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U-Pb and Pb-Pb ages of the Naauwpoort rhyolite, Kawakeup leptite and Okongava Diorite: implications for the onset of rifting and of orogenesis in the Damara belt, Namibia.

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The Naauwpoort quartz porphyry formed during local synsedimentary volcanism towards the end of the initial rifting phase in the central Damara belt of Namibia. SHRIMP U-Pb analysis of zircons from the Naauwpoort rhyolite dates this volcanism at 752±7 Ma whilst evaporation Pb-Pb analysis on the Kawakeup metarhyolite, a correlative unit from the southern Swakop terrane, suggests a minimum date of ~705 Ma. The pre-D_2 Okongava Diorite provides a SHRIMP zircon date of 558±5 Ma which is much younger than previously thought. Inherited zircon cores in the diorite document the presence of ~2 Ga zircons in the source origin of the diorite.

Introduction

The Pan-African belts of Namibia consist of the north-south trending Gariep and Kaoko belts and the northeast-trending, intracontinental Damara belt. The Damara belt can be divided, from south to north (Fig. 1), into a perip-heral foreland basin (Nama Terrane), a foreland fold and thrust belt (Hakos-Auas Terrane), an accretionary prism (southern part of southern Khomas Terrane), a forearc basin (northern part of southern Khomas Terrane and northern Khomas Terrane), a continental margin arc (Swakop Terrane), fold and thrusted continental basin (Outjo Terrane) and a retro-arc foreland basin (Otavi Terrane) (Kasch, 1983; Miller, 1983; Hoffmann, 1989; De Kock, 1992; Kukla, 1992). In the Swakop Terrane, intensity of deformation, grade of metamorphism and intensity of magmatic intrusion decreases from south to north.

Interpretation of the stratigraphic and lithological successions suggests that development of the basin in which the Damara Sequence was deposited was characterized by an initial rifting and a successive, although in places delayed, drifting phase (Miller, 1983). Immature to mature conglomerates and arkoses with limited volcanic successions were deposited towards the end of the rifting phase. Miller and Burger (1983) reported conventional U-Pb dates on zircons extracted from the unmetamorphosed and slightly deformed lower Naauwpoort Formation volcanic rocks occurring in the Outjo Terrane. They presented bulk population zircon upper intercept concordia dates of 750±60 Ma and 728±40 Ma for quartz porphyries using these results to interpret the onset of rifting to be older than 750±60 Ma. Hoffman *et al.* (1996) obtained single grain U-Pb (TIMS) zircon dates of 746±2 and 747±2 Ma for upper and lower Naauwpoort volcanic rocks, respectively; and a date of 756±2 Ma for the Oas Syenite which intrudes the base of the Naauwpoort Formation. Metamorphic dates, based on Rb-Sr dates of whole rocks, of 557±10 Ma and 521±45 Ma have also been reported for the Naauwpoort Formation by de Villiers (1968) and Hawkesworth *et al.* (1983).

Rifting was followed by subsidence and drifting and finally by a convergent phase during which deformation, metamorphism and intrusive magmatism occurred. The magmatic rocks vary from early tectonic metagabbro to syntectonic diorites to syn- and post-tectonic granodiorites and granites. These latter granitoids were

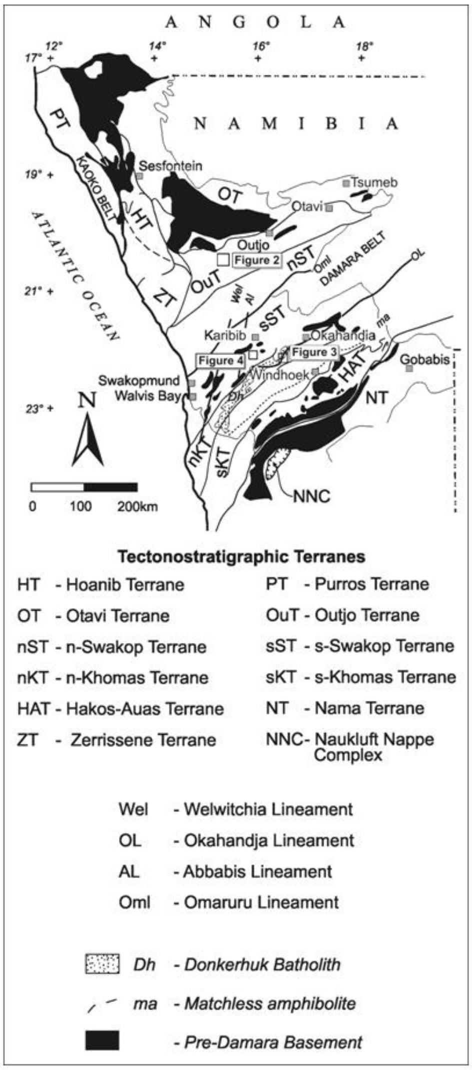

Figure 1 : The tectonostratigraphic terranes of the Pan-African Damara and Kaoko belts of Namibia with sample areas indicated.

produced in the middle crust during peak metamorphic and thermal relaxation conditions (Miller, 1983; de Kock, 1991). The early tectonic Palmental Diorite, an equivalent of the Okongava Diorite dated in the present investigation, was analysed by Kröner (1982) and gave Rb-Sr dates of 749±34 Ma (initial ratio 0,7057±2) and 651±20 Ma (initial ratio 0,7057±1). The older date was interpreted to reflect pre-tectonic intrusion with subsequent, post-D_1 resetting of the isotope systematics in some samples at ~0.65 Ga.

The Goas Granite, a Salem-type granitoid with large K-feldspar phenocrysts, intruded along the northwestern edge of the Okongava Diorite. Allsopp *et al.* (1983) dated this granite and determined dates of 580±30 Ma (U-Pb on selected zircon fractions) and 720±77 Ma (Rb/Sr-whole rock) while three biotite fractions defined a date of 535±8 Ma. Samples collected away from the intrusive contact defined a U-Pb date of $512^{+40}/_{-32}$ Ma, interpreted as indicating metamorphic resetting (Allsopp *et al.*,1983). The Goas Granite is considered to be a post-D_2 intrusion. Further southwest, Downing and Coward (1981) obtained a Rb-Sr date of 633±31 Ma on red granite in the Horebis River, which they considered a post-D_1 intrusion. They also obtained a Rb-Sr date of 554±33 Ma for the post-D_2 and pre-D_3 Salem-type granite in the Onanis River. The Palmental Diorite, a post-D_1 and pre-D_2 intrusion (Kröner, 1982), has similar mafic enclaves, chemical composition and tectonic foliation to the Okongava Diorite and has provided very poorly constrained Rb-Sr isotope dates of 756±35, 650±20, 702±64 and 564±55 Ma (Kröner, 1982; McDermott, 1986). All of these Rb-Sr dates are older than a zircon evaporation Pb/Pb date of 516±6 Ma obtained by de Kock and Walraven (1994). Clearly, the isotope systems in the Palmental Diorite must have suffered substantial post-crystallization modification.

In an attempt to determine the onset of the Pan-African rifting, dating has concentrated on pre- to syn-depositional magmatic rocks in the Damara belt. Zircons from samples of the Naauwpoort Formation were originally analyzed by Miller and Burger (1983), were selected from the NPRL, CSIR zircon mineral collection, now housed at the Council for Geoscience. Zircons were also extracted from the Kawakeup Formation to compare the timing of rifting in the Outjo terrane with that in the southern Swakop terrane. The onset of Damaran deformation has also been constrained by dating of the early tectonic Okongava Diorite.

Stratigraphic context

The stratigraphy of the Damara Supergroup, in which the Naauwpoort and Kawakeup Formations from the Outjo and southern Swakop Terranes occur, is briefly outlined in Table 1. The Nosib Group comprises a basal clastic unit, the Etusis Formation, overlain in places by volcaniclastic successions such as the Naauwpoort and Kawakeup Formations. Arkoses and conglomerates of the Etusis Formation represent rift-related deposits which were followed by volcanism towards the end of the rifting stage (Miller, 1983).

Naauwpoort Formation

The Naauwpoort Formation (Miller and Burger, 1983), which occurs in the Summas Mountains in the northern Outjo Terrane (Fig. 2), consists of an upper

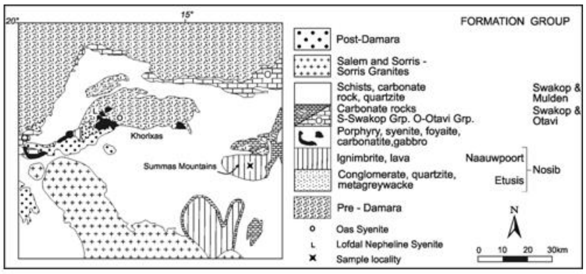

Figure 2: Distribution of the main occurrences and sample locality of the Naauwpoort Formation in the Outjo Terrane.

Table 1: Stratigraphy of the Damara Supergroup in the Outjo and Swakop terrane in the study regions.

	Outjo Terrane (after Hoffman *et al.*,1996)				**southern Swakop Terrane** (this study)			
	Group	Subgroup	Formation	Lithology	Group	Subgroup	Formation	Lithology
DAMARA SUPERGROUP	Mulden			Phyllite, schist, quartzite			Hureb	Mica and quartzitic schist
	Swakop	Khomas	Kuiseb	Mica schist	Swakop	Khomas	Fahlwater	Mica schist
			Karibib	Dolomitic and calcitic marble			Karibib	Marble, interbedded marble and schist, quartzite
							Omusema	Orthoamphibolite
							Okomis	Boulder conglomerate, pebbly schist
							Quelle	Calc-silicate, schist
							Adler	Marble
			Chuos	Mixtite, schist, iron formation, quartzite, marble				
		Ugab		Marble, schist				
	Nosib		Naauwpoort	Ignimbrite, lava	Nosib		Kawakeup	Rhyolitic leptite
							Etusis	Conglomerate, arkose.

and lower unit. The uppermost extrusions are interbedded with the dolomite sequences of the Swakop Group. The basal contact of the Naauwpoort Formation is not exposed. The Naauwpoort alkali rhyolites were extruded from two main centers 70 km apart during intracontinental block faulting and rifting. Those in the Summas Mountains are potassic (Miller, 1980) and those to the west, sodic (Frets, 1969). In the Summas Mountains, the lower Naauwpoort Formation consists mostly of ignimbrite, with massive, up to 830 m thick, grey quartz porphyry, occurring 3900 m from the top of the unit. A thin unit of brown quartz porphyry occurs about halfway up in the grey porphyry lava (Miller and Burger, 1983). Sample RM778 was taken from the grey potassic quartz porphyry.

The groundmass of the porphyry comprises irregular crypto-crystalline patches grading into areas of very fine-grained quartz and feldspar. Disseminated accessory opaque crystals occur throughout the rock. Muscovite and zircon are the other accessory minerals. Slightly clouded alkali feldspar and chess-board albite, up to 2 mm in size, are euhedral to anhedral. Phenocrysts of subhedral to anhedral quartz grains comprise less than 15% of the total rock volume. Strain induced undulose extinction (strain shadows) is common in the phenocrysts. Textures of the associated pyroclastic rocks point to extensive devitrification and recrystallization (Miller, 1980).

Kawakeup Formation

The Kawakeup Formation crops out in two domes on the farms Lievenberg 25 and Westfahlenhof 23 west of Otjimbingwe (Fig. 3) and is discordantly overlain by orthoamphibolite of the Omusema Formation and by schist, calc-silicate rocks, quartzite and marbles of the Karibib, Tinkas and Fahlwater Formations of the Swakop Group.

The Lievenberg Dome is structurally complex. Younger Swakop Group units were folded into the core of the dome during D_1 deformation. Recumbent, isoclinal D_1 folds were subsequently isoclinally refolded into D_2 recumbent folds. During D_3 doming these folds became draped over a southwest trending axis (De Kock, 1989). Contacts between the Kawakeup Formation and the younger infolded rocks are highly sheared. In the Lievenberg Dome, the Kawakeup Formation rocks have a distinctive, homogenous, tectono-metamorphic S_1 fabric parallel to the original bedding. In the Westfalenhof Dome the deformation appears less intense and total metamorphic recrystallization during D_1 produced very regular, continuous "beds" of 1-2.5 m thickness which are traceable for the exposed length of the dome (~14 km). Southeast-verging recumbent D_2 folds are abundant in the northeastern part of the dome.

The Kawakeup Formation occurs as an orange-red leptite within which all volcanogenic features have been destroyed. Grain size varies slightly as a function

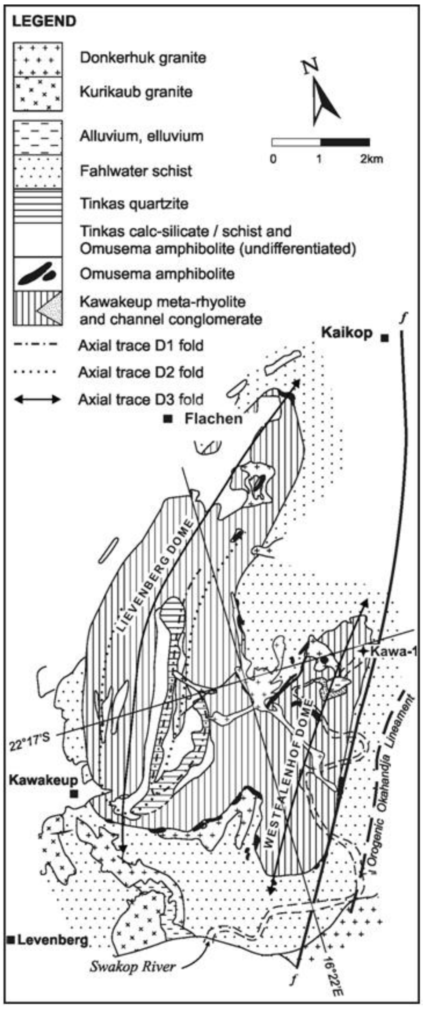

Figure 3: Distribution of the occurrences and sample locality of the Kawakeup Formation in the southern Swakop Terrane.

of intensity of deformation and proximity to fold hinges. Plagioclase and alkali feldspar vary from clear to extremely clouded depending on the state of saussuritization and sericitization. Both minerals are twinned and up to 2 mm in size with very rare metamorphic overgrowths of albite on the alkali feldspar. Quartz occurs as an intergranular phase to feldspar and mica. Rare muscovite and biotite occur as booklets and, in places, show chloritisation of the biotite. Idiomorphic opaque minerals occur evenly distributed through the rock. Euhedral zircon is abundant and occurs within the alkali feldspars and quartz or as inclusions in the biotite. Sillimanite, which is abundant in all the other clastic quartzo-feldspathic rocks, was not observed in the leptite despite the presence of K-feldspar, quartz and muscovite.

Sample Kawa 1 was collected in the Swakop River bed from exposures in the barrage on the border between Westfalenhof 23 and Hiradaub 26 (22°17.07'E; 16°22.77'S). The original position of this locality within the volcanic succession is not known because of tectonic duplication during subsequent deformation.

Okongava Diorite

Several dioritic bodies are present in the southern Swakop Terrane, especially in the area south of Karibib (Fig. 4). The metaluminous Okongava Diorite, the easternmost body, occurs to the west of the Otjua Dome, south-southeast of Karibib (Fig. 5) and contains mafic enclaves of the Audawib Gabbro and Okatuwo Monzodiorite. Both the Okatuwo Monzodiorite and Okongava Diorite are thought to have formed essentially co-evally, as indicated by features interpreted to represent magma mixing (De Kock, 1987; 1991).

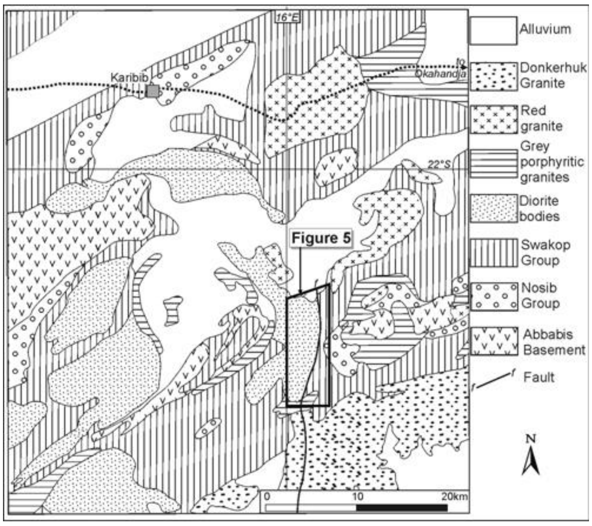

Figure 4: Distribution of the various igneous rock types in the area to the south of Karibib, southern Swakop Terrane.

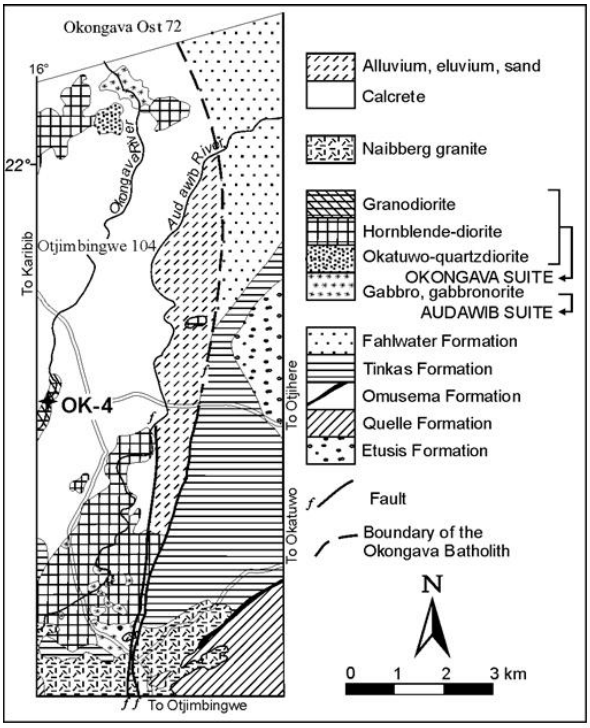

Figure 5: Simplified geological map of part of the Okongava Batholith and surrounding area with locality of sample OK-4.

The diorite is dark grey in colour, medium-grained with a very homogenous texture. It is composed of primary hornblende and plagioclase with subordinate quartz and K-feldspar. Titanite forms idiomorphic crystals which are often visible in hand specimen. Biotite is occasionally altered to chlorite. Magmatic differentiation resulted in a gradual change to a granodioritic composition with a decrease in hornblende, plagioclase and sphene and an increase in quartz, K-feldspar and biotite towards the center of the batholith. The more differentiated phase is light grey.

Foliation in the Okongava Diorite is defined by aligned hornblende grains and tabular biotite (in the granodioritic phase) and plagioclase laths. Grain boundaries are smooth and often form triple junctions. Undulose extinction of quartz is rare and suggests that the foliation formed at high-temperatures during or shortly after granitoid emplacement. The Okongava Diorite has a narrow contact metamorphic aureole causing localized anatexis and growth of metamorphic muscovite in the adjacent Tinkas pelitic schist. The full extent of this contact aureole has been masked by subsequent regional metamorphism.

Sample OK-4 is a granodiorite with minor hornblende and was collected in the Okongava River at 22°12’47”S, 16°00’10.6”E on Otjimbingwe 104 (Fig. 5).

Analytical technique

Samples were crushed and milled using the standard techniques of crushing, heavy liquid separation, magnetic separation and hand picking used by the Council for Geoscience for the separation of zircons.

Fully representative aliquots of the zircons were analysed at the Research School of Earth Sciences, Australian National University (ANU). The zircons were mounted in epoxy resin together with the zircon standards SL13 and AS3 and characterized using transmitted and reflected light, back-scattered electron imaging and cathodoluminescence imaging, the latter two techniques on the SEM at the electron microscopy unit at ANU. Analyses were performed on either SHRIMP I or II: spots were selected on the basis of the images obtained.

Analysis on SHRIMP and subsequent data reduction were performed following previously documented techniques (Compston *et al.*, 1984; Williams and Claesson, 1987; Compston *et al.*, 1992; Claoué-Long *et al.*, 1995). U/Pb in the unknowns was normalized to a $^{206}Pb^{*}/^{238}U$ value of 0.1859 (equivalent to an age of 1099.1 Ma) for AS3. U and Th concentrations were determined relative to those measured in the SL13 standard.

For spots in which the derived date is greater than 800 Ma, correction for common lead was made using the measured $^{204}Pb/^{206}Pb$ ratio and assuming the common lead evolution model of Cumming and Richards (1975). For areas younger than 800 Ma, correction for common lead was made using the measured $^{238}U/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios following Tera and Wasserburg (1972), as outlined in Compston *et al.* (1992) and Claoué-Long *et al.* (1995). Unless otherwise stated, dates older than 800 Ma are based on $^{207}Pb^{*}/^{206}Pb^{*}$ ratios and an assessment of the concordance of the data whereas dates younger than 800 Ma are based on $^{238}U/^{206}Pb^{*}$ ratios. In the Tera-Wasserburg concordia plots presented in this report, the data have been plotted uncorrected for common lead. This shows the dispersion of the data relative to the common lead content. The lower the common lead content, the closer the data points plot to the concordia curve.

All ages are calculated using the recommended decay constants of Steiger and Jäger (1977). Uncertainties in the results tables and plots are at 1 sigma whilst weighted averages and interpreted dates are quoted with 95% confidence uncertainties.

Zircon evaporation dating followed the technique of Kober (1986, 1987), as implemented at the Council for Geoscience (Walraven and Hattingh, 1993).

Weighted average $^{207}Pb/^{206}Pb$ (for zircon evaporation dates) and $^{206}Pb^{*}/^{238}U$ (for SHRIMP analyses) were calculated using the GEODATE for Windows package (Eglington and Harmer, 1999).

Sample descriptions

Naauwpoort Formation

Sample RM 778 (grey lava) was selected for reinvestigation as it contains abundant zircons which were most concordant in the original study of Miller and Burger (1983). Zircons are translucent to turbid and malacon, ranging in colour from hyacinth to brown. Crystals are predominantly subhedral, but euhedral and anhedral grains also occur. No overgrowths were found although inclusions were present in most grains. Zoning is rare and the zircons apparently represent a single magmatic population.

Kawakeup leptite

Zircons of the Kawakeup Formation were recovered from the 150-250 µm size fraction (length) of sample Kawa 1, and range in width from about 40 to 180 µm. The zircons vary from colourless to pale brown with a yellowish tinge (due to slight iron staining) to honey coloured. Morphologically the grains are moderately elongated with aspect ratios of about 2. Subhedral to euhedral grains predominate. Many grains have curvilinear crystal faces. Irregularly developed grains such as botryoidal shapes, fused grains and grains with negative faces are also present. Crystals selected for evaporation were generally subtransparent, whereas the bulk of the population displays a complete gradation to subtranslucent, metamict grains. Some crystals are structureless, whereas others display faint multiple growth zoning. In a few cases distinct growth lines are developed, thus delineating two or more domains within the host. Rare grains exhibiting a very limited, patchily clear phase are present. All the zircon grains carry a variety of shapes of inclusions such as rods, blebs and small regularly distributed spots. Alteration in the selected grains is displayed as patchy turbid domains. Rare microfractures contain altered material and iron oxide staining. No evidence of cores inherited from an older protolith were found.

Okongava Diorite

Abundant pale brown zircons, 100 to 200 µm in length, were extracted from sample OK-4 of the Okongava Diorite. The grains are essentially subhedral to euhedral and range in elongation from 1:2.5 to near equant, with crystal faces varying from straight to slightly curvilinear. Terminations of the grains range from sharp to slightly obtuse and are asymmetrical on many surfaces. Most of the grains are transparent and structureless, whereas others show multigrowth zoning. Older cores are evident in several of the grains. Inclusions present in most of the grains consist of stubby rods, negative crystals and blebs. A few grains show slightly turbid domains of alteration.

Results and interpretation

Naauwpoort Formation

Sample RM 778 provides a uniform distribution of $^{238}U/^{206}Pb^{*}$ dates (Table 2, Fig. 6) with a weighted average of 752±7 Ma (MSWD = 0.66, probability of fit = 0.782). This date is identical, within experimental error, to the 746±2 and 747±2 Ma dates obtained by Hoffman *et al.* (1996). These dates are believed to represent the time of lava extrusion in the Outjo Terrane towards the end of Nosib Group deposition.

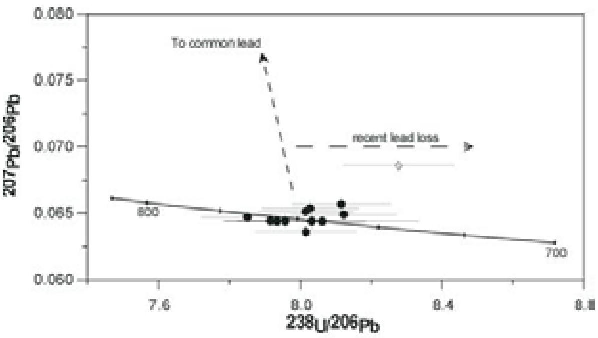

Figure 6: Tera-Wasserburg projection of sample RM-778, Naauwpoort Formation. Spots which are believed to have suffered lead loss are shown as open diamonds. Spots included in the weighted average are shown as solid circles. Note that the analyses are shown prior to correction for common lead so as to more easily distinguish the data points.

Table 2: Summary of SHRIMP U-Pb zircon results for sample RM-778, Naauwpoort Formation

Grain. Spot	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	$^{204}Pb/^{206}Pb$	F_{206} %	$^{238}U/^{206}Pb$	±	$^{207}Pb/^{206}Pb$	±	Radiogenic $^{206}Pb/^{238}U$	±	Age (Ma) $^{206}Pb/^{238}U$	±
1.1	412	212	0.51	52	0.000081	0.80	8.115	0.140	0.0657	0.0004	0.1222	0.0021	743	12
2.1	332	167	0.50	42	0.000021	0.71	8.122	0.150	0.0649	0.0005	0.1223	0.0023	744	13
3.1	393	199	0.51	50	0.000010	0.64	8.061	0.274	0.0644	0.0004	0.1233	0.0042	749	24
4.1	325	143	0.44	41	0.000010	0.55	8.016	0.144	0.0636	0.0005	0.1241	0.0022	754	13
5.1	443	245	0.55	56	0.000287	1.16	8.278	0.157	0.0686	0.0005	0.1194	0.0023	727	13
6.1	512	289	0.56	68	0.000010	0.68	7.851	0.131	0.0647	0.0004	0.1265	0.0021	768	12
7.1	350	188	0.54	45	0.000058	0.76	8.029	0.137	0.0654	0.0006	0.1236	0.0021	751	12
8.1	408	214	0.53	53	0.000049	0.64	7.934	0.135	0.0644	0.0005	0.1252	0.0021	761	12
9.1	455	244	0.54	59	0.000014	0.64	7.958	0.136	0.0644	0.0005	0.1249	0.0021	758	12
10.1	420	238	0.57	55	0.000072	0.73	8.015	0.136	0.0651	0.0005	0.1239	0.0021	753	12
11.1	329	150	0.46	42	0.000043	0.64	8.033	0.153	0.0644	0.0007	0.1237	0.0024	752	14
12.1	415	197	0.47	54	0.000010	0.65	7.916	0.135	0.0644	0.0006	0.1255	0.0021	762	12

Notes :
1. Uncertainties given at the one σ level.
2. f_{206} % denotes the percentage of ^{206}Pb that is common Pb.
3. Correction for common Pb made using the measured $^{238}U/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios following Tera and Wasserburg (1972) as outlined in Compston *et al.* (1992).

Kawakeup Formation

Sample Kawa 1 provides a multimodal evaporation $^{207}Pb/^{206}Pb$ distribution (Table 3, Fig. 7). The dominant frequency within this distribution suggests a date of 636±9 Ma, whilst lesser peaks are apparent at dates of 682 ±12 and 706±10 Ma. As noted earlier, no older cores are evident in the zircons. The ~0.7 Ga date is thus thought to be the best indication of formation age for this unit currently available. Cathodoluminescence analysis on additional grains from the population does not provide any information which can assist in distinguishing between the various modes in the distribution and microbeam techniques will need to be utilized in future to better constrain the extrusion age of this unit.

Table 3: Summary of evaporation $^{207}Pb/^{206}Pb$ zircon results for samples Kawa-1 (Kawakeup Formation) and OK-4 (Okongava Diorite).

Sample	Grain	Temperature (°C)	Date (Ma)[1]
Kawa-1	1	1410-1480	$635^{+9.5}/_{-9.6}$
	2	1410-1480	$649^{+11}/_{-11}$
	3	1440	$648^{+16}/_{-16}$
	3	1460	$706^{+9.7}/_{-9.7}$
	4	1410-1480	$682^{+12}/_{-13}$
OK-4[2]	All	1410-1480	$516^{+6.3}/_{-6.3}$

Notes :
1. Uncertainties given at 95% confidence level.
2. Results from De Kock and Walvaren (1994)

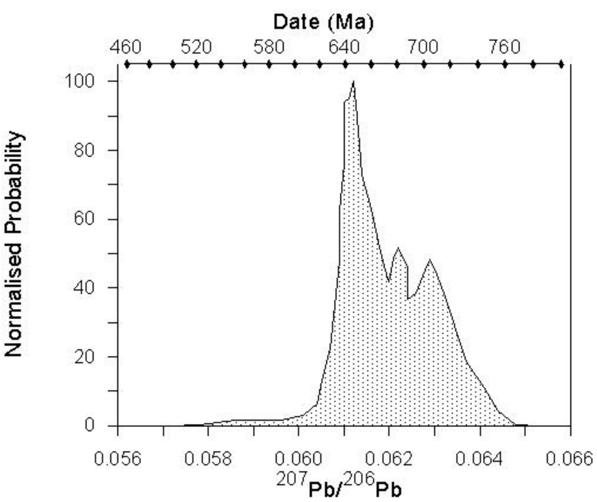

Figure 7: Normalised probability plot for zircon evaporation results for sample KAWA-1, Kawakeup Formation. Maximum probability has been normalised to a value of 100%.

Okongava Diorite

Spot analyses of zones within zircons from sample OK-4 which exhibit typical magmatic growth zoning during crystallization provide a $^{238}U/^{206}Pb$ * date of 548±7 Ma (MSWD = 2.1, probability of fit = 0.012) (Table 4). The probability of fit is less than 5%, which is unacceptably low. Several of the areas analyzed appear to have been affected by recent lead loss (Fig. 8). Exclusion of these spots from the weighted average provides a $^{238}U/^{206}Pb$ * date of 558±5 Ma (MSWD = 0.43, probability of fit 0.906) which is considered to be the best estimate of the age of crystallization for this intrusive body. Two analyses of cores identified from cathodoluminescence imagery provide $^{207}Pb^*/^{206}Pb^*$ model dates slightly older than 2 Ga (Table 5), indicative of the age of pre-existing basement in the area. Zircon evaporation isotope analysis of sample OK-4 pro-

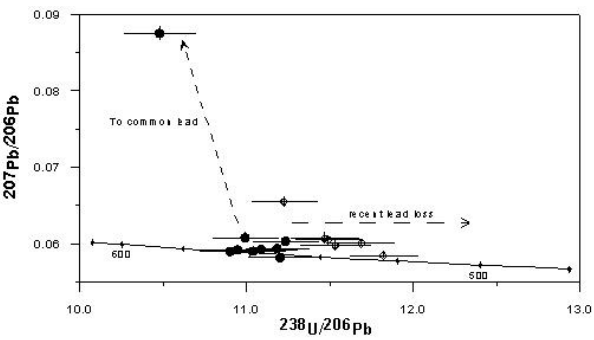

Figure 8: Tera-Wasserburg projection for sample OK-4, Okongava Diorite. Spots which are believed to have suffered recent lead loss are shown as open diamonds. Spots included in the weighted average are shown as solid circles. Note that the analyses are shown prior to correction for common lead so as to more easily distinguish the data points.

											Radiogenic		Age (Ma)	
Grain. Spot	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	$^{204}Pb/^{206}Pb$	F_{206} %	$^{238}U/^{206}Pb$	±	$^{207}Pb/^{206}Pb$	±	$^{206}Pb/^{238}U$	±	$^{206}Pb/^{238}U$	±
1.1	164	99	0.60	16	0.000368	0.78	11.223	0.200	0.0655	0.0006	0.0884	0.0016	546	9
2.1	291	204	0.70	29	0.000074	-	11.039	0.194	0.0590	0.0005	0.0906	0.0016	559	9
3.1	463	196	0.42	40	0.000138	-	11.817	0.205	0.0585	0.0004	0.0847	0.0015	524	9
3.2	101	85	0.84	11	0.002301	3.48	10.476	0.217	0.0875	0.0009	0.0921	0.0019	568	11
4.1	169	120	0.71	17	0.000144	0.01	11.085	0.219	0.0592	0.0006	0.0902	0.0018	557	11
5.1	500	152	0.30	42	0.000025	0.11	11.687	0.198	0.0601	0.0004	0.0855	0.0015	529	9
6.1	243	179	0.74	23	0.000305	0.17	11.489	0.200	0.0605	0.0006	0.0869	0.0015	537	9
7.1	627	273	0.43	58	0.000065	-	11.200	0.194	0.0582	0.0005	0.0894	0.0016	552	9
8.1	235	164	0.70	23	0.000068	0.08	11.531	0.214	0.0598	0.0007	0.0867	0.0016	536	10
8.3	153	103	0.68	15	0.000115	0.2	10.989	0.197	0.0608	0.0007	0.0908	0.0016	560	10
9.1	479	143	0.30	44	0.000010	-	10.898	0.182	0.0590	0.0005	0.0918	0.0015	566	9
10.1	291	215	0.74	29	0.000045	0.15	11.232	0.200	0.0603	0.0005	0.0889	0.0016	549	9
11.1	249	197	0.79	25	0.000183	0.19	11.466	0.207	0.0607	0.0008	0.0871	0.0016	538	9
12.1	311	222	0.71	31	0.000136	0.03	11.181	0.193	0.0594	0.0004	0.0894	0.0016	552	9
13.1	265	143	0.54	26	0.000010	0.01	10.944	0.197	0.0592	0.0005	0.0914	0.0016	564	10

Notes :
1. Uncertainties given at the one σ level.
2. f_{206} % denotes the percentage of ^{206}Pb that is common Pb; denotes no common Pb detected.
3. Correction for common Pb made using the measured $^{238}U/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios following Tera and Wasserburg (1972) as outlined in Compston *et al.* (1992).

vides a multimodal distribution (Fig. 9) with the major peak at ~530 Ma and minor peaks at ~500 Ma. These various peaks in the distribution are interpreted as reflecting post crystallization metamorphism and/or the effects of recent lead loss.

Discussion

The high precision dates obtained on the greenschist facies Naauwpoort volcanic rocks and Oas syenite indicate that rifting in the Outjo terrane, along the southern margin of the proto-Congo craton, was terminated by a short (<10 Ma) volcano-magmatic event during the period 756±2 Ma to 746±2 Ma (Hoffman *et al.*, 1996). The SHRIMP U-Pb date on the RM 778 zircons (752±7 Ma) presented here supports this interpretation.

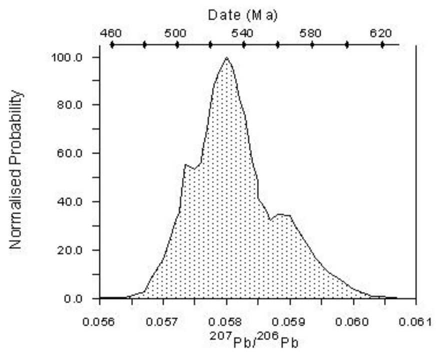

Figure 9: Normalised probability plot for zircon evaporation results for sample OK-4, Okongava Diorite. Maximum probability has been normalised to a value of 100%.

The 0.7 Ga date obtained by Pb-Pb evaporation analyses on the upper amphibolite facies Kawakeup zircons could indicate that volcanism occurred much later further to the south in the Swakop Terrane. However, a similar Pb-Pb evaporation date of ~705 Ma was provided by several RM 778 Naauwpoort zircons (de Kock and Walraven, 1994) whereas precise U-Pb dating on the same sample and others from the succession indicate that the true age of extrusion of the Naauwpoort Formation is ~750 Ma. No indication of a ~706 Ma event is evident in any of the zircons analyzed on SHRIMP nor in the data reported by Hoffman *et al.* (1996). It is not clear why zircons from the Naauwpoort Formation provide evaporation Pb-Pb dates which are younger than the extrusion age of the lavas. It is most probably due to lead loss during post-extrusion metamorphism or weathering. The date obtained for the Kawakeup Formation may have been similarly disturbed and should thus be considered a minimum estimate of the age of extrusion.

Kröner *et al.* (1978) obtained a Rb-Sr date of 651±34 Ma for the high-grade metamorphic event on the Karibib Formation calc-granofels near Usakos which predates the widespread granite intrusion. This 0.65 Ga date is similar to the Pb-Pb evaporation date of 636 ±8 Ma determined for the Kawakeup Formation and can be considered as the time when all volcanogenic features were destroyed by total recrystallization during the D_1 tectonometamorphic event in the southern Swakop terrane.

The Okongava Diorite provides an U-Pb date of

							Radiogenic Ratios						Ages (in Ma)						
Grain. Spot	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	$^{204}Pb/^{206}Pb$	F_{206} %	$^{206}Pb/^{238}U$	±	$^{207}Pb/^{235}U$	±	$^{207}Pb/^{206}Pb$	±	$^{206}Pb/^{238}U$	±	$^{207}Pb/^{235}U$	±	$^{207}Pb/^{206}Pb$	±	Conc. %
8.2	496	117	0.24	187	0.000010	0.018	0.3690	0.0063	6.275	0.113	0.1233	0.0005	2025	30	2015	16	2005	7	101
14.1	150	61	0.41	58	0.000015	0.026	0.3616	0.0065	6.240	0.123	0.1252	0.0007	1990	31	2010	17	2031	10	98

Notes :
1. Uncertainties given at the one σ level.
2. f_{206} % denotes the percentage of ^{206}Pb that is common Pb.
3. Correction for common Pb made using the measured $^{204}Pb/^{206}Pb$ ratios and the Cumming and Richards (1975) lead evolution model.
4. For % Conc., 100% denotes a concordant analysis.

558±5 Ma, which is much younger than the 651±20 Ma Rb-Sr date obtained by Kröner (1982) on the Palmental Diorite, a supposedly co-eval intrusion, and the 633±39 Ma Horebis River red granite (Downing and Coward, 1982). This 0.56 Ga date is within error of U-Pb and mica Rb-Sr dates reported by Allsopp *et al.* (1983) for the younger Goas Granite.

Palaeoproterozoic cores identified in zircons from the Okongava Diorite (Table 4) indicate that the deeper crust in the area must either contain Palaeoproterozoic material or sediments derived from a ~2 Ga source area. None of the zircon grains from the Okongava Diorite exhibit any signs of ages between the ~0.56 Ga date obtained here and the much older, ~2 Ga inherited cores. The ~0.56 Ga date obtained during the present study therefore calls into question earlier suggestions of intrusions at about 0.65 Ga. Furthermore, if the diorite was indeed intruded prior to D_2 tectonism, then this tectonic event must be much younger than previously thought.

Conclusions

The U-Pb (SHRIMP) and Pb-Pb (evaporation) dates obtained on zircons from the Naauwpoort and Kawakeup volcanic units of the early Nosib Group and the Okongava Diorite lead to the following conclusions:

i The basement in the southern Swakop Terrane is up to 2000 Ma old,

ii Volcanism towards the end of the initial rifting phase was of short duration (<10 Ma), occurring at about 0.75 Ga,

iii The crystallization age of 558±5 Ma for the Okongava Diorite conflicts with previous reported ~650 Ma Rb-Sr dates for supposedly co-eval diorites. The new data may indicate that post-D_1-pre-D_2 magmatism in the Swakop Terrane occurred much later than previously thought. This possibly requires further research.

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