochemical, Rb-Sr and U-Pb isotope studies of some acid volcanics from the Rehoboth Basement Inlier, Namibia. *Communs geol. Surv. Namibia*, **5**, 77-83.

Tankard, A.J., Jackson, M.P.A., Eriksson, K.A, Hobday, D.K., Hunter, D.R. and Minter, W.E.L 1982. *Crustal Evolution of Southern Africa. 3.8 Billion Years of Earth History*. Springer-Verlag, New York, 523 pp.

Von Brunn, V. 1967. *Acid and basic igneous rock associations west of Helmeringhausen, South West Africa*. Unpubl. Ph.D. thesis, Univ. Cape Town, 170 pp.

Waters, D.J. 1990. Thermal history and tectonic setting of the Namaqualand granulites, Southern Africa: clues to Proterozoic crustal development, 243-256. *In*: D. Vielzeuf and Ph. Vidal (Eds) *Granulites and Crustal Evolution*. Kluwer, Dordrecht, 585 pp.

Watters, B.R. 1974. Stratigraphy, igneous petrology and evolution of the Sinclair Group in southern South West Africa. *Bull. Precambr. Res. Unit, Univ. Cape Town*, **16**, 235 pp.

Ziegler, U.R.F. and Stoessel, G.F.U. 1991. Note: New constraints on the age of the Weener Intrusive Suite, the Gamsberg Granite and the crustal evolution of the Rehoboth Basement Inlier, Namibia. *Communs geol. Surv. Namibia*, **7**, 75-78.