Preliminary U–Pb Dating of Grove Mountains Rocks: Implications for the Proterozoic to Early Palaeozoic Tectonic Evolution of the Lambert Glacier–Prydz Bay Area (East Antarctica)

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Abstract - The Grove Mountains consist of layered grey migmatitic biotite±hornblende gneiss, leucocratic tonalite to granitic gneiss, quartzite, and biotite–garnet paragneiss, with rare mafic schist and calc-silicate rocks. Granite and granodiorite bodies crop out at a few localities and charnockite at Mount Harding. Two zircon size fractions from a paragneiss at Austin Nunatak and one from a felsic layer in the same sample have markedly discordant isotopic ratios. The coarser zircon fraction from the gneiss plots close to concordia at about 800–750 Ma, whereas the other fractions are much more discordant, indicating much older inherited components. Rutile from the felsic layer and titanite from a leucogranite are slightly discordant and their model ages point to a high-grade metamorphic event at about 510–508 Ma. Forcing the two most discordant zircon fractions through c. 500 Ma suggests derivation from Palaeoproterozoic sedimentary protoliths or, more likely, their felsic igneous source regions. Three magmatic zircon size fractions from the charnockite have nearly concordant ages of about 504±2 Ma, that are undistinguishable at the 2σ level, and are broadly similar to the rutile and titanite ages. In spite of being much younger, the charnockite has a very similar chemical composition to some of the abundant early Neoproterozoic (c. 980 Ma) charnockite plutons in the northern Prince Charles Mountains and Mawson Coast believed to have originated in a later-orogenic, rather than anorogenic, tectonic environment. By analogy, the Grove Mountains area was probably affected by major Pan-African (c. 500 Ma) tectonic activity. The Grove Mountains cannot be correlated with the mainly Archaean–Palaeoproterozoic Ruker Terrane of the southern Prince Charles Mountains on isotopic grounds, and neither do the new data indicate clear geochronological similarities with the widespread late Mesoproterozoic–early Neoproterozoic mobile belt. The intensity of the Pan-African event (high-grade metamorphism and late-tectonic charnockite emplacement) suggests some affinities with the Prydz Bay coast area, but it is possible that the Grove Mountains represent a distinct terrane.

INTRODUCTION

The Grove Mountains (72°25′–73°5′, 74°–75°20′E) are situated to the east of the Prince Charles Mountains (PCM) and Lambert Glacier (Fig. 1), and about 350 km south of the Prydz Bay coast. Until recently these isolated outcrops remained one of the least investigated areas of Antarctica. The Grove Mountains were first visited in 1958 by an Australian field party which examined outcrops consisting of migmatitic gneissic granite and a few layers of “hornfels”, cut by pink granite veins (McLeod, 1959). Specimens of orthopyroxene granite (charnockite) were collected from Mount Harding (72°53′S, 75°02′E) by a survey party in 1972 (Tingey & England, 1973), and the small Austin Nunatak, on the western side of the Grove Mountains (72°55′S, 73°22′E), was mapped and a number of specimens collected in 1974 (England & Langworthy, 1975). Most of this outcrop was reported to consist of isoclinally folded, migmatitic siliceous gneiss, containing biotite±biotite, layered calc-silicate rocks and finely banded microcline-rich gneiss, and diopside–microcline pegmatite. The quartz- rich rocks were thought to have originated from sedimentary precursors (i.e., they are paragneisses). Russian geologists visited the area during reconnaissance mapping in the 1965–66 and 1971–72 field seasons. They described layered grey migmatitic biotite–hornblende, biotite, and leucocratic granite gneiss and tonalite gneiss, quartzite, and biotite–garnet gneiss, with rare mafic schist. Granite or granodiorite bodies were found at a few scattered localities.

The Grove Mountains were recently studied by the Chinese Antarctic Expedition. Zhao et al. (2000) reported ion-microprobe (SHRIMP) U–Pb zircon ages for felsic gneiss (529±14 Ma), syntectonic granite (534±5 Ma), and a granodiorite dyke (501±7 Ma). They also found 950–870 Ma inherited zircon cores in the gneiss.

The geological and tectonic significance of the Grove Mountains rocks have remained poorly understood, and several different correlations have been proposed. England & Langworthy (1975) noted that some of the Grove Mountains rocks resemble those at Mount Twigg in the southern Prince Charles Mountains (SPCM), and therefore suggested a correlation with the metamorphic rocks of that area. Kamenev et al. (1990) and Kamenev (1993) also...
considered that the Grove Mountains form part of the mainly Archaean to Palaeoproterozoic Ruker Terrane distinguished in the SPCM. In contrast, Tingey (1991) suggested that the Grove Mountains have greater geological affinities with the Mesoproterozoic–early Neoproterozoic high-grade metamorphic rocks of the northern Prince Charles Mountains (NPCM).

In order to clarify these speculative relationships this paper presents geochronological and geochemical data for samples from the Grove Mountains. This information provides an improved insight into the geological structure and evolution of this poorly investigated part of East Antarctica.

**REGIONAL GEOLOGICAL OUTLINE**

The PCM and adjacent areas form part of a complex Mesoproterozoic to early Neoproterozoic mobile belt, albeit with several Archaean cratonic blocks and smaller relics, which extends through much of the East Antarctic coast and once-adjacent parts of Gondwana (Moores, 1991). Three major tectonic provinces were distinguished in the Lambert Glacier–Prydz Bay area (Tingey, 1982, 1991; Kamenev, 1993): the late Archaean granite–gneiss Vestfold Block, the mainly Archaean to Palaeoproterozoic Ruker Terrane in the SPCM, and the Mesoproterozoic to early Neoproterozoic mobile belt in the northern and central PCM (Beaver Belt), Mawson Coast, eastern Amery Ice Shelf, and Prydz Bay coast (Fig. 1).

The Vestfold Block consists of interfolded and transposed late Archaean to earliest Palaeoproterozoic high-grade metamorphic rocks. Undeformed and mostly unmetamorphosed dykes were dated at about 2240, 1750, 1380, and 1240 Ma (Collerson & Sheraton, 1986; Black et al., 1991; Lanyon et al., 1993).

The Ruker Terrane comprises an Archaean (c. 3200–3000 Ma: Kovach & Beliatsky, 1991) inferred granitic gneiss basement which appears to be overlain by a variety of metasedimentary and metavolcanic rocks of three distinct groups (Kamenev et al., 1993). The age of regional metamorphism of the Ruker Terrane is uncertain, but it is
tentatively assigned to the same Mesoproterozoic (c. 1000 Ma) metamorphism which resulted in formation of the Beaver Belt (Tingey, 1991). Widespread retrogression, and possibly local prograde metamorphism, occurred during a c. 500 Ma (i.e., ‘Pan-African’) event (Halpern & Grikurov, 1975; Ravich et al., 1984).

The central and NPCM consist mainly of felsic orthogneiss and metasediments, with minor mafic granulite, amphibolite, and gabbro, intruded by syn-tectonic biotite–hornblende tonalite and diorite, and syn- to late-tectonic orthopyroxene-bearing granitoid (charnockite) bodies (Fitzsimons & Thost, 1992). Mafic to felsic calc-alkaline orthopyroxene-bearing granitoid (charnockite) bodies (Fitzsimons & Thost, 1992). Mafic to felsic calc-alkaline orthopyroxene-bearing granitoid (charnockite) bodies (Fitzsimons & Thost, 1992). Mafic to felsic calc-alkaline orthopyroxene-bearing granitoid (charnockite) bodies (Fitzsimons & Thost, 1992).

These rocks were metamorphosed about 1000 Ma ago (Beliatksy et al., 1994; Kinny et al., 1997), and felsic plutonic rocks also have mainly Mesoproterozoic emplacement ages (1293±28 Ma, 1020±48 Ma: U–Pb zircon ages, Kinny et al., 1997).

In some areas the Pan-African event was of higher grade (up to granulite facies), with a more penetrative style of deformation. In particular, the southern part of the Prydz Bay coast experienced pervasive high-grade reworking and syn-tectonic granitic emplacement at c. 500 Ma (Hensen & Zhou, 1995; Carson et al., 1995, 1996; Fitzsimons et al., 1997).

**SAMPLES STUDIED**

Four samples, collected by Australian field workers (Tingey & England, 1973; England & Langworthy, 1975) and located in the Australian Geological Survey Organisation collection, were selected for heavy mineral studies:

72280876 Brownish massive fine-grained aphyric granite (‘charnockite’): biotite–hornblende–quartz–plagioclase–K-feldspar; a similar sample (not now available) contains orthopyroxene in addition; Mount Harding.


74282673 Grey thinly layered inhomogeneous fine-to-coarse-grained microcline-rich gneiss: titanite–oapques–diopside–quartz–albite–microcline; Austin Nunatak.

74282682 Grey layered medium-grained siliceous paragneiss: oapques–sercite–oligoclase–microcline–quartz; contains a concordant coarser-grained leucocratic quartz-rich layer (74282682a), which may be a migmatite vein or an original sedimentary feature; Austin Nunatak.

Zircon was recovered from only two samples: charnockite 72280876, and layered siliceous gneiss 74282682, with a separate population from the migmatitic layer (74282682a), which also yielded a rutile fraction. The two other rocks contain abundant titanite, which was separated from the oligoclase-rich leucogneiss 74282666.

The charnockite (monzogranite) is composed of plagioclase (35–40%), K-feldspar (orthoclase?), 30–35%, quartz (about 20%), biotite, dark green to brownish-green hornblende, and opaque minerals (mafic phases total 10–15%). The rock has a fine to medium-grained (0.5–1 mm, with plagioclase up to 3 mm) inequigranular granitic texture. It contains mostly highly elongated (needle-like) homogeneous transparent prismatic zircon grains and aggregates; a few dark-brown cloudy highly rounded (spherical or irregular) grains were also recovered. Transparent grains are likely to be magmatic zircon, whereas a few dark brown grains (insufficient for a separate analysis) may represent an inherited source component.

The siliceous gneiss (74282682) contains strikingly different zircon populations. Most zircon grains are transparent, isometric to short prismatic with slightly rounded terminations; a few have cloudy cores or patches. Other grains are cloudy, pinkish to light magenta, and spherical; these grains are much more abundant in the finer size fraction (<0.1 mm) than in the coarse fraction (>0.1 mm). The migmatitic layer contains similar zircon morphologies: predominantly small (<0.1 mm) cloudy short prismatic or somewhat rounded colourless or rarely pinkish grains, and just a few transparent prismatic grains.

**Tab. 1 - Chemical composition and CIPW norm of charnockite 72280876.**

<table>
<thead>
<tr>
<th>wt % or ppm</th>
<th>wt % or ppm</th>
<th>CIPW norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>63.85</td>
<td>V</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.73</td>
<td>Cr</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.75</td>
<td>Co</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.33</td>
<td>Ni</td>
</tr>
<tr>
<td>FeO</td>
<td>4.09</td>
<td>Rb</td>
</tr>
<tr>
<td>MnO</td>
<td>0.09</td>
<td>Sr</td>
</tr>
<tr>
<td>MgO</td>
<td>1.45</td>
<td>Y</td>
</tr>
<tr>
<td>CaO</td>
<td>3.46</td>
<td>Zr</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.76</td>
<td>Nb</td>
</tr>
<tr>
<td>K₂O</td>
<td>4.51</td>
<td>Ba</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.50</td>
<td>La*</td>
</tr>
<tr>
<td>LOI</td>
<td>1.92</td>
<td>Ce*</td>
</tr>
<tr>
<td>Total</td>
<td>100.44</td>
<td>Nd*</td>
</tr>
</tbody>
</table>

LOI, Loss on ignition. *Analyses by INAA, other trace elements by XRF. Major elements by wet chemistry.
The high SiO₂ (87%) and relatively high Al₂O₃ (5%) of the gneiss are consistent with a metasedimentary origin.

**GEOCHRONOLOGY**

Isotopic measurements were conducted at the Institute of Precambrian Geology and Geochronology (St Petersburg) on a Finnigan MAT-261 solid-source mass spectrometer under static mode, using eight collectors with simultaneous determination of the measured isotopes. Uncertainties on upper and lower intercept ages are stated at the 95% confidence level. Isotopic data are presented in table 2.

All three zircon size fractions recovered from the charnockite (sample 72280876) have virtually indistinguishable isotopic ratios which are nearly indistinguishable from host gneiss, and thus are consistent with a metasedimentary origin.

Metamorphic event. Rutile from the felsic layer plots closest to the concordia at about 800–750 Ma, whereas the finer fraction is much more discordant and contains an older inherited (possibly detrital) component, probably in the cloudy, pinkish to light magenta, spherical zircon population. If 510 Ma is taken to be the age of metamorphism, the three paragneiss zircon fractions could reflect events at 1990±10 Ma (felsic layer zircons forced through 510 Ma), 1738±18 Ma (finer zircon fraction from host gneiss), and 1105±36 Ma (coarser fraction). However, if the peak metamorphic conditions were attained at c. 530 Ma (Zhao et al., 2000), these tentative age estimates would be 30 to 60 Ma older.

The significance of these various ages is uncertain, but some of the Palaeoproterozoic event (or events) seems probable, either metamorphosis or, more likely, the age of the source of the sedimentary protoliths, which would presumably reflect a period of felsic igneous activity. A Mesoproterozoic (c. 1100 Ma) plutonic event is also possible, although the present data are far from unequivocal. Alternatively, the isotopic composition of the coarsest zircon fraction could reflect a geologically poorly-defined Neoproterozoic (c. 800–750 Ma) thermal event.

**IMPLICATIONS FOR CHARNOKITE PETROGENESIS AND TECTONIC SETTING**

The Grove Mountains charnockite has a very similar chemical composition to many of the early Neoproterozoic

<table>
<thead>
<tr>
<th>Zircon size fraction, mm</th>
<th>Weight (mg)</th>
<th>[Pb] ppm</th>
<th>[U] ppm</th>
<th>²⁰⁶Pb/²³⁸U</th>
<th>²⁰⁷Pb/²³⁵U</th>
<th>²⁰⁸Pb/²³⁵U</th>
<th>²⁰⁶Pb/²³⁸U</th>
<th>²⁰⁷Pb/²³⁵U</th>
<th>Rho</th>
<th>Age ²⁰⁶Pb/²³⁸U (Ma)</th>
<th>Age ²⁰⁷Pb/²³⁵U (Ma)</th>
<th>Age ²⁰⁸Pb/²³⁵U (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 74282682 (silicic paragneiss)</td>
<td>&gt;0.1</td>
<td>0.24</td>
<td>33.15</td>
<td>243.6</td>
<td>132.5</td>
<td>0.68855±1</td>
<td>0.12169</td>
<td>1.1783</td>
<td>0.546</td>
<td>709.5±9.2</td>
<td>754.3±3.1</td>
<td>894.2±18</td>
</tr>
<tr>
<td>&lt;0.1</td>
<td>0.67</td>
<td>24.1</td>
<td>79.94</td>
<td>245.6</td>
<td>0.08905±47</td>
<td>0.21341</td>
<td>1.92212</td>
<td>0.515</td>
<td>1088.8±27.5</td>
<td>937.6±4.3</td>
<td>1405.2±8.1</td>
<td></td>
</tr>
<tr>
<td>Sample 72280876 (charnockite)</td>
<td>&gt;0.1</td>
<td>0.32</td>
<td>159.0</td>
<td>1202</td>
<td>507.9</td>
<td>0.21762</td>
<td>0.14179</td>
<td>1.54466</td>
<td>0.458</td>
<td>948.4±3.7</td>
<td>776.9±2.5</td>
<td>1370.9±4.1</td>
</tr>
<tr>
<td>&lt;0.1</td>
<td>1.09</td>
<td>5.01</td>
<td>45.65</td>
<td>123.4</td>
<td>0.05742±13</td>
<td>0.11629</td>
<td>0.54220</td>
<td>0.39</td>
<td>319.9±11.1</td>
<td>427.0±2.0</td>
<td>507.8±52</td>
<td></td>
</tr>
<tr>
<td>Sample 74282682a (coarse-grained leucocratic layer in 74282682)</td>
<td>&gt;0.1</td>
<td>0.45</td>
<td>196.2</td>
<td>2367</td>
<td>5429</td>
<td>0.05812±6</td>
<td>0.12224</td>
<td>0.64499</td>
<td>0.08087</td>
<td>0.972</td>
<td>505.4±10.9</td>
<td>501.3±0.9</td>
</tr>
<tr>
<td>0.075–0.1</td>
<td>1.29</td>
<td>177.6</td>
<td>1988</td>
<td>5565</td>
<td>0.05801±5</td>
<td>0.10235</td>
<td>0.64472</td>
<td>0.08086</td>
<td>0.963</td>
<td>505.3±1.5</td>
<td>500.2±1.4</td>
<td>528.3±1.8</td>
</tr>
<tr>
<td>0.045–0.075</td>
<td>1.00</td>
<td>184.0</td>
<td>2269</td>
<td>5429</td>
<td>0.05799±7</td>
<td>0.11129</td>
<td>0.64436</td>
<td>0.08059</td>
<td>0.924</td>
<td>505.0±1.7</td>
<td>499.7±1.6</td>
<td>529.3±2.5</td>
</tr>
<tr>
<td>Sample 74282686 (leucocratic gneiss)</td>
<td>titanite</td>
<td>0.69</td>
<td>42.03</td>
<td>152.4</td>
<td>143.18</td>
<td>0.05626±34</td>
<td>2.23988</td>
<td>0.63871</td>
<td>0.56</td>
<td>501.5±3.6</td>
<td>510.1±1.8</td>
<td>462.6±13</td>
</tr>
</tbody>
</table>

All isotopic ratios were corrected on mass discrimination, spike composition, blank, and initial lead according to the model of Stacey & Kramers (1975) at appropriate age (except ²⁰⁶Pb/²³⁸U – measured values). The total procedure blank was 0.2±0.1 ng for Pb and 0.005 ng for U. The calculations were carried out using PbDAT-program (Ludwig 1991) under 95% confidence level. Rho is the coefficient of error correlation on axis.
7U–Pb Dating of Grove Mountains Rocks

(c. 980 Ma) orthopyroxene granitoids (charnockites) which form large plutons in the NPCM and Mawson Coast (Young & Ellis, 1991; Sheraton et al., 1996). In particular, it compares very closely with low-SiO₂ varieties (quartz monzonite to granite) which were probably derived by fractionation of mantle-derived mafic to intermediate magmas, in contrast to high-SiO₂ granites (s.s.) which probably have much larger crustal components (Sheraton et al. 1996). These low-SiO₂ charnockites are characterised by high Ba and HFSE (high-field strength elements: Ti, Y, Nb, Zr), as well as relatively low FeO*/(FeO*+MgO) and (K₂O+Na₂O)/CaO. Spiderdiagram patterns are very similar (Fig. 3), the only significant differences being the somewhat higher K₂O, Rb, Th, and U contents of the Grove Mountains charnockite, although the high Th and U may at least in part be due to sample heterogeneity as only a small amount of rock was available for analysis.

The early Neoproterozoic charnockites are syn- to late-orogenic (Young & Ellis, 1991; Tingey, 1991) and their petrogenesis probably involved both mantle-derived magma and high-temperature melting of overthickened crust (Sheraton et al., 1996). Magmatic underplating would have provided both a heat source and a parent magma for the more mafic charnockites. Neoproterozoic granitoids in the NPCM appear to have formed in a range of tectonic environments, from continental arc types (low–moderate LILE [large-ion lithophile elements: K, Rb, Ba, Sr], low HFSE), through mature arc types (higher LILE, low HFSE), to late-orogenic and, ultimately, within-plate (A-type) granitoids (high LILE and HFSE). Such a trend would be consistent with a tectonic evolution from an Andean-type plate margin, which existed about 1300 Ma ago, to one of continental collision by 1000 Ma (Sheraton et al., 1996). The very similar composition of the Grove Mountains charnockite suggests derivation from a similar source in a similar tectonic environment, even though its emplacement age is much younger. The relatively high LILE and lack of deformation suggest a late-orogenic setting, with emplacement post-dating the metamorphic peak.

**IMPLICATIONS FOR PROTEROZOIC AND EARLY PALAEOZOIC TECTONIC EVOLUTION**

The Proterozoic to early Palaeozoic tectonic evolution of the PCM–Prydz Bay coast area was complex. Most of the tectonic grain (except in the southern Prydz Bay coast) was formed in the late Mesoproterozoic, between about 1300 and 1000 Ma (Tingey, 1991, and many others), and high-grade metamorphism peaked at about 1000 Ma, although subsequent metamorphic events continued until about 500 Ma. Much of the c. 1000 Ma granulite-facies terrane displays a P–T history which can be explained by major crustal thickening in a convergent tectonic regime, most likely one of continental collision, followed by uplift due to erosion and/or extensional collapse (Fitzsimons & Harley, 1992). The area appears to be part of the global-scale Grenvillian (Mesoproterozoic to early Neo-proterozoic) orogenic belt which was apparently related to assembly of the Rodinia supercontinent (Powell et al., 1993). There is currently only a little isotopic evidence for the age of the protoliths of the Beaver Belt high-grade metamorphic rocks. Most are probably Mesoproterozoic, and no older zircons were found during ion-microprobe studies of felsic rocks in the Radok Lake area by Boger et al. (2000). However, some older (Archaean–Palaeoproterozoic) components are present locally, particularly in the central PCM (Tingey, 1991; Kinny et al., 1997).

Our preliminary data from the Grove Mountains demonstrate that Palaeoproterozoic tectonothermal processes were probably important in this inland part of East Antarctica. The metasedimentary rock protoliths are unlikely to be Archaean, and may not even be Palaeoproterozoic (if the older ages reflect those of the source region), so that they cannot be correlated with the Ruker Terrane of the SPCM. Nevertheless, a few other indications of Palaeoproterozoic events have been obtained from this part of East Antarctica. There is some isotopic evidence for a thermal event in the Ruker Terrane at about 1900 Ma (Tingey, 1991; V.P. Kovach & B.V. Beliatsky, unpublished data), and 2100–1800 Ma inherited zircon cores are present.
in felsic meta-igneous rocks and paragneiss from the NPCM (Kinny et al., 1997).

An obvious feature of our data is that there is only very equivocal evidence for a c. 1100 Ma event in the Grove Mountains, which makes any direct correlation with the c. 1000 Ma Beaver Belt of the NPCM tentative at best. However, this does not preclude the Grove Mountains rocks having undergone such an event, and the presence of metamorphic and/or plutonic late Mesoproterozoic protoliths cannot be discounted at present. It should be noted that no isotopic evidence for an event of this age has yet been found in certain Archaean rocks of the Rauer Islands (Prydz Bay coast), although they are interfolded with more abundant c. 1000 Ma high-grade metamorphics.

They do, however, show evidence for extensive resetting of the U–Pb system, probably reflecting Pb loss due to fluid infiltration, at about 520 Ma (Harley et al., 1998). Ion-microprobe dating of paragneiss from Mount Meredith (NPCM) found no c. 1000 Ma zircon, only older (2800–1800 Ma) components (Kinny et al., 1997). Similarly, nearly all the zircons in granodiorite orthogneiss from the Burner Hills crystallised during emplacement at about 1700 Ma, some 500 Ma before granulate-facies metamorphism (Sheraton et al., 1992), and much of the zircon in 3930 Ma tonalitic orthogneiss from Enderby Land predates c. 3000 and c. 2500 Ma high-grade metamorphism (Black et al., 1986). High-grade metamorphic zircon, even if present, may well form only volumetrically minor rims which would be very difficult to detect by conventional techniques. Hence, the possibility that fluid activity in the Grove Mountains metamorphic rocks during the Mesoproterozoic–early Neoproterozoic high-grade event was simply not conducive to significant zircon growth cannot be discounted. It is worth noting here that most of the U–Pb isotopic evidence for the c. 1000 Ma event in the NPCM, and elsewhere in the mobile belt, comes from syn to late-orogenic felsic igneous rocks, and there is very little isotopic data for older metasedimentary or meta-igneous rocks.

The alternative suggestion of an event at about 800–750 Ma is also consistent with isotopic evidence from several regions of the East Antarctic shield. Black et al. (1987) reported U–Pb zircon ages of about 760–765 Ma for granite and pegmatite from the western part of the Rayner Complex in Enderby Land. Clarke (1988) quoted a 718±10 Ma Rb–Sr age for biotite from pegmatite in Kemp Land, and some of the Rb–Sr isochron ages from the Beaver Belt given by Tingey (1991) are similar, to partial resetting during a younger metamorphic event, and/or plutonic late Mesoproterozoic protoliths cannot be discounted at present. It should be noted that no isotopic evidence for an event of this age has yet been found in certain Archaean rocks of the Rauer Islands (Prydz Bay coast), although they are interfolded with more abundant c. 1000 Ma high-grade metamorphics.

They do, however, show evidence for extensive resetting of the U–Pb system, probably reflecting Pb loss due to fluid infiltration, at about 520 Ma (Harley et al., 1998). Ion-microprobe dating of paragneiss from Mount Meredith (NPCM) found no c. 1000 Ma zircon, only older (2800–1800 Ma) components (Kinny et al., 1997). Similarly, nearly all the zircons in granodiorite orthogneiss from the Burner Hills crystallised during emplacement at about 1700 Ma, some 500 Ma before granulate-facies metamorphism (Sheraton et al., 1992), and much of the zircon in 3930 Ma tonalitic orthogneiss from Enderby Land predates c. 3000 and c. 2500 Ma high-grade metamorphism (Black et al., 1986). High-grade metamorphic zircon, even if present, may well form only volumetrically minor rims which would be very difficult to detect by conventional techniques. Hence, the possibility that fluid activity in the Grove Mountains metamorphic rocks during the Mesoproterozoic–early Neoproterozoic high-grade event was simply not conducive to significant zircon growth cannot be discounted. It is worth noting here that most of the U–Pb isotopic evidence for the c. 1000 Ma event in the NPCM, and elsewhere in the mobile belt, comes from syn to late-orogenic felsic igneous rocks, and there is very little isotopic data for older metasedimentary or meta-igneous rocks.

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The effects of the late Neoproterozoic–early Palaeozoic Pan-African event appear to be much more widespread in the East Antarctic shield. Most areas show evidence for felsic magmatism and isotopic resetting at about 550–500 Ma (Krylov, 1972; Tingey, 1991). Deformation in the NPCM attributed to this event was largely confined to formation of shear and mylonite zones, but the presence in them of gneisschist to amphibolite or even granulite-facies assemblages indicates that the terrane was still at considerable crustal depths. Moreover, recent geological and isotopic studies have indicated the existence of Pan-African mobile belts in some parts of East Antarctica. For instance, Zhao et al. (1992), Hensen & Zhou (1995), and Carson et al. (1996) showed that the southern Prydz Bay coast area underwent high-grade metamorphism, ductile deformation, and syn-tectonic granite emplacement at about 500 Ma, followed by decompression of the terrane. The age data of Zhao et al. (2000) indicate high-grade metamorphism, deformation, and syn-tectonic granite emplacement in the Grove Mountains at c. 530 Ma, and granodiorite dyke emplacement at 501±7 Ma. The latter coincides with our charnockite emplacement age of 504±2 Ma, whereas the former may reflect peak metamorphic conditions, and our metamorphic age of c. 510 Ma (obtained for a rock from Austin Nunatak, the westernmost outcrop of the Grove Mountains) may indicate the time of the waning stages of metamorphism.

Other areas of significant Pan-African activity include the Lützw-Holm Complex, and possibly part of the nearby Rayner Complex, which underwent amphibolite to granulate-facies metamorphism about 550–520 Ma, the first reported Pan-African mobile belt in East Antarctica (Shiraishi et al., 1992). Jacobs et al. (1998) reported a high-grade metamorphic/deformation event and syn-tectonic granite emplacement in the central Dronning Maud Land at c. 530–510 Ma, which exactly coincides with the Grove Mountains data. Orthopyroxene-bearing syenite in the Humboldt Mountains of central Dronning Maud Land has given a U–Pb zircon age of 512±2.3 Ma (Mikhalsky et al., 1997), and syenitic plutons were emplaced in the Denman Glacier area at 516±1.5 Ma (Black et al., 1992).

Many of the late Neoproterozoic to early Palaeozoic granitic intrusive rocks of the PCM–Prydz Bay area have anorogenic (A-type) affinities (Manton et al., 1992; Sheraton et al., 1996). Plutons of similar age in nearby parts of the East Antarctic shield commonly have syenitic compositions. Emplacement of A-type hornblende–biotite granite plutons in the Prydz Bay area at about 500 Ma (Sheraton & Black, 1988) suggests that intrusion of such granitoids occurred relatively soon after major tectonic processes had ceased. However, it is noteworthy that the c. 500 Ma Grove Mountains charnockite has a very different composition to typical anorogenic granitoids (Fig. 4), which would be more consistent with this terrane having undergone a prolonged tectonic evolution during the late Neoproterozoic and early Palaeozoic. This contrasts with the Beaver Belt of the NPCM, which appears to have largely, although not entirely, stabilised soon after emplacement of compositionally similar charnockites.
1. The protoliths of the Grove Mountains metasediments about 980 Ma ago.

Like the c. 1000 event, the c. 500 Ma Pan-African event is widely considered to have been related to continental assembly, in this case of Gondwana, which was probably not completed until the early to middle Cambrian (Powell et al., 1993; Unrug, 1996). However, the exact nature of this event, at least in this part of Antarctica, is even more enigmatic than that of the earlier one, as neither suture zone nor ophiolite marking the palaeo-oceanic basin closure, nor juvenile volcanic rocks of this age yet have been found. Nevertheless, a collisional plate tectonic setting has been proposed for the Pan-African event elsewhere in East Antarctica (Sheraton et al., 1995), and the available chemical and isotopic data for the Grove Mountains charnockite, though far from conclusive, are consistent with emplacement in a late-orogenic tectonic environment.

CONCLUSIONS

1. The protoliths of the Grove Mountains metasediments are either of Palaeoproterozoic age or derived from source rocks of this age. They appear to have undergone regional high-grade metamorphism at about 500 Ma, and may also have been affected by events at about 1100 or 800 Ma (plutonic activity or metamorphism?).

2. An orthopyroxene granite (charnockite) pluton was emplaced at about 504 Ma. It is compositionally very similar to early Neoproterozoic (c. 980 Ma) charnockites in the NPCM and Mawson Coast, and is thus likely to have formed in a late-orogenic, rather than an anorogenic, environment. Hence, major early Palaeozoic (Pan-African) tectonic activity (penetrative deformation, metamorphism, and late-tectonic granite emplacement) probably affected the Grove Mountains area.

3. The Grove Mountains rocks are probably not related to the mainly Archaean to Palaeoproterozoic Ruker Terrane in the SPCM. The highly equivocal evidence for a c. 1100 Ma event also precludes any clear correlation with the extensive Mesoproterozoic (c. 1000 Ma) mobile belt of the NPCM and adjacent parts of the East Antarctic Shield, although such a correlation cannot be discounted, and it is possible that the Palaeo- to Mesoproterozoic histories of the two areas have at least some features in common. However, major c. 500 Ma tectonic activity suggests that the Grove Mountains may have closer geological affinities with the Prydz Bay coast area. Alternatively, they may represent a distinct terrane, although more extensive structural, geochemical, and isotopic studies will be needed to confirm this.

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