Mafic dykes in the southern Prince Charles Mountains: A tale of Pan-African amalgamation of East Antarctica questioned

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Summary We present new geochemical and U–Pb zircon data on mafic dykes from the southern Prince Charles Mountains. The dykes crystallised at ca 1700 Ma and 1300–1350 Ma. Apparently the oldest (ca 2400 Ma) are high-Mg orthopyroxene-bearing dykes which are also known from the Enderby Land and the Vestfold Hills. Abundant younger dykes are variously enriched in the LILE and comprise low- and high-LILE geochemical groups, as do the dykes in the abovementioned areas. The dykes in the southern Prince Charles Mountains are roughly co-eval and compositionally identical to those reported from the Enderby Land and the Vestfold Hills and were derived from the same or quite similar mantle source(s). This suggests that these parts of East Antarctica were conjugated and behaved as a single continental landmass since the early Palaeoproterozoic and questions a widely accepted model of Pan-African amalgamation of these blocks.

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Introduction

Mafic dykes are known from Archaean crustal blocks in the East Antarctica: the Enderby Land (Sheraton & Black, 1981), Vestfold Hills (Collerson & Sheraton, 1986), the southern Prince Charles Mountains (sPCM, Tingey, 1991). Mafic dykes in the Enderby Land were dated at ca. 2350 Ma and ca. 1200 Ma (Rb–Sr whole-rock isochron determinations, Sheraton & Black, 1981), in Vestfold Hills – at ca 2400–2240 Ma, ca 1800–1750 Ma, ca 1380–1250 Ma (Rb–Sr and U–Pb studies, Collerson & Sheraton, 1986, Black et al., 1991, Lanyon et al., 1993). A metamorphosed mafic dyke from the southern Mawson Escarpment has given a zircon Pb–Pb model age of ca 2400 Ma (Mikhalsky et al., 1992). The southern Prince Charles Mountains (sPCM, Fig. 1) are underlain by the Archaean Ruker Terrane which comprises an Archaean granite−gneiss basement, which experienced major tectono-magmatic activities between 3380 Ma and 2650 Ma (Boger et al., 2006, Mikhalsky et al., 2006).

Here we present the preliminary results of U–Pb isotopic study of zircons from two mafic dykes in the southern Mawson Escarpment in the sPCM and the geochemical data which allow a much more substantial comparison with the dykes known from the other Archaean Antarctic terranes than it was possible before.

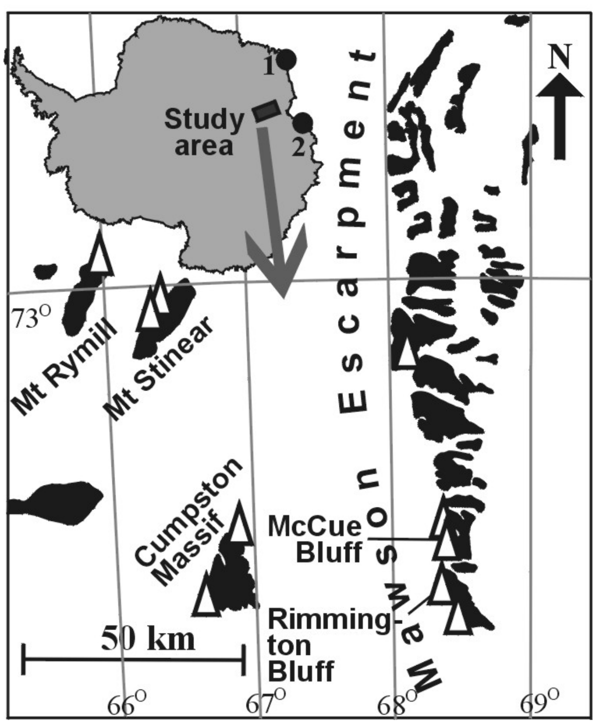

Figure 1. Locality map of the southern Prince Charles Mountains and major dyke occurrences (triangle). The Enderby Land (1) and the Vestfold Hills (2) are indicated in the inset.

The geological background

At McCue Bluff (Fig. 1) undeformed dykes form a network with complex cross-cutting relationships, but elsewhere they tend to be sheared (e.g., Mt Stinear) or folded (e.g., north-eastern Cumpston Massif). Our research mostly involves those dykes which are apparently not or only slightly sheared. The dykes are mostly thin (1–5 m, rarely up to 20 m). They trend different directions, clustering in four groups: east–west (85–95°, dipping north 30–50°), north–south (0–20°, dipping west 40–60°), northwest–southeast (120–135°, commonly steeply dipping northeast), and northeast–southwest (60–65°, dipping northwest 20–70°). The few observed dyke cross-cuttings show that the earliest dykes are east–west trending, gently dipping and strongly sheared; most of these dykes are composed heavily retrogressed and sheared mafic to ultramafic dolerite or amphibolite (hornblende 70–80%, biotite up to 20%, plagioclase <20%). Only rarely original doleritic texture is preserved. Pyroxene is completely replaced by talk, biotite and minor amphibole, but orthopyroxene relicts were distinguished in one sample. These rocks have peculiar high-Mg, high-Cr compositions.

The youngest generation is represented by steeply dipping, north–south or northwest–southeast trending dolerite dykes. These are less melanocratic (M = 45–70) fine-grained massive to schistose rocks with typical doleritic to subophitic texture. The fresh rocks are composed of clinopyroxene (50–60%) and plagioclase laths (40–50%).

Age data

Two zircon grains were recovered from a sheared dyke in Rimmington Bluff (sample sPCM 71.1). Zircon grains are short-prismatic, with clear magmatic zoning, have high Th/U ratios (0.5–0.9). Four analyses were obtained and all are discordant, but plot close to the concordia (Fig. 2). The regression line for these four analyses when forced through 0 Ma point gives an upper intercept at 1725±48 Ma which interpret as the dolerite crystallisation age.

Only one zircon grain was recovered from a north-east–south-west trending (the youngest generation). It has oval shape and has high U concentration (400–700 ppm) and lower Th/U (0.09–0.37). Three analyses were obtained and all are slightly discordant, but are spread along the Concordia between 1300–1350 Ma (Fig. 2). This estimate may be at best considered as the dyke crystallisation age. As no similar ages have yet been reported from the area, this age may not be inherited from the metamorphic host.

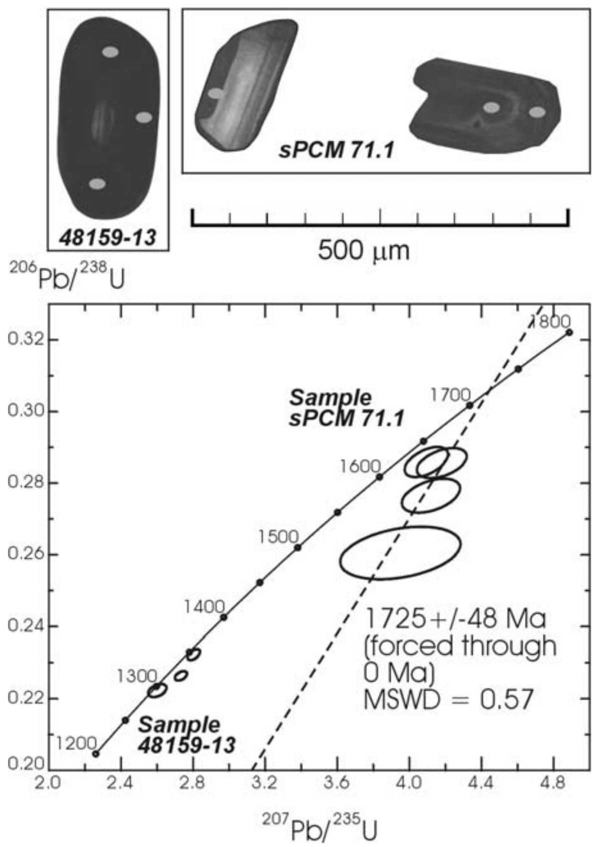

Figure 2. Cathodoluminescent images of zircon grains and the U–Pb concordia plot for the dyke rocks 48159-13 and sPCM 71.1.

Geochemistry

High-MgO, high-Cr rocks have index mg (mg = 100MgO/(MgO+FeO), molec.) mostly 65–73. These rocks are normative quartz–hypersthene-bearing. Apart from high MgO (8–18%) and Cr (800–3600 ppm), these rocks have also high Ni (200–960 ppm) and low Al_2O_3 (mostly <13%), TiO_2 (0.3–0.8%), Na_2O (<2%), Sr (20–150 ppm), Zr (<90 ppm), Nb (<6 ppm), V (<300 ppm), Pb (<5 ppm) compared with the other dyke rocks in the area. In a mantle normalized incompatible trace element diagram (not presented) these rocks have rather spiked but consistent patterns, and most samples show considerable negative Nb anomalies. The high-Mg group dykes, one of which yielded a model Pb–Pb age of ca 2400 Ma (Mikhalsky et al., 1992), have specific geochemical features, that are characteristic of siliceous high-Mg basalts (SHMB) and which point to an origin of these rocks by a large degree of partial melting of mantle peridotite.

The younger dyke rocks vary widely in terms of most major and trace elements: SiO_2 46–56%, TiO_2 0.6–2.9%, MgO 4.2–7.7%. North–south trending dykes as compared with dykes of other directions show some systematic differences. They tend to have somewhat lower concentrations of K_2O (<0.7%), P_2O_5, Rb, Ba, Th, La, Ce and higher Cr. These dykes may be distinguished as a *low-LILE group (1)*. One of the low-LILE group rocks gave an age of 1350–1300 Ma (this study). Most dykes of other directions (northwest–southeast and northeast–southwest), have somewhat higher K_2O (generally >1%), as well as other LILE, and will be referred to as a *high-LILE group (2)*. Apart from prominent LILE enrichment these rocks have elevated LREE abundances and prominent negative Nb, and Sr anomalies (Fig. 3). These groups have quite similar the HFSE ratios (Zr/Y, Zr/Nb, P/Zr), which indicates that these rocks originated from the same or broadly similar mantle source region(s). However, the group 2 rocks show higher LILE/HFSE ratios (e.g., Ba/Nb, K/Zr). These properties may be explained by various degrees of metasomatic enrichment of the mantle source(s). The fractionation (maybe combined with crustal assimilation in intracrustal chambers) led to higher trace element abundances in the more evolved rocks of both groups. Mikhalsky et al. (1992) reported Sm–Nd data on dykes from the southern Mawson Escarpment. The samples showed ε_{Nd}(1.3 Ga) in the range from –1.7 to 1.4. These values indicate the rocks originated from enriched mantle sources.

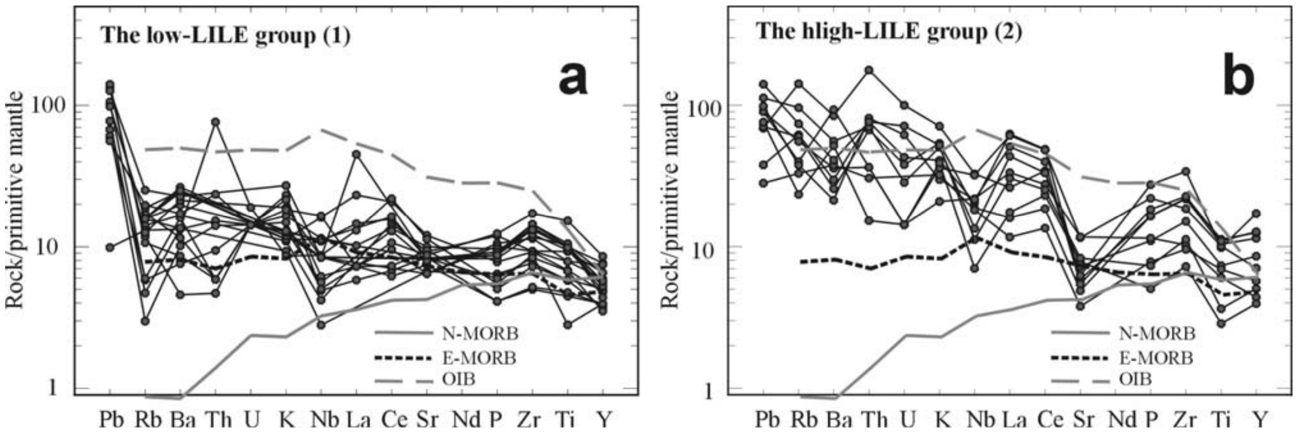

Figure 3. Primitive mantle-normalized trace element abundance diagrams for mafic dykes from the southern Mawson Escarpment: a) the low-LILE group, b) the high-LILE group. Normalization factors from Sun and McDonough (1989). The N-MORB, E-MORB and OIB compositions (Sun and McDonough, 1989) are shown for a comparison

Discussion and implications

In the Vestfold Hills dyke rocks Collerson & Sheraton (1986) noticed correlation between the extent of the LILE enrichment and negative Nb anomaly, and explained the nature of the characteristic Nb anomaly by metasomatism of the mantle source with a metasomatic fluid phase formed under conditions of Ti-oxide stability. Based on a detailed investigation of major and trace element ratios, Kuehner (1989) induced at least two separate source regions, each with primitive chondritic chemical characteristics modified by an incompatible-element enrichment event. The Enderby Land dykes have apparently quite similar compositions, as found by Sheraton et al. (1987), among others. The presence of two geochemical groups in the sPCM may be similarly explained by the involvement of two mantle sources (primitive and enriched mantle) or one variously enriched source.

The low-Mg mafic dykes from the sPCM are continental tholeiites and are virtually identical in composition to the most abundant suites of tholeiites in the Enderby Land (group II Amundsen Dykes) and the Vestfold Hills (group II) (Fig. 4). The group 2 rocks of the sPCM compared with the rocks of Group I of the other areas show many features in common, although K/Nb, Zr/Nb, Rb/Sr are higher. Similar enrichment in the Mesoproterozoic Group II dolerites from Enderby Land and the Vestfold Hills was attributed by Sheraton & Black (1981) and Collerson & Sheraton (1986) to metasomatism of the subcontinental lithosphere with a possibly subduction-derived LILE-rich fluid or melt. It must be noted that our group 2 corresponds in many respects (e.g., Ti/P, K/Rb ratios) to the Group I rocks from the Vestfold Hills. Our data confirm the close geochemical similarities with dated Mesoproterozoic dolerite dykes in all the Archaean cratons in this part of East Antarctica (the Vestfold Hills, the Enderby Land, and the Prince Charles Mountains). The composition of high-Mg early Proterozoic dykes in the Enderby Land and in the Vestfold Hills are also strikingly similar to the sPCM and in a spiderdiagram (Fig. 4) these rock suites nearly completely overlap.

These data show that the Archaean crustal blocks experienced three major mafic dyke injection episodes: at ca 2400–2250, 1800–1700 and 1300 Ma. The geochemical compositions of these dykes are also quite similar, which points to an origin from the same or very similar mantle sources. This fact questions the model proposed by Boger et al. (2001), among others, assuming these blocks evolved separately and were not conjugated before the Pan-African time. In that case their co-eval magmatic record is a matter of coincidence, which we do not think would be the case. The high-Mg dykes are not a common feature of other Gondwana fragments, and it is more likely that these blocks (the Enderby Land–the Vestfold Hills–the sPCM) composed a single edifice which experienced a complex evolution of rifting, extension and subsequent convergence responsible for the juvenile crust formation in Paleo- and Mesoproterozoic (Mikhalsky et al., 1996), but they did not exist as separate (or parts of separate) continents which drifted in the Proterozoic independently and collided in the Early Palaeozoic to form the East Antarctic.

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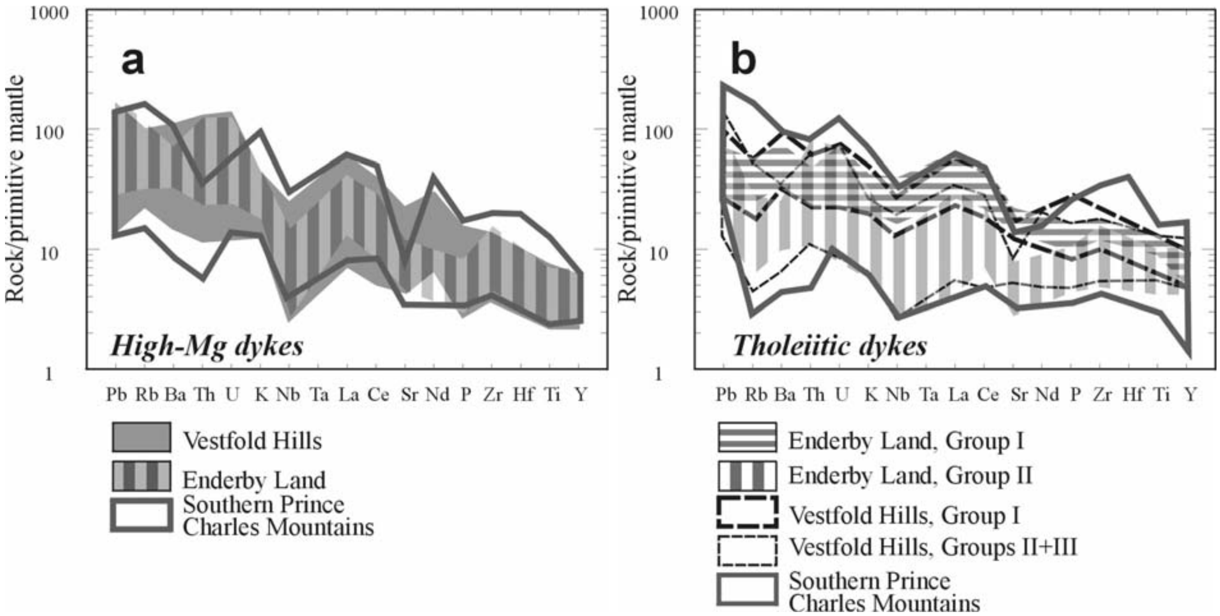

Figure 4. A comparison of dyke rocks (a – high-Mg, b – tholeiitic) from the Enderby Land, the Vestfold Hills and the southern Prince Charles Mountains in primitive mantle-normalized trace element abundance diagrams. The data for the Enderby Land and the Vestfold Hills – mostly unpublished data from J.W. Sheraton. Normalization factors from Sun & McDonough (1989).

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