Formation of continental crust by anatectic reworking and differentiation at active plate margins

M. Brown[1], C. M. Fanning[2], F.J. Korhonen[3], C.S. Siddoway[4] and C. Yakymchuk[1]

[1]Laboratory For Crustal Petrology, University of Maryland, College, Park, USA

[2]Research School of Earth Sciences, The Australian National University, Australia

[3]Geological Survey of Western Australia, East Perth, Australia

[4]Department of Geology, The Colorado College, Colorado Springs, USA

Anatectic reworking and differentiation at active plate margins is the principal process by which new crust becomes stabilized as part of the continents. This process is well illustrated by the Fosdick migmatite–granite complex of Marie Byrd Land, West Antarctica, which preserves evidence of two high-temperature (suprasolidus) metamorphic events (Devonian–Carboniferous and Cretaceous) along the former active margin of East Gondwana (Korhonen et al., 2010a, b; 2012). Residual migmatitic gneisses and associated granites exposed in the Fosdick complex were derived from Early Paleozoic quartzose turbidites of the Swanson Formation and early components of the Devonian–Carboniferous calc-alkaline Ford Granodiorite suite by melting that was broadly contemporaneous with ongoing calc-alkaline magmatism during Pacific-style accretionary margin convergence. Inverse phase equilibria modeling of paragneisses and forward modeling of the regionally exposed turbidite and calc-alkaline protoliths constrains conditions of M1 metamorphism to 820–870°C at 7.5–11.5 kbar if garnet was part of the assemblage (Korhonen et al., 2010a, 2012), or 760–800°C at 6.0–9.5 kbar if not. Modeling the range of protolith compositions shows that the turbidites could have produced 4–25 vol.% melt at the P–T conditions for the exposed crust, with melt fractions reaching the melt connectivity transition (~7 vol.% under static conditions) for most compositions and at least 70% of the melt produced being lost. Although the plutonic rocks would have produced only 2–3 vol.% melt at this crustal level during M1, melt derived from slightly deeper in this source accumulated and crystallized within the Fosdick complex during the M1 event (Korhonen et al., 2010a, b, 2012). A second event during the Cretaceous (M2) resulted in additional melting of the residual paragneisses as well as anatexis of fertile turbidites that did not melt during the M1 event. Inverse phase equilibria modeling of the residual gneisses constrains conditions of M2 metamorphism to 830–870 °C and 6–7.5 kbar (Korhonen et al., 2010a, 2012). At these conditions, the fertile turbidites would have produced 5–30 vol.% melt, whereas the calc-alkaline rocks again were not a significant source of melt at this crustal level. In addition, the residual paragneisses could have produced an additional ~12 vol.% melt during M2 (Korhonen et al., 2010a, b, 2012).

In the Fosdick complex, granites of both Devonian–Carboniferous and Cretaceous age have distinct chemical signatures that reflect different melting behavior in contrasting sources (Korhonen et al., 2010a; Yakymchuk et al., 2013). Based on whole rock major and trace element geochemistry, and Sr–Nd isotope compositions, the more common low Rb/Sr Devonian–Carboniferous granites were interpreted to be dominantly products of melting of the calc-alkaline rocks (Korhonen et al., 2010b). Conversely, scarce high Rb/Sr Devonian–Carboniferous granites were interpreted as derived mostly from the turbidites (Korhonen et al., 2010b), consistent with a large proportion of the melt produced from this source being lost to shallower crustal levels, and suggesting a minimal supracrustal component deeper in the crust (Korhonen et al., 2010a, b, 2012). In contrast, the Hf–O isotope composition of zircons from all analyzed Devonian–Carboniferous granites is best explained by mixtures of materials from both crustal sources (Yakymchuk et al., 2013), which is consistent with the earlier conclusion that these granites record crustal reworking without input from a more juvenile source. The Cretaceous granites are divided into two distinct groups. An older group of granites (c. 115–110 Ma) has elemental and Sr–Nd isotope compositions consistent with derivation from a dominant calc-alkaline source, whereas a younger group of granites (c. 109–102 Ma) with distinct light rare earth element depleted signatures has Sr–Nd isotope compositions suggesting that they were derived predominantly from both fertile turbidites and residual paragneisses. Although the Hf–O isotope composition of zircons from the older Cretaceous granites is consistent with derivation from calc-alkaline and turbidite protoliths (Yakymchuk et al., 2013), the younger granites require a contribution from a more juvenile source in addition, consistent with other evidence for the availability of mantle-derived melts (Saito et al., 2012). Thus, anatectic reworking along the East Gondwana margin resulted in initial stabilization of continental crust in the Devonian–Carboniferous and further intracrustal differentiation associated with a juvenile input in the Cretaceous. The relatively nonradiogenic εHf isotopic characteristics of zircons from the Fosdick complex granites are similar to those from Permo-Triassic granites from the Antarctic Peninsula. However, they contrast with coeval granites in other localities along and across the former active margin of Gondwana, including the Tasmanides of Australia and the Western Province of New Zealand, where the wider range of more radiogenic εHf values suggests that crustal growth through the addition of juvenile material may play a larger role in granite genesis.

Korhonen, F.J., Brown, M., Grove, M., Siddoway, C. S., Baxter, E.F. and Inglis, J.D., 2012. Separating metamorphic events in the Fosdick -granite complex, West Antarctica. Journal of Metamorphic Geology, 30, 165–192.

Korhonen, F.J., Saito, S., Brown, M. and Siddoway, C.S., 2010a. Modeling multiple melt loss events in the evolution of an active continental margin. Lithos, 116, 230–248.

Korhonen, F.J., Saito, S., Brown, M., Siddoway, C.S. and Day, J.M.D., 2010b. Multiple generations of granite in the Fosdick Mountains, Marie Byrd Land, West Antarctica: Implications for polyphase intracrustal differentiation in a continental margin setting. Journal of Petrology, 51, 627–670.

Saito, S., Brown, M., Korhonen, F.J., McFadden, R.R. and Siddoway, C.S., 2012. Geochemistry of Cretaceous mafic intrusive rocks in the Fosdick Mountains, West Antarctica: melting of the sub-continental arc mantle along the Gondwana margin. Gondwana Research, http://dx.doi.org/10.1016/j.gr.2012.08.002.

Yakymchuk, Y., Siddoway, C.S., Fanning, C.M., McFadden, R.R., Korhonen, F.J. and Brown, M., 2013. Crustal differentiation along the active margin of Gondwana: A zircon Hf–O perspective from granites in the Fosdick migmatite–granite complex, West Antarctica. Geological Society (London) Special Publication (in press).