Lithos 111 (2009) 47–71

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Intra-sill magmatic evolution in the Cummings Complex, Abitibi greenstone belt: Tholeiitic to calc-alkaline magmatism recorded in an Archaean subvolcanic conduit system

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ARTICLE INFO

Article history:
Received 8 May 2008
Accepted 12 March 2009
Available online 24 March 2009

Keywords:
Sill
Archaean
Cumulate
Peridotite
Tholeiitic
Calc-alkaline

ABSTRACT

The stratigraphy of the Abitibi greenstone belt in the Chibougamau area (southern Superior Province, Québec), is dominated by 2 cycles of mafic–felsic metavolcanic and metasedimentary rocks constituting the Roy Group, which is riddled by metagabbroic sills (25%). The Doré Lake Complex (DLC, 2728 Ma) is emplaced into the lower Roy Group. The Cummings Complex sills (2717 Ma) were injected between the Bruneau member and Blondeau Formations of the 2nd Roy Group cycle. The sills of the Cummings Complex (Roberge, Ventures and Bourbeau Sills) contain metaperidotite, metapyroxenite, metagabbro and metagranophyric facies. The trace element contents of melts in equilibrium with these metacumulate rocks were calculated and are compared to Roy Group lavas to clarify the regional magmatic history. Many DLC model melts have fractionated trace element profiles, with LILE-LREE-enrichment, HREE-depletion, and negative Nb–Ta-anomalies suggesting that the DLC formed largely from calc-alkaline melts extracted from garnet-bearing residues. The DLC is coeval with, and shows geochemical resemblances to Waconichi Formation tuffs (the felsic cap of the 1st Roy Group cycle), suggesting it could represent the Waconichi's shallow magma chamber. Meta-anorthosite rafts from the para-autochtonous zone of the Grenville province yield model melts closely resembling those of the DLC and are correlated on this basis. Most Roy Group sills yield model melts with trace element patterns typical of Archaean tholeiites, suggesting they fed the regionally-dominant tholeiitic volcanic plain lavas of the Roy Group. Models for the Cummings Complex imply that it contained two types of magma. Model melts from the Roberge Sill have strongly fractionated calc-alkaline-like trace element patterns, while those of the Ventures and Bourbeau Sills are mostly flat, N-MORB-normalized tholeiitic-like patterns that cannot be derived from the Roberge Sill melts by fractional crystallization. The Roberge Sill must have a separate magmatic stem, and represents the feeder system for a calc-alkaline volcano, possibly represented in part by Blondeau Formation rhyolites, andesites and basalts? If this is correct, the Roberge may be older than the Ventures and Bourbeau Sills, which would have fed the tholeiitic base of a third magmatic cycle, since eroded.

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1. Introduction

By studying the nature of their feeder systems, we can improve our understanding of how major volcanic fields are generated and evolve. Sills might represent the principal transfer mechanism between the mantle source and the surface in many contexts (e.g. Bédard et al., 1984; Thomson and Hutton, 2004; Shervais et al., 2006;Thomson 2007; Bédard et al., 2007), and are favoured locations for dynamic fractionation and crustal assimilation (e.g. Lightfoot et al., 1990; Bédard et al., 2007). Subvolcanic intrusive complexes are significant components of many Archaean greenstone belts, but have largely been neglected, despite their potential petrogenetic and economic importance (e.g. Naldrett, 2005). Perhaps the greatest obstacle to progress in linking plutonic and extrusive rocks is the lack of reliable liquid compositions, which hampers development of quantitatively-testable hypotheses. This problem is particularly acute when the rocks are metamorphosed, preventing *in-situ* trace element analysis of igneous minerals. In this paper we present data and inverse whole-rock trace element models (Bédard, 1994) for Archaean subvolcanic sills and intrusions from the Abitibi greenstone belt, providing insights into the nature of the plumbing system that fed tholeiitic to calc-alkaline volcanism, and documenting linkages between intrusive and extrusive components.

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doi:10.1016/j.lithos.2009.03.013

2. Regional geology of the Archaean Abitibi Belt

The 2.79–2.65 Ga east–west-trending Abitibi belt of the southern Superior craton is the world's largest Archaean greenstone belt (Condie, 1981; Goodwin, 1996; Bleeker, 2003; Fig. 1). Volcanic and sedimentary assemblages defined for the Abitibi belt support a broadly autochthonous evolution (Ayres and Thurston, 1985; Thurston, 2002; Ayer et al., 2002; Daigneault et al., 2004), although recent work in Ontario by Bleeker et al. (2008) suggests that the stratigraphic succession is dislocated by thust-faults. Sub-greenschist to lower amphibolite facies, mafic to felsic volcanic and sedimentary rocks of the Abitibi belt generally show well preserved textures and are cored by felsic plutons (Racicot et al., 1984; Sutcliffe et al., 1993; Mortensen, 1993; Chown et al., 2002; Goutier and Melançon, 2007).

The north of the belt is limited by the older gneisses of the 2.8–3.1 Ga Opatica Subprovince (Davis et al., 1995) and the south is bounded by metasedimentary rocks of the Pontiac Subprovince (Davis, 2002) which may be derived in part from erosion of the Abitibi belt. To the west, Proterozoic deformation exhumed Archaean lower crust along the Kapuskasing tectonic zone (Percival and West, 1994); while to the east, the Parautochtonous belt of the Grenville Province contains relicts of the Abitibi belt (Allard, 1979; Ciesielski, 1994; Bandyayera et al., 2006). Proterozoic fabrics trend NNE–SSW to N–S, and overprint Archaean rocks as far as 50 km away from the Grenville Front (Allard, 1979; Daigneault et al., 1990).

The oldest exposed rocks in the Abitibi belt are rare 2791–2757 Ma felsic lavas and tuffs (Mortensen, 1993; Bandyayera et al., 2004), but most of the volcanic rocks erupted during three major magmatic pulses at 2750–2725, 2724–2711 and 2710–2697 Ma (Ayer et al., 2002; Chown et al., 2002; Goutier and Melançon, 2007). Differentiated ultramafic to mafic intrusions are coeval with the volcanic assemblages (Allard, 1976, 1979; Daigneault and Allard, 1990; Barrie et al., 1991; Maier et al., 1996; Legault et al., 2002). In the western and southeastern Abitibi belt, the absence of old inherited zircons implies that the oldest volcanic assemblages are probably juvenile and ensimatic (Ayer et al., 2002). In the eastern part of the belt, however, $^{207}Pb/^{204}Pb$ isotopic ratios of metasedimentary rocks suggests contributions from an old (ca. 2.9–3.1 Ga) sialic basement (Thorpe et al., 1984; Gariépy and Allègre, 1985). Zircon xenocrysts in lavas and plutons suggest that once established, the Abitibi mafic crust matured and was continuously reworked by younger magmatic pulses (Mortensen, 1993; Ayer et al., 2002; McNicoll et al., 2007), with calc-alkaline rocks resulting principally from remelting of basaltic crust (Bédard et al., 2008). This view contrasts markedly with the common interpretation of the Abitibi as a collage of arc terranes (e.g. Daigneault et al., 2004). A complete critique of plate tectonic interpretations for Archaean settings is beyond the scope of this paper, but interested readers might want to read Bédard et al. (2003), Bédard (2006b) and Pearce (2008) for an alternate conception.

3. The Chibougamau area

3.1. Stratigraphy

The Archaean stratigraphy in the Chibougamau area (Fig. 2) is dominated by two conformably-deposited cycles of volcanic rocks constituting the Roy Group (Allard et al., 1979, 1985; Mueller et al., 1989; Leclerc et al., 2008). In the first cycle, depleted mafic tholeiitic lavas of the Obatogamau Formation are capped by intermediate to felsic calc-alkaline to tholeiitic lavas, tuffs, ironstones and turbidites of the Waconichi Formation (2726.7 ± 0.7 and 2729.7 + 1.9/− 1.6 Ma; Bélanger, 1979; Ludden et al., 1984; Mortensen, 1993; McNicoll et al., 2007; Leclerc et al., 2008). The weakly-enriched tholeiites of the David member are only present north of Chibougamau Lake (Fig. 2), and are tentatively correlated with the upper Obatogamau Formation; while the calc-alkaline tuffs and lavas of the Allard member are now attributed to the Waconichi Formation on the basis of geochemical and age data (McNicoll et al., 2007; Leclerc et al., 2008). In the second Roy Group volcanic cycle, depleted tholeiitic lavas of the newly-defined Bruneau member of the Gilman Formation are overlain by

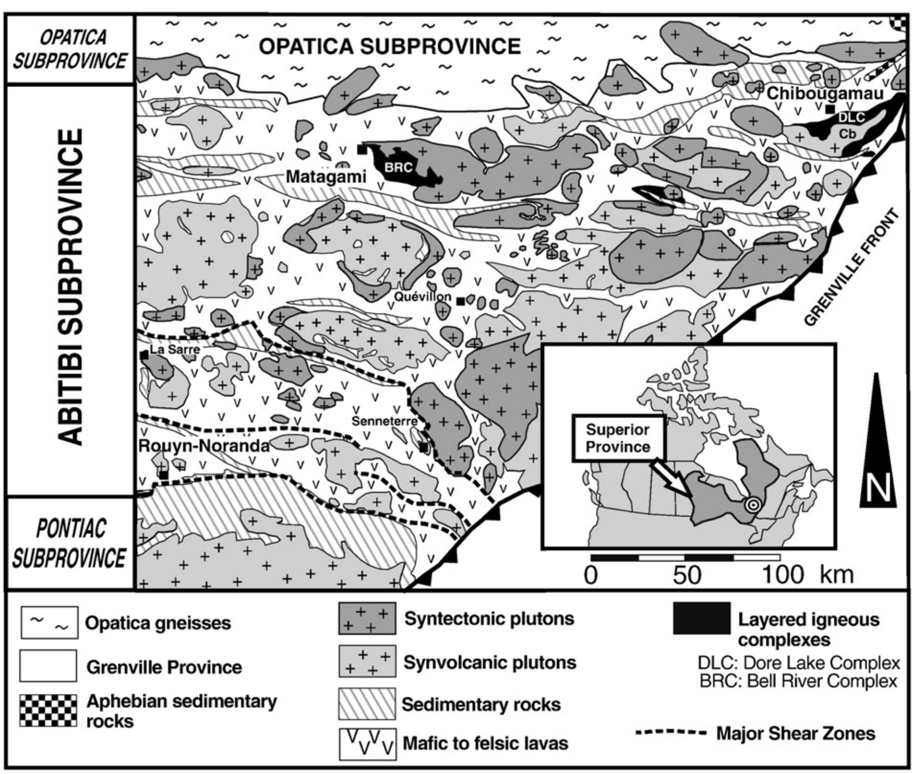

Fig. 1. Map of the Abitibi greenstone belt, with inset showing location in North America. Adapted from Goutier and Melançon (2007), Daigneault et al. (1990, 2004) and Chown et al. (1992). Cb is the Chibougamau Pluton.

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