
Integrated multi-parameter footprint of the Canadian Malartic gold deposit, Québec, Canada

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Abstract. The metasomatic halo of the Canadian Malartic gold deposit has been investigated using and integrating multiple geological and geophysical methods. Over 50 structural, lithogeochemical, mineralogical, petrophysical and geophysical parameters were identified and they provide the spatial distribution of alteration zones within the deposit footprint as well as vectoring information. This communication highlights the main parameters that define the Canadian Malartic footprint and on-going progress regarding their geological, geospatial and geostatistical integration.

1 Introduction

The NSERC-CMIC Multidisciplinary Mineral Exploration Footprints project (http://cmic-footprints.ca/), aims to characterize the distal signature of major ore systems, to identify new exploration criteria, and to develop exploration methodologies by integrating geological, structural, lithogeochemical, mineralogical, petrophysical and geophysical datasets.

This communication presents a synthesis of some of the multi-parameter footprints and vectors toward the mineralization that have been identified for the world-class Canadian Malartic deposit (>18.6 Moz, Gervais et al. 2014), which is located south of the Cadillac Larder Lake Deformation Zone, Abitibi Subprovince, Canada (Fig. 1).

2 Geological setting

2.1 Host rocks and deformation

The Canadian Malartic gold deposit is hosted by Archean meta-sedimentary rocks (Pontiac Group) and quartz-monzodiorite intrusions of the Pontiac Subprovince, and by meta-volcanic rocks of the Abitibi Subprovince (Piché Group). These lithologies were intruded by basic dykes prior to the mineralization event(s). Upper greenschist metamorphism overprints all host rocks, mineralization and associated alteration.

Three major deformation events have been recognized in the area (Derry 1939; Perrouty et al. 2017) and include: 1) a pre-mineralization and pre-intrusion D₁ deformation event that produced isoclinal F₁ folds and a pressure-bedding parallel S₁ cleavage, 2) a syn-mineralization D₂ deformation event that produced open to tight steeply dipping F₂ folds, an east-plunging L₂ stretching lineation and a NW-SE-trending penetrative biotite/amphibole foliation, and 3) a post-mineralization minor D₃ deformation event that produced open F₃ folds, a subtle NE-SW-trending crenulation S₃ cleavage and kinks. The D₃ event postdates the metamorphic peak and may correlate with late dextral transcurrent movement along the Cadillac Larder Lake Deformation Zone (Bedeaux et al. 2017).

2.2 Mineralization

Low grade, large-tonnage gold mineralization in the Canadian Malartic deposit is structurally controlled by the E-W Sladen Fault Zone (which is connected to the Cadillac Larder Lake Deformation Zone) and NW-SE high-strain bands (Derry 1939). Ore zones are spatially associated with quartz monzodiorite intrusions (Helt et al. 2014). The proximal alteration mineralogy consists of biotite, K-feldspar, albite, white mica, quartz, carbonate, pyrite, rutile, scheelite in the meta-sedimentary rocks (Helt et al. 2014, De Souza et al. 2015, 2016) and biotite, quartz, carbonate, chlorite, pyrite, rutile, epidote in the meta-basic dykes (Perrouty et al. 2015).

3 Integrated multi-parameter footprints

3.1 Structural footprint

Orogenic and intrusion-related gold systems are all structurally controlled. At Canadian Malartic, the relationship between the deformation and the mineralization was recently investigated by De Souza et al. (2015, 2016), who demonstrate a syn-D₂ timing for the main gold mineralization event and estimate it to be around 2664 Ma.

Perrouty et al. (2017) showed that gold occurrences in the Canadian Malartic district are systematically associated with structurally complex zones, which are interpreted to be joined F₁ and F₂ fold hinges. They also highlighted spatial variations in the intensity of the S₂ biotite foliation in greywacke and tentatively interpreted it as a consequence of the alteration by mineralizing fluids during the D₂ deformation event.
3.2 Geochemical footprint

Lithogeochemical variations throughout the footprint of the deposit are controlled by the protolith composition and by alteration. Whole-rock geochemical analyses were conducted by ACTLABS, ALS and SGS laboratories and were supplemented by a whole-rock stable isotope study (see Raskevicius et al., 2017).

Mass changes were calculated for meta-sedimentary rocks and meta-basic dykes in order to generate a series of representative mass gain and loss maps. Gold and associated elements (Ag, Te) have the most significant mass gains proximal to the deposit in both rock types. Elements such as S and C are intimately associated with gold mineralization and are enriched in the vicinity of the deposit. Significant mass gains are also observed for large-ion lithophile elements and for light rare-earth elements, but their distributions highlight a more distal alteration signature, which is particularly well recorded in the meta-basic dykes (Fig. 2).

Differences in analytical methods (partial vs total leaches) can also be used to detect alteration.

3.3 Mineralogical footprint

Mineralogical changes within the footprint of the Canadian Malartic gold deposit are linked with lithogeochemical changes during the hydrothermal alteration process. Major mineral proportions are highly dependent on the protolith in the meta-sedimentary rocks (greywacke vs siltstone vs mudstone) and the resultant variations can therefore be difficult to interpret. However, the relative abundances of minor minerals such as carbonates, pyrite, and rutile increase in the vicinity of the mineralized zones.

The meta-basic dykes are more reactive to the hydrothermal fluids than the Pontiac meta-sedimentary rocks. Their mineralogy evolves from a distal amphibole-rich composition to a proximal biotite–carbonate–quartz–pyrite–rutile mineral association (Perrouty et al., 2015).

Mineral chemical variations were also evaluated. Biotite and white mica compositions are highly dependent on the protolith and metamorphic conditions (Gaillard et al., 2015), but a distinct “hydrothermal” signature can nevertheless be identified around the Canadian Malartic deposit. Hyperspectral (SWIR) methods have also been shown to efficiently detect and map mineral compositional changes (see Lypaczewski et al., 2017).

Glacial dispersion from the Canadian Malartic deposit in the surficial till is also being investigated (Taylor et al., 2017).
3.4 Petrophysical footprint

Rock physical properties are controlled by multiple parameters including mineralogy and structures. Measurements were acquired at the Geological Survey of Canada Paleomagnetism and Petrophysics Laboratory and at École Polytechnique de Montréal. Density is highly dependent on the mineralogy and porosity. Major mineralogical changes during alteration result in density variations across the Canadian Malartic footprint, which are particularly strong for meta-basic dykes.

Magnetic susceptibility and remanence are mainly controlled by minerals such as magnetite and pyrrhotite. The spatial distributions of these minerals in the footprint is complex. Pyrite is the most common sulfide mineral in the deposit and is commonly associated with destruction of magnetite. It is, however, progressively replaced by pyrrhotite towards the south, which is tentatively interpreted to be a metamorphic overprint on the alteration assemblage. The anisotropy of the magnetic properties along geological structures is also being investigated and correlated with structures.

Low-frequency electrical properties were also measured and interpreted based on rock texture, sulfide mineral proportions and grain size distribution (Bérubé et al. 2017).

3.5 Geophysical footprint

The detection of orogenic intrusion-related disseminated gold deposits by geophysical methods is very challenging because the petrophysical contrasts are often not sufficient to provide a perceptible geophysical signature.

Geophysical datasets in the area consist of airborne magnetic and EM surveys provided by Canadian Malartic Corporation, and several ground IP lines that were acquired in collaboration with Abitibi Geophysics during this project. Airborne data were used mainly to delineate geological structures and units, and are not sensitive to alteration signature. High resolution (meter-scale) time-domain and spectral induced polarization ground surveys were conducted at the Bravo gold occurrence and appear to detect graphitic mudstone and mineralized greywacke layers (Bérubé et al. 2017).

3.6 Data integration

Three major data integration analyses are being conducted in this project: 1) geological “physical” integration between parameters (e.g., carbonate alteration => density

Figure 2. Schematic diagram summarizing the main parameters that define the footprint of the Canadian Malartic gold deposit from the most distal (left) to the most proximal (right).
decrease), 2) geospatial integration (e.g., gold, quartz-
monzodiorite intrusions and F1-F2 fold hinges are spatially
associated), and 3) geostatistical integration (e.g., principal
component analysis, K-means clustering, machine
learning), which are still in progress.

Over 50 individual vector and footprint parameters can
be used to characterize the proximal, medial, and distal
alteration zones. Combinations of these parameters
enhance their capacity to vector toward the deposit and
decrease the possibility of false positive results. The
identification of a minimum set of parameters that best
describe the footprint and that are applicable to exploration
is a critical goal of this project.

4 Summary and conclusion

Many individual mineralogical, lithogeochemical and
petrophysical parameters vary across the Canadian
Malartic footprint (Fig. 2), and therefore define the
footprint of the deposit. However, some of these
parameters are physically linked together (e.g., mass gain
in potassium => biotite formation => density decrease in
meta-basic dykes.). Extensive data integration will be used
to identify the best combination of variable that define
the Canadian Malartic footprint and permit vectoring from
the periphery toward the high grade core, which can then
potentially be used to target similar ore systems.

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Footprints Network Contribution 136.

References

structural evolution and associated gold mineralization of the
Cadillac Fault, Abitibi, Canada. Ore Geol Rev 82:49–69
Bérubé CL, Chouteau M, Olivo GR, Perrouty S, Shamshipour P, Enkin
RJ (2017) Spectral Induced Polarization signature of altered
metasedimentary rocks from the Canadian Malartic gold deposit
Bravo zone, Québec, Canada. Ext. Abstract. 30th SAGEEP, 19-
23 March 2017, Denver, USA, pp 5
Derry DR (1939) The geology of the Canadian Malartic gold mine,
N. Quebec. Econ Geol 34:495–523
De Souza S, Dubé B, McNicoll VJ, Dupuis C, Mercier-Langevin P,
Creaser RA, Kjarsgaard IM (2015) Geology, hydrothermal
alteration, and genesis of the world-class Canadian Malartic
stockwork-disseminated Archean gold deposit, Abitibi, Quebec.
In: Dubé B, Mercier-Langevin P (Eds), Targeted Geoscience
Initiative 4: Contributions to the Understanding of Precambrian
Lode Gold Deposits and Implications for Exploration. Geological
Survey of Canada, Open File 7852, 113–126

De Souza S, Dubé B, McNicoll VJ, Dupuis C, Mercier-Langevin P,
Creaser RA, Kjarsgaard IM (2016) Geology and Hydrothermal
Alteration of the World-Class Canadian Malartic Gold Deposit:
Genesis of an Archean Stockwork-Disseminated Gold Deposit in
the Abitibi Greenstone Belt, Québec. Econ Geol Rev 19, pp 29
Gaillard N, Williams-Jones AE, Clark JR, Salvi S, Beziat D,
geochemical vectors to ore: the alteration halo of the Canadian
Malartic gold deposit. Ext. Abstract. 13th SGA Biennial Meeting,
24-27 August 2015, Nancy, France, pp 4
Estimates for the Canadian Malartic Property. Mine Canadian
Malartic, pp 460
Helt KM, Williams-Jones AE, Clark JR, Wing BA, Wares RP (2014)
Constraints on the Genesis of the Archean Oxidized, Intrusion-
Related Canadian Malartic Gold Deposit, Quebec, Canada. Econ
Geol 109:713–735
Hyperspectral characterization of white mica and biotite mineral
chemistry across the Canadian Malartic Gold Deposit, Quebec,
Canada. Ext. Abstract. 14th SGA Biennial Meeting, 20-23
August 2017, Quebec, Canada, pp 3
Perroux S, Gaillard N, Piette-Lauzière N, Mir R, Bardoux M, Olivo
GR, Linnen RL, Bérubé CL, Lypaczewski P, Guilmette C, Feltrin
L, Morris WA (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 84:185–201
Perroux S, Linnen RL, Lypaczewski P, Gaillard N, Olivo GR, Lesher
CM, Piette-Lauzière N, Crocker M, Piercey SJ, El Goumi N,
Enkin RJ, Bouchard F (2015) Footprint of the Canadian Malartic
Gold Deposit, QC, Canada: Preliminary Evaluation of Mafic
Dyke Alteration. Ext. Abstract. 13th SGA Biennial Meeting, 24-
27 August 2015, Nancy, France, pp 3
Raskevicius T, Beudoin G, Kyser K (2017) Whole Rock δ18O and
δ2H footprint of the Canadian Malartic gold deposit, Abitibi
subprovince, Quebec, Canada. Ext. Abstract. 14th SGA Biennial
Meeting, 20-23 August 2017, Québec, Canada, pp 4
Taylor CE, Taves R, Ross M, Clark JR, Perroux S (2017) Tungsten-
rich rutile as a potential indicator mineral in surficial till for
Malartic-type gold deposits. Ext. Abstract. 14th SGA Biennial
Meeting, 20-23 August 2017, Québec, Canada, pp 4