Structural Geology and Timing of Deformation at Gibraltar Cu-Mo Porphyry Deposit; Cariboo Region, British Columbia

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Introduction

The Gibraltar Cu-Mo porphyry, located northwest of Williams Lake is hosted in the Granite Mountain batholith (217 M ±12) (Bysouth et al., 1995). The main ore zone, hosted within the Mine Series Phase tonalite, is structurally dismembered by several different deformation events. Questions still exist regarding the relationship between mineralization (215 ± 1.0 – 210 ± 0.9 M (Harding, 2012)) and the earliest deformation.

This study is part of the Targeted Geoscience Initiative 4 project which aims to expand knowledge of deep intrusion-related ore deposits across Canada.

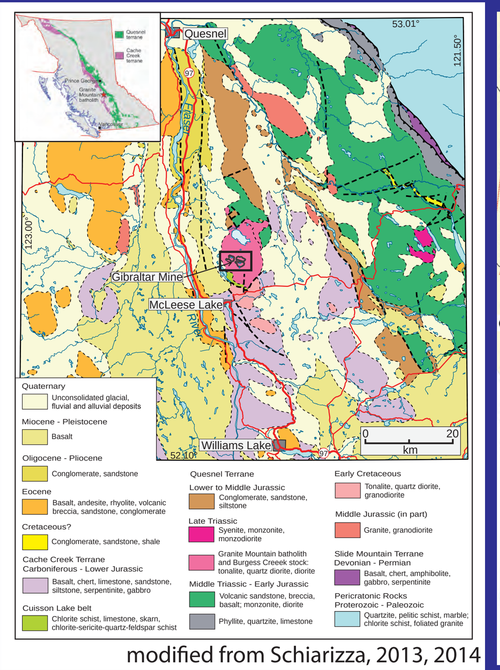
Objectives

1) Unravel the geometry and kinematics of deformation that have affected ore distribution;

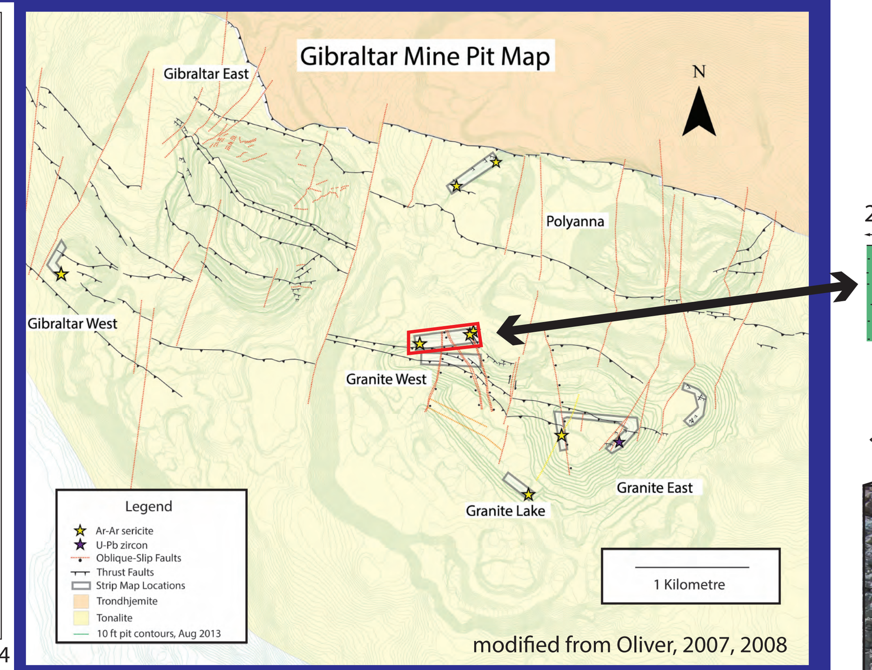
2) Place constraints on the timing of deformation structures, and;

3) Determine if batholith emplacement and mineralization were syn-kinematic with the earliest deformation structures or if structural modification of the deposit occurred post emplacement and mineralization

Regional Geology & Mine Geology



modified from Schiarizza, 2013, 2014



modified from Oliver, 2007, 2008

Left: Regional geology with Gibraltar mine in centre inset with four main pits outlined. Inset top left: British Columbia and the Cache Creek and Quesnel terranes and their spatial relationship to Gibraltar mine.
Right: Gibraltar pit map with the locations of the 7 bench walls mapped as part of this study. Granite Lake Faults (GLF - represented as thrust faults on map) are cross cut by N-S trending oblique-slip faults mapped by Oliver (2007, 2008). Modifications to some N-S trending faults within the Granite Lake pit are based on detailed structural mapping and ore displacement modelled on Leapfrog Geo 3-D visualization tools.

The Granite Mountain batholith contains highly sheared mafic phases south of the mine property and becomes increasingly more felsic towards the north, consisting of diorite, quartz diorite phases, tonalite phase and trondjhemite; locally, intrusions of late leucocratic quartz porphyry dikes are observed.
The Mine phase tonalite is relatively equigranular with an average grain size of 2-4 mm, comprising of ~15-25% qtz, 40-50% plagioclase and 25-35% chlorite (altered hornblende) and hosts most of the mineralization at Gibraltar porphyry.

The deformation intensity generally contains a positive correlation between the alteration and mineralization (e.g. Oliver, 2007; van Straaten et al., 2013). Veins predominantly comprise different alteration zone assemblages. The chart below is based on field mapping and drill core logging observations: this data was used to construct cross sections of the Granite Lake operational pit.

Hydrothermal Alteration Assemblage	Alteration Characteristics	Vein Assemblage	Vein Shape and Texture	Mineralization Stage
Saussurite-Chlorite (Albite-Epidote-Zoisite)	No alteration to pale yellow-green saussuritization of feldspars, chloritized-Hbl and presence of epidote veinlets	Ep	1 mm planar veinlets and 4-5 cm wide diffused flooding	Pre-mineralization
Propylitic (Chlorite-Epidote)	Increase in pale yellow-green saussuritization of feldspars, chloritized-Hbl, epidote grains and veinlets, and Chl-Ep veins*	Chl+Ep±Py±Cpy±Qtz±Cb	1-15 mm wide Chl-Ep vein. a) thin, planar; b) wider, diffuse margins; c) wider, diffuse Qtz-envelope; d) Cb and cubic Py in the centre ±Cpy	Early
Chlorite-Quartz	Alteration intensity characterized by vein density and ranges from no pervasive matrix alteration to prevalent Qtz and Chl replacement of Fsp*	Qtz±Chl±Mag ±Py±Cpy±Mo	2-20 mm wide Qtz-vein with Chl-halo. Sometimes Mag/Chl/Mo/Cpy±Py aligned in centre. a) sharp boundaries; b) no margins, grey Qtz; and c) disconnected, wavy veins with more diffuse Qtz-Chl margins*	Main
Quartz-Sericite	Qtz-Ser flooding	Qtz+Ser	Qtz-Ser flooding and replacement of Chl-Qtz-Fsp alteration	Late
Quartz-Sericite-Chlorite	Finely disseminated Ser± pale Chl*±Qtz alteration of matrix. Euhedral grains of Py are sparse	~	No specific vein is closely associated with this alteration	Late
Phyllic (Quartz-Sericite-Pyrite)	Occurs in varying intensities. Weak QSP alteration is distinguished by 1-3 cm wide sheeted veins, while stronger QSP alteration is characterized by pervasive replacement of the matrix by Qtz and Ser*	Qtz+Ser+Py± Cpy±Mo	a) 1-3 cm wide sheeted grey Qtz-veins, with Ser-Qtz envelopes and cubic Py aligned in the centre. b) 1-200 cm wide milky-white veins, with parallel sheeted Mo-veinlets, host bulk Mo-mineralization (Harding, 2012)	Late
Ankerite-Quartz	Pale Ank-Qtz alteration commonly associated with high strain zones. Sulphide mineralization may occur with Ser±Chl folia*	Ank-whisps	2 mm in size, separated sinuous whisps. Veins were either completely deformed or transposed as they are unidentifiable	Late
~	Not associated with any specific alteration assemblage	Qtz+Chl±Cpy ±Py±Cb	10 cm-1 m thick, boudinaged Qtz-veins with Chl-knots ±Py±Cpy blebs, enveloped by Chl/Ser-folia	Late or Post-mineralization

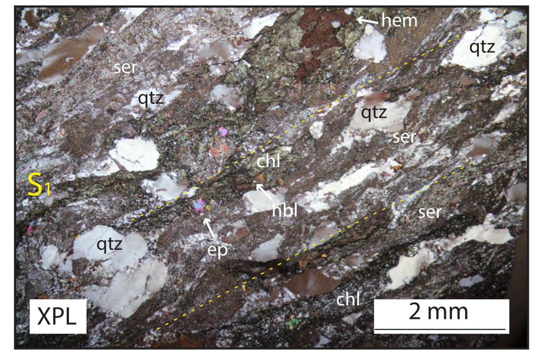
Modified from van Straaten et al., 2013

All references are available upon request

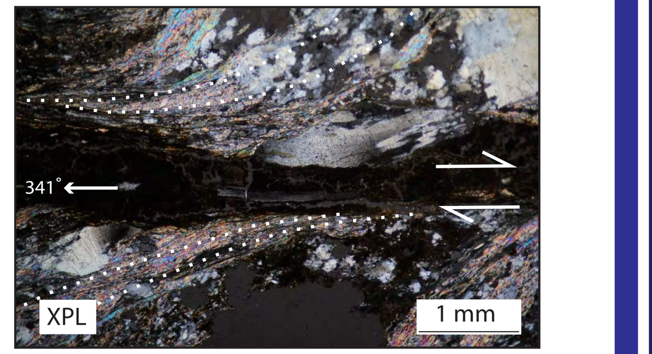
Field Observations

Alteration assemblages are based on the predominant (>50%) alteration assemblage.
Foliation intensity increases with decreasing space between form (strike) lines

Discontinuous sub-horizontal high strain zone oblique to inclined boudinaged qtz-vein.

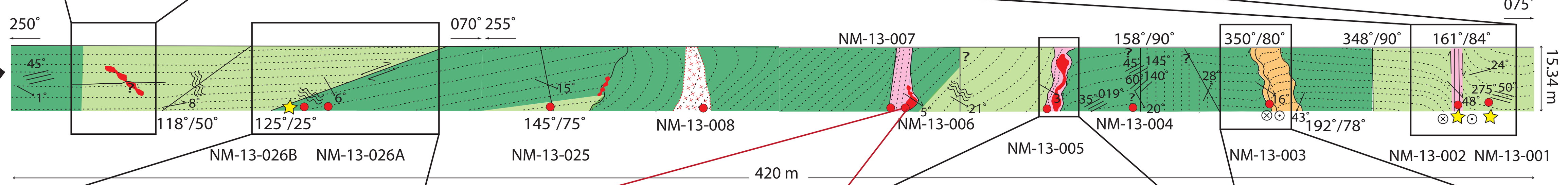


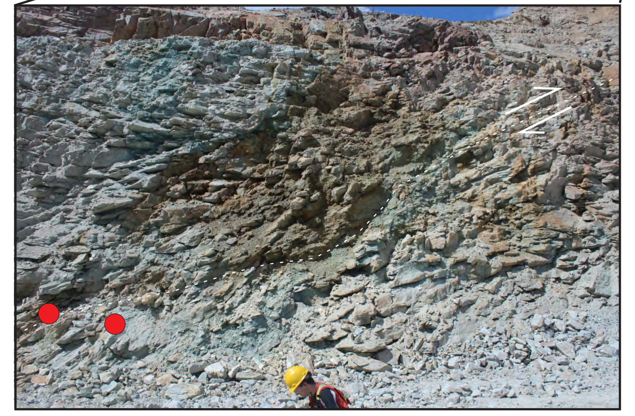
Propylitically altered Mine phase tonalite with S1 fabric defined by elongate qtz porphyroclasts and chloritized hbl, ep and chl. Drill core sample colllected from Granite Lake West pit.



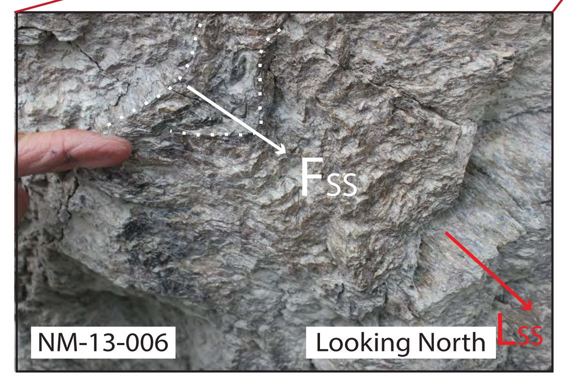
Left: N-S trending dextral, oblique strike-slip fault with ~2m wide cataclastic zone. High-angle fault cross-cuts and drags S1 foliation, displaying east-side down kinematics.
Above: Photomicrograph looking down on the fault in left photo; dextral shear sense is shown by the dragging of sericite by micro-fault.

Granite Lake West: 3770' - 3950' Ramp

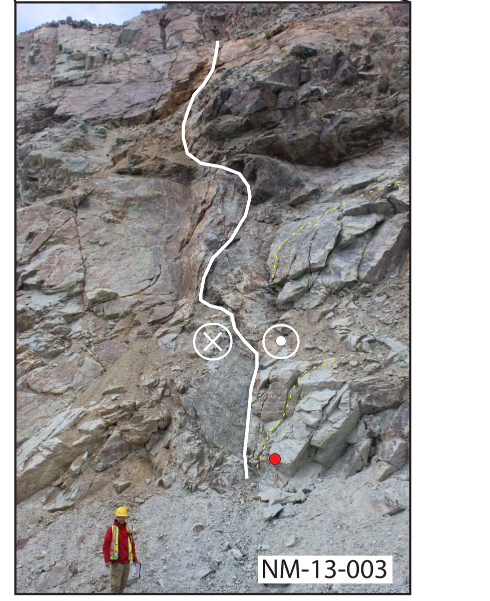




Above: Smaller scale thrust fault with the same attitude as the larger pit-scale GLF. Blue colour represents elevated copper oxides in the fault zone. Below: hand sample collected from the left red dot shown above in the fault zone, showing mylonitic fabric.

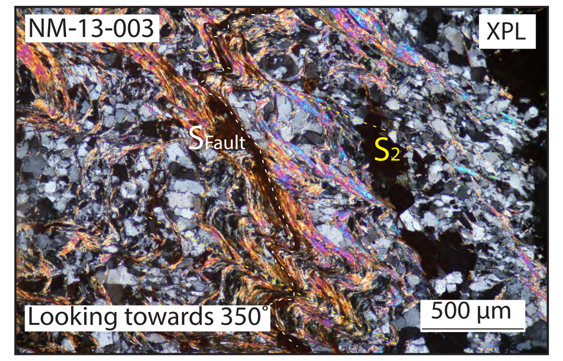


Above: Crenulated cataclastic fault fabric with fold axes parallel to slickenside and intersection lineations, all plunge shallowly to the SE.



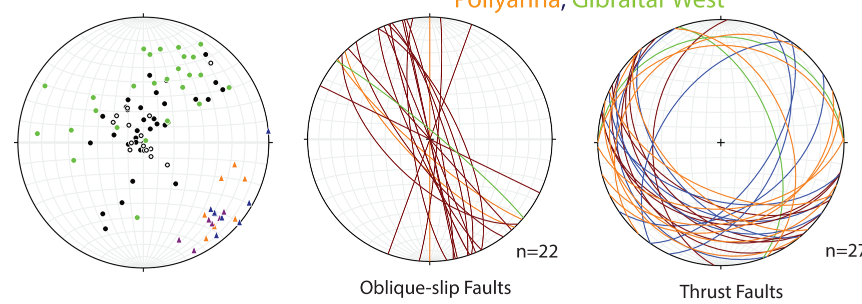
Above: Folded and highly oxidized N-S trending dextral, oblique strike-slip fault. Fold axes are SE-plunging and parallel to all other lineations.

Above: High-angle oblique-slip fault zone with west-side down kinematics and commonly observed cataclastic developed in the fault zone core. Steeply-inclined boudinaged qtz-vein are common in high-angle faults and have shallowly SE-plunging lineations defined by the boudin necks.
Right: Photomicrograph of fault directly above it; fault fabric is crenulated with a weak crenulation cleavage (S2) parallel to dynamically recrystallized qtz (subgrain rotation recrystallization).



Faults: Granite Lake West; Granite Lake East; Pollyanna; Gibraltar West

Stereograph Legend
- Poles to Chl-Ep veins
- Poles to Magmatic Foliation, S_M
- Poles to Tectonic Foliation, S_1
- Intersection Lineations, L_I
- Fold Axes, F_{SS}
- Slickensides, L_{SS}



Oblique-slip Faults

Thrust Faults

Tectonic Foliation; Magmatic Foliation; Fold Axis; Lineation (Slickensides, mineral); Fault/High strain-zone; Crenulation cleavage; Crenulation lineation; Crenulation axial surface; Shear sense; Boudinaged Qtz-vein; Qtz-mo vein; Chl-Ep vein; Folded Chl-Ep veins; NM-13-001 Sample ID; Sample location; Ar-Ar illite location

Alteration: Sausserite-Chl; Chl-Ep; Chl-Qtz; Qtz-Ser-Chl/Qtz-Ser; Qtz-Ser-Py

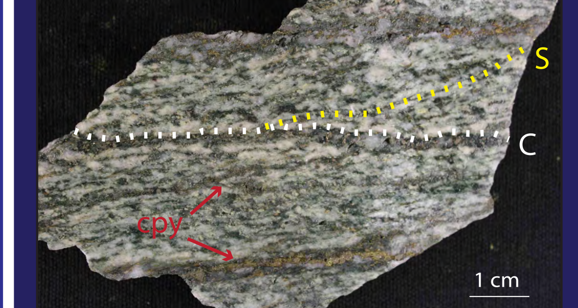
Lithology: Feldspathic tonalite; Leucocratic tonalite; All other rock is Mine phase tonalite

Relative Timing of Deformation

1. SM; Magmatic foliation
2. S1; tectonic foliation, variable intensity
3. Discontinuous sub-horizontal high strain zones
4. Thrust faults
5. NW-SE trending dextral, oblique strke-slip fault zones
6. S2; Crenulation cleavage

Relative Timing of Intrusion and Deformation

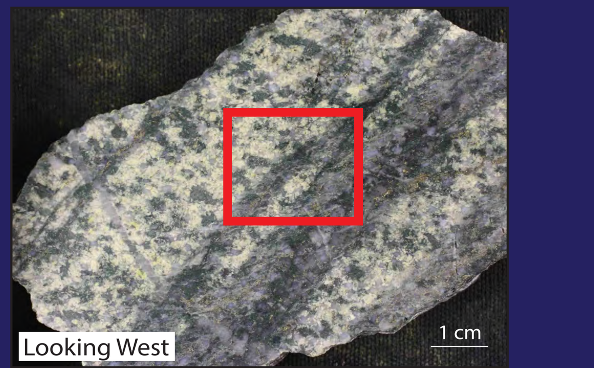
I: Foliation overprints mineralized veins

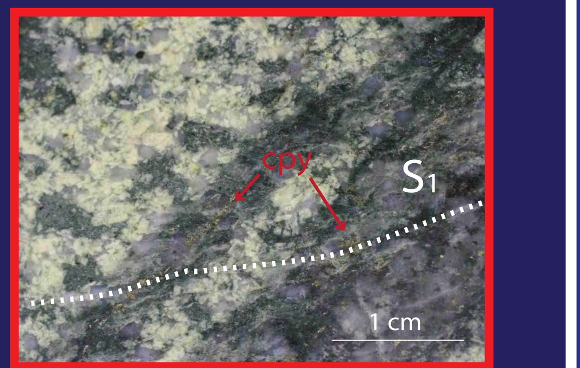


Far left: S-C fabric defined by early-stage sheeted mineralized veins (Chl-Ep: C-surfaces), oriented oblique and parallel to sub-parallel to the tectonic foliation, with a top to the NE direction (Oliver et al., 2009; Ash & Riveros, 2001; Drummond et al., 1976; Sutherland Brown et al., 1974). S-surfaces defined mostly by elongate qtz.

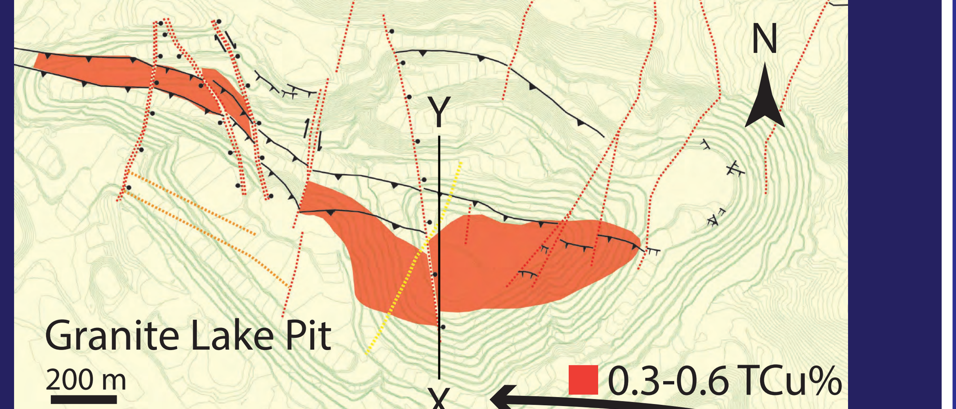
Near left: Folded early-stage mineralized veins, likely formed under the same stress as the boudinaged qtz-vein. Qtz-vein contains large chl-knots and large py and cpy blebs

Right: S1 foliation defined by sericite and a weak chlorite alignment, the sericite foliation overprints previously saussuritized, and veined Mine phase tonalite and refracts into a steeper orientation in the vein.





The orebody in Granite Lake pit is confined to a "panel" within the two main GLFs (Oliver, 2008), and are offset by NW-SE trending dextral, oblique strike-slip faults. Orebody was interpolated on Leapfrog and projected onto a 2013 pit map with faults mapped by Oliver (2008), and modified by the author using microstructural analysis, field observations and Leapfrog.

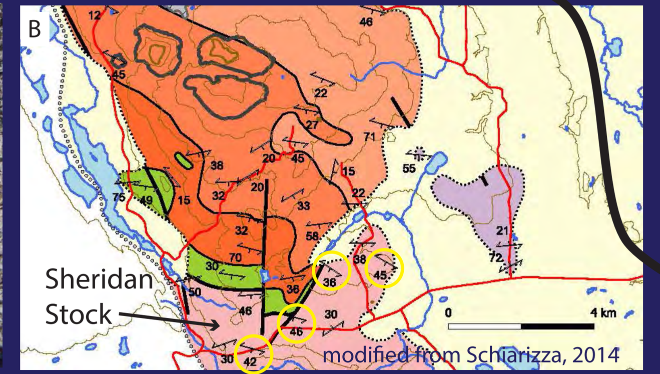


II: Sheridan stock

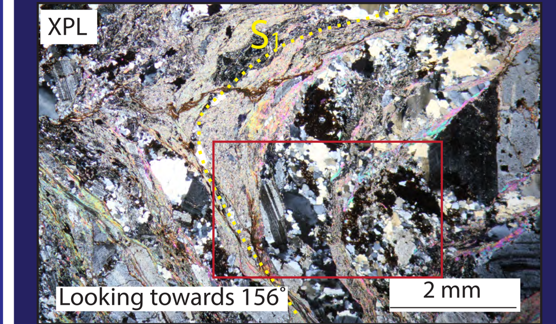
A: Foliated Sheridan stock tonalite with foliation oriented 085/46, looking down on outcrop.

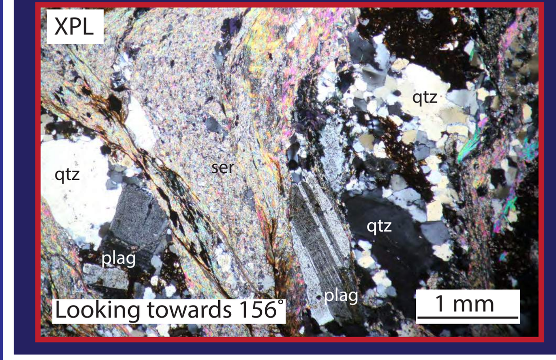
B: Variably foliated tonalite. Foliation defined by elongate qtz and sericite-illite lamellae. Foliation is E-W striking, and south dipping as observed in locations demarcated by yellow circles on the map. Data from Schiarizza, 2014.

We interpret this fabric to be the same as S1 in the Gibraltar porphyry



III: Temperature of deformation





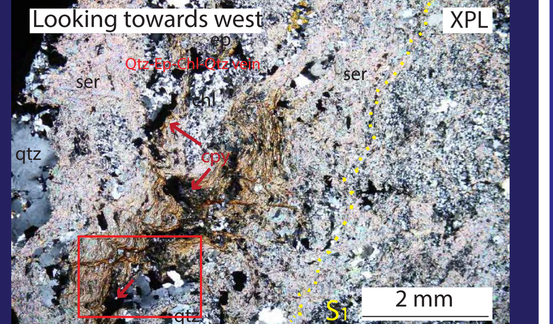
Left: S1 defined by elongated qtz sericite lamellae. Folded with vergence towards the NE.

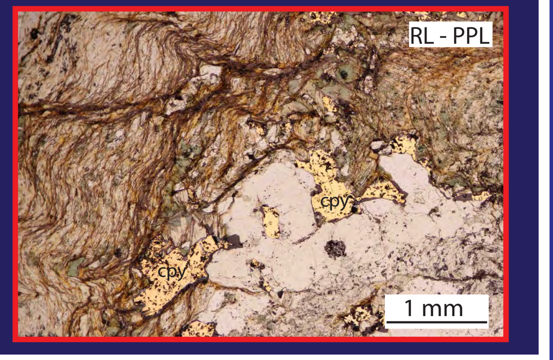
Weak subgrain rotation and bulging recrystallization of qtz are indicative of dislocation creep and temperatures of >300°C to <400°C in dry conditions.

However, given the involvement of hydrothermal alteration and veining, fluids likely play a large role in deformation and would ultimately lower the required temperature for qtz deformation.

Plagioclase is relatively undeformed and displays minor undulose extinction indicating <450°C.

Right: Moderately dipping, and crenulated S1, parallel to mineralized vein with cpy. Cpy brittly deformed by shallowly dipping S2 crenulation cleavage.

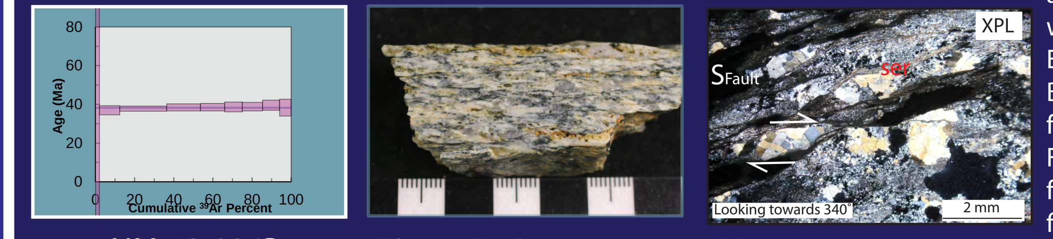




Ar-Ar (Muscovite) Geochronology

NM-13-001 — S1 Foliation: 54.1 ± 6.4 Ma

NM-13-039 — Sub-horizontal discontinous high strain zone: 41.4 ± 4.8 Ma



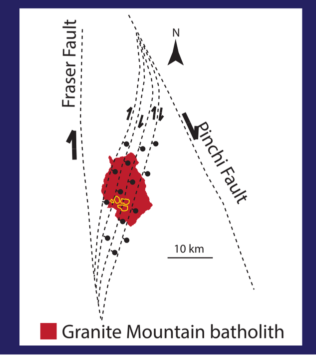
NM-13-026B — Thrust Fault: 38.30 ± 0.75 Ma

NM-13-002 — High-angle oblique-slip fault: 40.91 ± 0.96 Ma

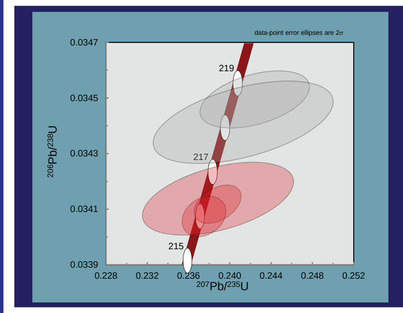
Eocene ages for Ar-Ar (muscovite) geochronology of various structures at Gibraltar mine range from 54-38 Ma. We interpret these age results as follows:

1. a) Dextral strike-slip faults are Eocene and related to the Fraser and Pinchi fault systems.
   b) Other structures may have:
   i) All formed in the Eocene
   OR
   S1, thrust faults and subhorizontal high strain zones formed earlier than Eocene, but the Ar-Ar has been reset to Eocene ages

2. Because of the range of Eocene ages obtained, we speculate that resetting was caused by episodic fluid flow in the Eocene, rather than by intrusive activity. Below we speculate a step-over strike-slip fault system formed from the Pinchi and Fraser faults to have formed the N-S striking faults at Gibraltar, and provided conduits for fluid flow.

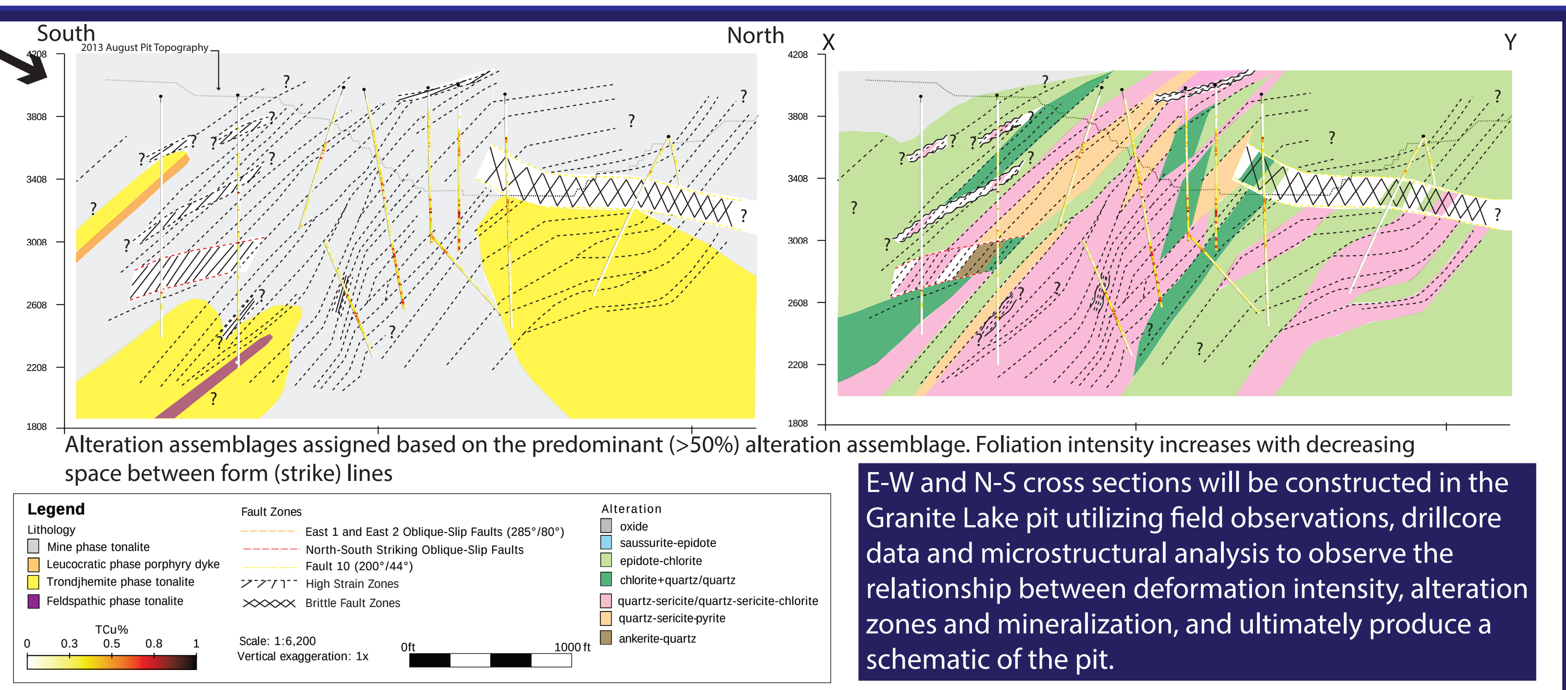


U/Pb (zircon) TIMS Analysis - 216.17 ± 0.24 Ma



Previous U-Pb (zircon) age-dates of the Mine phase tonalite contained large error bars: 211.9 ± 4.3 Ma (Oliver, 2009); 208 ± 12 Ma (Drummond et al., 1976).

Concordia plot (far left); top right: zircons collected and used for U-Pb analysis; bottom right: NM-13-009, Mine phase tonalite collected in Granite Lake East pit.



Alteration assemblages assigned based on the predominant (>50%) alteration assemblage. Foliation intensity increases with decreasing space between form (strike) lines

E-W and N-S cross sections will be constructed in the Granite Lake pit utilizing field observations, drillcore data and microstructural analysis to observe the relationship between deformation intensity, alteration zones and mineralization, and ultimately produce a schematic of the pit.

Acknowledgements

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