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Whole-rock $\delta^{18}O$ and $\delta^{2}H$ footprint of the Canadian Malartic gold deposit, Abitibi Subprovince, Québec, Canada

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Abstract. The O and H isotopic footprint to the Canadian Malartic deposit is the fossilized remnants to a hydrothermal system that has altered the host metasedimentary rocks and igneous intrusions. Mapping whole rock $\delta^{18}O$ and $\delta^{2}H$ outlines the hydrothermal footprint to the deposit up to 2 km outside of the open pit. The isotopic footprint consists of a decrease in whole rock $\delta^{2}H$ values, from –59‰ to –91‰, towards mineralization. In gabbro dykes, $\delta^{18}O$ values increase from 8.3‰ to 9.1‰ towards gold mineralization. Modelling of isotopic data suggests the isotopic footprint is the result of decreasing fluid/rock ratios away from mineralization at a temperature of isotope exchange of ca. 300°C.

1 Introduction

The Canadian Malartic gold deposit, Quebec, Canada, contains 10.8 Moz of gold in 314.2 Mt with an average grade of 1.07g/t (Gervais et al. 2014). The deposit is located in the Archean Superior province immediately south of the Cadillac-Larder Lake Tectonic Zone (CLLTZ) that marks the boundary between the Abitibi and Pontiac subprovinces.

The deposit is dominantly hosted by the metasedimentary rocks of the Pontiac Group but mineralization also occurs in metavolcanic rocks of the Piché Group, dioritic porphyries, and gabbro dykes. Dating of detrital zircons and intrusions in the Pontiac Group constrain the age of the sedimentary rocks between 2685±3 Ma and 2682±1 Ma (Davis 2002). Porphyritic intrusions have been dated from 2677 to 2679 Ma (Helt et al 2014; De Souza et al 2015).

Mineralization occurs dominantly south of the CLLTZ within envelops adjacent to the Sladen fault. Gold typically occurs as microscopic disseminations associated with pyrite or in quartz-carbonate veins parallel to the dominant S_2 foliation. Re/Os dating of molybdenite from the mineralized area yields an age of 2664 Ma.

2 Results

2.1 Whole-rock geochemistry and isotopes

A total of 120 samples were collected over a 4 by 5 km area south of the Canadian Malartic deposit. These samples consist of both Pontiac greywacke (n = 87) and gabbro dykes (n = 33). Major element geochemistry for the greywackes is typical of this rock type in the geochemical classification of sedimentary rocks by Herron (1988). Similarly, data from meta-basic dykes plot mostly within the field of tholeitic gabbro of Wilson (2007)

$\delta^{18}O$ values of greywacke range from 7.8‰ to 11.9‰ and are normally distributed ($\bar{x} \pm 1\sigma = 9.9 \pm 0.7$‰). $\delta^{2}H$ values of greywacke are also normally distributed with values from -91‰ to -41‰ ($\bar{x} \pm 1\sigma = -59 \pm 8$‰). $\delta^{18}O$ values of gabbro dykes are also normally distributed with the exception of two outlying samples with high values of 11.6‰ and 12.2‰. With these outliers removed, the $\delta^{18}O$ values of gabbro dykes range from 6.8‰ to 9.8‰ ($\bar{x} \pm 1\sigma = 8.2 \pm 1.3$‰). The $\delta^{2}H$ values of gabbro dykes contain one outlying value of -105‰. Excluding this sample, the range of $\delta^{2}H$ is between -84‰ and -55‰ ($\bar{x} \pm 1\sigma = -71 \pm 7$‰).

Petrography of the outlying gabbro dyke samples indicates that the two samples with high $\delta^{18}O$ values contain a higher proportion of quartz and feldspar. The sample with a low $\delta^{2}H$ value contains relict feldspars that have been altered to fine grained phyllosilicates. These samples have been removed from subsequent geostatistical analysis.

2.2 Principal component analysis (PCA)

The PCA was performed using whole rock O and H isotopic values, and centred-log ratio (CLR) transformed geochemical data including: major element oxides, Au, C, H_2O and S content for both rock types. The geochemical datasets have been CLR transformed in order to eliminate the effects of closure (Aitchison 1986). From the greywacke dataset, principal components 1 and 2 (PC1 and PC2) account for 54.05% and 13.15% respectively, of the variance exhibited by the data (Fig. 1a). Similarly from the gabbro dyke dataset, PC1 and PC2 capture 53.75% and 11.41% respectively of the total variance (Fig. 1b). Subsequent components capture less than 10% each and are not discussed.

PCA plots (Fig. 1) cluster together components that are positively correlated whereas components that are inversely correlated plot on opposite sides of the diagram. In both instances, PC1 indicates Au, C, S and $\delta^{18}O$ covary and are inversely related to major rock forming elements

(SiO_2, Al_2O_3, MgO, and Fe_2O_3) and δ^2H. PC2 is orthogonal to the first and reflect changes in alkali-bearing minerals and are attributed to potassic alteration.

The PCA of both greywackes and gabbro dykes indicate that carbonatization and sulfidation are linked to gold mineralization along with increasing $\delta^{18}O$ and decreasing δ^2H.

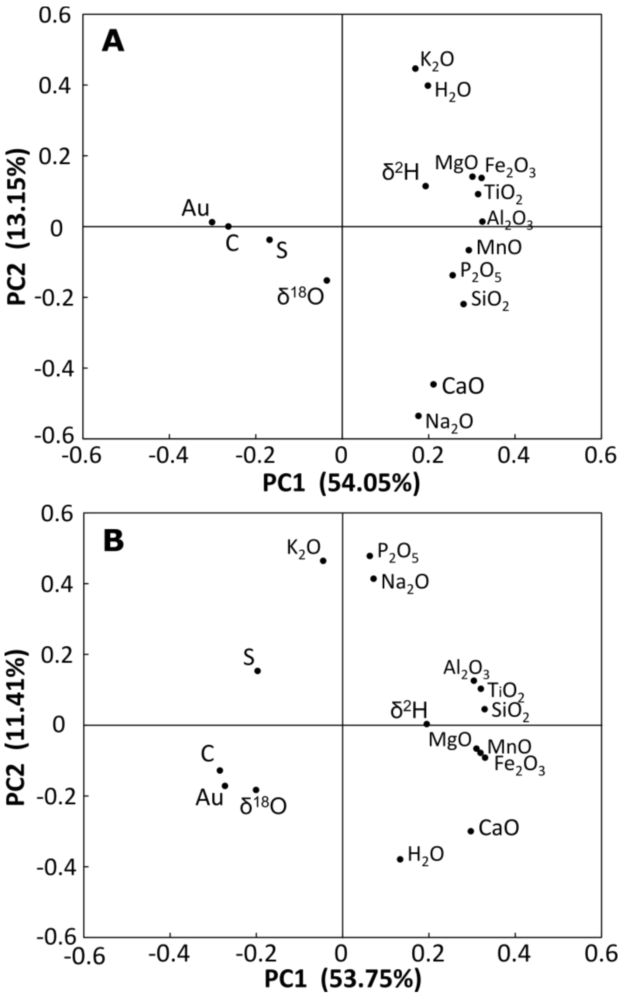

Figure 1. PCA loading plots for the hostrocks of the Canadian Malartic deposit. **a** Greywacke and **b** gabbro dykes.

2.3 O and H isotopic footprint

Mapping the whole rock isotopic values of the host rocks to the Canadian Malartic deposit reveals an isotopic footprint that can be attributed to mineralization (Figs. 2 and 3). The regional trends in $\delta^{18}O$ and δ^2H values are derived from kriging based on variogram parameters. In greywacke, this footprint is best identified by a decrease in δ^2H toward mineralization from values near -59‰ in regional background, 1 to 2 km outside of the pit, to values near -91‰ in the mineralization (Fig. 2b). $\delta^{18}O$ values of greywackes show a subtle footprint delineated by the 9.9‰ isopleth S and SE of the deposit. (Fig. 2a).

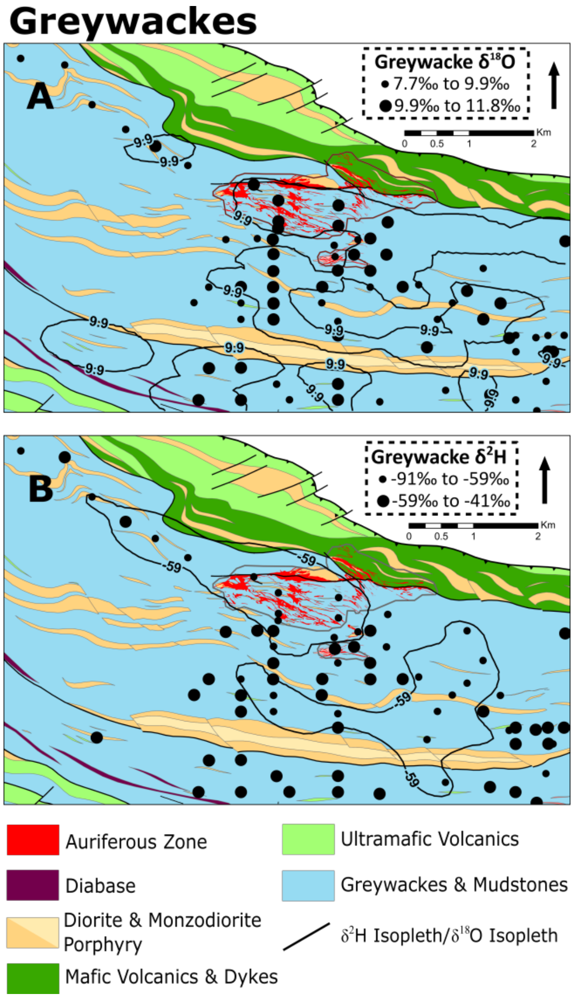

Figure 2. Isotopic footprint using kriged $\delta^{18}O$ and δ^2H values in greywacke. **a** $\delta^{18}O$. **b** δ^2H. Geologic map modified after Perrouty et al. (2017) .

In gabbro dykes, the footprint is outlined by a decrease in $\delta^{18}O$ from values greater than 9.0‰ in mineralization to background values near 8.3‰ up to 1 km outside of the pit. (Fig. 3a). The δ^2H footprint in gabbro dykes highlights an area of δ^2H lower than –73‰, up to 2 km S and SE of the deposit (Fig. 3b)

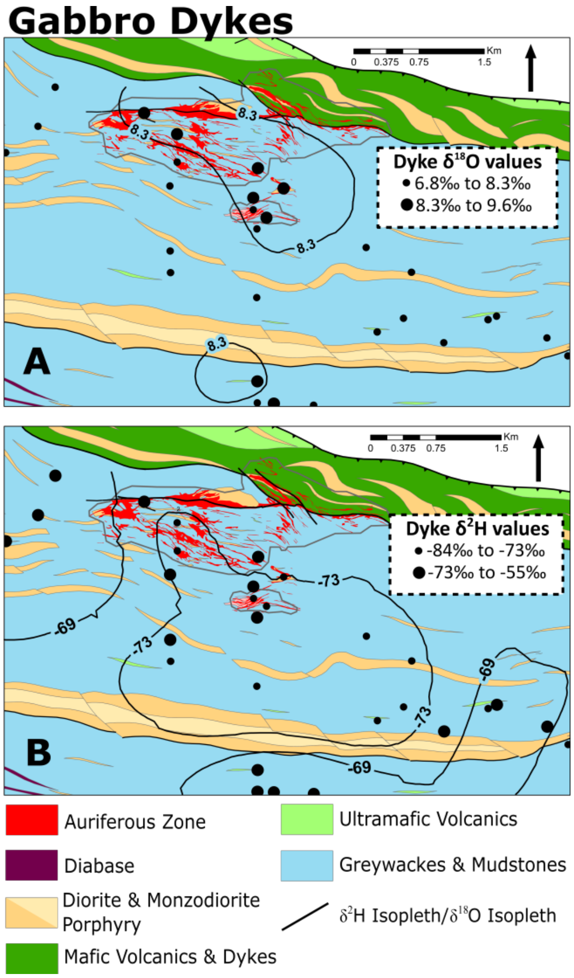

Figure 3. Isotopic footprint in gabbro dykes. **a** Threshold δ^{18}O values are outlined by the kriged 8.3‰ isopleth. **b** Threshold δ^{2}H are outlined by the kriged -73‰ isopleth. Geologic map modified after Perrouty et al. (2017).

3 Discussion

3.1 Fluid O and H isotopic composition

The isotopic composition of water in equilibrium with the Pontiac Group metasediments at the greenschist-amphibolite transition can be approximated using the fractionation equations of Bottinga and Javoy (1975) and Matsuhisa et al. (1979). Assumptions used in this calculation include (1) the initial isotopic composition of the rock given by the average greywacke from outside of the -59‰ δ^{2}H isopleth ($\delta^{18}O^{i}_{Rock}$ = 9.7‰, $\delta^{2}H^{i}_{Rock}$ = -53‰), (2) the mineralogy for greywacke simplified to 50 vol% biotite and 50 vol% quartz, and (3) a temperature of reaction of 475°C. This fluid has been calculated to have a δ^{18}O value of 7.6‰ and a δ^{2}H value of -12‰. These values are similar to the isotopic composition computed from vein biotite and quartz from the Canadian Malartic deposit (Beaudoin and Raskevicius 2014; Helt et al 2014) and to mineralizing fluids of nearby orogenic gold deposits (Beaudoin and Pitre 2005; Beaudoin and Chiaradia 2016). The O and H isotopic composition indicates a metamorphic fluid (Beaudoin and Raskevicius 2014) interpreted to be the primary source of mineralization for the Canadian Malartic deposit, and which is used for subsequent fluid/rock isotopic exchange models.

3.2 Modelling fluid/rock reactions

The computation of fluid/rock isotopic exchange models requires assumptions with respect to (1) the mineralogy and (2) the initial isotopic composition of the host rocks. For greywacke, the assumptions are outlined in section 3.1. For gabbro dykes, a simplified mineralogy of 45 vol.% hornblende, 45 vol.% biotite and 10 vol.% anorthite has been used, and the initial isotopic composition was approximated by the average dyke outside of the -69‰ δ^{2}H isopleth ($\delta^{18}O^{i}_{Rock}$ = 7.3‰, $\delta^{2}H^{i}_{Rock}$ = -63‰). Using these assumptions, we compute the final rock compositions for both rock types using equations outlined by Taylor (1978) for fluid/rock ratios of 0 to 8 assuming open system conditions at temperatures of 350°C, 300°C and 250°C to span the geologically relevant temperatures of greenschist facies metamorphic rocks (Fig. 4).

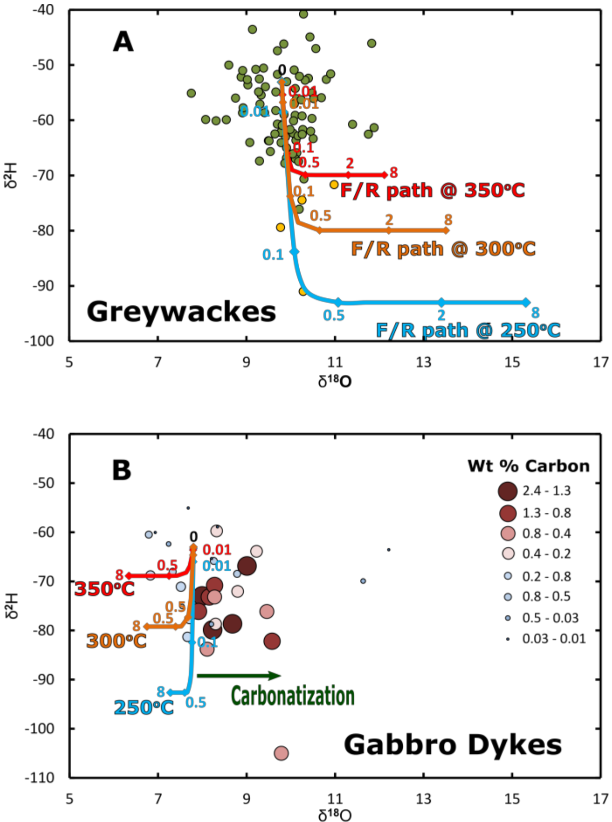

Figure 4. Plots of δ^{18}O and δ^{2}H values of **a** greywacke and **b** gabbro dykes. Ticks along fluid/rock exchange paths represent atomic fluid/rock ratios. Greywacke with >0.1ppm Au are shown as yellow points. Variance of δ^{18}O in gabbro dykes may be ascribed to carbonate content in this rock.

The isotopic values of mineralized greywackes are best approximated by the 300°C fluid/rock reaction path (Fig. 4a). This model suggests that rocks in the footprint to Canadian Malartic deposit have reacted at a temperature of ca. 300°C with the mineralizing fluid at atomic fluid/rock ratios up to 0.5. The greywacke data indicates that the system was rock-dominated and fluid/rock reaction has extensively altered greywacke δ^2H values while leaving the δ^{18}O values mostly unchanged.

In gabbro dykes, the footprint is characterized by an increase in δ^{18}O proximal to mineralization. This shift may be caused by precipitation of epigenetic carbonates during mineralization. The PCA shows carbon to correlate with gold (Fig. 1 and 4B) and petrography shows carbonates to commonly occur in gabbro dykes proximal to mineralization. The preferential precipitation of carbonate minerals in gabbro dykes is most likely due to the chemical affinity for carbonate to complex with ferromagnesian minerals in the rock. Moreover, carbonates tend to have high δ^{18}O values when precipitated from hydrothermal fluids ($\Delta_{\text{ankerite-water}}$ = 6.2‰ at 300°C; Zheng, 1999).

The PCA of both greywackes and gabbros throughout the study area indicates δ^2H is inversely correlated with Au, S, C and δ^{18}O values. This is consistent with the lower δ^2H values in greywackes proximal to mineralization and higher δ^{18}O values in gabbro dykes observed in the isotopic footprint to the Canadian Malartic deposit. Modelling suggest that the stable isotope data throughout the footprint is best explained using an initial fluid composition in equilibrium with Pontiac sediments at ca. 475°C. That interacted with the host rocks precipitate gold, carbonates and sulphides at a higher structural level at ca. 300°C, at lower W/R ratios away from the mineralized area.

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References

Aitchison J (1986) The Statistical Analysis of Compositional Data. 44:365–374

Beaudoin G, Chiaradia M (2016) Fluid mixing in orogenic gold deposits: Evidence from the H-O-Sr isotope composition of the Val-d'Or vein field (Abitibi, Canada). Chem Geol 437:7–18. doi: 10.1016/j.chemgeo.2016.05.009

Beaudoin G, Pitre D (2005) {Bibliography}Stable isotope geochemistry of the Archean Val-d'Or (Canada) orogenic gold vein field. Miner Depos 40:59–75. doi: http://dx.doi.org/10.1007/s00126-005-0474-z

Beaudoin G, Raskevicius T (2014) Constraints on the genesis of the archean oxidized, intrusion-related Canadian malartic gold deposit, Quebec, Canada--a discussion. Econ Geol 109:2067–2071. doi: 10.2113/econgeo.109.3.713

Bottinga Y, Javoy M (1975) Oxygen isotope partitioning among the minerals in igneous and metamorphic rocks. Rev Geophys 13:401–418. doi: 10.1029/RG015i002p00251

Davis DW (2002) U–Pb geochronology of Archean metasedimentary rocks in the Pontiac and Abitibi subprovinces, Quebec, constraints on timing, provenance and regional tectonics. Precambrian Res 115:97–117. doi: 10.1016/S0301-9268(02)00007-4

De Souza S, Dubé B, McNicoll VJ, et al (2015) Geology, hydrothermal alteration, and genesis of the world-class Canadian Malartic stockwork-disseminated Archean gold deposit, Abitibi, Quebec. 113–126. doi: 10.4095/296624

Helt KM, Williams-Jones AE, Clark JR, et al (2014) Constraints on the Genesis of the Archean Oxidized, Intrusion-Related Canadian Malartic Gold Deposit, Quebec, Canada. Econ Geol 109:713–735

Herron MM (1988) Geochemical classification of terrigenous sands and shales from core or log data. J Sediment Res 58:820–829.

Matsuhisa Y, Goldsmith JR, Clayton RN (1979) Oxygen isotopic fractionation in the system quartz-albite-anorthite-water. Geochim Cosmochim Acta 43:1131–1140. doi: 10.1016/0016-7037(79)90099-1

Perrouty S, Gaillard N, Piette-Lauzière N, et al (2017) Structural setting for Canadian Malartic style of gold mineralization in the Pontiac Subprovince, south of the Cadillac Larder Lake Deformation Zone, Québec, Canada. Ore Geol Rev 100. doi: 10.1016/j.oregeorev.2017.01.009

Taylor HP (1978) Oxygen and hydrogen isotope studies of plutonic granitic rocks. Earth Planet Sci Lett 38:177–210. doi: 10.1016/0012-821X(78)90131-0

Wilson M (2007) Igneous Petrogenesis: a global tectonic approach. Springer, Dordrecht, The Netherlands

Zheng Y-F (1999) Oxygen isotope in carbonate fractionation and sulfate minerals. Geochem J 33:109–126. doi: 10.2343/geochemj.33.109