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Mantle petrology and mineralogy of the Thetford Mines Ophiolite Complex

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Abstract

The Ordovician Thetford Mines ophiolite complex (TMOC) formed by boninite-fed seafloor-spreading, probably in a fore-arc environment. The mantle section is dominated by foliated harzburgite (≤5–6% clinopyroxene), cut by dunitic (±chromitite cores) and orthopyroxenitic veins and dykes. Contrasting structures, textures and mineral compositions allow us to subdivide the mantle. The granular-textured rocks of the Duck Lake Block (DLB) have two steeply-dipping foliations. The older foliation strikes NW, is sub-perpendicular to the Moho, and is interpreted to have resulted from upflow of the asthenosphere beneath the spreading ridge. This fabric is overprinted by a 2nd ductile foliation striking ENE, oriented sub-parallel to the Moho, which we interpreted as having formed by crust–mantle shear as the lithosphere migrated away from the spreading ridge. The DLB mantle has a limited range of spinel Cr# (100Cr / (Cr + Al) = 51–71). Comparison with experimentally determined residual spinel compositions (equilibrium melting) implies a maximum loss of 27–38% melt if the protolith had a fertile MORB mantle composition. However, interstitial-textured clinopyroxene may have high TiO_2 (<0.04wt.%) and Na_2O (<0.27wt.%), and some interstitial spinel has higher TiO_2 (<0.09wt.%), suggesting interaction with (or crystallization from) an "impregnating" melt. Interstitial tremolitic amphibole also indicates the passage of late hydrous fluids. The harzburgite in the Caribou Mountain Block (CMB) has a porphyroclastic texture, with a strong, locally mylonitic foliation striking roughly N–S, parallel to the orientation of seafloor-spreading related paleo-normal faults in the crust. These fabrics and textures imply a colder, lithospheric deformation, possibly related to tectonic denudation (oceanic core complex). This would explain problematic lava/mantle contacts, favour infiltration of seawater, serpentinization, and reduced fO_2 conditions. The CMB mantle shows a wider range of mineral compositions than the DLB, with spinel Cr# (28–86) implying ≤15–45% of equilibrium melting. Locally higher TiO_2 in spinel (<0.05wt.%) and clinopyroxene (<0.11wt.%), a local rimward decrease in spinel Cr#, clinopyroxene Cr#, and olivine Fo-content, and traces of interstitial amphibole, are attributed to the circulation of an evolved hydrous melt during peridotite deformation. This suggests that the lower limit to the extent of melting inferred for the CMB (15%), established on the basis of Al-rich spinel rims and neoblasts, is probably too low. On the other hand, the higher inferred degree of depletion of the CMB is probably unaffected by the metasomatic overprint and is a more robust conclusion.

Keywords: Thetford Mines Ophiolite; Mantle Melting; Mantle Metasomatism; Mineral Chemistry; Southern Québec Appalachians

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1. Introduction

In the southern Québec Appalachians, well-preserved ophiolitic massifs represent the vestiges of Iapetus Ocean marginal basins, obducted and accreted to the Laurentian margin during the Taconian Orogeny (St-Julien and Hubert, 1975; Hébert and Laurent, 1989; Laurent and Hébert, 1989; Fig. 1). The crust of the Thetford Mines Ophiolitic Complex (TMOC) is dominated by cumulates, dykes, and lavas of boninitic affinity (Church, 1977, 1987; Hébert and Laurent, 1989; Laurent and Hébert, 1989; Bédard et al., 2001, 2006), and the massif is interpreted to represent a fragment of fore-arc lithosphere (Hébert and Laurent, 1989; c.f. Bédard et al., 1998; Hébert and Bédard, 2000; Kim and Jacobi, 2002; Schroetter et al., 2003). Evidence of syn-magmatic normal faulting and generation of a boninitic sheeted dyke complex in the TMOC crust imply that boninitic volcanism was associated with seafloor-spreading (cf. Bédard et al., 1998; Schroetter et al., 2003; Pagé, 2006). Our investigation of the TMOC mantle rocks documents the first-order lithological, mineralogical and structural characteristics of a residue that has presumably formed in a fore-arc environment, and so represents an extreme end-member of the mantle compositional spectrum complementary to boninite genesis (cf. Pearce et al., 1992). Such rocks are rarely exposed in modern fore-arcs, as they are typically buried beneath thick sedimentary sequences (e.g. Bloomer et al., 1995). The exceptionally well-preserved mantle rocks of the TMOC make them a ‘type’-section for fore-arc mantle.

This article is based on the petrographic and mineralogical study of 70 samples (36 harzburgites, 22 dunites, 5 orthopyroxene-bearing dykes and 7 chromitites). We describe and analyze all facies and primary minerals of the TMOC mantle in order to reconstruct the tectonic, magmatic, and metasomatic history, and to better link petrologic and mineralogical evolution, degree of melting, and intensive parameters (T°, fO_2). Sample profiles across fossil intra-mantle magma channels (dunite and pyroxenite) allow us to estimate the effects of magmatic circulation and metasomatism.

2. Geology of the southern Québec Appalachians

Tectonic deformation in the Canadian Appalachians began with accretion of ca. 480Ma oceanic terranes (Dunnage Zone) onto the Laurentian continental margin and its sedimentary cover (Humber Zone) during the Lower-to Middle-Ordovician Taconian Orogeny (Williams, 1978; Williams and St-Julien, 1982). The limit between the Humber and Dunnage Zones, known as the Baie–Verte Brompton Line (BBL: Fig. 1) is studded with ophiolites and can be followed for more than 2000 km (Williams and St-Julien, 1982). In southern Québec, the Dunnage Zone includes four assemblages: 1) Remnants of Iapetus Ocean or its marginal basin lithosphere: the Thetford Mines, Asbestos, Brompton Lake and Mt.-Orford ophiolites (Hébert and Laurent, 1989; Laurent and Hébert, 1989). 2) The St.-Daniel “mélange”, representing a piggy-back sedimentary basin fed initially by local erosion of the ophiolitic sheets, with a progressive increase in the proportion of Laurentia-derived detritus (Schroetter et al., 2006). 3) The Magog Group, representing a fore-arc flysh deposit (Cousineau and St-Julien, 1994). 4) A dismembered, younger (ca. 460Ma) volcanic arc, the Ascot Complex (Tremblay et al., 1989).

3. The Thetford Mines Ophiolitic Complex

The Thetford Mines Ophiolitic Complex (TMOC) preserves a complete ophiolitic sequence (Fig. 2); including thick mantle (~5 km) and crustal (~1–5 km) sections. The plutonic crust includes dunitic, pyroxenitic and gabbroic rocks, and shows trace element signatures indicating a dominant boninitic affinity (Bédard et al., 2001, 2006). These are capped by igneous breccias, and boninitic sheeted dykes and lavas; with a lower mixed volcanic unit that also contains subordinate arc tholeiites (Laurent and Hébert, 1977; Church, 1977; Hébert, 1983; Crocket and Oshin, 1987; Laurent and Hébert, 1989; Bédard et al., 2001; Pagé, 2006). U/Pb ages on zircons from trondhjemites imply crystallization ages of 478–480±3My (Dunning et al., 1986; Whitehead et al., 2000). The contact between the TMOC mantle and Laurentian margin rocks is underlined by a dynamothermal amphibolite sole (477±5My Ar–Ar on amphibole: Whitehead et al., 1995). The coeval Asbestos Ophiolitic Complex (Fig. 1; Laurent, 1975a,b; Laurent et al., 1979; Hébert, 1980; Hébert and Laurent, 1989) is located ~20 km to the southwest of the TMOC and is probably correlative (Schroetter et al., 2005).

In its southern part, the TMOC is dominated by crustal rocks that are dissected into a series of tilted, ~1 km blocks by syn-magmatic, paleo-normal faults, striking N–S (Fig. 2), which were assigned to a phase of seafloor-spreading (Schroetter et al., 2003) fed by boninitic magmas. The northern part of the complex has a ~5 km-thick mantle section, with a thin plutono-volcanic crust (~1.0–1.5 km). The contact between the mantle and crust is seldom exposed, and the original Moho is nowhere preserved. In places (Caribou Mountain Block) lavas are in contact with mantle rocks (Figs. 2 and 3b), but it is not clear if this is a depositional or a fault contact.