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Archean calc-alkaline lamprophyres of Wawa, Ontario, Canada: Unconventional diamondiferous volcaniclastic rocks

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Abstract

Unusual diamondiferous rocks are found in the Wawa subprovince of the Southern Superior Craton. They are dated at 2.67–2.7 Ga and comprise part of a calc-alkaline volcanic sequence of the Michipicoten Greenstone Belt. Detailed mapping of an ~40 km^2 area showed that the rocks are metamorphosed polymict volcaniclastic breccia (PVB) and lamprophyre. The breccia occurs as thick, 60–110 m conformable beds traceable in intermittent outcrops along strike for more than 4 km, whereas younger lamprophyre occurs as 0.5–3 m dykes. Magmatic predecessors for the metavolcanic rocks were determined on the basis of detailed mineralogical and petrographic observations, and are found to be calc-alkaline lamprophyres. The only preserved magmatic phenocryst phase is coarse, oscillatory-zoned amphibole of edenitic and pargasitic compositions. The parent magmas are similar in bulk composition to that of Abitibi lamprophyres and other Archean calc-alkaline lamprophyres, and may have thus also contained phenocrystal clinopyroxene and phlogopite. The Wawa lamprophyric magmas formed contemporaneously with felsic to mafic volcanic rocks and late orogenic intrusives of cycle 3 of the Michipicoten Greenstone Belt. They were emplaced episodically in local extensional areas, in an active Archean subduction zone. The breccia formed as a volcaniclastic deposit and contains fragments of pyroclastic lapilli and juvenile material. Stratigraphy, a wide range in clast lithologies, poor sorting and paucity of sedimentary structures suggests the breccia formed in a debris flow. The Wawa diamondiferous rocks may be ancient equivalents of modern lamprophyric cinder cones and demonstrably associated epiclastic deposits.

Keywords: Archean; Michipicoten Greenstone Belt; Diamonds; Calc-alkaline lamprophyre; Volcaniclastic; Debris flow

1. Introduction

Primary economic diamond deposits have been found in only two volcanic rock types, kimberlites and lamproites. They occur in Archean cratons and Proterozoic mobile belts (Helmstaedt and Gurney, 1995) as late, cross-cutting units with Proterozoic

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to Cenozoic ages (Kirkley et al., 1991; Heaman et al., 2004). Recently, an unusual suite of diamond-bearing metavolcanic rocks was discovered in the Wawa and Abitibi subprovinces of the Superior Craton (Ayer et al., 2003; Vallancourt et al., 2003; Fig. 1). The rocks of the Michipicoten Greenstone Belt in Wawa are the target of focussed diamond exploration by major and junior mining companies. To date, thousands of stones have been recovered, 95% of which are microdiamonds (<0.5 mm in one dimension) with grade estimates ranging from 0.2 to 1 ct/t (Buckle, 2002). The macrodiamonds display a variety of colours, a predominantly octahedral morphology (Lefebvre et al., 2003), and very little mechanical wear, all typical of diamonds hosted in primary volcanic rocks.

This recent diamondiferous finding has several unique characteristics with scientific and economic significance. Firstly, their emplacement age is Archean (Stott et al., 2002; Ayer et al., 2003), thus making them one of the oldest known primary diamondiferous rocks. Secondly, some of the diamondiferous rocks are reported to be shoshonitic lamprophyres (Ayer et al., 2003; Vallancourt et al., 2003), i.e. the K-rich variety of calc-alkaline lamprophyres (Rock, 1991), thus making them the first confirmed occurrence of diamonds in calc-alkaline rocks. Finally, the subduction-zone setting of the Wawa and Abitibi diamond-bearing volcanic rocks (Sage, 1994 and references therein), while not unknown (Barron et al., 1996; Capdeliva et al., 1999; Griffin et al., 2000), is nonetheless an extremely rare setting for primary deposits.

We undertook detailed study of the geology and petrology of the Wawa diamondiferous metavolcanic rocks on the Band-Ore Resources property, 20 km north of Wawa, (Fig. 1), along with reconnaissance examination of outcrops of similar rock types to the north and northwest of the mapped area (inset of Fig. 1). We identify two types of diamondiferous metavolcanic rocks—breccias and intrusive dykes—each with distinct styles of emplacement. We provide petrographic confirmation that the diamondiferous rocks are calc-alkaline lamprophyres, a new unconventional diamond source. We also examine the volcanology of the breccias and find modern analogues for the tectonic setting and volcanic processes that created the Wawa diamondiferous rocks.

2. Regional geologic and tectonic setting

The Michipicoten Greenstone Belt is considered a western extension of the Southern Volcanic Zone of the Abitibi greenstone belt (Ludden et al., 1986), but differs from it in that the mafic and felsic volcanic rocks record the three cycles of igneous activity (approximately 2.89, 2.75 and 2.70 Ga; Turek et al., 1982, 1992), versus one (approximately 2.75–2.7 Ga) in the latter. All of the Michipicoten cycles are bimodal basalt–rhyolite suites; the 2.89 Ga volcanic units also contain komatiites (Sage et al., 1996). The third cycle of volcanism is represented by massive and pillowed, intermediate to mafic, tholeiitic lava flows, conformably overlain by intermediate to felsic tuff, breccia and clastic sedimentary rocks (Williams et al., 1991; Sage, 1994). Intrusive rocks generated by this cycle of magmatism include gabbro to quartz–diorite sills and dykes (Sage, 1994) and syenites (Stott et al., 2002). The Michipicoten Greenstone Belt was strongly deformed by the Wawan phase of the Kenoran orogeny (approximately 2.67 Ga; Stott, 1997), which resulted in large-scale recumbent folding and thrusting, followed by upright folding and high-angle reverse faulting (Arias and Helmstaedt, 1990; McGill, 1992). This deformation has produced local stacking of stratigraphy (Williams et al., 1991). A four-stage

Fig. 1. Location of the Wawa subprovince within the Michipicoten Greenstone Belt in the Superior Craton. Dashed lines divide subprovinces of the Superior Craton (Card and Ciesielski, 1986). A star shows location of the shoshonitic diamondiferous lamprophyres (Wyman and Kerrich, 1993; Williams, 2003) within the Abitibi subprovince and dots—locations of calc-alkaline lamprophyres within the Uchi and Wabigoon subprovinces (Wyman and Kerrich, 1989). The inset illustrates locations of previously dated samples of PVB (squares), lamprophyres (diamonds), diamond occurrences (circles) and volcanic and intrusive rocks of cycle 3 (modified after Vallancourt et al., 2003). Felsic volcanic rocks of cycle 3 are shown in grey, PVB and lamprophyres of map area (Fig. 2) are black. Sources for the U–Pb ages are: (1) Lamprophyre dykes at outcrops 58 and 145 (Stott et al., 2002); (2) breccia of Cristal occurrence (Stachel et al., 2004); (3) breccia of Mumm occurrence (Ayers, unpublished data); (4) calc-alkaline dacite (Ayer et al., 2003); (5) felsic tuff (Ayers, unpublished data); (6) lamprophyre of the Sandor occurrence (Stott et al., 2002; Ayer et al., 2003); and (7) lamprophyre dyke (Ayer et al., 2003).