Diamonds in an Archean greenstone belt: Diamond suites in unconventional rocks of Wawa, Northern Ontario (Canada)

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Introduction and geology

Diamonds typically are found on Archean cratons entrained by younger Phanerozoic kimberlites. In contrast, diamonds of the Michipicoten Greenstone Belt (MGB) are hosted in “unconventional”, non-kimberlitic rocks that formed simultaneously with the mafic and sedimentary rocks of the Archean greenstone belt.

We studied two diamond suites that are hosted within metamorphosed greenschist facies rocks of MGB (Eastern Canada). The 2.9-2.7 Ga MGB (140 km by 38 km) is located in the southwest portion of the Superior Craton. The ~2.7 Ga rocks of MGB consist of intermediate to mafic volcanic metavolcanics, capped by intermediate to felsic metavolcanics and interfingering with the metasedimentary Doré Formation.

The first diamond suite henceforth referred to as the Wawa breccia diamonds, are hosted in calc-alkaline lamprophyres and volcaniclastic breccias (Fig. 1), ranging in ages from 2.68-2.74 Ga. The diamondiferous lamprophyric rocks are contemporaneous with pillow basalts and felsic volcanics of Cycle 3 of the MGB. This cycle is made up of high magnesium and high iron tholeiites displaying pillowed and massive texture with amygdules and capped with more intermediate to felsic metavolcanics. It has been postulated this cycle has a flood basalt origin (Sage et al., 1996a,b) or is related more to the subduction zone (Sage, 1994). The second suite, the Wawa conglomerate diamonds, are hosted in a poorly sorted sedimentary unit that alternates between a matrix and clast supported polymictic conglomerate. Basalt, rhyolite, gabbro, and sandstone make up the majority of the clasts. The conglomerate is the stratigraphically lowermost part of the Doré Formation which is interpreted as an alluvial fan debris-flow facies and a submarine fan deposit facies in a basin of varying stability and water depth (Rice and Donaldson, 1992). This suite has no known nearby primary volcanic source with an appropriate age. The conglomerate hosts kimberlitic indicator minerals as well as diamonds, while the breccia suite only contain diamonds

Our fieldwork and TIMS U-Pb dating on zircons in the collected samples further expanded the known ages of the lamprophyric breccias and constrained the ages of the diamondiferous conglomerates. The breccias were known to occur at several stratigraphic levels with ages from 2744±43 Ma to 2687–2680±1. Our new date suggests the Wawa breccia formed as recent as 2618.1±1.8 Ma. The ages of the diamondiferous conglomerate are constrained by the dating of a fine-grained felsic dyke that crosscuts the conglomerate, and ages of granite and gabbro clasts. From these data, the conglomerate has been dated between 2700.4±1.0 Ma and 2697.2±1.8 Ma.

Diamond Characteristics

The goal of this study is to characterize the Wawa conglomerate diamond suite and confirm or reject the hypothesis that the conglomerate diamonds are sourced from a distinct primary volcanic rock. We studied 384 diamonds 0.4-2.0 mm in sizes and compared them to breccia diamonds (80 crystals 0.1- 2 mm) described in De Stefano et al, 2006.

1. Morphology and colour

Both the breccia and conglomerate diamonds had comparable results for crystal habit and diamond colour. Crystal habits of both suites are as follows (breccia %: conglomerate %): octahedral and its various forms (57%: 40%), cubic and its various forms (11%:12%), cubo-octehedral (8%:7%), macle (8%: 3%), and undetermined (5%: 22%). Crystals with undetermined habit are grossly disproportionate between the two suites because the breccia diamond histograms did not take broken crystals and fine aggregates into account. Both suites display similar percentages of colour (breccia %: conglomerate %): colourless (50%: 64%), yellow (11%: 11%), grey (3%: 4%), brown (10%: 2%), black (3%: 1%). Conglomerate diamonds had a wider variety of colours that were not seen in the breccia diamonds, including green and pink.

The diamond suites are dissimilar in the aspect of resorption. The breccia diamonds have 21% of diamonds showing high degrees of resorption (classes 1-3,), using McCallum's (1994) classification scheme. Diamonds falling into classes 4-5 (or slight) resorption make up 60%, while only 8% display no resorption. The conglomerate diamonds also show a comparable degree of class 1-3 resorption (24%), but only 26% fall into classes 4-5, and 43% showing no resorption at all.

2. Nitrogen systematics

The conglomerate diamonds have nitrogen contents below 400 ppm N, whereas breccia diamonds have a majority of N below 300 ppm. Approximately one third of the conglomerate diamonds belongs to Type II having no measurable N. Nitrogen-free Type IIa diamonds comprise 34% of the breccia diamond population. Nitrogen-bearing diamonds from conglomerates are Type IaA (47%) and Type IaAB (23%) with 5-84% of totally aggregated N. Among the breccia diamonds, Type IaA stones comprise 17%, whereas IaAB stones make up 49% of the population. The N aggregation states of breccia diamonds showed a bimodal distribution and clustering of the stones into non-aggregated (<30% of fully aggregated N) or high aggregated (>60% of fully aggregated N). We do not see this in conglomerates; most diamonds (93%) contain <30% fully aggregated nitrogen. In general, we see a significantly higher percentage of IaA crystals in conglomerates.

3. Cathodoluminescence

The conglomerate diamonds displayed optical CL colors of various intensities. Diamonds showed green as the most common CL color, followed by yellow, orange, pink and red-orange . Only one macrodiamond displayed blue CL color typical for diamonds in unmetamorphosed rocks (Bulanova et al. 1995). Rarely, microdiamonds (< 0.5 mm in one dimension) demonstrated patches of multiple CL colors either due to heterogeneity within the crystal or due to the polycrystalline growth. CL spectroscopy showed that in all macro- and microdiamonds the most intensive peak is localized at 520 nm. This peak is accompanied by a minor peak at 440 nm for macrodiamonds, and by peaks at 576 and 600 nm for microdiamonds.

Breccia diamonds displayed (in descending abundance) orange-red, yellow, orange-green and green, but none displayed blue CL color (De Stefano et al. 2006). CL emittance of all Wawa diamonds consisted of a broad band at 520 nm, a sharp peak at 575.5 nm, several lines at 550–670 nm and, in some diamonds, a broad low-intensity peak at 440 nm.

Discussion and conclusions

The two suites of Wawa diamonds, according to the morphology and nitrogen studies, are deemed to be different. The conglomerate diamonds are significantly less resorbed and contain less aggregated N, with 47% of the suite being Type IaA stones. These results suggest that diamonds in conglomerates cannot be sourced from the same occurrence of a diamondiferous volcanic rock that brought up the breccia diamonds.

Despite the distinct origins of the breccia and conglomerate diamonds, they have similar orange-red cathodoluminescence colours caused by the CL emission primarily at 520 nm. We ascribe the similar CL colours of the distinct suites of Wawa diamonds to the late imprint of metamorphism.
The diamonds are found within greenschist facies rocks with peak P-Ts of 2-3 kb and 325˚-450˚C. The metamorphic origin of the CL colour is confirmed by studies of microdiamonds from the Kokchetav massif, Kazakhstan, and the Erzgebirge Terrane, Germany (Bruce et al., submitted). Our study and other studies of metamorphic diamonds (Ogasawara 2005; Iancu et al. 2008) confirmed that they do not have the prevalent CL emittance at 415-440 nm, unlike diamonds found in unmetamorphosed rocks, and the maximum CL emittance of metamorphic diamonds shifts to higher wavenumbers, 490-670 nm. This causes CL colours to change from blue, common to diamonds in kimberlites and placers, to green, yellow-orange and red, characteristic of diamonds in metamorphic rocks (Bruce et al., submitted).

In conclusion, our study proves that diamonds that occur in the Wawa breccia and conglomerate have different primary volcanic sources. We hypothesize that the primary volcanic rock of the conglomerate diamonds may be a kimberlite, as evidenced by the presence of kimberlitic indicator minerals in the conglomerate. Thus, the MGB must have experienced an episode of the Archean, pre-2,7 Ga kimberlite magmatism besides multiple emplacement episodes of the 2.7 Ga calc-alkaline lamprophyric magmas that also carried diamonds. These kimberlites may have been emplaced proximal to the Wawa conglomerates as evidenced by low mechanical abrasion of the conglomerate diamonds and indicator minerals, and the preservation of garnet kelyphitic rims (Ryder, 2008).

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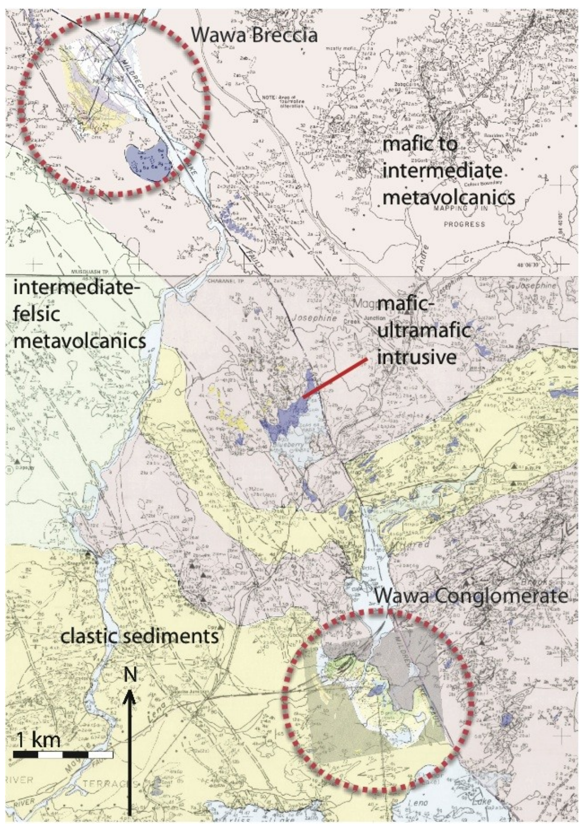

Fig. 1: Geologic map and locations of the diamondiferous suites of Wawa, Norther Ontario (Canada).