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Neoproterozoic–Early Devonian magmatism in the Antigonish Highlands, Avalon terrane, Nova Scotia: Tracking the evolution of the mantle and crustal sources during the evolution of the Rheic Ocean

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ABSTRACT

The Antigonish Highlands lies in the Avalon terrane (Avalonia) in the Canadian Appalachians and records four episodes of continental rift-related bimodal magmatism ranging in age from Late Neoproterozoic to Middle Devonian. The oldest episode (ca. 615 Ma Clydesdale Formation) was emplaced in a local rift setting in an Andean-style arc when Avalonia resided along the northern Gondwanan margin. Early Cambrian magmatism (Arbuckle Brook Formation) occurred in a local transtensional setting after arc magmatism had given way to a San Andreas-type transform environment. Middle Ordovician (Dunn Point and Bears Brook formations) magmatism occurred in a local rift in an ensialic island arc setting, analogous to the modern Taupo Volcanic Zone in northern New Zealand, after Avalonia had separated from Gondwana. Middle Devonian (McArras Brook Formation and correlatives) occurred after Avalonia had collided with Laurentia. In each episode, mafic rocks are characterized by high FeO^t, FeO^t/MgO, TiO_2, Zr/Y and Ti/Y typical of differentiated within-plate mafic magmas. Multi-element spider-diagrams indicate that all four episodes were generated in an enriched sub-continental lithospheric mantle. LIL, HFS and REE patterns indicate that the Clydesdale, Dunn Point/Bears Brook and McArras Brook formations were sourced in the shallow (spinel lherzolite) mantle, and that the Arbuckle Brook Formation was generated in the deeper (garnet lherzolite) mantle. In each episode, coeval felsic rocks were generated by crustal anatexis. Taken together, the Sm–Nd isotopic data for the mafic rocks form an envelope that defines the evolution of the mantle source beneath the Antigonish Highlands that was enriched between 0.8 and 1.1 Ga and has an average Sm/Nd ratio of ca. 0.24 (a value that is typical of an enriched mantle source). Sm–Nd isotopic data for the felsic rocks are characterized by a recurrence of T_{DM} ages between 0.95 and 1.0 Ga, interpreted to reflect repeated melting of the lower crust that was itself derived from a depleted-mantle source between 0.95 and 1.1 Ga.

The remarkable geochemical and isotopic similarity of the Neoproterozoic, to Middle Devonian mafic and felsic magmas indicate that the crust and sub-continental lithospheric mantle beneath the Antigonish Highlands were coupled during the rift and drift of Avalonia from the Gondwanan margin during the formation of the Rheic Ocean in the Ordovician, its accretion to Baltica and to Laurentia in the Silurian, and post-accretionary strike-slip movement of Avalon along the Laurentian margin.

Although the Sm–Nd isotopic data suggest that Avalonian basement and lithospheric mantle formed over the same time interval (0.8 to 1.1 Ga), the divergence of their respective envelopes with time reflects their differing ε_{Nd} values and Sm/Nd ratios. We suggest that Avalonian crustal basement and its enriched mantle were both formed between 0.8 and 1.1 Ga in a Panthalassa-type ocean that surrounded the supercontinent Rodinia and were accreted to the northern Gondwanan margin at about 650 Ma, prior to the oldest magmatic event in the Antigonish Highlands.

1. Introduction

The tectonothermal history of Avalonia is of the first-order importance in the understanding of the evolution of the Rheic Ocean because its Paleozoic rocks preserve evidence of the origin, evolution and demise of the ocean. A combination of paleomagnetic, faunal, geochronological and geochemical data indicate the Avalonia was one of several peri-Gondwanan terranes that drifted from the Gondwanan margin in the Late Cambrian or Early Ordovician thereby forming the Rheic Ocean (Fig. 1). By 460 Ma Avalonia was about 2000 km north of the Gondwanan margin and was separated from

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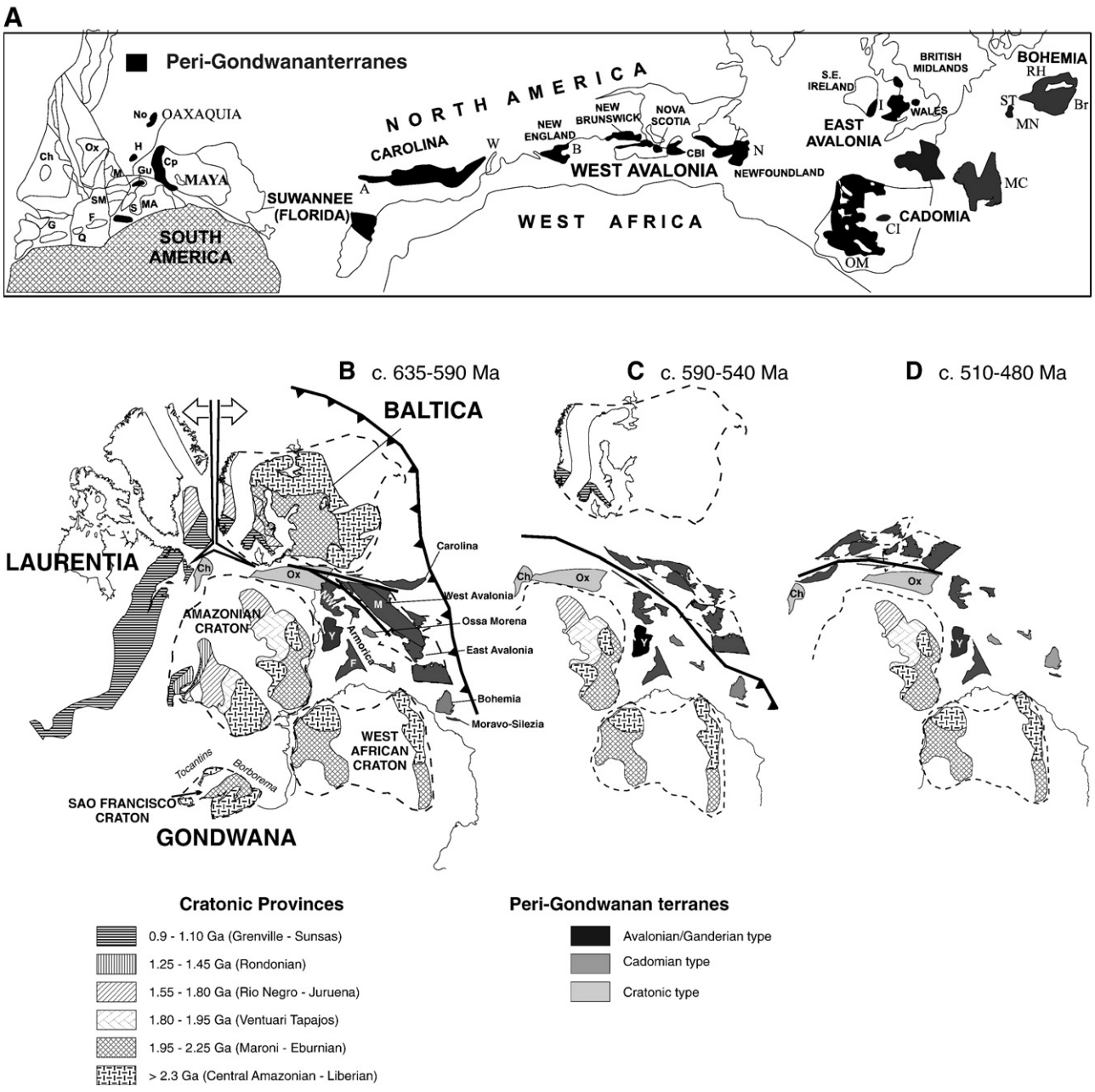

Fig. 1. A: The locations of Precambrian peri-Gondwanan terranes in an Early Mesozoic reconstruction of Pangea A, (modified Nance and Murphy, 1994; Weil et al., 2001; Keppie et al., 2003). Abbreviations: A = Atlanta, B = Boston, Br = Brunia (includes Moravo–Silesia and W. Sudetes), CBI = Cape Breton Island, Ch = Chortis, CI = Central Iberia, Cp = Chiapas, F = Floresta, G = Garzón, Gu = Guajira, H = Huiznopala, I = Ireland, M = Mixtequita, MA = Mérida Andes, MN = Moldanubian, N = Newfoundland, No = Novillo, OM = Ossa-Morena, Ox = Oaxacan Complex, Q = Quetame, RH = Rheno-Hercynian, S = Santander, SM = Santa Marta, ST = Saxo-Thuringian, W = Washington. B–D: Late Neoproterozoic–Early Paleozoic (635–480 Ma) reconstructions showing the location of Avalonia and related peri-Gondwanan terranes along the northern margin of Gondwana. (Ch = Chortis Block, Ox = Oaxaquia, Y = Yucatan Block, F = Florida, NIA = Neoproterozoic Iberian Autochthon). Figure modified after Nance and Murphy (1994, 1996), Linnemann et al. (2000), Linnemann and Romer (2002) and Murphy et al. (1999a), Nance et al. (2002), Keppie et al. (2003), Murphy et al. (2004b), Murphy et al. (2006).

Laurentia and Baltica to the north by the Iapetus Ocean, and from Gondwana to the south by the Rheic Ocean (Fig. 2). Between the Late Silurian and Late Carboniferous Avalonia resided along the northern margin of a converging Rheic Ocean, the closure of which eventually resulting in the amalgamation of Pangea.

All of these major tectonothermal events were accompanied by igneous activity and most studies of igneous rocks with Avalonia have focused on the geochemical and petrologic evolution of individual igneous suites in a given region, and have then compared them with suites of a similar age from neighboring regions. In a brief overview, Murphy and Dostal (2007) showed that a complimentary approach, that of comparing the geochemistry of igneous rocks of different ages in the same region, can provide additional insights into the evolution of the mantle and crustal sources of the magmas. For example, the Antigonish Highlands of Nova Scotia, a small fault-bounded block within Avalon, preserves (i) a record of Neoproterozoic and Early Cambrian magmatism, which would have occurred along the Gondwanan margin, (ii) Middle Ordovician magmatism, which took place when Avalonia was a New Zealand-style microcontinent, and (3) Middle Devonian magmatism, which occurred after Avalonia became accreted to Laurentia. The geochemistry and isotopic signature of these volcanic rocks shows a remarkable degree of inheritance from earlier tectonic events. In this paper, we develop these themes and provide a more detailed analysis of the geochemistry and Sm–Nd