Magnesian andesites, Nb-enriched basalt-andesites, and adakites from late-Archean 2.7 Ga Wawa greenstone belts, Superior Province, Canada: implications for late Archean subduction zone petrogenetic processes

Abstract Magnesian andesites (MA) occur with ‘normal’ tholeiitic to calc-alkaline basalt-andesite suites in four greenstone belts of the 2.7 Ga Wawa subprovince, Canada. Collectively, the magnesian andesites span ranges of SiO₂ = 56–64 wt%, Mg-number = 0.64–0.50, with Cr and Ni contents of 531–106 and 230–21 ppm, respectively. Relative to ‘normal’ andesites, the magnesian andesites form distinct trends on variation diagrams, with relatively high Th and LREE contents, uniform Yb over a range of MgO, more fractionated HREE, and lower Nb/Th, and Nb/La, ratios. Niobium-enriched basalts and andesites (NEBA; Nb = 7–16 ppm), and an Al-enriched rhyolite (adakite) suite are associated in space and time with the magnesian andesites. Nb-enriched basalts and andesites are characterized by high TiO₂, P₂O₅, Th, and Zr contents, variably high Zr/Hf (36–44) ratios, and more fractionated HREE (Gd/Yb = 1.3–4.1) compared to the ‘normal’ tholeiitic to calc-alkaline basalt-andesite suites. The adakite suite has the high Al (Al₂O₃ = 16–18 wt%), high La/Yb (21–43), and low Yb (0.4–1.2 ppm) of Archean tonalite trondhjemite-granodiorite (TTG) suites and Cenozoic adakites, indicative of liquids derived mainly from slab melting. The basalt-andesite suites are not characterized by normal tholeiitic or calc-alkaline fractionation trends of major or trace elements. Rather, compositional trends can be accounted for by some combination of fractional crystallization and variable degrees of metasomatism of the source of basalt and/or andesites by adakitic liquids.

Introduction

Volcanic successions in late Archean greenstone belts of the Superior Province, and Archean greenstone belts in general, are dominated by two associations. Tholeiitic basalts with near-flat REE patterns and komatiites form one association (Sun and Nesbitt 1978; Arndt and Nesbitt 1982; Xie et al. 1993; Polat et al. 1998; Kerrich et al. 1999a), whereas bimodal basalts and dacites to rhyolites constitute the second (Condie 1981; Thurston et al. 1985; Laffèche et al. 1992). The former are interpreted largely as intra-oceanic plateau sequences, whereas the latter are as intra-oceanic arcs (Polat et al. 1998).

Andesites are rare in Archean greenstone volcanic successions, and there are still fewer known magnesian andesites (Taylor and McLennan 1985; Condie 1986; Thurston 1990). This paper reports geochemical data for recently recognized but rare magnesian andesites (MA) in four calc-alkaline basalt-andesite arc volcanic successions of the 2.7 Ga Wawa subprovince of the Superior Province. Greenstone belts sampled for this study include the Schreiber-Hemlo, White River-Dayohessa rah, Winston-Big Duck Lake, and Manitouwadge belts. Associated with the magnesian andesites are Nb-enriched basalts and andesites (NEBA; Nb = 7–16 ppm),...
and adakites (aluminous dacites to rhyolites) with compositions akin to Archean high-Al, tonalite-trondhjemite-granodiorite (TTG) suites, and Cenozoic adakites, both of which are considered to be slab-derived melts (cf. Drummond et al. 1996). Compositional boundaries between these suites are transitional for many elements.

Structural studies indicate that Wawa greenstone belts underwent a complex history of faulting, folding, and fabric development, resulting in destruction of original stratigraphic relationships between different lithological units (Polat et al. 1998; Polat and Kerrich 1999). Consequently, the presently exposed abundance of each unit or magmatic suite may not reflect the original relative abundance.

Geochemical characteristics of volcanic rocks in Archean greenstone belts have been shown to be useful in providing information concerning the petrogenesis, tectonic setting, and geodynamic evolution of these belts (e.g., Condé 1981; Lafflèche et al. 1992; Polat et al. 1998, 1999, and references therein). Accordingly, the purpose of this study is to document the composition of the newly recognized, volcanic suites present, and compare these to counterparts in Cenozoic arcs where the spatial and temporal relationships of the arc basalt-andesite, magnesian andesite, adakite, Nb-enriched basalt-andesite association is well constrained in a plate-tectonic context. Structural and geochemical analyses of areally extensive, plume-related tholeiitic basalts and komatiites as well as arc-related magmas and associated siliciclastic trench turbidites in Wawa subprovince greenstone belts have been the subject of separate studies (Polat et al. 1998, 1999; Polat and Kerrich 1999).

**Geological setting**

The Superior Province, the largest Archean craton globally, is composed of plutonic, volcanic-plutonic, high-grade gneiss and metasediment-dominated sub-provinces (Fig. 1; Card and Ciesielski 1986; Card 1990; Thurston et al. 1991; Percival et al. 1994). The total range of ages of these various subprovinces is from 3.1–2.67 Ga. These subprovinces are considered to have been amalgamated by accretionary tectonics over a period of 2.74–2.65 Ga (Card and Ciesielski 1986; Card 1990; Percival et al. 1994). Extensive geochronological studies on their prekinematic, synkinematic, and postkinematic igneous rocks reveal that the assembly of these subprovinces was diachronous from north to south (Thurston 1990; Percival et al. 1994; Stott 1997).

Greenstone belts in the Archean Superior Province are 1–100-km-scale areas of supracrustal rocks within composite granitoid-greenstone terranes with tectonic or intrusive boundaries. A greenstone belt may consist of one or more lithotectonic assemblages, each characterized by stratified volcanic and/or sedimentary rock units built during a discrete interval of time in a common depositional or volcanic setting (Thurston et al. 1991).

The Schreiber-Hemlo, White River-Dayohessarah, Winston-Big Duck Lake, and Manitouwadge greenstone belts are located in the northeastern section of the volcanic-plutonic Wawa subprovince of the Superior Province, which extends from the Vermilion district of Minnesota in the west to the Kapuskasing structural zone in the east (Fig. 1; Williams et al. 1991). According to Williams et al. (1991), these greenstone belts can be divided into various lithotectonic assemblages. The Schreiber-Hemlo greenstone belt is divided into three lithotectonic assemblages, i.e., the Schreiber (SC), Hemlo-Black River (HEBR), and Heron Bay (HB) assemblages. The Schreiber and Hemlo-Black River assemblages are separated by the Proterozoic Coldwell alkali complex (Fig. 1). The Hemlo-Black River and Heron Bay assemblages are located to the north and south of the right-lateral Lake Superior-Hemlo fault zone (LSHFZ), respectively (Fig. 1). Similarly, the Winston-Big Duck Lake belt is divided into two lithotectonic assemblages, these being the Winston Lake and Big Duck Lake assemblages. The White River-Dayohessarah and Manitouwadge greenstone belts have not been divided into distinct lithotectonic assemblages. All these assemblages are composed of similar volcanic and siliciclastic sedimentary rocks, and are multiply intruded by synkinematic, high-Al, high-La/Yb, TTG plutons, and late-kinematic lamprophyre dikes (Williams et al. 1991; Zaleski and Peterson 1995; Polat et al. 1998; Polat and Kerrich 1999).

Stratigraphic relationships between different lithological units are commonly obscure and often marked by shear zones. Volcanic rocks consist mainly of tholeiitic ocean plateau basalts, including both pillow basalts and massive flows, komatiites and komatiitic basalts with well preserved spinnifex texture, and oceanic island arc tholeiitic to calc-alkaline basalts, andesites, dacites, and rhyolites (Polat et al. 1998). There are minor cherts, iron formations, and gabbros within these volcanic sequences. Although the original stratigraphic relationships between different volcanic rocks have been disrupted and complicated by subsequent deformation (Polat and Kerrich 1999), in a few areas (e.g., Hemlo, Heron Bay) it appears that the tholeiitic basalt-komatiite oceanic plateau association occurs mainly at the base of volcanic sequences, whereas tholeiitic to calc-alkaline bimodal volcanic are sequences are more abundant at the upper tectonostratigraphic levels.

Sedimentary rocks consist of interbedded turbiditic greywacke sandstones, siltstones, and shales (Williams et al. 1991; Muir 1997; Polat et al. 1998). Conglomerates are minor, occurring primarily in turbidite channels. Primary sedimentary structures (e.g., parallel bedding, cross-bedding, and grading) are intensely deformed and transposed to a large extent throughout the belt.

The greenstone belts are typically metamorphosed at greenschist to amphibolite facies. Amphibolite facies metamorphism occurs primarily proximal to TTG batholiths. Regional metamorphic studies suggest an apparent northward increase in metamorphic grade in