Characteristics of ore fluids and mineralization at the Troilus Gold Project, Quebec: Implications for ore transport and exploration

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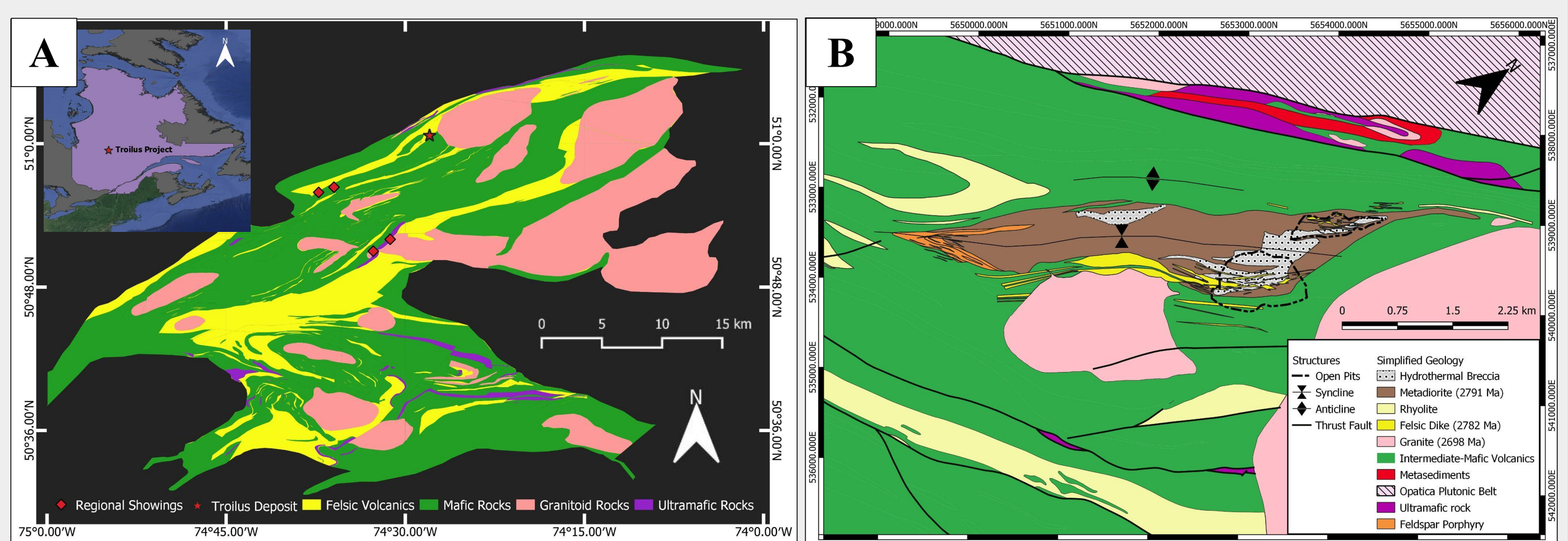
I. Introduction and Geologic Background

- The Frotet-Evans Greenstone Belt (FEGB) is a 2.79-2.75 Ga represents a preserved Meso-Archaean ocean island arc setting spanning over 300 km between James Bay and Lac Mistassini, Quebec. The FEGB hosts numerous gold and copper targets, many of which are currently undeveloped.
- The Troilus Gold Project is located in the Frotet-Troilus domain in the easternmost limb of the FEGB (Fig. 1A). This domain consists of tholeiitic ocean floor basalts overlain by mafic to felsic volcanics and intrusions of transitional to calc-alkaline affinity capped by late- to post-tectonic granites (Boily and Dion, 2002).
- The Troilus deposit lies along a steeply dipping, northeast-southwest striking suite of volcano-plutonic rocks arranged around a central body of diorite (Gosselin, 1996; Fig 1B). Locally, volcano-stratigraphy of the Troilus deposit consists of a tholeiitic basalt footwall, with a hanging wall comprised of transitional to calc-alkaline volcanic rocks ranging from basaltic andesite to rhyolite, typically becoming more felsic higher in the stratigraphic column (Enno, 2022; Fig. 1C).
- Mineralization is located along strike of the major rock units of the Troilus deposit within a corridor that is roughly 2 km thick and over 20 km in length (Goodman et al., 2005). The Troilus deposit consists of multiple ore assemblages of primarily Au-Cu +/- Ag mineralization with minor Mo, Bi, and Ni (Valliant, 2021). As a result, numerous conflicting genetic models have been proposed including Archaean porphyry, orogenic, and mixed genetic origin.
- This project focuses on constraining a wholistic genetic model of the Troilus deposit through characterization of mineralization and alteration assemblages coupled with identify the possible sources and temperature conditions of ore fluids in high-grade intervals.



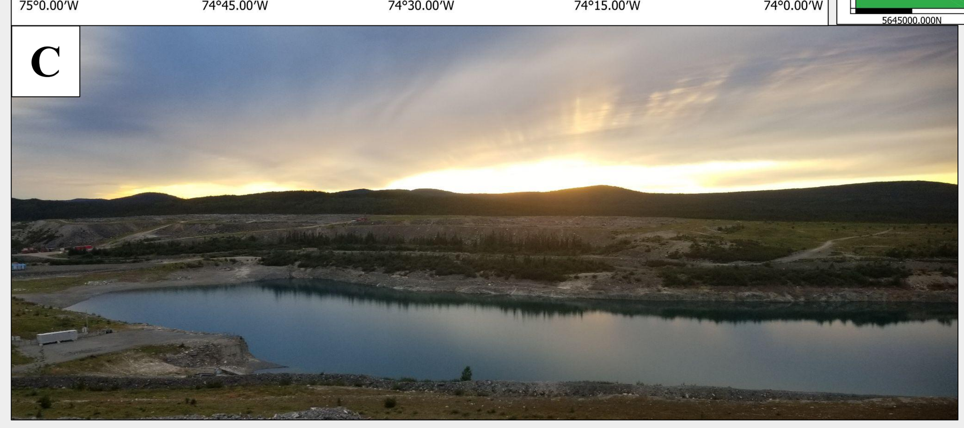
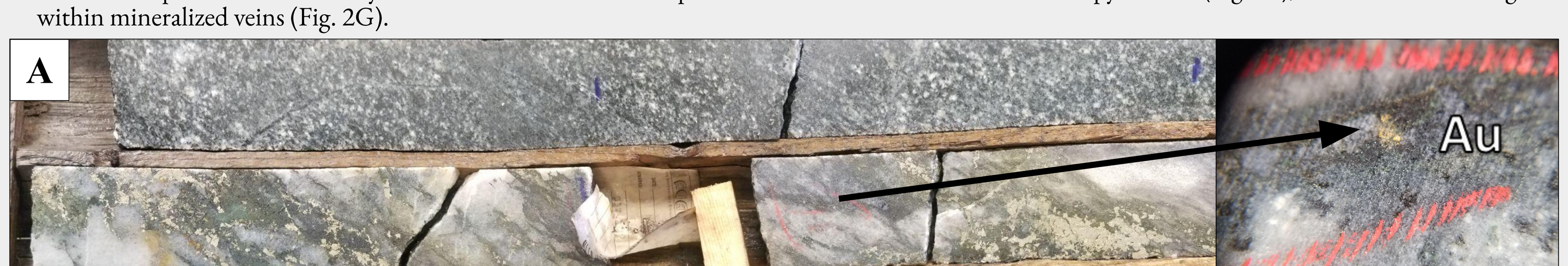


Figure 1: A: Simplified geologic map of the Frotet-Troilus domain including the location of the Troilus deposit and regional gold targets included in the present study.
B: Local geologic map of the Troilus Deposit including outlines of the open pits, major structures and lithotypes. UTM coordinates are in NAD 83, Zone 18.
C: Photo of the J4 open pit taken from the east atop the waste pile during the 2022 field season.

II. Petrographic Characterization

- 86 samples of drill core were collected from 66 diamond drillholes (DDH) of the Troilus Project during the 2022 field season (Fig. 2A). Mineralization occurs in all rock types with the exception of granite intrusions.
- Two groups of mineralized veins were identified in samples from the Troilus deposit. Stages are separated by peak metamorphic conditions in the region with earlier veins undergoing transposition into the plane of regional foliation while later veins crosscut the foliation at high angles.
- Alteration mineralogy depends on the phase of mineralization. Early stages of mineralization are associated with potassic alteration (biotite/sericite; Fig. 2B) and magnetite. Later stages are associated with chlorite, epidote, and occasionally tourmaline (Fig. 2C). Host rock sulphidation is often observed along the margins of veins in core.
- Sulphide mineralization range from semi-massive to disseminated and veinlet types. Dominant sulphides include pyrite, pyrrhotite, chalcopyrite, and sphalerite (gold and silver are often associated with sulphide grain boundaries; Fig 2D,E).
- Anomalous pentlandite and molybdenite were observed in samples- the former as exsolution lamellae in pyrrhotite (Fig. 2F), the latter as isolated grains within mineralized veins (Fig. 2G).



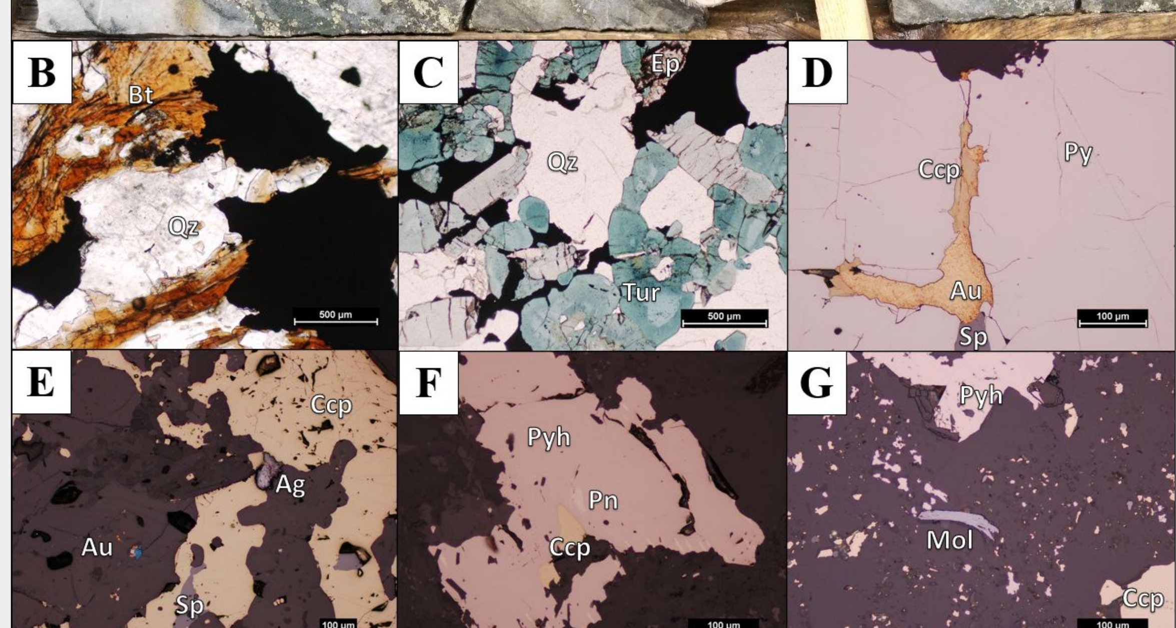
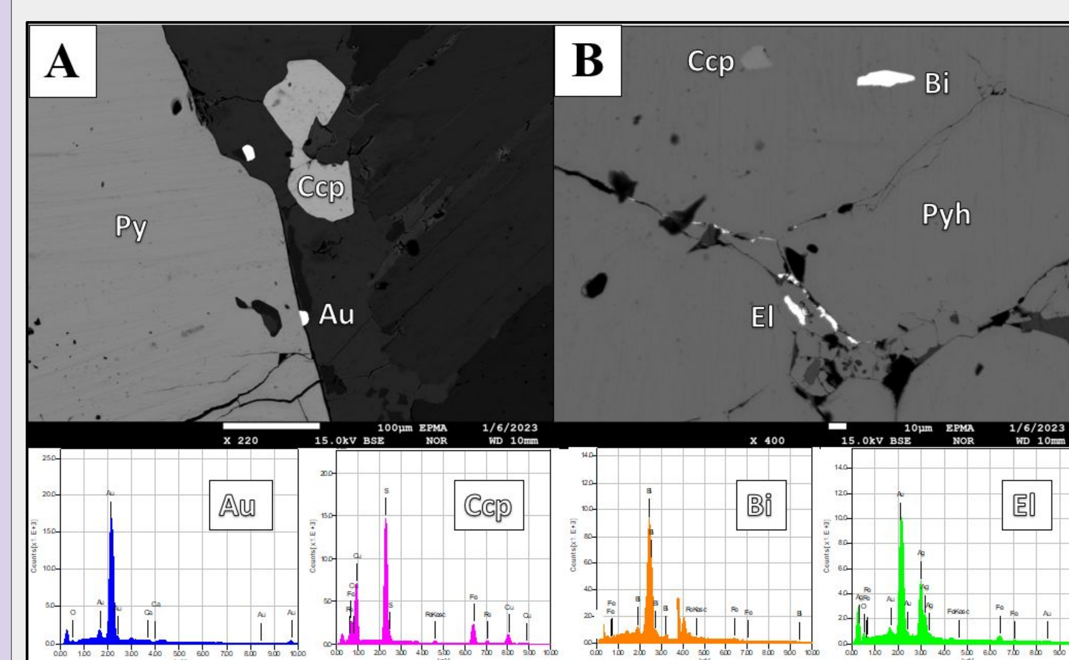


Figure 2: A: Auriferous shear zone in diorite from DDH TLG-Z8718-020. Shear is flanked by a pyrite halo, indicating host rock sulphidation. Gold grains enlarged for reference.
B: Biotite alteration within mineralized basalt from DDH TLG-ZJ418-072; transmitted PPL.
C: Mineralized vein containing tourmaline in a feldspar porphyry from DDH 87-21-408; transmitted PPL.
D: Gold intergrown with chalcopyrite, sphalerite, and trace pyrrhotite which fill fractures in pyrite from DDH J-21-303; reflected PPL.
E: Native silver within a grain of blebby chalcopyrite and sphalerite. Discrete gold grains are hosted by quartz from DDH TLG-Z87N21-265; reflected PPL.
F: Exsolved pentlandite within pyrrhotite associated with chalcopyrite from DDH FRG-19-07; reflected PPL.
G: Molybdenite spatially associated with pyrrhotite and chalcopyrite from DDH 87-21-408; reflected PPL.

III. Electron Probe Microanalysis (EPMA)

- EPMA was performed at the Earth and Planetary Materials Analysis facility at Western University using the JEOL JXA-8530F field-emission electron microprobe.
- Qualitative elemental point analysis was collected for ore mineral phases of interest using Electron Dispersive Spectroscopy (EDS).
- Gold is deposited most often as electrum in samples, although rare grains of native gold were observed (Fig. 3A). Electrum exhibits variable Au/Ag ratios. Spatially, gold is often associated with other ore minerals including bismuth, chalcopyrite, pyrrhotite, sphalerite, and pyrite (Fig. 3B,C).
- Native silver and acanthite (argentite) were observed in association with blebby chalcopyrite (Fig. 3D) or in some instances, substituted into the lattice (Fig. 3E). It is likely that silver was liberated from gold during remobilization.



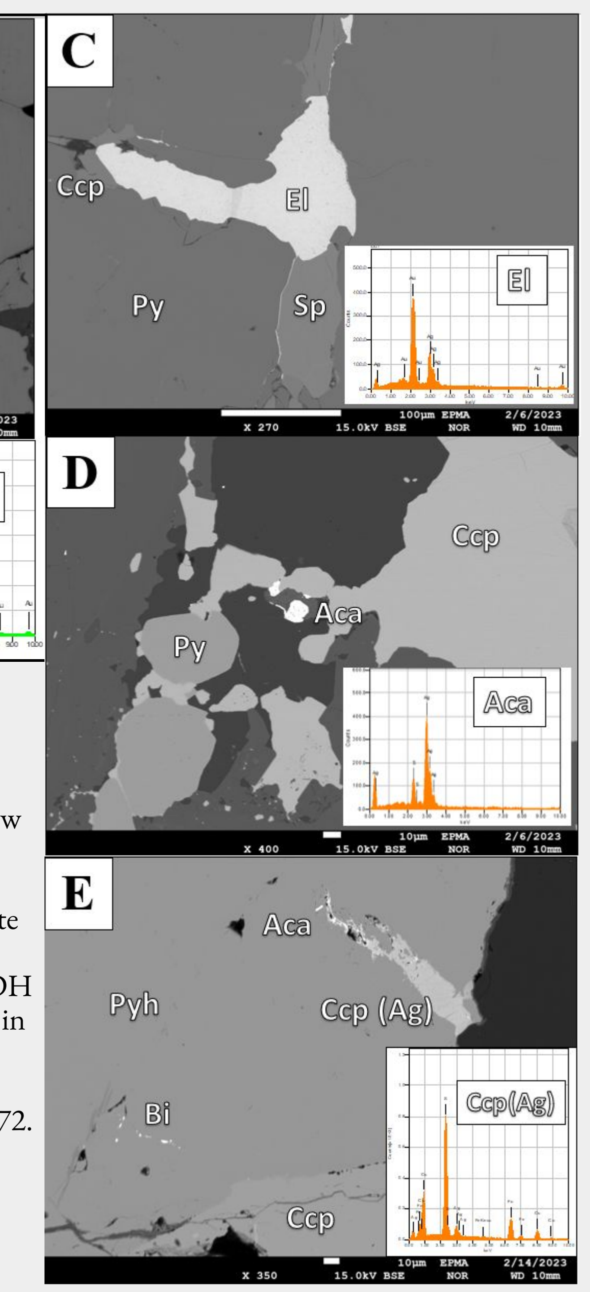


Figure 3: A: Backscattered electron (BSE) image containing native gold disseminated along the margin of euhedral pyrite from DDH TLG-Z8718-002. EDS spectra below show relative elemental abundances of gold and chalcopyrite phases.
B: BSE image of electrum hosted by fractures in pyrrhotite from DDH J-21-303. Spatially associated with electrum is native bismuth and chalcopyrite. EDS spectra show minor iron substitution in bismuth while electrum is gold dominant with lesser silver and trace iron.
C: BSE image of electrum deposited with sphalerite and chalcopyrite in fractured pyrite from DDH J-21-303. EDS spectrum displays a qualitative Au/Ag ratio of electrum.
D: BSE image of acanthite (argentite) deposited with chalcopyrite and pyrite from DDH TLG-Z87N21-265. Qualitative mineral chemistry of acanthite (argentite) is displayed in EDS spectrum.
E: BSE image of chalcopyrite hosting silver in association with sub-micron grains of acanthite (argentite) along the margin of blebby pyrrhotite from DDH TLG-ZJ418-072. Trace native bismuth is grown within pyrrhotite. Note the difference in brightness between silver-hosting chalcopyrite with chalcopyrite at the bottom of the image. The EDS spectrum of silver-hosting chalcopyrite displays the relative amounts of silver substituted in chalcopyrite.

IV. Microthermometry

- Microthermometry was performed on 100µm thick sections collected using the Linkham THMSG600 temperature-controlled geology system connected to a petrographic microscope (Fig. 4A).
- Secondary fluid inclusions were measured as they are interpreted to have formed contemporaneous to mineralization (Fig. 4B,C).
- Freezing temperatures range from -40°C to -59°C indicate the presence of carbonic fluids.
- Melting temperatures range from -40°C to 10°C, often coinciding with clathrate melting. The wide range in temperatures are likely the result of post-emplacement deformation of fluid inclusions.
- Homogenization temperatures range from 120°C to 299°C. Fluid inclusions not homogenized before 300°C often decrepitated shortly after reaching 300°C
- High-salinity fluid inclusions were interpreted as evidence of early intrusion-associated mineralization overpinted by metamorphic fluids (Fig. 4D).

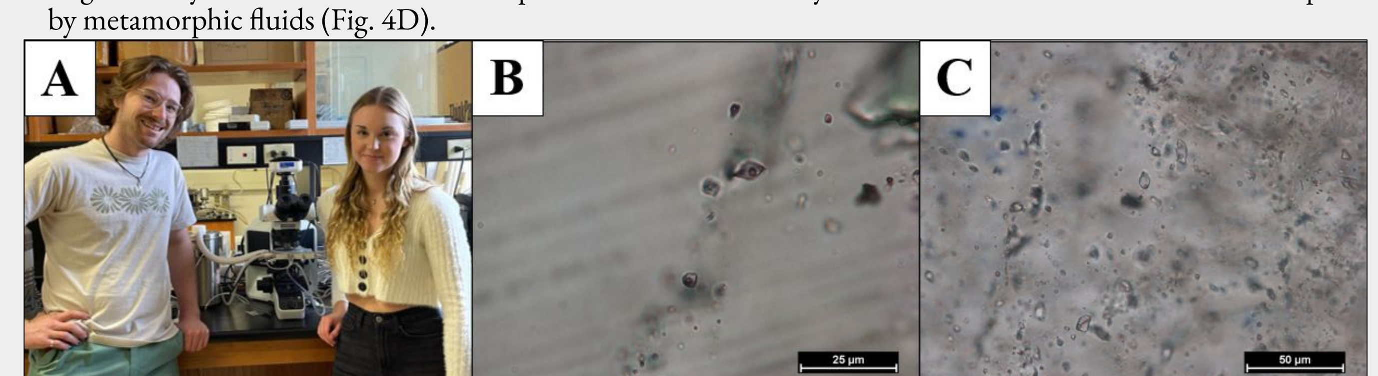
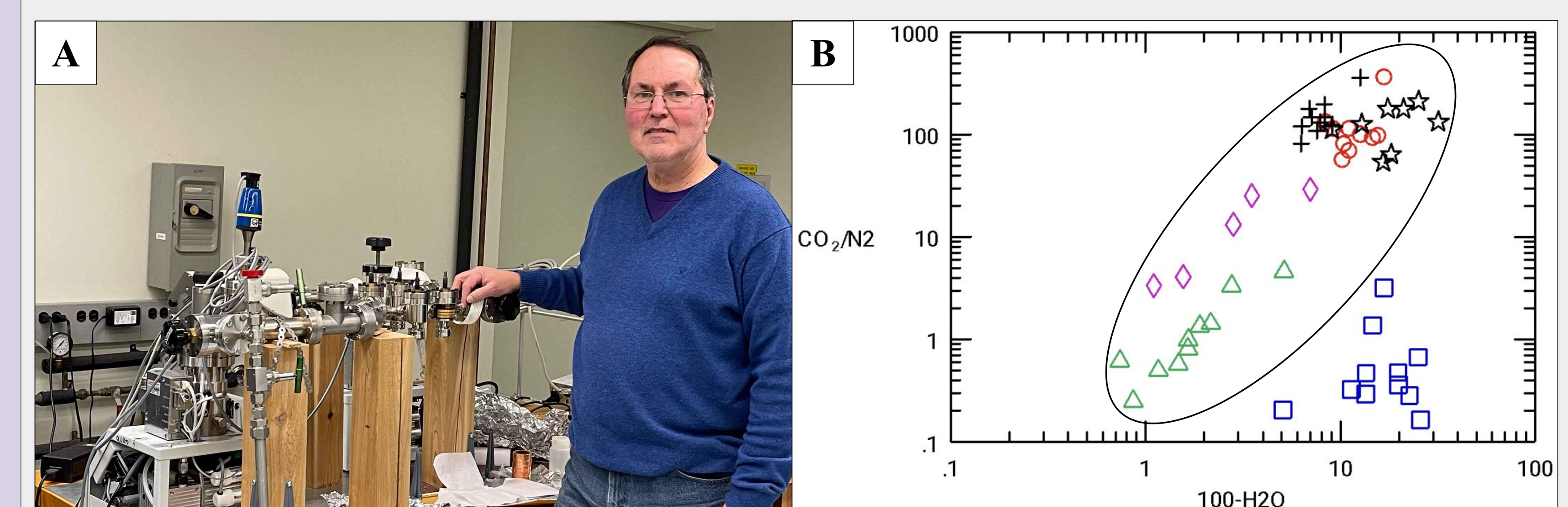


Figure 4: A: Tavis Enno (Left) and Amy Lefebvre (Right) in front of the microthermometry at Western University.
B: Fluid inclusion trail in quartz containing visible aqueous and vapour phases. The largest inclusion has been deformed. From DDH TLG-Z8718-017; transmitted PPL.
C: Multiple superimposed secondary fluid inclusion assemblages in quartz from DDH TES-21-002; transmitted PPL.
D: Preserved daughter halite in fluid inclusions interpreted as being intrusion-associated from DDH 87-21-408; transmitted PPL.

V. Quantitative Fluid Inclusion Gas Analysis

- Quantitative fluid inclusion gas analysis was conducted and interpreted using the method of Blamey (2012).
- Fluid inclusion volatile hosted in mineralized quartz veins were crushed using the crush-fast scan method, with analysis being performed using a quadrupole mass spectrometer (Fig. 5A).
- Volatiles in the majority of samples exhibited a positive slopes indicating a condensation trend (Fig. 5B). It is interpreted that mineralization was transported in the vapour phase before being deposited upon the condensation of fluids.
- Fluids have low N2/Ar ratios and variable Ar/He ratios plotting outside the typical range of fluids sourced from calc-alkaline magmas (Fig. 5C). N2/Ar values are 3 and 65, with values above 30 indicating possible mixing of low N2/Ar metamorphic fluids with a combination of magmatic (N2/Ar >100) and meteoric (N2/Ar =38) fluids.
- High argon values in fluids likely represent radioactive decay products of K-40 to Ar-40. Temperatures encountered during regional metamorphism often rise above the closing temperature of potassic minerals. This results in the diffusion of radiogenic Ar-40 into metamorphic fluids which are trapped upon cooling.



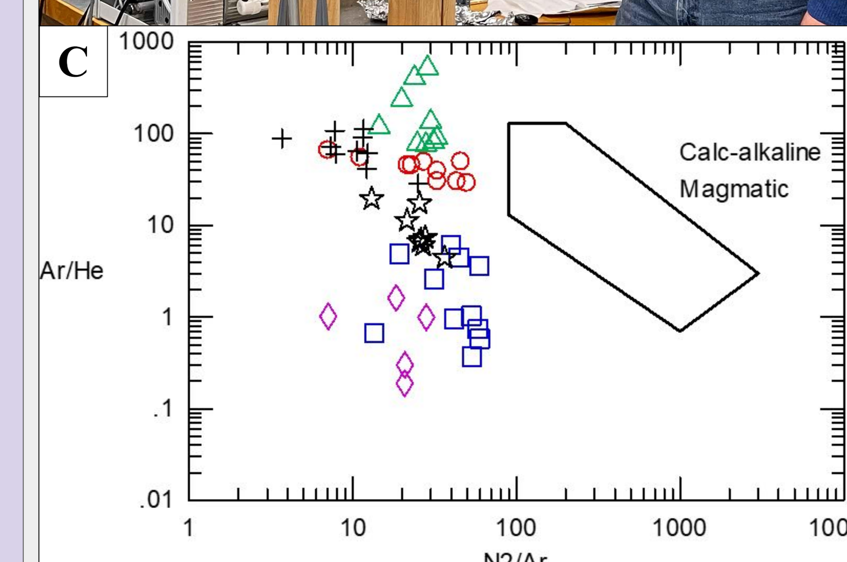


Figure 5: A: Dr. Nigel Blamey pictured with the quadrupole mass spectrometer used to perform quantitative fluid inclusion gas analysis.
B: CO2/N2 vs. Total Gas plot of volatiles liberated from quartz veins. Positive slopes interpreted as condensation trends are circled above. Trends were observed in two samples from DDH TLG-Z8718-002 (green triangles) and DDH J-21-303 (purple diamonds). DDH TES-21-005 (black crosses) also potentially show the same slope. Samples from DDH FRG-19-07 (red circles), TLG-Z8718-017 (blue squares), and TLG-ZJ418-065 (black stars) do not display a clear condensation slope.
C: Ar/He vs. N2/Ar plot used to discriminate calc-alkaline magmatic fluids. All samples plot outside the range of calc-alkaline fluids. N2/Ar ratios are lower than 100 in all samples with the sample from DDH TES-21-005 (black crosses) having N2/Ar ratios below 10. Ar/He ratios that near 1 are most often associated with basinal fluids. Samples from DDH TLG-Z8718-017 (blue squares) and J-21-303 (purple diamonds) have Ar/He ratios below 10.

VI. Conclusions and Future Work

- The Troilus deposit formed as the result of multiple stage of mineralization and remobilization, with an initial endowment of Au-Cu-(Ag) +/- Mo-Bi-Ni being associated with the intrusion of diorite.
- Metamorphic remobilization of intrusion-associated mineralization redeposited ore shoots in shear zones often located along previously active fluid conduits.
- Exploration should be conducted using a multi-stage orogenic model due to pervasive remobilization of the ore system. Competent intrusive rocks lying above Fe-rich units should be prioritized due a tendency to brittlely fracture during deformation coupled with iron decreasing the activity of sulphur in fluids to precipitate ore minerals.
- Petrography and EPMA suggest a genetic link between Au-Cu mineralization with petrography identifying textures evident of remobilization and EPMA showing variable Au/Ag ratios and mineral phases indicative of a reworked ore system.
- Quantitative fluid inclusion gas analysis indicates metal transport in the vapour phase prior to deposition upon condensation. Ratios of N2/Ar and Ar/He suggest ore was carried by metamorphic fluids.
- Continued petrographic analysis coupled with EPMA will be performed to better understand the textures and compositions of host rocks and mineralization.
- A fineness study on gold using WDS will be conducted to identify pulses of mineralization and aid geometallurgical studies.
- As a result of the complex history of the ore system present at the Troilus deposit, it is unlikely that primary evidence for an intrusion-associated system has been preserved. A future geochemical study of the diorite is required to assess magmatic fertility using Zr vs. Y ratios.
- Mass balance calculations will be performed using whole-rock geochemistry to understand element enrichment or depletion in samples to constrain the styles of alteration associated with mineralization.

VII. Acknowledgements

We would like to acknowledge that this research was conducted within the Eeyou Istchee James Bay region on the traditional lands of the Cree Nation of Misstissini. Thank you to Troilus Gold Corporation for their continued support of our research. Thank you to Stephen Wood and Sue Black for thin and thick section sample preparation. Thank you to Dr. Joshua Laughton for assisting with EPMA work.

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