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Zircon U-Pb ages from an ultra-high temperature metapelite, Rauer Group, east Antarctica: Implications for overprints by Grenvillian and Pan-African events

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Abstract SHRIMP U-Pb dating of zircon from an ultra-high temperature (UHT, ~1000 °C) granulite-facies metapelite from the Rauer Group, Mather Peninsula, east Antarctica, has yielded evidence for two episodes of metamorphic zircon growth, at ~1.00 Ga and ~530 Ma, and two episodes of magmatism in the source region for the protolith sediment, at ~2.53 and ~2.65 Ga, were identified from the zircon cores. Successive zircon growth at ~1.00 Ga and ~530 Ma records a sequence of distinct, widely spaced high-temperature metamorphic and/or anatectic events related to Grenvillian and Pan-African orogenesis. This study presents the first robust geochronological evidence for the timing of UHT metamorphism of the Rauer Group, supporting arguments that the peak UHT metamorphic event occurred at ~1.00 Ga and was overprinted by a separate high-grade event at ~530 Ma. The new age data indicate that the UHT granulites of the Rauer Group experienced a complex, multi-stage tectonothermal history, which cannot simply be explained via a single Pan-African (~500 Ma) high-grade tectonic event. This is critical in understanding the role of the eastern Prydz Bay region during the assembly of the east Gondwana supercontinent, and the newly recognized inherited Archaean ages (~2.53 and ~2.65 Ga) suggest a close tectonic relationship between the Rauer Group and the adjacent Archaean of the Vestfold Hills.

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Introduction

The ultra-high temperature (UHT) metamorphic granulites of the Rauer Group on the Mather Peninsula (Fig. 1) provide an important window into understanding the geological histories of the complex high-grade terranes of eastern Prydz Bay, east Antarctica. However, the age of ultra-high temperature granulite-facies metamorphism in the Rauer Group remains controversial (e.g. Harley et al., 1998). Whether the peak UHT granulite assemblages formed in the late Proterozoic (Grenvillian) event at ~1.00 Ga (Harley et al., 1998; Tong and Wilson, 2006) or in the early Palaeozoic (Pan-African) tectonic event at ~530 Ma (Harley, 2003; Kelsey et al., 2003) has not yet been determined. The Mather Paragneiss is commonly considered to preserve evidence of an older, more extreme granulite-facies event than other rock types in the Rauer Group (Harley and Fitzsimons 1991). Although the sapphirine-bearing Mather paragneiss bears a clear metamorphic imprint of Pan-African orogenesis at ~511 Ma (Kelsey et al., 2003), whether the UHT event occurred at ~500 Ma or ~1.00 Ga is still debated. The timing of the major orogenic events that affected the UHT metapelites has not yet been clearly defined, and their pre-Pan-African history remains obscure. Here we present new SHRIMP ion probe zircon U-Pb ages from a sample of sapphirine-bearing, granulite facies metapelite from the Mather Peninsula that show evidence of two metamorphic episodes. The pre-Pan-African geologic history preserved in this rock correlates with other parts of the East Antarctic shield and reveals both ~2.53 and ~2.65 Ga magmatic activity in the source region of the protolith sediment.

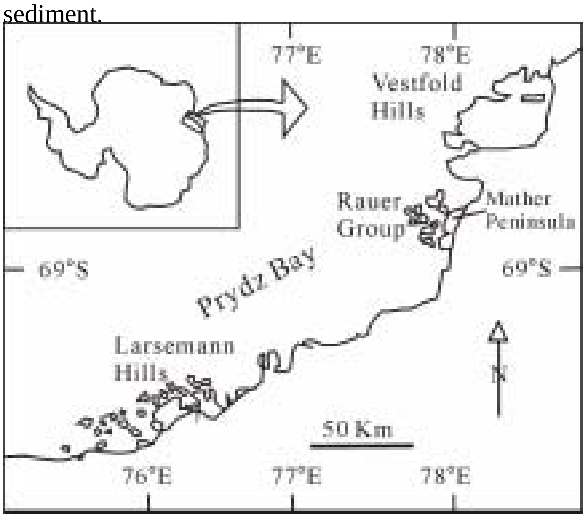

Figure. 1 Location of the Rauer Group within Prydz Bay, showing the Mather Peninsula within the eastern Rauer Group.

Geological setting

The Mather paragneiss comprises a variety of rock types (Harley et al., 1998) hosted by felsic orthogneiss that outcrop discontinuously as a gneissosity-parallel unit over a strike length of~3 km in the eastern Rauer Group. UHT (1030 °C) metamorphism is recorded in the Rauer Group at Mather Peninsula by the stability of Mg-rich orthopyroxene + garnet + sillimanite assemblages that are sequentially overprinted by sapphirine-and cordierite-bearing mineral reaction textures (Harley, 2003). High-temperature sapphirine-bearing metamorphic assemblages are preserved in the high-strain zone of the Rauer Group and are overprinted by retrograde biotite-cordierite-bearing assemblages that Kelsey et al. (2003) attributed to early Palaeozoic (~511 Ma) orogenesis.

The Archaean in the Rauer Islands is dominated by >3.30 Ga and ~2.84–2.80 Ga orthogneisses (Kinny et al., 1993; Harley et al., 1998). These gneisses, extensively dyked and then deformed again by younger events, are interleaved with Mesoproterozoic metasediments and 1.03–1.00 Ga felsic to mafic intrusives that have also experienced high-grade metamorphism. Despite the extensive isotopic evidence for high-grade metamorphism in the Rauer Islands at ~530 Ma (Hensen & Zhou, 1995; 1997), the preservation of monazite U-Pb ages near 1.00 Ga in the metasedimentary gneisses of the Filla Supracrustals confirm the importance of the ~1.00 Ga event (Kinny, 1998). The ~1.00 Ga isotopic record in this domain is associated with granulite facies metamorphism and deformation. Garnet-matrix Sm-Nd mineral isochrons from two closely-spaced (within 10 m) samples of the Mather Paragneiss yielded ages of 600 and 485 Ma, which have been interpreted as being close to the age of garnet formation in these samples (Hensen & Zhou, 1995). Harley et al. (1998) concluded that the ultra-high temperature near-isothermal decompression may reflect either a temporally unrelated tectonic event (e.g. Archaean) or just an early stage of a single event at either ~1.00 Ga or ~500 Ma. Hokada & Harley.(2003) reported electron microprobe chemical ages of monazites from Mather UHT gneisses, 580-450Ma, with minor ~700 Ma inheritance. They also obtained low precision electron microprobe chemical ages of zircons, the preliminary analyses suggest preservation of late-Archaean protolith zircons, ~1.0 Ga, but few zircons in the 580-450 Ma age range determined for the monazites in the same rocks and textural microdomains. Kelsey et al. (2003) argued, however, that the ultra-high temperature event was associated with a single ~500 Ma tectonic event.

SHRIMP U-Pb results

Sample R1 is a coarse-grained sapphirine-biotite gneiss from Mather Peninsula in the eastern Rauer Islands. The region consists of heterogeneous gneisses, including felsic orthogneiss, enderbitic gneiss, felsic-mafic composite gneiss, fosterite marble, leucogranitic orthogneiss, and mafic or ultramafic orthogneiss (Harley, 1998). Sample R1 contains orthopyroxene, garnet, sillimanite, sapphirine, cordierite, K-feldspar, biotite, and minor plagioclase with accessory monazite and zircon. The highest grade metamorphic conditions recorded from comparable samples at this locality are about 11–12 kbar and 1033 ± 30 °C (Harley, 1998).

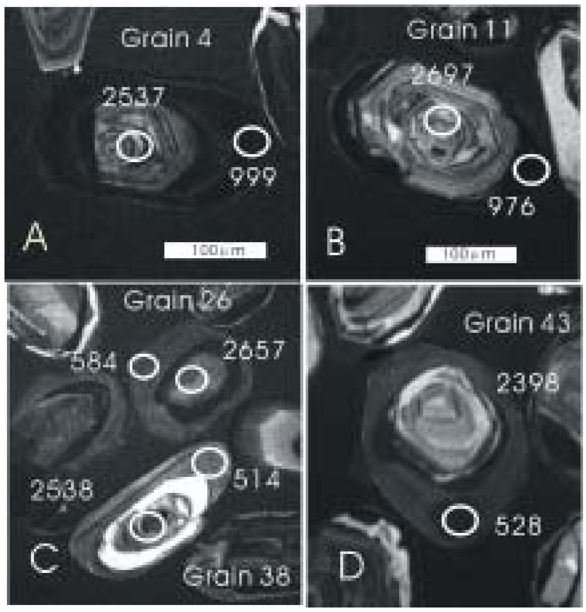

Figure. 2 Cathodoluminescence (CL) images of representative zircons from R1, showing locations and sizes of analysis areas. Each analyzed grain shows U-Pb age in Ma (generally $^{207}Pb/^{206}Pb$ age for >800 Ma, and $^{206}Pb/^{238}U$ age for <800 Ma zircons. A & B: Grain 4 and Grain 11, showing Archaean cores with igneous growth banding, and Proterozoic overgrowths (999 and 976 Ma on the spots in grain4 and 11 are 100% and 98% concordant). C: Scale is the same as for A and B. Grains 26, 38 and 43, showing Pan-African overgrowths on Archaean cores. Grain 43 core analysis yielded a slightly discordant age of 2398 ± 10 Ma. Minor Pb-loss was seen in the grain 38 overgrowth analysis.

The SHRIMP U-Pb analytical procedures followed those outlined by Williams (1998) and references therein. Standard techniques were used to separate zircons and prepare a sectioned epoxy disk with representative grains from R1 and the TEM reference zircon (Black et al., 2003). Cathodoluminescence (CL) images were used to identify zircon crystal domains (Fig. 2).

Forty seven individual zircon grains from R1 were analysed during a single extended SHRIMP session. Most grains consisted of discrete centers with overgrowths, yielding 74 individual U-Pb ages (Fig. 3). Uncertainties for individual analyses are quoted at the 1σ level. All age calculations are given with uncertainties at 95 % confidence levels.

Archaean zircon cores

Most of the zircons have distinct cores, typically equant or prismatic domains with faceted to rounded shapes. Their internal growth structure includes oscillatory zoning (Fig. 2A, grain 4 and 11), which is common in igneous zircons. Analyses of cores yielded two main age populations (Fig. 2): one with a weighted mean $^{207}Pb/^{206}Pb$ age of 2657 ± 17 Ma (2σ, n=8) and a second with a weighted mean $^{207}Pb/^{206}Pb$ age of 2532 ± 12 Ma (2σ, n=14). These ages reflect the crystallization of an igneous parent. The clustered ages may reflect two magmatic episodes, at ~2.65 and ~2.53 Ga, suggesting that eroding igneous rocks of this age were the source for the protolith of the metapelite. The similarity of these ages to the 2526 Ma age of the Mossel gneiss (Black et al., 1991; Snape et a., 1997) in the Vestfold Hills 20 km north of the Rauer Group suggests that this Archaean magmatism produced primary, juvenile crust in the East Antarctic Shield.

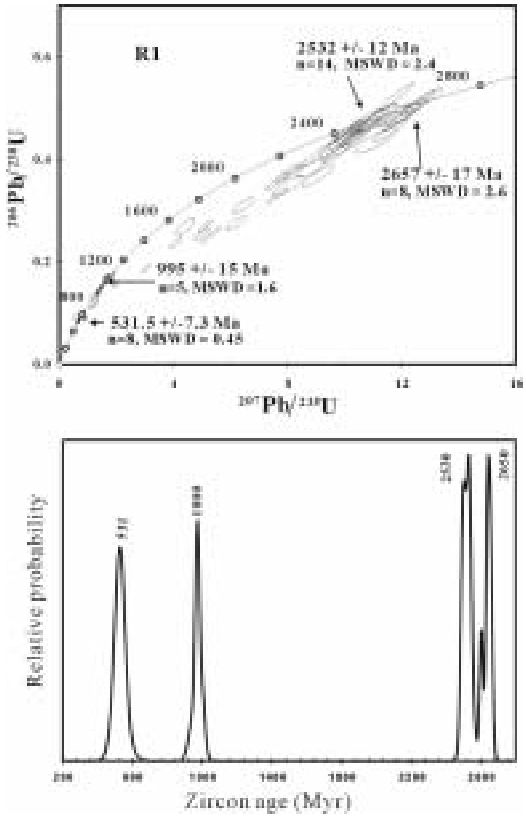

Figure. 3 Concordia diagram for sample R1 zircons (Uncertainties are 1 σ) and Probability density distribution of SHRIMP zircon U-Pb ages (35 analyses 95–105% concordance). Generally $^{207}Pb/^{206}Pb$ age for >800 Ma, and $^{206}Pb/^{238}U$ age for <800 Ma zircons.

Grenvillian age (~1.00 Ga) overgrowths

Distinctive zircon that has weak CL and is either texturally homogeneous or weakly sector zoned occurs as wide overgrowths on the Archaean cores (Fig. 2A and 2B, grains 4, 11). The overgrowths cover cores with slightly round external shapes, suggesting topotactic growth on a primary core. The absence of oscillatory zoning and very low Th/U (average 0.02) are consistent with metamorphic zircon growth.

Analyses of such overgrowths yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 995 ± 15 Ma (e.g. Grain 4, spot 4.2 core: $^{207}Pb/^{206}Pb$ age, 2537 ± 13 Ma, Th/U = 0.57; 4.1 rim: $^{206}Pb/^{238}U$ age, 999 ± 18 Ma, Th/U = 0.01, 100% concordant), with some discordance toward 530 Ma. Many analyses yielded highly discordant compositions that reflect significant Pb loss ~1.00 Ga and/or 530 Ma. Those domains were wide overgrowths on Archaean cores with prismatic external terminations. The scale, morphology, and internal texture of these overgrowths indicate that the 1.00 Ga event involved new metamorphic grain growth, as opposed to anatexis or recrystallization, because (1) oscillatory growth zoning is absent; (2) Th/U ratios are distinct and low, with the overgrowths having Th/U values (0.01–0.02) that are considered to be consistent with a metamorphic rather than a magmatic origin (Th/U >0.1; Williams et al., 1996). The 1.00 Ga domains may therefore reflect high-temperature heating during crustal orogenesis.

Pan-African age (~530 Ma) overgrowths

The two types of texturally 'young' zircon overgrowths are found on many grains. First type of zircon comprises spheroidal to ellipsoidal grains (Fig.2 C & D, grains 26, 43). In CL, these grains comprise a resorbed core of oscillatory-zoned, zircon mantled by darked rim, too thin to analyse, possibly similar to the ~1.00 Ga overgrowths, succeeded outwards by wide outer rims that have high Th/U values (Th/U >0. 2). Eight analyses of these outer rims have yielded a weighted mean $^{206}Pb/^{238}U$ age of 532±7 Ma. This is interpreted to reflect new zircon growth at ca. 530Ma related to the crystallization of melts. Their occurrence on rounded or embayed mantles, indicating crystallization on dissolution surfaces formed by partial melting (Vavra et al., 1999). The second type of texturally 'young' zircon overgrowth occurs on stubby-to elongate grains (Fig.1C, grain 38). These overgrowths are moderately luminescent and show oscillatory zoning over brighter zircon mantles. The oscillatory-zoned overgrowths have high Th/U values (Th/U >0.3) and yield ca. 530Ma ages that again are inferred to date magmatic crystallization associated with Pan-African thermotectonic activity in the region (Carson et al., 1996).

Discussion and conclusions

Using the Sensitive High Resolution Ion Microprobe (SHRIMP) zircon U-Pb dating technique, we have obtained multiple zircon ages from a UHT sapphirine-bearing metapelite from the Rauer Group, Mather Peninsula, east Antarctica, which we attribute to four geologic events between ~2.65 Ga and 530 Ma. The zircon cores record two igneous episodes, at 2.53 and 2.65 Ga, and the mantles and rims two metamorphic episodes at ~1.00 Ga and 530 Ma, respectively. This is the first evidence recognized in the Rauer Islands for an age similar to that of the 2.53 Ga Mossel gneiss in the adjacent Vestfold Hills. The new data suggest that Vestfold Hills and Rauer Group terranes were possibly amalgamated in the Archaean.

The zircon overgrowths on Archaean cores represent metamorphic and/or anatectic modifications to these rocks at ~1.00 Ga and 530 Ma. Wide overgrowths of both ages reflect substantial new zircon growth at high temperatures. There is no doubt that the UHT metapelite was subjected to Grenville and Pan-African overprints at ~1.00 Ga and 530 Ma. Our data are the first to conclusively identify a period of Grenville metamorphism in UHT metapelite of the Rauer Group, and they correspond closely to SHRIMP ages from felsic orthogneiss from Filla Island (Kinny et al., 1993). The ~1.00 Ga overgrowths have Th/U of 0.01–0.02, suggesting a metamorphic rather than a magmatic origin (Williams et al., 1996). These data reveal an important period of orogenic activity ~1.00 Ga which we interpret to have been the UHT metamorphic event that affected the sapphirine-bearing metapelite. We think that the ultrahigh temperature event may be intimately associated with the enderbitic magmatism. The ultrahigh temperature event may have occurred during the c. 1.00 Ga, synchronously with the enderbitic magmatism. The enderbitic orthogneiss hosting the Mather paragneiss could be late Mesoproterozoic, as an identical enderbitic orthogneiss on Macey peninsula is late Mesoproterozoic (c. 1.0 Ga) (Tong et al., 2006). Given that the Fe-Al-rich metapelite represents part of Filla paragneiss, the Filla and Mather paragneisses have been suggested to have had a shared P-T history (Tong & Wilson, 2006), while the former is commonly hosted by the c.1.0 Ga felsic orthogneiss, and may have experienced granulite metamorphism at c. 1.0 Ga (Kinny, et al., 1993; Kinny, 1998), Whereas the (Th-U)-Pb monazite age of Pan-African directedly retrieved from symplectic and coronal textures (Kelsey, 2003) maybe associated with post-peak decompression-cooling and retrograde metamorphism during the Pan-African age tectonic event.

We interpret the 530 Ma overgrowths with igneous oscillatory growth zoning as recording magmatic crystallization following anatexis during the Pan-African orogeny. Wilson et al. (2007) argued on the basis of structural evidence and $^{40}Ar/^{39}Ar$ ages that the Rauer Group extends southwards from Prydz Bay into the southern Prince Charles Mountains and represents intracratonic deformation during the Pan-African event. Our data indicate that the present metamorphic and structural character of the Prydz Bay region is the result of episodic reactivation between Grenvillian and Pan-African orogenic activity.

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