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Granodiorites of the South Mountain Batholith (Nova Scotia, Canada) derived by partial melting of Avalonia granulite rocks beneath the Meguma terrane: Implications for the heat source of the Late Devonian granites of the Northern Appalachians

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ABSTRACT

The Late Devonian South Mountain Batholith (SMB) of Nova Scotia is the largest batholith of the northern Appalachians. The peraluminous granitic rocks range from biotite granodiorite to leucogranite. Samples collected from a drill core of the Scrag Lake granodioritic pluton of the western SMB are chemically homogeneous from the surface to a depth of ~1425 m. The homogeneous composition implies that the granodiorite was derived from a relatively homogeneous source and that country rock assimilation was not an important source for the parental magma. Equilibrium partial melt modeling of underlying sub-Meguma granulite rocks indicates that they are the primary source rocks of the granodiorites. We suggest that mantle-derived magmas intruded the lower crust and induce large-scale melting of the granulite basement rocks to produce the granodiorites. Fractional crystallization of the granodiorites plus assimilation of Meguma Supergroup metasediments likely produces the silica-rich rocks of the SMB. The cause of mantle melting is uncertain however it may be related to the transitioning of the northern Appalachians from a position above the deep mantle Pacific large low shear velocity province (LLSVP) to a higher shear velocity region of the mantle.

1. Introduction

During the Late Devonian extensive, post-Acadian orogeny plutonism occurred throughout Atlantic Canada and northern New England (Clarke et al., 1997; Dorais, 2003; Dorais and Paige, 2000; Faill, 1997a, b; Murphy et al., 1999; Tomascak et al., 2005). The largest of the northern Appalachian granitic batholiths is the South Mountain Batholith (SMB) located in the Meguma terrane of Nova Scotia and consists of at least eleven individual plutons ranging in composition from peraluminous granodiorite to leucogranite, one of which hosts a world class Sn deposit. The framework petrogenetic model of the SMB indicates that fractional crystallization of magmas derived from melting of sub-Meguma (i.e. Avalon terrane) granulites plus mixing with melts derived from country rocks contributed to the formation of the various plutons (Clarke and Carruzzo, 2007; Clarke et al., 2000, 2004; Dostal and Chatterjee, 2010; Dostal et al., 2006; Eberz et al., 1991; Erdmann et al., 2007; Halter et al., 1998; MacDonald et al., 1992; Shellnutt and Dostal, 2012). However the melting conditions, proportion of melt derived from sub-Meguma granulites versus country rock, and the heat source are poorly understood (Clarke et al., 2004; Dunning et al., 2002; Murphy et al., 1999; Shellnutt and Dostal, 2012).

One of the most contentious issues regarding the formation of the SMB and other Late Devonian plutons in the northern Appalachians is the heat source required for melting (Chamberlain and Sonder, 1990; Dorais and Paige, 2000; Dunning et al., 2002; Murphy et al., 1999; Tomascak et al., 2005). Many hypotheses have been proposed for the cause of crustal melting and they involve one or more of the following: 1) injection of mantle-derived mafic magmas (Dorais and Paige, 2000; Shellnutt and Dostal, 2012; Tate and Clarke, 1995); 2) crustal thickening (Clarke et al., 1997); 3) decompressional melting (Keppie and Dallmeyer, 1987, 1995; Lynch and Tremblay, 1994); 4) the passage of a mantle plume beneath the crust (Keppie and Krogh, 1999; Murphy et al., 1999) or 5) radioactivity of anomalously U-enriched sediments (Chamberlain and Sonder, 1990). The presence of spatially and temporally associated mafic to ultramafic rocks with moderately depleted Nd isotope values indicates that mantle melting was occurring at the same time as the emplacement of the Late Devonian plutons and suggests the melting regime in the region was anomalously high however the reason for the elevated mantle temperatures is not constrained (Dorais, 2003; Dorais and Paige, 2000; Shellnutt and Dostal, 2012; Tate and Clarke, 1993, 1995).

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In this paper, we present whole rock data from samples collected from a ~1.5 km deep drill core of the Scrag Lake granodiorite pluton (SLP) in western Nova Scotia in order to petrogenetically model the possible origin of the granodiorites of the SMB. Using geologically reasonable conditions (i.e. pressure, temperature, relative oxidation state, and water content) and starting compositions equal to the sub-Meguma (i.e. Avalon) granulite xenoliths collected from Late Devonian lamprophyric dykes, the results of equilibrium partial melting models are presented in order to constrain the possible thermodynamic conditions and source compositions for the formation of the granodiorites (i.e. Scrag Lake pluton) of the SMB. Based on the thermodynamic constraints from the models, we also suggest a possible explanation for the heat source that is required to induce mantle as well as crustal melting in the northern Appalachians during the Late Devonian.

2. Geological background

The Meguma terrane, the most easterly terrane of the northern Appalachians (Fig. 1), stretches across mainland Nova Scotia for ~750 km. It was the last terrane accreted to the eastern side of the Appalachians. The terrane, as well as the adjoining Avalon exotic terrane, was accreted to North America (Laurentia) during continental collision in the early to middle Paleozoic during the closure of the Rheic Ocean (i.e. Acadian Orogeny). The Meguma terrane is composed mainly of two lithotectonic units; (1) the Cambro-Ordovician Meguma Supergroup (~10 km thick sequence of flyshoid meta-sedimentary rocks) and (2) Late Devonian granitoid rocks of the South Mountain batholith. The Meguma sediments, probably representing a turbidite fan deposited on a continental margin (Schenk, 1997), were deformed and metamorphosed to lower greenschist to upper amphibolite facies during the Acadian Orogeny (~400 Ma in this region). This event also affected overlying Silurian–lower Devonian (Emsian) sedimentary and volcanic formations.

The SMB, exposed over an area of ~7300 km^2, is a post-tectonic composite body made up of several granitoid plutons emplaced within a narrow time interval (<5 My) at ~375 Ma and at a depth of 10–12 km (Clarke et al., 1997). The batholith intruded the Meguma Supergroup and overlying Siluro-Devonian volcano-sedimentary sequences after the peak of regional metamorphism. Lower Carboniferous (Namurian to Tournaisian) sedimentary rocks unconformably overlie the batholith implying rapid uplift and exhumation (lasting ~10 My) attributed to the final stages of collision between the Meguma and Avalon terranes. These two terranes are separated by a steeply dipping E–W dextral fault system (Keppie and Dallmeyer, 1987).

The SMB is composed of peraluminous, S-type granitoid rocks. The rocks range from biotite granodiorite (with up to 20% biotite) to leucogranite (with <1% biotite). The differentiated rocks locally contain primary muscovite, cordierite, andalusite and garnet.

The Meguma terrane hosts minor mafic intrusions which are approximately coeval with the SMB. They include a swarm of lamprophyric dykes along the eastern shore of Nova Scotia emplaced at ~370 Ma (Greenough et al., 1988; Kempster et al., 1989; Ruffman and Greenough, 1990). These northwesterly trending calc-alkaline lamprophyres typically cut the Meguma Group rocks and are steeply dipping with narrow chilled margins (Tate and Clarke, 1993). The lamprophyres are spessartites with phenocrysts of amphibole, clinopyroxene and rare biotite enclosed in a groundmass containing plagioclase, K-feldspar, and quartz. The dykes range in thickness from <1 m to ~15 m. According to Tate and Clarke (1993), the chemical composition of the lamprophyre dykes is similar to the average spessartites of Rock (1991). Some of the dykes contain gneissic/granulitic xenoliths up to 1 m in diameter which were interpreted to represent fragments of the basement of the Meguma terrane (Eberz et al., 1991; Greenough et al., 1999; Owen et al., 1988). The majority of the xenoliths are either pelitic granulites or mafic to intermediate orthogneisses. Orthogneisses typically contain >50% of orthopyroxene ± clinopyroxene (variably converted to amphibole) enclosed in plagioclase (andesine) and a quartz-rich groundmass (Eberz et al., 1991; Owen et al., 1988). Pelitic xenoliths typically contain garnet, graphite, biotite, quartz, and feldspar with variable, but minor amounts of saphirine, sillimanite, kyanite, spinel, orthopyroxene, and clinopyroxene. Owen et al. (1988) concluded that the xenoliths are granulites that underwent an early metamorphic event at a pressure ~450–600 MPa and temperature ≥ 600 °C. The mineral assemblages were subsequently overprinted by high temperature

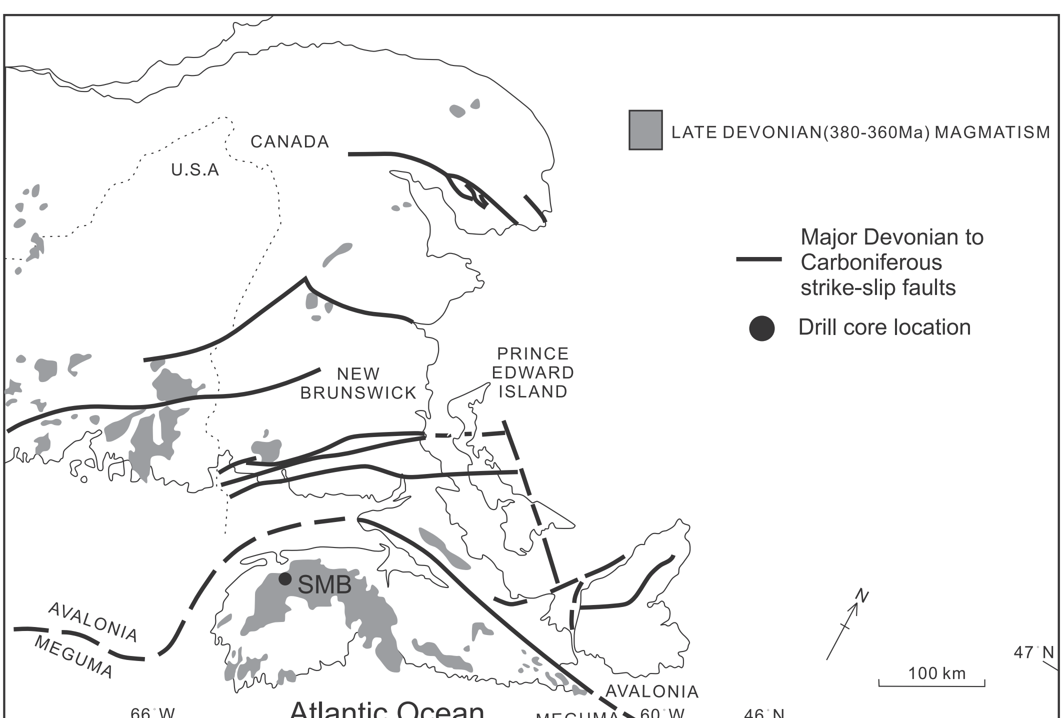

Fig. 1. Distribution of Late Devonian plutons of the northern Appalachians showing the location of the SMB and the Scrag Lake deep drill hole (modified from Murphy et al., 1999).