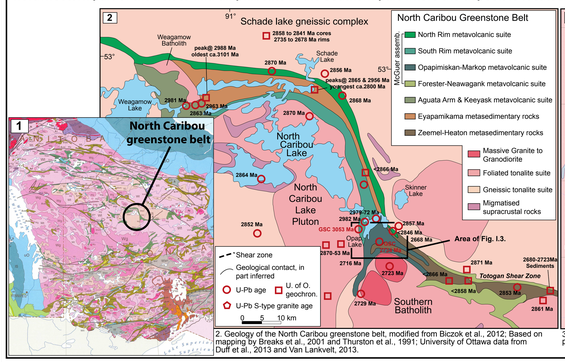
New insights on the structural and geological setting of the world-class Musselwhite gold deposit, Superior Province, northwestern Ontario

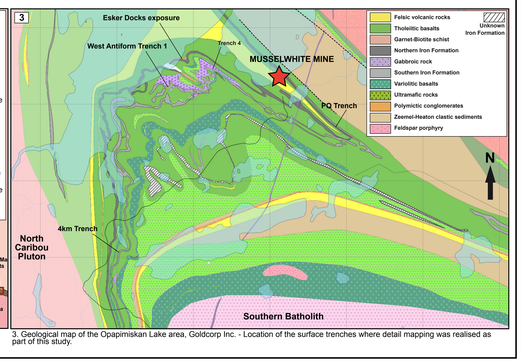
Oswald, W.[1], Dubé, B.[2], Castonguay, S.[2], McNicoll, V.[3], Biczok, J.[4], Mercier-Langevin, P.[2], Malo, M.[1], Skulski, T.[3]

I. Introduction and Geological setting:

The Musselwhite mine is a world-class gold deposit hosted by amphibolite facies Algoma-type banded iron formation (BIF), comprised in the Mesoarchean North Caribou greenstone belt, (NCG) Superior Province, northwestern Ontario (Fig. 1). The deposit is located 2km west of a major fault zone that defines the tectonic boundary with the gneissic tonalite suite of the Island Lake Domain.
A multidisciplinary multi-scale cooperative study has been undertaken to gain new knowledge on the regional and deposit-scale geological setting and on the source, controls and timing of gold mineralisation of the Musselwhite mine in order to develop better genetic models and exploration vectors. Research activities include regional and detailed surface (III.) and underground mapping (IV.) in conjonction with structural analyses and targeted U-Pb geochronlogy (Fig. 2). The belt comprises seven lithotectonic assemblages that have been submitted to three ductile to brittle-ductile deformation phases and at least one additional brittle deformation phase (Breaks et al., 2001). Metamorphic grades go from mid- to upper greenschist in the northwestern part of the belt to mid-amphibolite in the southern part where the deposit is located.



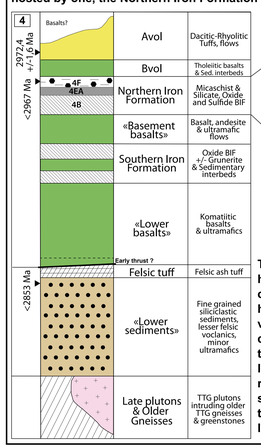
2. Geology of the North Caribou greenstone belt, modified from Biczok et al., 2012; Based on mapping by Breaks et al., 2001 and Thurston et al., 1991; University of Ottawa data from Duff et al., 2013 and Van Lankveit, 2013.

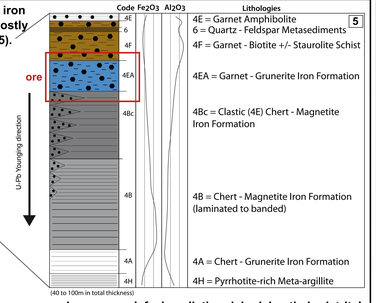


3. Geological map of the Opapimiskan Lake area, Goldcorp Inc. - Location of the surface trenches where detail mapping was realised as part of this study.

II. Opapimiskan Lake & Northern Iron Formation sequence:

The Opapimiskan-Markop metavolcanic suite includes two iron formation (IF) sequences but the Musselwhite deposit is mostly hosted by one, the Northern Iron Formation - NIF (Fig. 4 & 5).

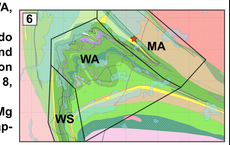


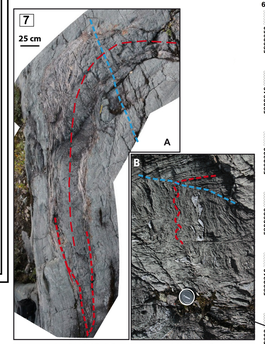


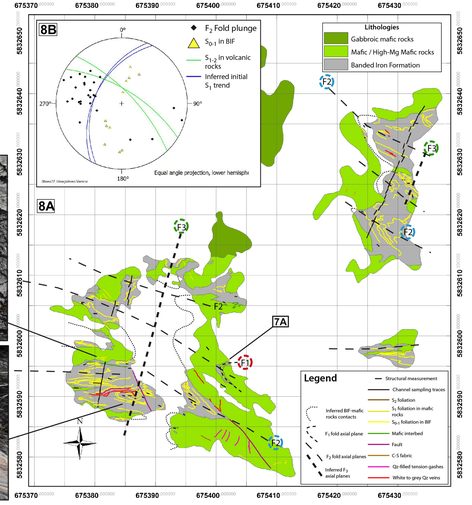
The NIF sequence comprises several facies distinguished by their detrital, hydrothermal and hydrogenous signatures (Fig. 5). According to the new geochronology data (Fig. 2), the facies succeed each other as follow: 4F and 4E have a strong detrital input, which steadily decreases while hydrothermal activity builds up (4EA, 4Bc). Hydrothermal activity culminates (4B) before decreasing and stopping (4A, 4H). The Southern Iron Formation (SIF) comprises two sequences of 4B/4A facies interbedded with fine grained sedimentary layers. These two IF sequences have a common structural evolution but remarkedly different gold endowment (Fig. 12; Biczok et al., 2012). Beside the strong correlation between silicate facies iron formation and gold mineralisation, the study aims at reaching a complete understanding of the structural evolution of the Opapimiskan Lake area (III).

III. Structure and surface mapping:

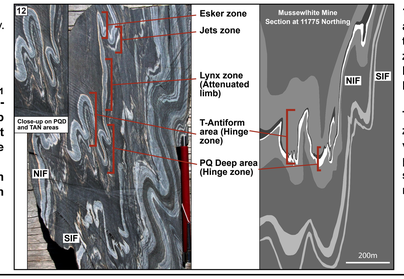
The Opapimiskan Lake area is located at a triple point in the NCG and includes at least three separate structural domains: MA, mine area and immediate surroundings; WA, West Antiform area; WS, western most and southern areas (Fig. 6).
Exposures of the iron formation sequences in each domain have been selected to do detailed surface mapping (Fig. 3), starting with West Antiform Trench 1 (WAT1) and Esker Docks exposure (EDE) as they are located in an area of lower D_2 deformation intensity and thus are more likely to contain preserved D_1-related structures (Fig. 7, 8, 9 & 10).
The WAT1 includes two main areas of chert-magnetite IF, hosted by mafic and high-Mg volcanic rocks (Fig. 7A). Those latter lithologies show a penetrative S_1 foliation wrapped around asymmetric to chevron-like F_2 folds (Fig. 7B).
The EDE is one of the few NIF exposures. It is solely composed of cherty garnet-biotite schist (4F) and is intensely folded.







7. A, S_0 fabric (heavy red dash line) in an F_1 fold (thin red dash line) refolded by an F_2 antiform (blue); B, S_1 foliation (red) affected by F_2 folds (camera cap diameter ~7cm); C, Doubly plunging F_2 synform (blue), inferred F_3 axial plane (green).
8. A. Detailed geological map of the West Antiform Trench 1, observed and inferred fold axial plane traces are drawn as dashed lines; B. Stereographic projection of structural measurements.



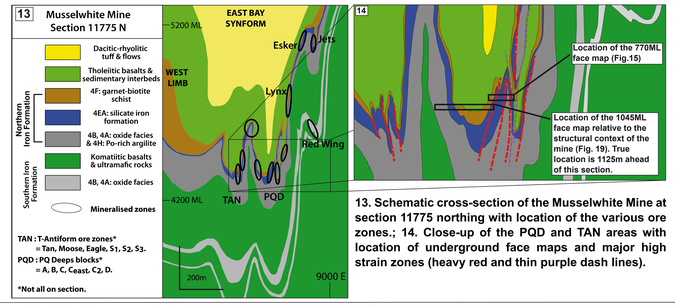
12. Surface sample from Trench 4 and the mine section at 11775 Northing: the sample is a mesoscopic illustration of the geometry of the various Musselwhite ore zones, located in fold hinge zones and along attenuated limbs, including parasitic structures such as the Esker-Jets fold.

The layered anisotropy induced by competent BIF horizons embedded in less competent mafic and ultramafic volcanic rocks strongly influenced rheological response to deformation, both at macro and microscopic scales, and hence played an important role in gold-bearing fluids flow and ore formation and distribution (IV).

IV. Mineralisation:

The bulk of the ore is hosted by the Northern BIF and occurs as stratabound pyrrhotite-rich replacement zones and associated silica flooding of the 4EA BIF facies with local discordant syn-tectonic grey quartz ± pyrrhotite veins (Fig. 15, 16, 17 & 18). The ore zones are associated with D_2-related high strain zones concentrated along hinges (T Antiform and PQ Deeps) or strongly attenuated fold limbs (e.g. Lynx Zone) of tight shallowly northwest-plunging F_2 folds (Fig. 13 & 14).

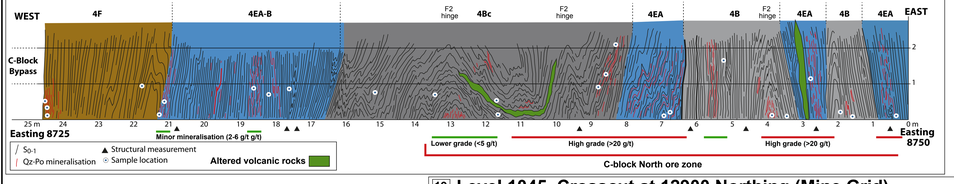
Volcanic rocks proximal to the ore zones display a strong biotite alteration (Fig. 18). The high-grade ore zones are associated with iron carbonates, Ca-amphiboles and hedenbergite and display a metasomatic-metamorphic layering with ~50% coarse almandine garnet porphyroblasts, intergrown with fine grained, bladed grunerite-cummingtonite (5-10%) and biotite (≤10%) aligned sub-parallel to the S_2 foliation (Fig. 16 & 17). Because such mineral assemblage is also associated with regional metamorphism, a careful petrographic characterization close to the ore is instrumental in uncovering the hydrothermal footprint of the deposit.

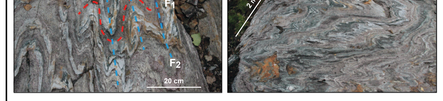


13. Schematic cross-section of the Musselwhite Mine at section 11775 northing with location of the various ore zones.; 14. Close-up of the PQD and TAN areas with location of underground face maps and major high strain zones (heavy red and thin purple dash lines).

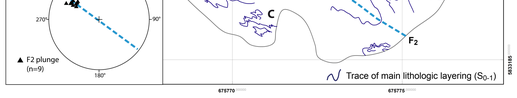
15 Level 770, Crosscut at 11780 Northing (Mine Grid)

The underground mapping of the C-block North illustrates: 1- the main ore shoots are located in high strain zones that are at high angle with F_2 fold hinges zones; 2- the predominance of 4EA as host of mineralisation instead of 4B.
F_2 folds have a shallow NW plunge with an upright axial plane. S_2 is axial planar to the F_2 folds. The metasomatic layering in the mineralised high strain zones can be defined as S_2.

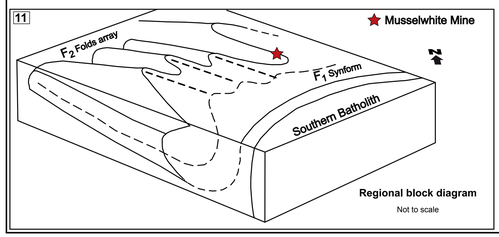




9. A. Geological map of the Esker Docks exposure. The whole exposure is composed of cherty garnet-biotite facies that displays open to tight F_2 folds. B. Stereographic projection of measured F_2 fold plunges. Yellow dash line = S_{0-1} fabric.



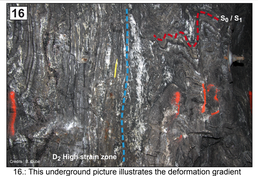
10.: A, Closeup on preserved S_1 foliation in the hinge of an F_2 fold; B, Preserved S_1 foliation in F_2 fold hinge zones, note the contrast of deformation rate with garnets in the center of the biotite rich bands; C, refolded F_1 folds forming a type 3 fold interference pattern (blue dash line = F_2 folds axial plane, red dash line = F_1 fold axial plane); D, Broad view of the S_{0-1} geometry.



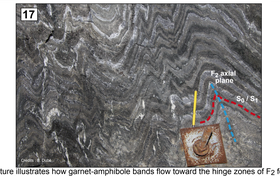
REGIONAL IMPLICATIONS

Multiple occurrences of decimeter to meter scale refolded F_1 folds, along with S_0 and S_1 geometries (III.), indicate the presence of megascopic F_1 folds that are strongly overprinted by D_2 in the immediate mine area (Fig. 3). Stratigraphic reappraisal and ongoing U-Pb geochronological work (Fig. 2) indicate that the mine sequence is inverted, the deposit occurring along the overturned limb of a map-scale F_1 syncline, which axis lies to the South of Opapimiskan Lake (Fig. 3 & 11).
There is no known exposure of the NIF close to the Southern Batholith, but the repetition of the variolitic basalts and ultramafic rocks (Fig. 3) suggests it could be present at depth (Fig. 10).

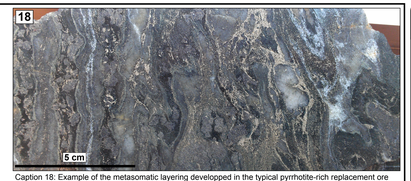
11.: Regional sechematic 3D diagram of F_1-F_2 folds generations interference pattern.



16.: This underground picture illustrates the deformation gradient between the mineralised high strain zone and their adjacent open folded areas.

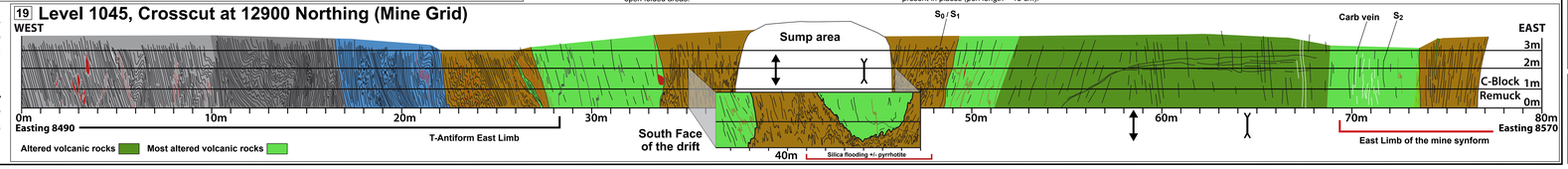


17.: This picture illustrates how garnet-amphibole bands flow toward the hinge zones of F_2 folds. Those folds are cut by low angle to axial planar veins and at times brittles faults. Bedding-parallel veins are also present in places (pen length = 15 cm).



Caption 18: Example of the metasomatic layering developped in the typical pyrrhotite-rich replacement ore zones. Silica-flooded /chert-rich bands can be distinguished from the garnet-biotite-pyrrhotite bands.

19 Level 1045, Crosscut at 12900 Northing (Mine Grid)



19.: Geological face map of the 1045 ML-Main Ramp crosscut with the trace of lithologic layering and S_1 fabric. Asymmetric F_2 folds are visible at all scales. The trace of the S-3 mineralised zone (part of the T-Antiform area) is located in the sump area and composed of qz-flooded 4F facies.

This section is located above the hinge zone of the mine synform. It illustrates the contrast of deformation between the iron formation sequence and the volcanic host rocks. It is particularly visible at the hinge of a decametric F_2 synform around 45 m.

V. Conclusion:

- **The stratigraphy and structural setting of the Musselwhite deposit are more complex than previously portrayed. Detailed mapping of key exposures, preliminary structural analysis and geochronological data indicate that the Musselwhite sequence is inverted and probably located along the overturned limb of a regional-scale F_1 syncline, variously overprinted by D_2.**
- **The intensity of the D_2 overprint increases eastward toward the mine where mineralisation is strongly controlled by the location of D_2-related high strain zones associated with tight to ioclinal F_2 folds and of dilational zones within fold hinges.**
- **Of the numerous BIF facies of the Musselwhite stratigraphy, the silicate facies, exclusive to the Northern Iron Formation, is an efficient trap for gold due to both its chemical reactivity with Au-rich fluids and heterogeneous strain response.**
- **The results of this study provide new knowledge on the setting and controls of the BIF-hosted Musselwhite gold deposit, which could have important implications for local and regional controls on the distribution of the BIF-hosted deposits and exploration models.**

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