Age of Metavolcanic rocks at the northern margin of the Namaqua-Natal Metamorphic Province in the Karas Mountains, Namibia, defined by SHRIMP U-Pb dating of zircons

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ABSTRACT

Mapping in the Karas Mountains area of southern Namibia has shown the presence of a major lithotectonic boundary at the northern margin of the Namaqua-Natal Metamorphic Province. The area is subdivided into the Northern Volcanic Zone largely comprising mafic, intermediate and felsic volcanic and intrusive rocks metamorphosed to greenschist to amphibolite facies, and the Southern Sedimentary Zone, dominated by pelitic rocks, metamorphosed at amphibolite to granulite facies, and intruded by syntectonic granites. The intervening Lord Hill Boundary Zone is characterized by anastomosing mylonite belts with dips and lineations plunging steeply to the south, within less-deformed metalavas and intrusions similar in character to those of the Northern Volcanic Zone. The intrusive and metavolcanic rocks of the Northern Volcanic and Lord Hill Boundary Zones have geological characteristics of present-day volcanic arcs. Texturally well-preserved felsic metavolcanic rocks of the Lord Hill Boundary Zone have been dated by SHRIMP U-Pb isotope analysis of zircons, and gave an age of 1286.0 ± 7.3 Ma. The age and tectonic setting are very similar to those of the Jannelsepan and Copperton Formations in South Africa, and point to an extensive Mesoproterozoic volcanic arc at the southern edge of the Kalahari Craton.

Introduction

The Namaqua-Natal Metamorphic Province (NNMP) in South Africa and Namibia is one of a number of medium to high-grade metamorphic belts of Mesoproterozoic age in sub-Saharan Africa. Recent work in the NNMP has focussed on the South African parts of the belt (Thomas *et al.*, 1999; Kruger *et al.*, 2000; Eglington and Armstrong, 2003), whereas little modern work has been carried out in the Namibian sector. This paper is presented as a contribution to the geological and geochronological understanding of the northern boundary of the NNMP through remapping and isotopic dating of metavolcanic rocks in southern Namibia.

Regional geological setting

The Mesoproterozoic NNMP, which wraps around the southern margin of the Kalahari craton (Figure 1 inset), has been divided by Hartnady *et al.* (1985) into a number of subprovinces, which may represent distinct plate tectonic and palaeogeographic environments (terranes). These distinct terranes were juxtaposed during a presumed period of accretion and collision between ~1.3 and ~1.0 Ga (Thomas *et al.* 1994, Eglington, 2006).

The study area in the Karas Mountains of Namibia (Figure 1) straddles the boundary between the Gordonia Subprovince of the NNMP and the Rehoboth Subprovince, (Figure 1 inset). The Gordonia Subprovince of Hartnady *et al.* (1985) incorporates the Kakamas terrane of Thomas *et al.* (1994), and is characterised by high-grade (amphibolite to locally granulite facies) metamorphosed pelitic metasediments, intruded by abundant syn- to late tectonic granites and charnockites (Jackson, 1979; Thomas *et al.*, 1994).

The Rehoboth Subprovince is poorly known, due to being largely covered by thick sequences of Neoproterozoic and Phanerozoic continental sediments. Wright and Hall (1990) used deep seismic data to infer that much of the covered Rehoboth Subprovince represents extended cratonic crust. Based on xenoliths in kimberlites, the Rehoboth Subprovince is inferred to contain both cratonic and non-cratonic components aged about 2.0 to 2.2 Ga (Hoal *et al.* 1995). It is inferred to have been amalgamated with the Archaean Zimbabwe and Kaapvaal Provinces to form the Kalahari Craton during the Palaeoproterozoic to Mesoproterozoic eras (Hartnady *et al.*, 1985).

doi:10.2113/gssajg.110.1.47

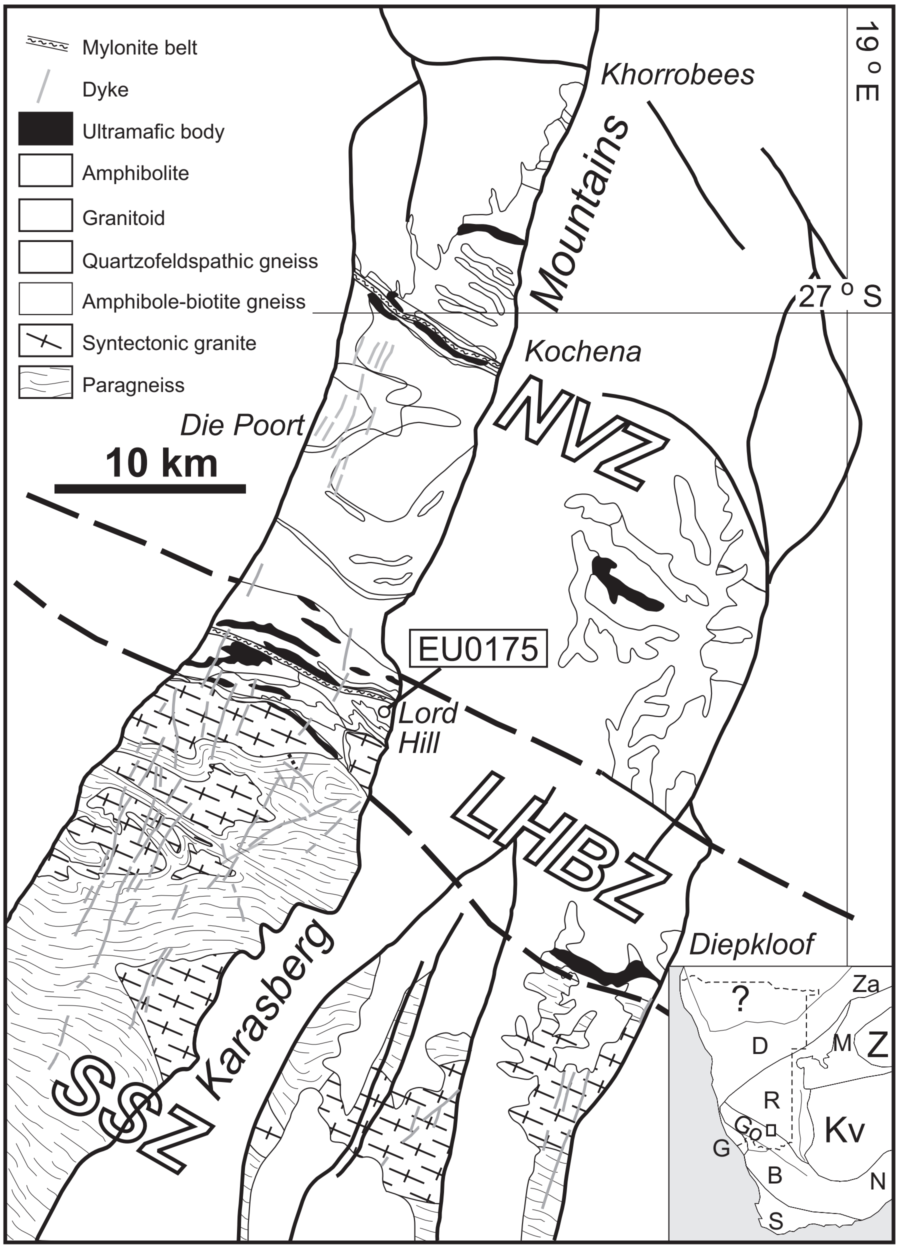

Figure 1. Geological map of the Karas Mountains area, based on Namibia Geological Survey map (1978), together with recent mapping and Landsat-geophysical interpretation. Unshaded area is covered by Nama Group and Karroo Supergroup sedimentary rocks. Abbreviations – see text. Inset: tectonic provinces of southern Africa with Namibia outlined by dashed line and study area outlined as solid box, modified from Hartnady *et al*. (1985). Abbreviations –B, Go, N, Bushmanland, Gordonia and Natal Subprovinces of Namaqua-Natal Metamorphic Province (Mesoproterozoic – white); R, Rehoboth Subprovince (Meso-Palaeoproterozoic – diagonal stripe pattern); D, G, S, Za Damara, Gariep, Saldania and Zambezi Subprovinces (Neoproterozoic – dotted pattern); M, Magondi Province (Palaeoproterozoic – vertical bars); Kv, Z, Kaapvaal and Zimbabwe Provinces (Archaean – V-pattern).

Previous geological mapping in the Karas Mountains area and age dating in southern Namibia

The NNMP in southern Namibia has been much less intensively studied than equivalent areas in South Africa. The first geological mapping of the Karas Mountains was carried out by Waibel (1925). Geological Survey mapping of the Karas Mountains was carried out by J T Wessels in 1937 to 1939: this was subsequently updated by Schreuder in 1971 and published by the Geological Survey of Namibia (GSN: 1:250,000 scale geological map sheet 2718, Grünau, 1978). On this GSN map, the Karas Mountains form a north-northeasterly-trending, fault-bounded corridor of metamorphic rocks, which otherwise are largely covered by flat-lying continental foreland sedimentary rocks of the Nama Group and Karoo Supergroup (Figure 1). The GSN map shows the Karas Mountain area to be divided into a southern part of biotite-garnet-sillimanite and biotite-garnet-cordierite gneisses intruded by syntectonic garnet- or sillimanite-bearing gneissic granites, and a northern part with a wide variety of metamorphic rocks, including biotite-amphibole schist, garnet-chlorite-sericite schist, biotite schist, metaquartzite, pretectonic granodiorite gneiss and porphyroblastic quartz-feldspar gneiss.

Most of the mapping of the NNMP by the Precambrian Research Unit of the University of Cape Town in the 1960's and 1970's was carried out to the south and west of the Karas Mountains (Blignault *et al.*, 1974; 1983; Jackson, 1979), and was focussed on tectonometamorphic aspects. However, Blignault (1974) conducted a geological reconnaissance of the study area, confirming the wide variety of rock types of probable volcano-sedimentary origin in the Karas Mountains. He also noted a major zone of mylonites near what he considered the northern boundary of the NNMP in this region, which he termed the Lord Hill structure, and he noted its association with hypabyssal intrusive rocks. This shear zone was extrapolated under cover to connect with the Excelsior mylonite belt to the northwest (Blignault *et al.* 1974). This shear zone was identified by Blignault *et al.* (1974; 1983) as a major metamorphic boundary, forming the northern limit of their Central Zone of the NNMP in Namibia (corresponding to the Gordonia subprovince of Hartnady *et al.* 1985).

No further regional mapping has been undertaken since Blignault, although the area has been subject to mineral exploration by among others Consolidated Diamond Mines, Anglo American Prospecting Services, Falconbridge Limited, and BHP-Billiton (Open File reports at Geological Survey of Namibia).

No attempts to date the metamorphic rocks of southern Namibia were made by Blignault and coworkers (1974), and they assumed that the metavolcanic rocks of his Northern Marginal Zone belonged to the so-called Kheis Province, at that time generally believed to be of early Proterozoic to Archaean age (Martin, 1965). The only other age dating carried out in southern Namibia has been of granites of the Warmbad and Lüderitz areas (Burger and Coertze, 1975), and a series of dating of rocks of the Sinclair area to the northwest (Hoal *et al.*, 1989; Hoal and Heaman, 1995).

New mapping and reinterpretation of previous mapping

Background and methods

Reconnaissance mapping of the Karas Mountains, in conjunction with interpretation of structure and alteration patterns on Landsat 7 images was carried out between June and October 1998 during mineral exploration ativities. Regional aeromagnetic anomaly maps, available from the Geological Survey of Namibia website (see Eberle *et al.*, 2002), were used to extrapolate the results of mapping to east and west under the Nama Group cover. The result of the mapping and reinterpretation is presented as Figure 1.

To the east and west of the Karas Mountains, a thin veneer of gently undulating, unmetamorphosed strata of the Nama Group overlies the metamorphic rocks. The Nama Group and underlying basement are cut by prominent north-northeasterly-trending faults, which divide the area into a series of elongate fault blocks with different levels of erosion. An almost continuous exposure of Namaqua metamorphic rocks is seen in the Groot Karas Mountains fault block, while windows of the metamorphic rocks are seen in steep-sided river valleys and on the edge of fault escarpments to the east of the Karas Mountains (Figure 1).

The new mapping has confirmed two distinct geological terranes in the Karas Mountains. In the northern terrane, metamorphosed intrusive and extrusive igneous rocks of mafic, intermediate and felsic composition dominate the lithologies. In the southern terrane, lithologies are dominated by metapelitic rocks that underwent a high grade of metamorphism, and by S-type granitoids. These are termed here the Northern Volcanic Zone (NVZ) and Southern Sedimentary Zone (SSZ) respectively (Figure 1). The NVZ corresponds with the Northern Marginal Zone, and the SSZ with the Central Zone as defined by Blignault *et al.* (1974). The new mapping indicates that a 5 km wide transitional zone, the Lord Hill Boundary Zone (LHBZ), which is marked by a series of discrete steep mylonitic shear zones, separates the two zones.

Northern Volcanic Zone

This zone extends from Lord Hill in the south to the farm Khorrobees in the north (Figure 1). On Landsat images, the area is characterised by patchy, small-scale variations of lithology and surface alteration. The predominantly mafic character is seen in Landsat images as prominent reflectance in the mid-infra-red, signifying enrichment of iron oxide at the surface. Lighter coloured areas represent pervasive weak kaolin alteration of felsic rocks. Bands of amphibolitic and ultramafic composition can be distinguished by their dark, low-reflectance character.

Structural trends are highly variable showing evidence of large scale cross-folding or doming, but at the southern and northern margins the trends are dominantly west-northwest to east-southeast. The axes of abundant minor folds in cherts of the Die Poort locality plunge moderately to steeply southeastwards.

The dominant rock types of this zone are quartzofeldspathic and amphibole-biotite-chlorite schists and gneisses of felsic to intermediate composition, together with a wide variety of lesser intrusive and metasedimentary rocks. Rocks of undoubted metasedimentary character are not abundant, and include contorted layers of cherty marble, thin manganiferous and pyritic quartz-rich bands, sometimes associated with muscovite and biotite-rich schists. The metamorphic mineralogy ranges from plagioclase-quartz-biotite(-chlorite) to quartz-feldspar-biotite, representative of felsic to intermediate rocks at greenschist to amphibolite facies. The rocks are largely schistose with only locally preserved primary textures, however, they can be interpreted as a sequence of felsic to intermediate volcanic or volcaniclastic rocks, interlayered with subordinate sedimentary, mafic volcanic and intrusive rocks.

The metavolcanic and metasedimentary rocks are intruded by a variety of weakly foliated pink granite and grey granodiorite bodies, as well as porphyritic metadiorite and metabasaltic andesite dykes. These intrusive bodies often preserve primary igneous textures such as phenocrysts of quartz and plagioclase, and appear to have been metamorphosed at a lower grade than surrounding gneisses.

Crosscutting all the above rocks is a series of consistently north-northeasterly to northeasterly-oriented large mafic dykes (up to 50 m across), which are virtually unmetamorphosed and undeformed. They have dark, chilled basaltic margins, while their centres have medium to coarse-grained ophitic textures, with prominent radiating clusters of plagioclase. The dykes have not been observed to intrude the Nama Group and it is presumed that they predate the Nama sedimentation. These dykes are correlated with the Gannakouriep dyke swarm, which has the same orientation to the south of the present area (Blignault *et al.*, 1974; Reid *et al.*, 1987).

Lord Hill Boundary Zone

The LHBZ is a package of rocks about 3 to 5 km wide between the NVZ and the SSZ. The dominant rocks within the LHBZ are mafic and felsic metavolcanic rocks, although metapelitic sedimentary.rocks are more common than in the NVZ. Several discrete west-northwest to east-southeasterly-trending shear zones, including the main Lord Hill Shear Zone cut through these rocks. These shear zones are from 5 to 100 m wide and dip steeply to the south. The dominant plunge of stretching lineations is steeply down dip to the south or southwest. The shear zones themselves range from protomylonite to ultramylonite textures (Figure 2a).

The rocks in between the mylonite zones appear to have undergone less pervasive strain than similar rocks in the NVZ. Primary volcanic and volcaniclastic textures are well preserved in 1 to 10 metre-scale blocks and lenses surrounded by anastomosing schistose zones. It appears that strain partitioning has been particularly heterogeneous in this boundary zone. For example, undeformed lenses of metabasalt 2 to 5 m wide containing round calcite-filled amygdaloidal structures are found some 200 m north of the major mylonite zone (Figure 2b). These metabasalt rocks have plagioclase-hornblende mineral assemblages, so the boundary zone has a grade of metamorphism at least as high as greenschist facies, similar to that in the adjacent part of the NVZ. Some 500 m south of the shear zone, coarse felsic agglomerate and finer quartz-feldspar porphyry textures are well preserved, although the clasts are somewhat flattened. These rocks appear similar in texture and metamorphic grade to the hypabyssal intrusive rocks of the NVZ.

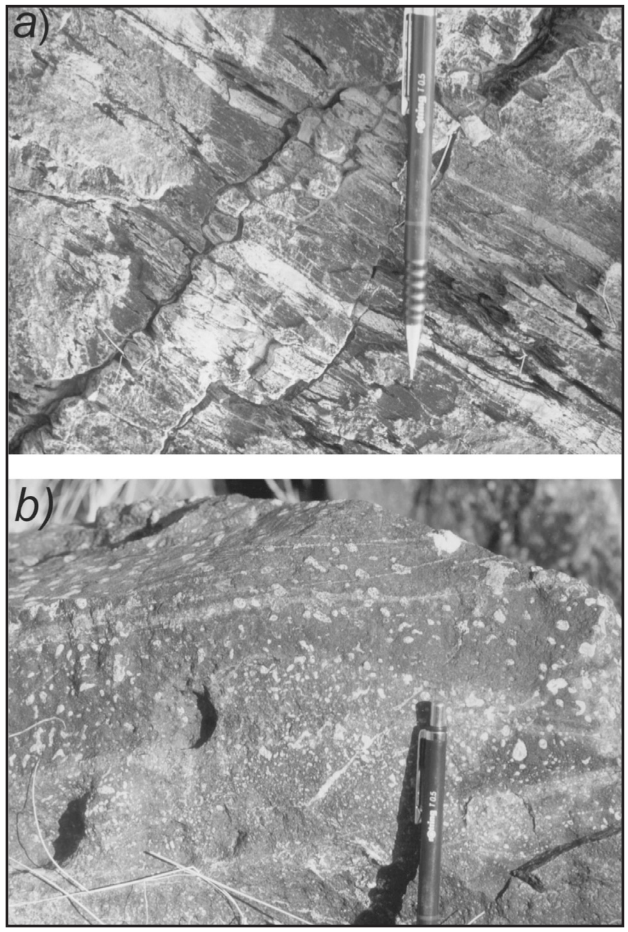

Figure 2. (**a**) Photograph of sheared protomylonite textures in amphibolite within main Lord Hill mylonite zone. (**b**) Photograph of scarcely deformed amygdaloidal metabasalt from close to Lord Hill mylonite zone.

Towards the southern margin of the boundary zone, metasedimentary rocks become more common, including sillimanite-cordierite-garnet gneisses similar to those found to the south in the SSZ, and unusual kyanite-bearing gneisses not seen elsewhere. Such kyanite gneisses in the Diepkloof locality (Figure 1) contain coarse tabular kyanite that is retrogressed to muscovite with a crude corona-like texture in a biotite-bearing quartzofeldspathic matrix. These metasedimentary gneisses are interbanded on a 1 to 100 m scale with metavolcanic rocks such as fine-grained, pink quartzofeldspathic gneisses.

The unmetamorphosed Gannakouriep dykes cut through the mylonites of the LHBZ with no offsets, indicating that the shear zones predate the dykes. Study of the regional aeromagnetic anomaly maps (published by the Geological Survey of Namibia at http://www.gsn.gov.na/magnetics.htm – see Eberle *et al.*, 2002 for details) suggests that a prominent geophysical boundary coincides with the transition from metavolcanic to metasedimentary rocks. This geophysical boundary is not necessarily linear on a detailed scale. It does not coincide with the main mapped mylonite zones, but rather maps the southern limit of magnetic metavolcanic rocks.

Southern Sedimentary Zone

There is a very distinct change of rock types in the southern part of the mapped area (Figure 1). Rocks of volcanic affinity are absent, and the dominant rock types are garnet-sillimanite-biotite and garnet-sillimanite-cordierite paragneisses, with sheets of intercalated syntectonic gneissic granites. Thin layers of fine-grained quartzite and quartz-garnet rock are interbanded with the biotitic gneisses. These paragneisses represent pelitic and semi-pelitic sedimentary rocks metamorphosed at amphibolite-granulite facies. On Landsat images, the pelitic gneisses have a relatively dark reflection colour, and show evidence of banding.

The syntectonic gneissic granites characteristically contain large K-feldspar megacrysts 2 to 6 cm in length. The megacrysts are usually oriented with a planar fabric parallel to the regional west-northwest strike, but in places a fabric is absent. Adjacent to the metasedimentary rocks, the granite-gneiss is interbanded with, and contains enclaves of the biotite gneiss. Pale pink almandine garnet is a ubiquitous accessory mineral in the gneissic granite, while biotite is the principal mafic mineral.

Unmetamorphosed mafic dykes trending north-northeast to northeast cut across the metamorphic rocks of the SSZ. These are of the same family that cut the NVZ and LHBZ, and are similarly interpreted to belong to the Gannakouriep dyke swarm.

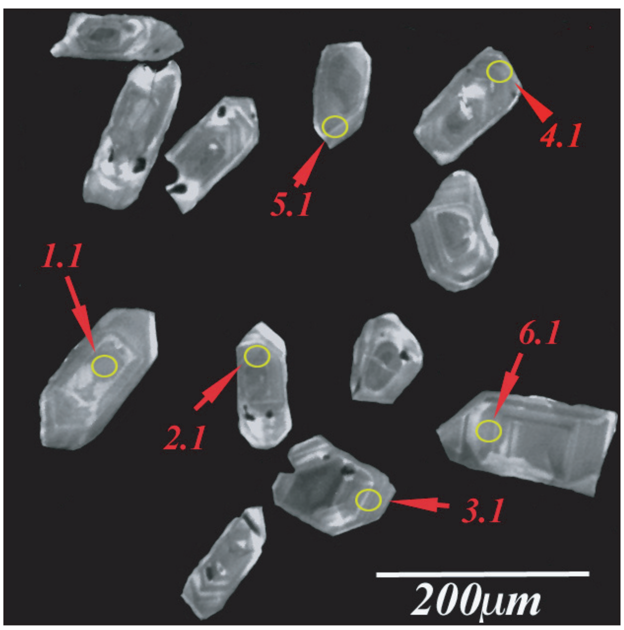

Figure 3. Cathodoluminescence image of representative zircon grains, showing features such as zoning, overgrowth and magmatic resorbtion textures. Numbered ovals represent the location of some of the analytical spots in Table 1.

U-Pb dating of volcanic rocks of the LHBZ

Sampling and methods

During the mapping, samples of texturally well-preserved metavolcanic rocks were taken from the LHBZ for geochemical analysis and isotopic dating of extracted zircons. Whole-rock geochemical analysis of three samples was carried out by XRF at the University of Natal, Durban to check for alteration.

About 10 kg of one of the least altered of the above samples (EU0175; an unweathered, weakly deformed porphyritic metarhyolite; see Figure 1 for location) was taken for dating. Zircon separates were extracted at the Research School of Earth Sciences, Australian National University (ANU) by normal physical mineral separation methods, including final hand-picking with a binocular microscope. The extracted zircon grains were mounted in resin, together with standard zircon SL13 of ANU, and polished and etched to reveal their interior structure. The polished zircons were imaged by cathodoluminescence in a scanning electron microscope in order to select the best grains and areas of grains for analysis (Figure 3).

Zircon dating by U-Pb isotope analysis on the SHRIMP II was undertaken by PRISE (Precise Radiogenic Isotope Services) at ANU, using standard operating procedures and data reduction methods as described by Williams and Claesson (1987) and Compston *et al.* (1992). The U and Th concentrations were measured relative to those of the SL13 standard. The correction for common lead was made by using the measured ^{204}Pb and the appropriate common lead composition according to the model of Cumming and Richards (1975). Uncertainties in the isotopic ratios and ages in Table 1 and of individual data points in Figure 4 are given to 1s level. However, the final weighted mean ages are reported to 95% confidence limits, as calculated with the Isoplot/Ex software of Ludwig (1998).

Results of U-Pb dating of zircons

The sample EU0175 yielded relatively abundant zircon grains. These extracted zircons are mainly euhedral and elongate, and internally the grains contain oscillatory zoning under cathodoluminescence (Figure 3). Such concentric zoning represents variations of U and Th, and is typical of magmatic as opposed to metamorphic crystallization. Some zircons show evidence of resorption or rapid crystal growth, as is typical in silicic magmas. The zircons extracted from sample EU0175 are thus presumed to be largely of magmatic origin. A few grains may have anhedral unzoned (xenocrystic?) cores, but these cores were avoided in SHRIMP analysis (dark rounded cores in Figure 3). No metamorphic rims were observed on the zircons.

The SHRIMP U-Pb isotopic analyses for twenty-one zircons grains are presented in Table 1 and as a concordia diagram in Figure 4. The Th/U ratio of these grains is 0.53, with levels of U between 66 to 291 ppm, which is normal for felsic and intermediate igneous rocks. Most SHRIMP point analyses on these grains

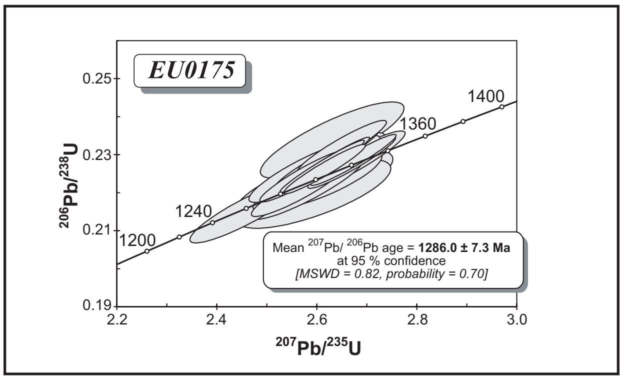

Figure 4. U-Pb concordia diagram of $^{206}Pb/^{238}U$ vs. $^{207}Pb/^{235}U$ SHRIMP analyses for sample EU0175. As most of the spot analyses cluster on the concordia, the mean $^{206}Pb/^{207}Pb$ age is taken as the best estimate of the age of the rock.

cluster as a single group on the Concordia diagram, and are close to concordant within error. Additionally, the percentage of ^{206}Pb that is attributed to common lead is much less than 1% in most points, thus the common lead correction is very small. Therefore the age of this sample is determined by the weighted mean of $^{207}Pb/^{206}Pb$ ratios in zircons to be 1286.0 ± 7.3 Ma (95% confidence level, weighted by data point errors only, MSWD 0.82). Due to textural considerations discussed above, and the concordance of the analyses, this age is taken to represent an igneous eruption/emplacement age for the metarhyolite.

Discussion and Conclusions

There is a pronounced transition from homogeneous ductile deformation in the SSZ to heterogeneous brittle-ductile deformation, with locally well-preserved primary textures, in the LHBZ. A locally sharp lithotectonic boundary marks the southern limit to the volcanics within the LHBZ, which coincides with a marked geophysical boundary and the presence of kyanite gneisses. It is proposed that the southern limit of the LHBZ represents a terrane boundary between the dominantly volcanic NVZ and the sedimentary SSZ, which has been later reactivated by discrete oblique-slip to dip-slip mylonite zones. However, both the NVZ and LHBZ have been subject to greenschist to amphibolite facies metamorphism and deformation.

The NVZ and LHBZ are related in being volcanic dominated, with rocks of mafic to intermediate composition being prevalent. Although the volcanic rocks of the LHBZ appear less strained than those of the NVZ due to strain partitioning between mylonite zones, they appear to have suffered an equivalent grade of metamorphism (greenschist to amphibolite facies). Better-preserved metabasalts in the LHBZ contain abundant amygdales, which indicate a shallow marine or even subaerial eruption environment. Volcaniclastic and Mn-rich chemical metasedimentary rocks suggest local volcanic debris and fumarolic activity in the NVZ. Metavolcanic and sedimentary rocks have been intruded by a variety of intermediate, often porphyritic hypabyssal intrusions. These field characteristics indicate that the igneous rocks of the LHBZ and NVZ are equivalent, and that both had their origin in a volcanic arc.

These volcanic rocks of the Karas Mountains can be directly compared with equivalents along strike to southeast and northwest. To the southeast, mafic to intermediate metalavas of the Areachap Group in South Africa have a calc-alkaline arc-type character according to Geringer *et al* (1986). Volcanic rocks of the Jannelsepan Formation in the Areachap Group at Upington in South Africa have been dated to between ~1.27 to ~1.32 Ga (whole-rock Rb-Sr method, Barton and Burger, 1983). At Prieska, Cornell *et al.* (1990) have dated the Copperton Formation metalavas, correlatives of the Jannelsepan Formation, at 1285 ± 14 Ma, and inferred the growth of an island arc at that time.

Further to the east, similar arc-like metavolcanic rocks of the Quha Formation in the Natal subprovince of the NNMP have been dated by SHRIMP analysis of U-Pb on zircons to about 1235 ± 9 Ma by Thomas *et al.* (1999). To the northwest, rocks of similar metamorphic grade and volcanic origin to those of the LHBZ are described in the basement to the Sinclair Group (Watters, 1976). These rocks have been dated to between 1461±169 Ma (Kairab Complex metabasalts, whole-rock Rb-Sr; Hoal *et al.* 1989) to 1376+1.7/-1.6 Ma (Aunis tonalite gneiss, U-Pb on zircon separates; Hoal and Heaman, 1995).

The Wilgenhoutsdrif Group metavolcanic rocks, which lie to the northeast of the Areachap Group were dated by Barton and Burger (1983) at ~1.34 or ~1.29 Ga ($^{207}Pb/^{206}Pb$ date on two zircon separates, no errors given). These dates agree well within error with a whole-rock Rb-Sr age of 1331 ± 100 Ma obtained from the same lavas (Barton and Burger, 1983). The Wilgenhoutsdrif metalavas have primitive, mantle derived Sr and Pb isotope signatures suggestive of back-arc spreading, while the Jannelsepan Formation metalavas have indications of a greater crustal component (*e.g.* slab sediments) in their Pb isotope ratios (Barton and Burger, 1983; Geringer *et al.*, 1986).

The radiometric ages obtained for the Jannelsepan, Copperton, Wilgenhoutsdrif and the Lord Hill metalavas are within error of each other at ~1.29 Ga. The field relations of the Lord Hill and Jannelsepan metavolcanic rocks are similar (Geringer *et al.*, 1986), and it is proposed here that they might be equivalent components of a long-lived and extensive northwest to southeasterly- trending volcanic arc terrain. Earlier and later components of this arc are seen in the Kairab Complex and the Quha group respectively, suggesting a a diachronous development of the arc from northwest to the east. This arc was active at or to the south of the southern margin of the Kalahari craton between ~1.46 and 1.23 Ga and was consolidated with the craton prior to the deposition of the weakly-deformed sedimentary and volcanic rocks of the Sinclair and Koras Groups at ~1.22 and 1.17 Ga respectively (Hoal and Heaman, 1995, Gutzmer *et al.* 2000).

Table 1. Summary of SHRIMP U-Pb isotopic analysis in zircons for sample EU0175

Grain. spot	U (ppm)	Th (ppm)	Th/U	±	Pb* (ppm)	$^{204}Pb/^{206}Pb$	f_{206} %	Radiogenic Ratios $^{206}Pb/^{238}U$	±	$^{207}Pb/^{235}U$	±	$^{207}Pb/^{206}Pb$	±	Ages (in Ma) $^{206}Pb/^{238}U$	±	$^{207}Pb/^{235}U$	±	$^{207}Pb/^{206}Pb$	±	Conc. %
1.1	175	93	0.53	0.003	41	0.00013	0.21	0.2230	0.0054	2.599	0.086	0.0845	0.0017	1298	29	1300	25	1305	38	100
1.2	127	78	0.61	0.004	31	0.00006	0.10	0.2240	0.0046	2.571	0.058	0.0832	0.0006	1303	24	1292	17	1275	15	102
2.1	277	171	0.62	0.003	68	0.00009	0.15	0.2250	0.0053	2.568	0.071	0.0828	0.0010	1308	28	1292	20	1264	24	104
3.1	156	79	0.51	0.004	38	0.00001	0.02	0.2268	0.0058	2.617	0.078	0.0837	0.0011	1317	31	1306	22	1286	25	103
4.1	174	86	0.50	0.004	40	0.00001	0.02	0.2144	0.0055	2.452	0.073	0.0830	0.0011	1252	29	1258	22	1268	25	99
5.1	252	136	0.54	0.004	60	0.00001	0.02	0.2235	0.0056	2.577	0.072	0.0836	0.0008	1301	29	1294	21	1284	19	101
6.1	115	50	0.44	0.005	28	0.00011	0.18	0.2336	0.0067	2.628	0.096	0.0816	0.0016	1354	35	1309	27	1236	38	110
7.1	236	146	0.62	0.006	57	0.00024	0.39	0.2216	0.0062	2.592	0.105	0.0848	0.0022	1290	33	1298	30	1312	51	98
8.1	291	194	0.67	0.006	70	0.00015	0.24	0.2199	0.0058	2.535	0.079	0.0836	0.0012	1281	31	1282	23	1283	28	100
9.1	157	76	0.48	0.004	38	0.00001	0.02	0.2273	0.0058	2.660	0.076	0.0849	0.0009	1320	31	1317	21	1313	20	101
10.1	230	109	0.48	0.004	53	0.00005	0.09	0.2192	0.0061	2.591	0.103	0.0857	0.0022	1278	32	1298	30	1332	50	96
11.1	150	75	0.50	0.004	35	0.00001	0.02	0.2208	0.0055	2.578	0.075	0.0847	0.0010	1286	29	1294	22	1309	24	98
12.1	206	130	0.63	0.005	50	0.00014	0.24	0.2229	0.0058	2.570	0.080	0.0836	0.0012	1297	31	1292	23	1284	28	101
13.1	207	112	0.54	0.003	50	0.00002	0.03	0.2273	0.0047	2.618	0.057	0.0835	0.0004	1320	25	1306	16	1281	10	103
14.1	66	26	0.40	0.005	16	0.00009	0.15	0.2270	0.0053	2.617	0.072	0.0836	0.0010	1319	28	1305	20	1283	24	103
15.1	113	50	0.44	0.003	27	0.00001	0.02	0.2283	0.0045	2.671	0.057	0.0849	0.0005	1326	24	1321	16	1312	12	101
16.1[5]	86	36	0.42	0.002	21	0.00001	0.02	0.2277	0.0046	2.668	0.058	0.0850	0.0006	1322	24	1320	16	1315	13	101
17.1	122	71	0.58	0.004	29	0.00001	0.02	0.2203	0.0047	2.560	0.063	0.0843	0.0008	1283	25	1289	18	1299	19	99
18.1	192	131	0.68	0.004	48	0.00003	0.04	0.2258	0.0044	2.612	0.055	0.0839	0.0005	1312	23	1304	15	1291	12	102
19.1	190	118	0.62	0.004	47	0.00001	0.02	0.2266	0.0046	2.608	0.056	0.0835	0.0004	1317	24	1303	16	1281	10	103
20.1	95	40	0.43	0.003	23	0.00000	0.00	0.2292	0.0049	2.633	0.060	0.0833	0.0005	1330	26	1310	17	1277	12	104
21.1	99	45	0.45	0.003	24	0.00007	0.12	0.2317	0.0047	2.648	0.060	0.0829	0.0007	1344	25	1314	17	1266	15	106

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 $^{204}Pb/^{206}Pb$ ratio. (4) For Conc. %, 100% denotes a concordant analysis. (5) Spot 16.1 was not used in the $^{207}Pb/^{206}Pb$ age average

Acknowledgements

This work is presented as a contribution to I.G.C.P. Project 440 (Assembly and break-up of Rodinia). BHP-Billiton Limited is thanked for the funding of, and permission to publish the isotopic data. Amanda Boutwood undertook early reconnaissance mapping of the Northern Volcanic Zone. Greg Walker assisted with geophysical interpretations, while David Spatz provided advice on Landsat spectral interpretation. The manuscript was much improved by careful reviews by Bruce Eglington, Hartwig Frimmel and Bob Thomas.

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Editorial handling: L. D. Ashwall