Age of boron- and phosphorus-rich paragneisses and associated orthogneisses, Larsemann Hills: New constraints from SHRIMP U-Pb zircon geochronology

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Summary SHRIMP U-Pb detrital zircon geochronology of a phosphate-rich metaquartzite from the Larsemann Hills, southern Prydz Bay, suggests that the maximum constraint on deposition was latest Neoproterozoic, possibly as young as ca. 550 Ma. The metaquartzite, together with metapelite, metapsammite and boron-rich units, collectively the 'Brattstrand Paragneiss', were deposited on composite ca. 1125 Ma and ca. 940-990 Ma felsic orthogneiss basement, which was subsequently interleaved with the metasediments during ca. 515-530 Ma regional high-grade tectonism. The presence of ca. 550-870 Ma rims indicates detrital contribution from sources characteristic of the East African orogen and adjacent regions. The unusual boron and phosphate enrichment in the Neoproterozoic Brattstrand Paragneiss of the Larsemann Hills could have resulted from subseafloor alteration of clastic sediments related to an exhalative-synsedimentary hydrothermal system that mobilised boron from underlying non-marine evaporite borate, suggesting deposition of the Brattstrand Paragneiss in a deepening continental back-arc rift or basin.

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Introduction

The Larsemann Hills, a coastal exposure in southern Prydz Bay, East Antarctica, is underlain by migmatitic metasediments, deformed felsic orthogneisses, and early Palaeozoic granites and post-tectonic pegmatites (e.g. Stüwe et al., 1989, Zhao et al., 1992; Carson et al., 1995). The lithological units exposed in southern Prydz Bay can be divided into the Søstrene Orthogneiss, a unit dominated by felsic orthogneiss with variable amounts of interleaved mafic material (Fitzsimons 1997) and the Brattstrand Paragneiss, a sedimentary sequence dominated by rocks derived from pelitic, psammitic and volcanogenic rocks, but containing mappable units enriched in B, Fe or P. Henson and Zhou (1995) tentatively proposed that the Søstrene Orthogneiss represents basement, metamorphosed at ca. 980 Ma, onto which the Brattstrand Paragneiss was deposited. The Brattstrand Paragneiss in the Larsemann Hills uniquely comprises several B- and P-rich units including tourmaline quartzite, well-lineated grandidierite-prismatine-sillimanite gneiss, prismatine-bearing magnetite-rich rocks, and biotite-plagioclase gneisses containing large nodules (ca. 30 cm dia.) of apatite and segregations of porphyroblastic prismatine and granular tourmaline in cordierite or feldspar (e.g. Grew et al., 2006a,b). The Tassie Tarn Metaquartzite contains disseminated apatite and has 0.6-1.4 wt% P_2O_5 and is LREE enriched relative to typical clastic sediments. Grew et al. (2006a) suggested the precursors to these rocks are clastic and volcanogenic rocks altered by submarine hydrothermal processes analogous to those proposed for tourmaline-rich rocks associated with Pb-Zn-Ag deposits in Broken Hill, Australia (e.g., Slack et al., 1993). The source of B for the precursors could have been non-marine evaporite borate deposited in a continental rift setting.

The coastal exposures of southern Prydz Bay, including the Larsemann Hills, experienced a major high-grade tectonothermal event during the early Palaeozoic (530-515 Ma; e.g. Zhao et al., 1992; Hensen and Zhou, 1995; Carson et al., 1996), however recent studies have re-examined the existence of an early Neoproterozoic tectonothermal event (ca. 950-990 Ma; e.g. Hensen and Zhou 1995; Kelsey et al., 2007), which also appears to be characterised by widespread felsic magmatism (e.g. Wang et al., 2003, 2005). Geochronological studies in Prydz Bay have focussed on understanding the timing of multiple tectonothermal events, whereas only one study (Zhao et al., 1995) has analysed detrital zircons from the Brattstrand Paragneiss to constrain the maximum age of deposition. Zhao et al. (1995) concluded that the paragneisses were at least mid-Neoproterozoic in age (based on the youngest identified zircon Pb-Pb age of 766 Ma) and were tectonically juxtaposed and interleaved with adjacent ca. 940 Ma orthogneiss. An improved chronology of sedimentation and basin formation in southern Prydz Bay and a better understanding of the depositional environment of the Brattstrand Paragneiss are necessary for determining the role played by Prydz Bay in the evolution of East Gondwana.

In this abstract we present preliminary U-Pb SHRIMP data that place important constraints on 1) the depositional age of a phosphorus-rich unit of the Brattstrand Paragneiss based on detrital zircons; 2) the emplacement age of a deformed felsic orthogneiss (Blundell Orthogneiss) that is interleaved with the paragneisses and finally, 3) the emplacement age of a deformed felsic orthogneiss that is thought to represent local basement (Søstrene Orthogneiss).

Samples and analytical techniques

Three samples were collected for U-Pb zircon SHRIMP geochronology. The Tassie Tarn Metaquartzite, (sample 11/28/02A, hereafter called '28'; all rock names after Carson and Grew, 2007) was collected south of Johnston Fjord, Stornes Peninsula (69° 24.934'S, 076° 4.635'E) for constraining the depositional age of the Brattstrand Paragneiss. The Blundell Orthogneiss (sample 12/31/04, or '31') was collected northwest of Tumbledown Hill, Stornes Peninsula (69° 25.287'S, 076° 4.414'E) to determine an emplacement age. This orthogneiss is interleaved with paragneisses on an outcrop scale. Finally, the felsic biotite + orthopyroxene Søstrene Orthogneiss (sample 12/29/01, or '29') was collected from northeast McLeod Island (69° 21.537'S, 076° 6.400'E) in order to determine an emplacement age.

Isotopic analyses were undertaken on the SHRIMP II at the Research School of Earth Sciences, Australian National University (ANU). Analytical procedures follow, for example, Stern (1997) with data reduction via SQUID and ISOPLOT (Ludwig, 2001, 2003). Whole-rock samples were analysed at the Dept. of Earth and Marine Sciences, ANU.

U-Pb SHRIMP Results and Interpretations

Tassie Tarn Metaquartzite

Fifty eight analyses were obtained from sample 28, of which 52 show discordance ≤10% (Fig. 1). The majority of analyses were collected on concentric oscillatory zoned cores (blue ellipses and bars in Fig. 1). These analyses form a prominent grouping of age spectra at ca. 1100 Ma that tapers off to ca. 1300 Ma with a broad cluster of analyses at ca. 1600-1750 Ma. Several of the grains are overgrown by unstructured narrow rims with Th/U values of <0.04 (red ellipses and bars in Fig. 1) and gave younger ages between ca 550-870 Ma.

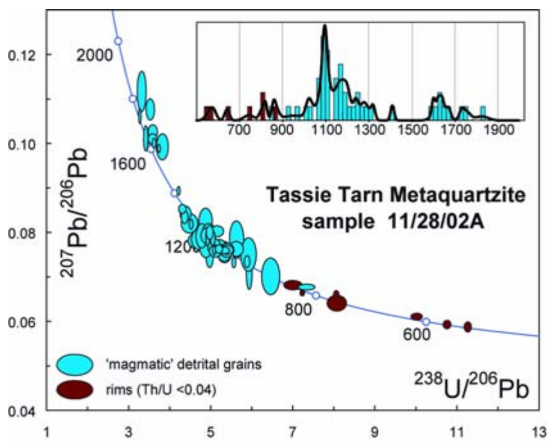

Figure 1. Tera-Wasserburg (T-W) diagram for the SHRIMP U-Pb data from metaquartzite. Blue = magmatic detrital grains; red = low Th/U rims.

Blundell Orthogneiss (central Stornes Peninsula)

Twenty five analyses were collected from sample 31, of which 23 analyses show ≤10% discordance (Fig. 2). Two analyses were omitted from the weighted mean calculations: the open red ellipse at ca. 1300 Ma interpreted to represent a xenocryst and the solid red ellipse at ca. 670 Ma, which is a low Th/U analysis (0.03). The remaining 21 analyses define a model 2 chord (forced lower intercept of 520 ± 10 Ma) with an upper intercept of 969 ± 16 Ma; the MSWD of 3.3 indicates scatter in excess of that expected from analytical error alone. A weighted mean $^{207}Pb/^{206}Pb$ age of 13 selected analyses yields 968 ± 11 Ma (MSWD = 1.2). These ages of ca. 970 Ma are interpreted to date magmatic crystallisation of the Blundell Orthogneiss.

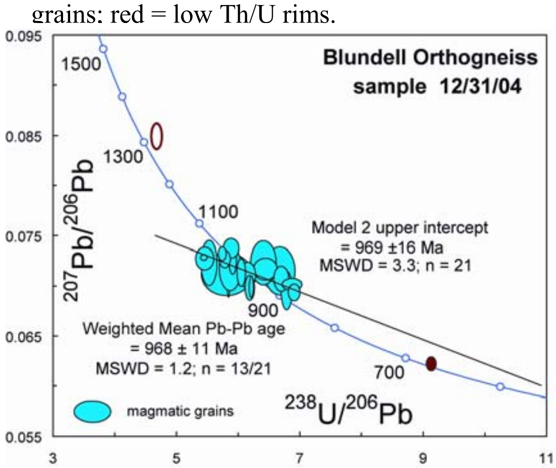

Figure 2. T-W diagram for SHRIMP U-Pb data from Blundell Orthogneiss.

Søstrene Orthogneiss (McLeod Island)

Sixteen analyses were collected on 14 individual zircons from sample 29, of which only one analysis was rejected due to excessive discordance. Accepted analyses plot (Fig. 3) on a poorly defined chord between ca. 1125 Ma and ca. 950 Ma. We interpret these data to suggest that the Søstrene Orthogneiss (McLeod Is.) was emplaced at ca. 1125 Ma and subsequently metamorphosed at ca. 950 Ma resulting in significant zircon Pb-loss.

Conclusions

These data permit discussion on the timing of deposition of the Brattstrand Paragneiss, the provenance of the detritus and of the age of the basement orthogneiss complex in the Larsemann Hills. If all analysed zircons, including low Th/U rims, from the Tassie Tarn Metaquartzite represent detritus, then in principle the maximum age of deposition of the Tassie Tarn Metaquartzite is constrained by the age of the youngest analysis, 548 ± 4 Ma (2σ, Th/U = 0.01; U-Pb age), that is, latest Neoproterozoic. However, we acknowledge that, in practise, a single analysis may not be sufficient to constrain deposition, and a statistical grouping may be preferred. A more conservative estimate for the maximum deposition age of the metaquartzite might then be represented by the minor peak at ca. 850 Ma. Further work is envisaged to better constrain the maximum deposition age. Interestingly, none of the rim ages fall in the range of 530-515 Ma currently recognised for the regional Early Palaeozoic high-grade event.

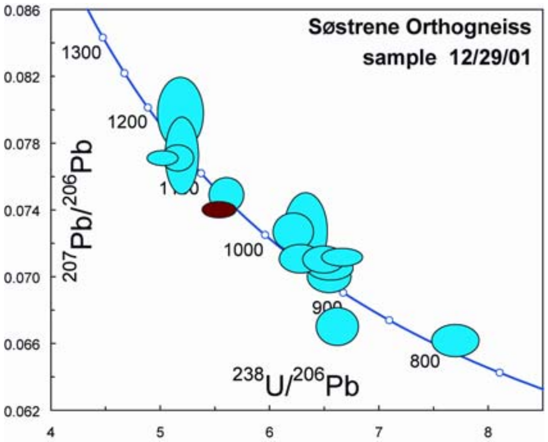

Figure 3. T-W diagram for SHRIMP U-Pb data from the Søstrene Orthogneiss.

The preferred maximum age constraint for deposition (≤ ca. 548 Ma) is significantly younger than previously obtained by Zhao et al. (1995) whose youngest detrital zircon yielded a somewhat older Pb-Pb age of ca. 766 Ma. The metasediment analysed by Zhao et al. (1995, their 'migmatitic paragneiss' = Broknes Paragneiss) may either represent a significantly older stratigraphic unit or simply may not have received the younger detrital component present in the Tassie Tarn Metaquartzite. Alternatively, and most probably, that since only eleven zircons were analysed by Zhao et al. (1995), this younger material was simply not identified.

The six rim analyses between 548-870 Ma with markedly low Th/U (<0.04) in the detrital spectra for the Tassie Tarn Metaquartzite (Fig. 1) are striking in another respect. The low Th/U ratios are generally accepted to be characteristic of metamorphic zircon, but metamorphic events in this age range are not recognised locally in the East Antarctic Shield, or from the Mawson Block, the pre-Gondwana amalgam of Australia and the majority of East Antarctica. Instead we speculate that such material was probably derived from the arrangement of metamorphic sutures that evolved during the assembly of West Gondwana and which are presently exposed along eastern Africa, Madagascar and in Dronning Maud Land (e.g. East African orogen; 550-750 Ma). Somewhat older metamorphic detrital material is also present (750-870 Ma). These grains could also have been derived from Africa. Elements of the Arabian-Nubian Shield include ca. 870-670 Ma continental margin and intra-oceanic arc terranes that were amalgamated by ca. 600 Ma (Johnson and Woldehaimanot, 2003). Detritus of this age is also known from southwestern Madagascar (Boger unpublished data) consistent with the recycling and eastward transport of material after terrane collision in north-eastern Africa.

A cluster of magmatic analyses between 1060-1120 Ma could have an southern African origin. These ages overlap with volcanic and metamorphic events recognised in the Maud-Natal Belt of southern Africa and Dronning Maud Land. An obvious source for the older cluster of ages between 1140-1320 Ma is difficult to identify. However derivation of this and the younger ca. 1060-1120 Ma population could also be from other more local sources such as the Mt Willings-Fisher Massif region of the northern Prince Charles Mountains (nPCM) to the south or the Wilkes Province to the east, or simply from the ca. 1125 Ma Søstrene Orthogneiss which represents, in part, local basement to the Brattstrand Paragneiss. Although the suggestion that the detrital zircon data from the metaquartzite indicates derivation from West Gondwana is appealing, there is a marked lack of Archaean detritus, which might be expected to contribute to the detrital budget given the relative proximity of the Kaapvaal-Grunehogna and Congo Cratons to the inferred African sources. However these cratons may not have been exposed at the time when the zircon source areas were eroded.

Irrespective of the derivation of the detritus comprising the Brattstrand Paragneiss sequence, deposition after ca. 550 Ma implies that these rocks were deposited after the formation and metamorphism of the orthogneissic basement complex that includes the two orthogneisses dated here, i.e. the Blundell Orthogneiss, (ca. 970 Ma) and the Søstrene Orthogneiss (ca. 1125 Ma), which supports the conclusions of Zhao et al. (1995). In conjunction with emplacement ages previously reported (Grovness Orthogneiss, ca. 990 Ma, Wang et al., 2005; Zhong Shan Gneiss, ca. 940 Ma, Zhao et al., 1995; Nella mafic-granulite, ca. 1100 Ma, Wang et al., 2005), it is evident that the basement in Prydz Bay represents a composite terrain that is characterised by 1125 Ma and 940-990 Ma felsic intrusives. The younger of these intrusions appear to have been accompanied by high-grade metamorphism; the lower intercept of ca. 950 Ma on the Søstrene orthogneiss (Fig. 3), and ca. 940-980 Ma Sm-Nd isochron ages (Hensen and Zhou, 1995) are consistent with this conclusion. Detrital zircon populations within the Tassie Tarn Metaquartzite of ca. 1125 Ma and 940-980 Ma, characteristic of the felsic orthogneisses dated here, implies that the felsic orthogneiss complex represents true basement to the Brattstrand Paragneiss, rather than being structurally juxtaposed during early Palaeozoic tectonism.

The age of the basement complex in Prydz Bay is regionally significant as these rocks can, in part, be correlated with rocks exposed in the nPCM and the Mawson coast. These regions were deformed and metamorphosed between ca. 990-920 Ma and accompanied by widespread emplacement of voluminous granites and charnockites (e.g. Kinny et al., 1997; Boger et al., 2000), a period of magmatism and metamorphism that, in part, coincides with that recorded for basement orthogneisses in Prydz Bay. Although no attempt has been made to determine the emplacement age of pre-orogenic orthogneisses exposed in the nPCM, it is possible that ca. 1150-1100 Ma intrusions, similar to those observed in Prydz Bay, are present in the nPCM but remain unrecognised. We speculate that the basement orthogneiss complex represented in Prydz Bay may correlate with pre-tectonic orthogneisses and ca. 990-920 Ma felsic intrusives exposed in the nPCM and that these two regions share a common early Neoproterozoic crustal evolution prior to the deposition of Neoproterozoic sediments and early Palaeozoic orogenesis (530-515 Ma) observed in Prydz Bay.

Tectonic implications

A possible geodynamic model for the evolution of the Prydz Bay region (which incorporates the Gondwana assembly model of Boger and Miller, 2004) involves a broad continental back-arc setting with extension and basin formation. In this scenario, a zone of dynamic continental rifting of the ca. 1125-940 Ma basement complex, with associated high geothermal gradients, developed on the eastern margin of the Indo-Antarctic element of West Gondwana (now Prydz Bay coastline). The Brattstrand Paragneiss was deposited into this evolving continental back-arc basin with detritus derived from both local sources and, in part, from the East African Orogen located to the west.

The abundance of boron in the Brattstrand Paragneiss suggests that basin formation and deposition occurred under (initially) non-marine conditions. By analogy with the model Slack et al. (1993) developed for tourmalinites associated with the stratabound Pb-Zn-Ag deposits at Broken Hill, Australia, the precursors to the boron-rich units in the Brattstrand Paragneiss could have formed by tourmalinisation of clastic sediments in an exhalative-synsedimentary hydrothermal system in which boron had been mobilised from underlying non-marine evaporite borate. Elevated LREE in the Tassie Tarn Metaquartzite and boron-rich paragneisses are also evidence for an active subseafloor hydrothermal system. Deposition of the Brattstrand Paragneiss was soon followed by basin inversion and tectono-metamorphism, culminating with continent-continent orogenesis in Prydz Bay due to the arrival of East Gondwana and development of the Kuunga suture at ca. 530-515 Ma. According to our model, the continental back-arc basin in the Prydz Bay region evolved in response to a west-directed subduction site located to the east of Prydz Bay and as a broad consequence of westward accretion and unification of East Gondwana with West Gondwana.

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