The AGS Fluorite Deposit, St. Lawrence: Paragenetic sequence, fluid inclusion analysis, structural control, host rock geochronology and implications for ore genesis

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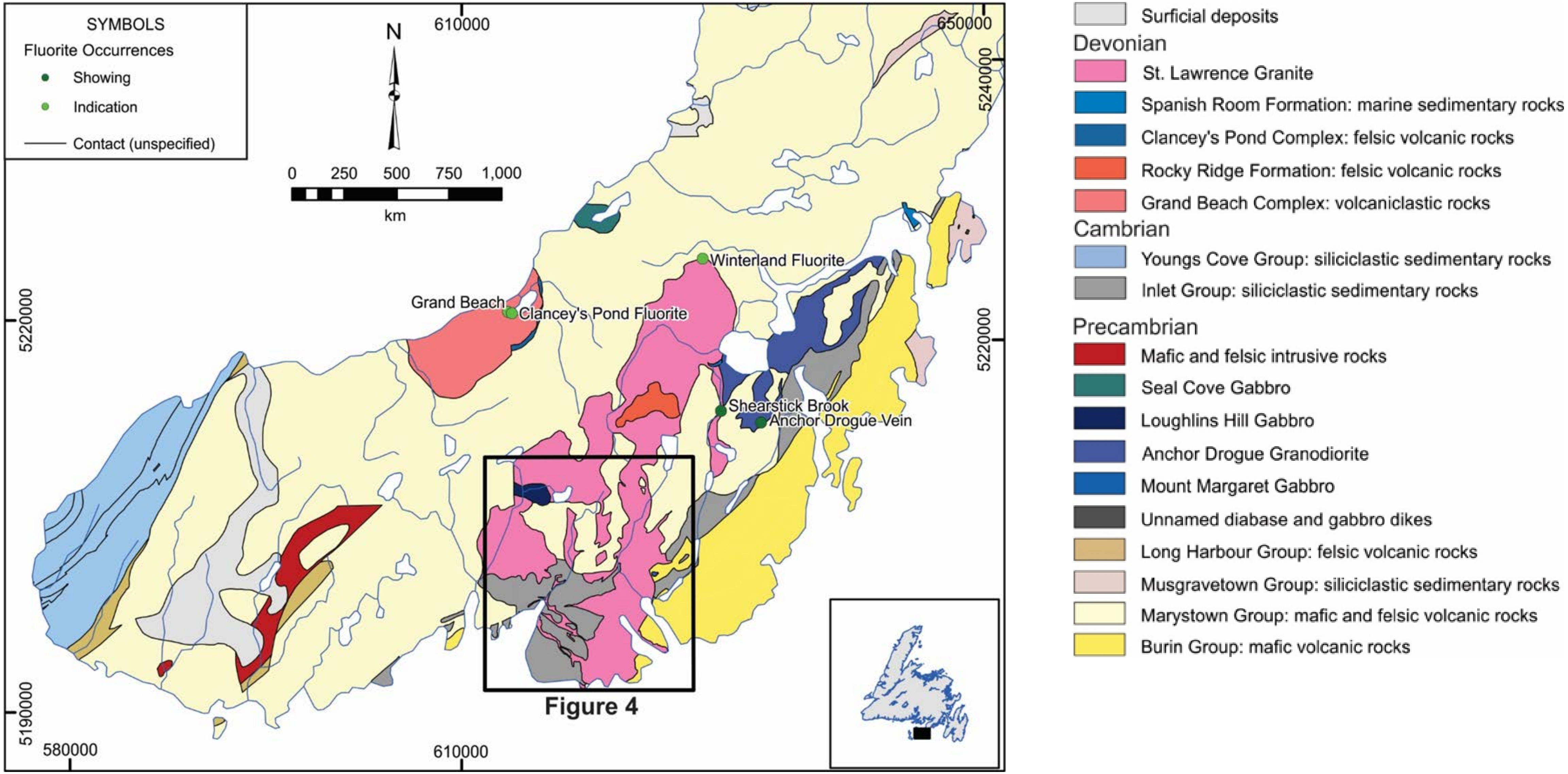
Outline

- Purpose of study
- Regional and local geology
- St. Lawrence fluorite deposits
- AGS Deposit
    - ❖ Rhyolite sills
    - ❖ Geochronology
    - ❖ Structure of the AGS deposit
    - ❖ Paragenetic sequence
    - ❖ Fluid inclusion analysis
- Discussion

Purpose of Study

- In the past all economic fluorite mineralization in St. Lawrence was found in veins hosted in St. Lawrence granite
- AGS is the first fluorite deposit of economic importance not entirely hosted in granite
- Investigate AGS vein system to better understand how it formed, which may help identifying similar ore bodies in the St. Lawrence area and elsewhere in Newfoundland

Regional and Local Geology

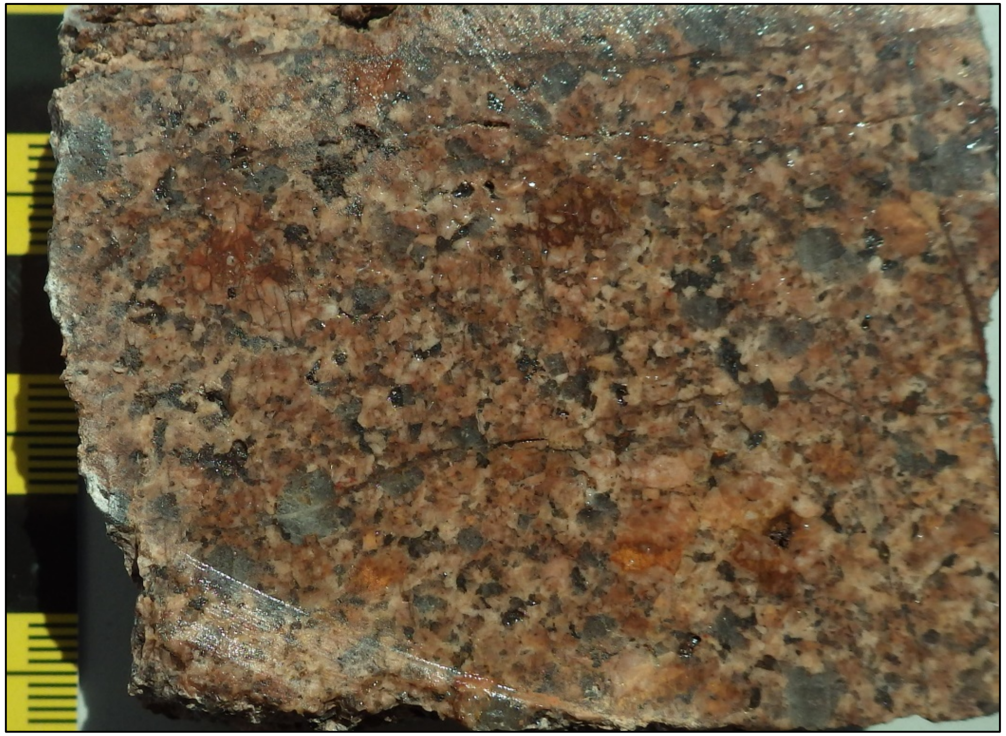


St. Lawrence Granite (SLG)

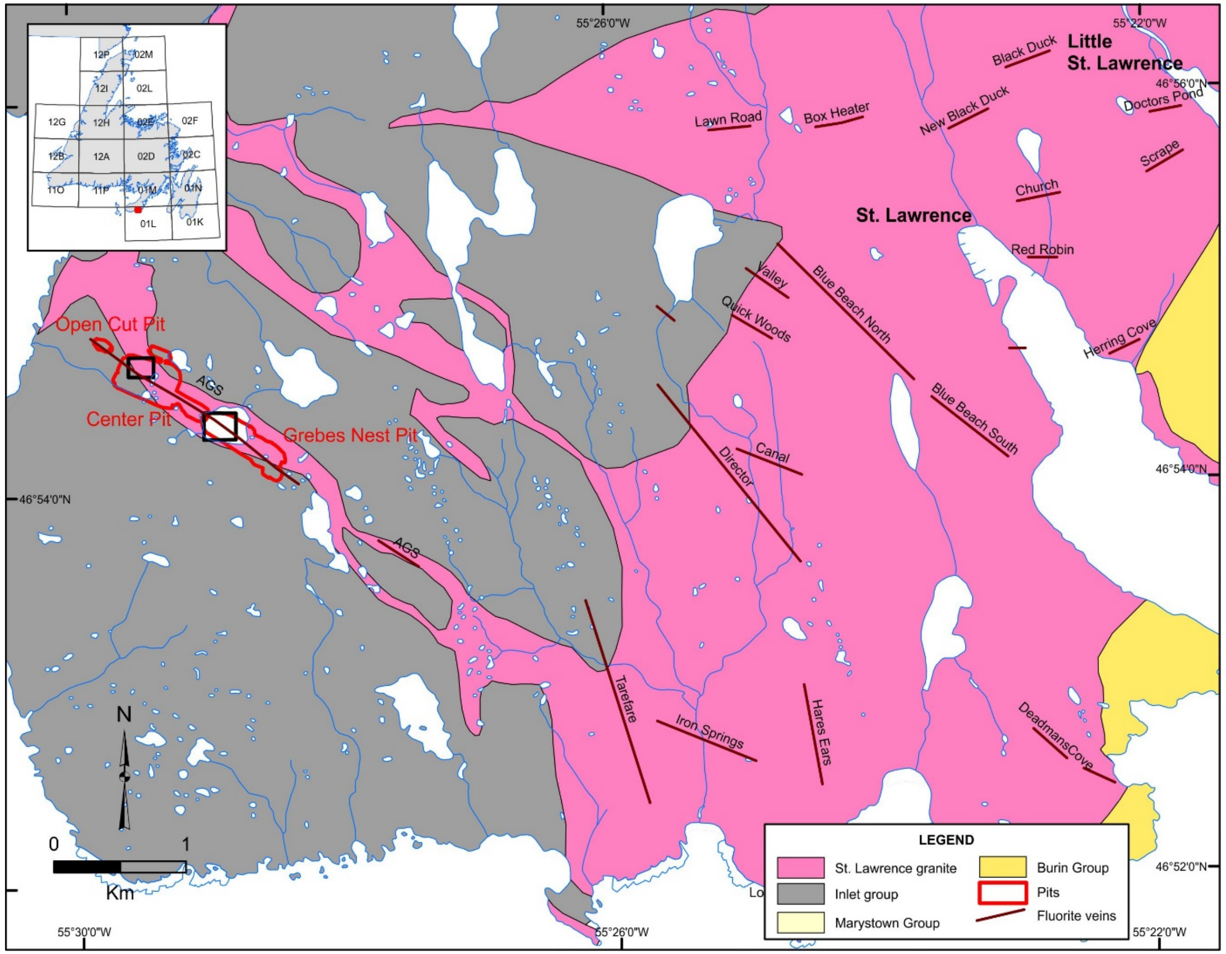
Intruded along pre-existing normal faults
Several phases: coarse-, medium-, fine-grained and porphyritic granite (rhyolite sills), tuffisites (gas breccia)
Age of the main granite is 374 ± 2 Ma (Kerr et al., 1993) and the rhyolite sills is 377.2 ± 1.3 Ma (this study)
Intruded at shallow depth suggested by

- presence of extensive dyke swarms of rhyolite porphyries,
- preserved portions of a volcanic cover sequence (Rocky Ridge Formation),
- miarolitic cavities, gas breccias (tuffisites), and
- vuggy pegmatitic segregations indicative of volatile exsolution

Roof of the pluton is around St. Lawrence (abundance of porphyritic phases and fluorite veins)
Peralkaline, WPG (A-type) granite with quartz, K-spar, minor plagioclase, aegirine, riebeckite as the main minerals



St. Lawrence fluorite



Over 40 fluorite veins

Up to 30 m in width and 3 km in length

4 types:

- N-S trending low-grade veins
- E-W trending high-grade veins
- NW-SE trending veins in sedimentary rocks (AGS)
- E-W trending peripheral veins

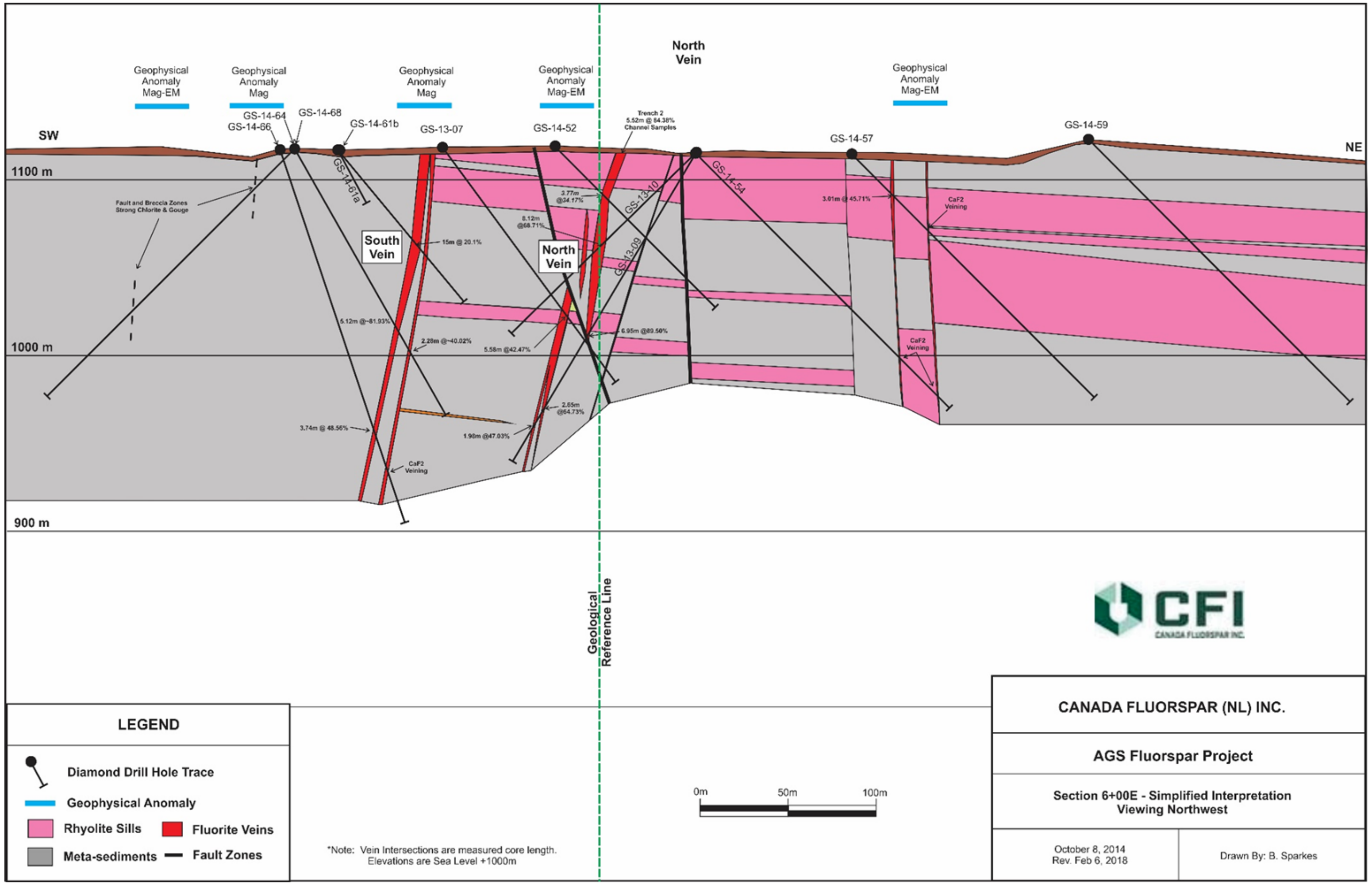
Fluorite mineralization formed as open-space fillings in tension fractures created by regional stresses and contraction resulting from the cooling granite

F-rich fluids separated from the cooling granite underneath, migrated upwards and precipitated fluorite in fractures formed in the upper part of the granite

Lack of economic fluorite outside the granite is explained by:

- Sediments became hornfelsed and impermeable
- Open fissures in the cooling and contracting granite hosting fluorite closed as they entered the country rocks that were not subjected to cooling

AGS Deposit



1.85 km long

Several fluorite veins pinching and swelling

Veins are up to 30 m wide and 700 m long

Hosted in sedimentary rocks and rhyolite sills intruding them

Main SLG intersected at 250 to 300 m

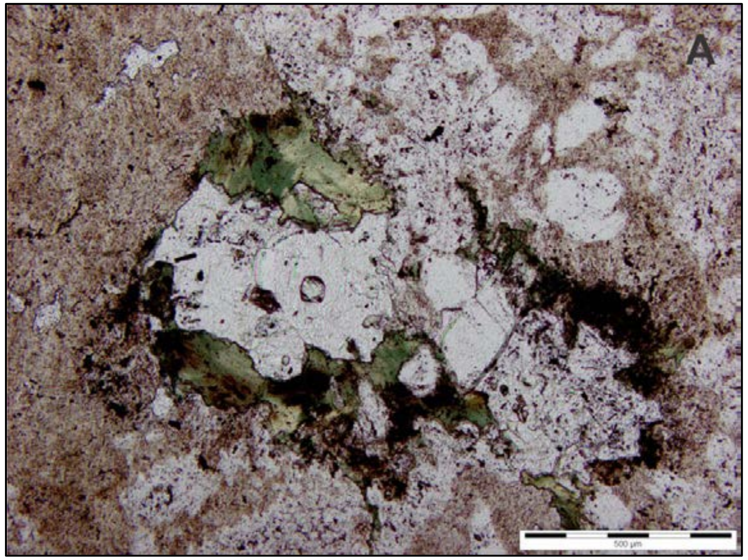
Veins continue into main SLG

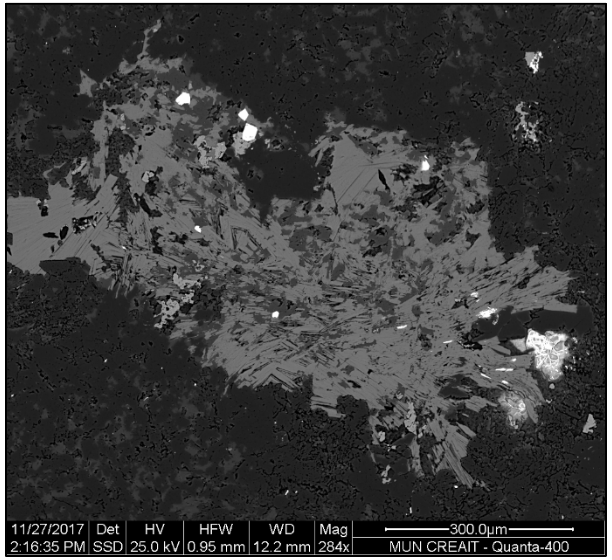
Resource is 9,389,049 tonnes at 32.88% fluorite (2014, NI 43-101 compliant)

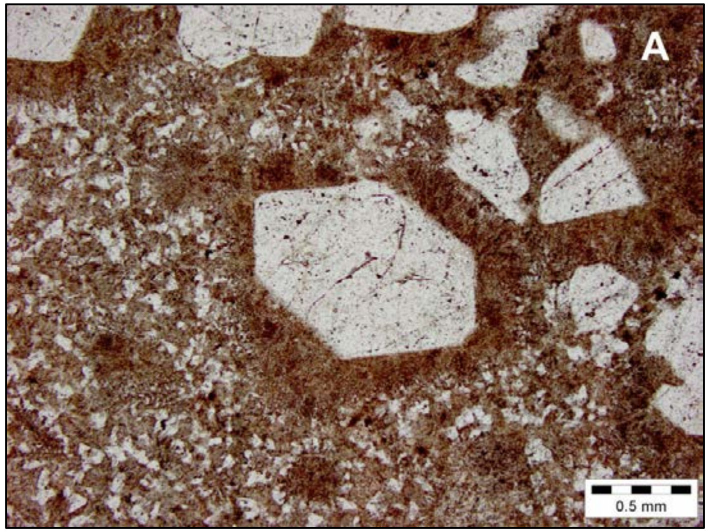
Controls on fluorite mineralization:

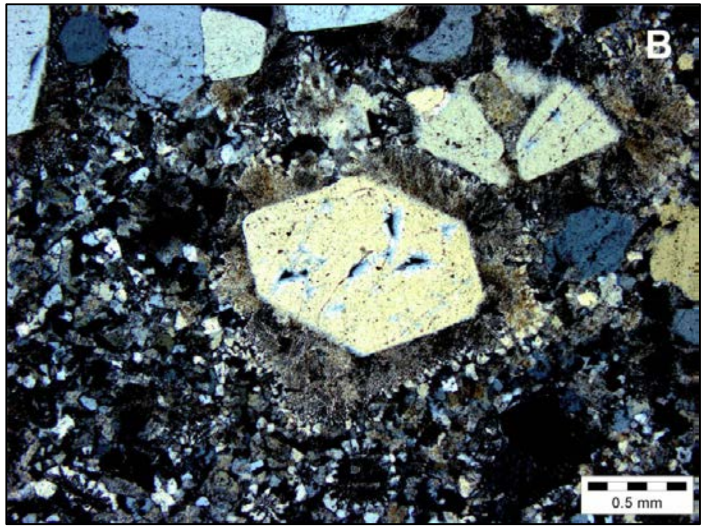
- Rhyolite sills
- Faults
- Main SLG underneath

Rhyolite







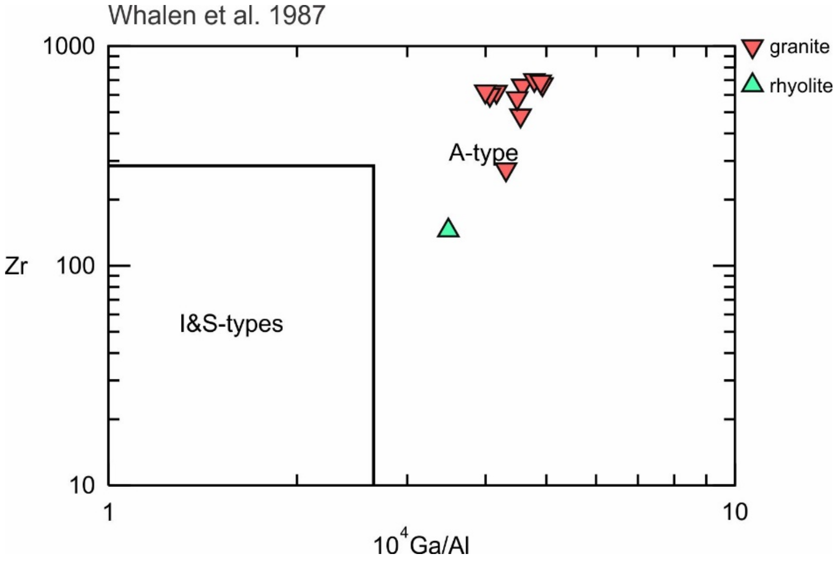


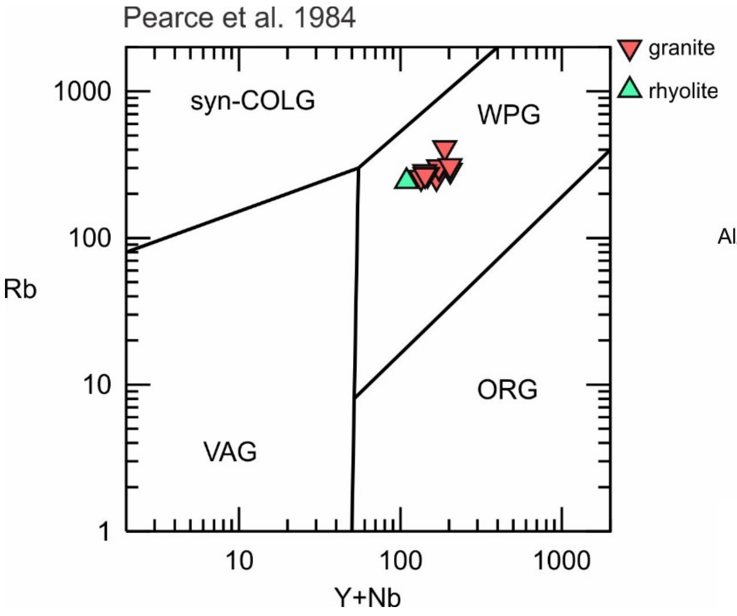
Minerals in rhyolite include: quartz, K-spar, albite, chlorite (alteration after mafic minerals), sericite (alteration after feldspar), zircon, REE-minerals, fluorite, hematite

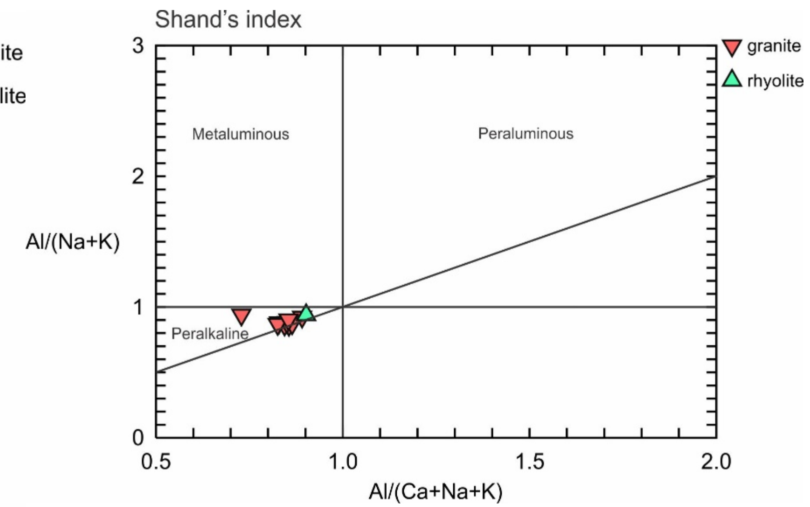
Fluorite, chlorite, zircon, REE-minerals and hematite occur in miarolitic cavities and/or interstitially to the other mineral, suggesting they crystallized last, common in peralkaline granites

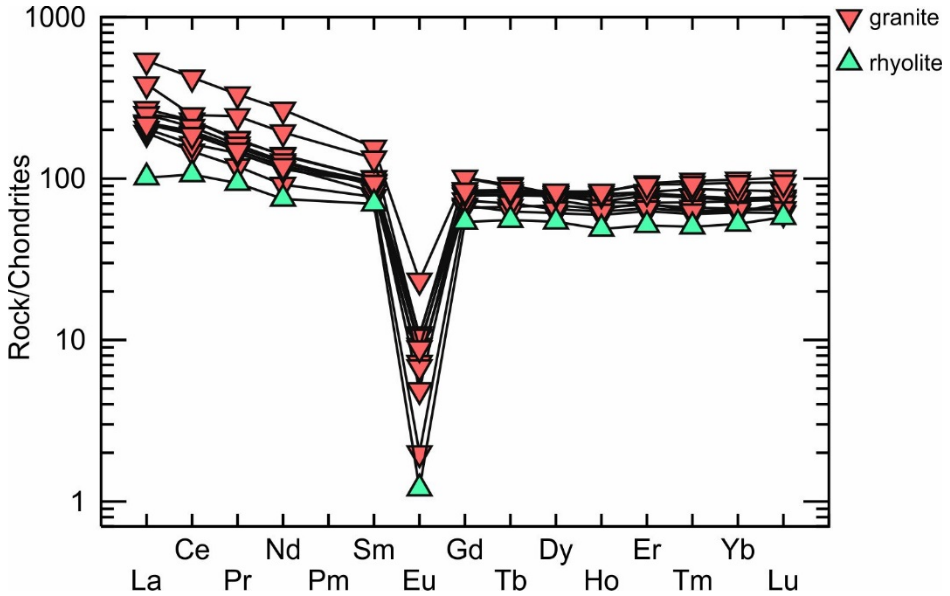
Same minerals as phenocrysts and in groundmass suggest two-stage cooling with undercooling in the second stage (abundant granophyric texture, skeletal, dendritic K-spar surrounding phenocrysts)

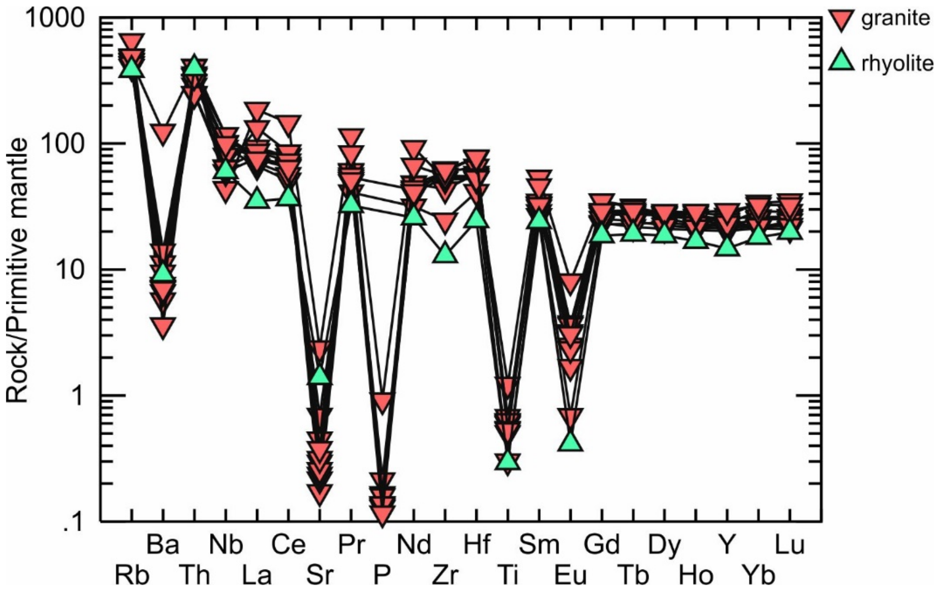
SLG geochemistry











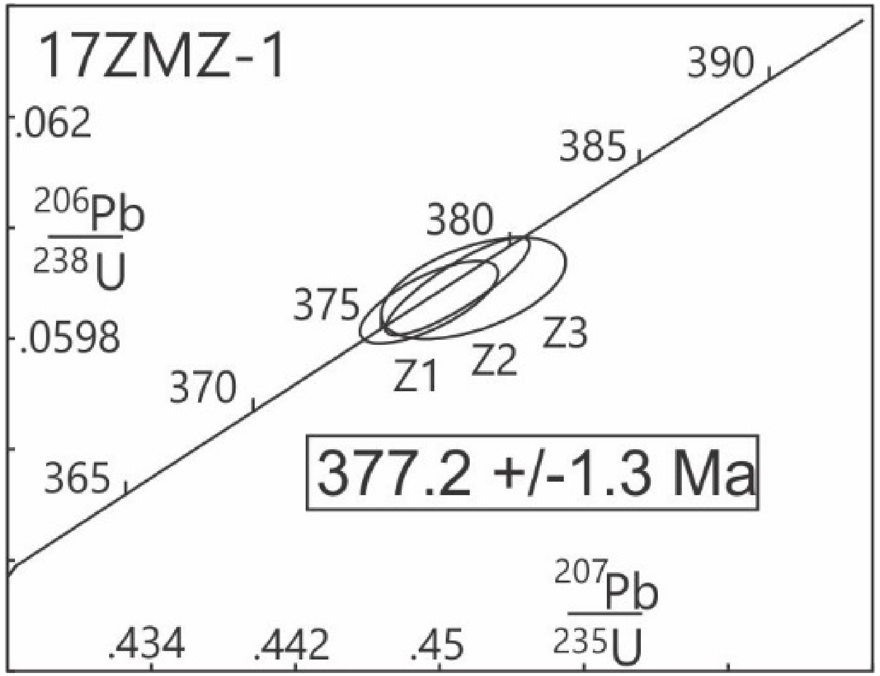
Geochronology of the rhyolite sills

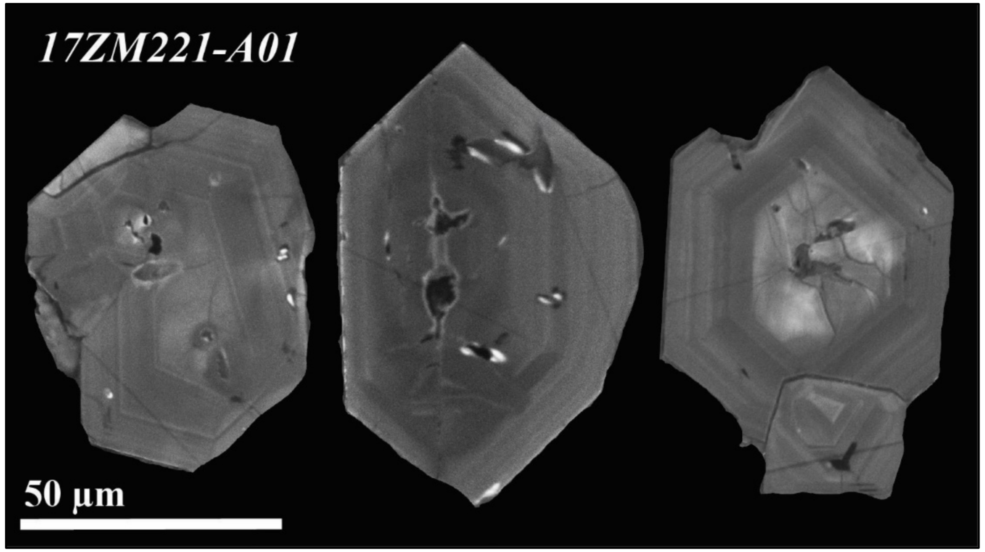
U-Pb in zircon

Result 377.2 +/-1.3 Ma

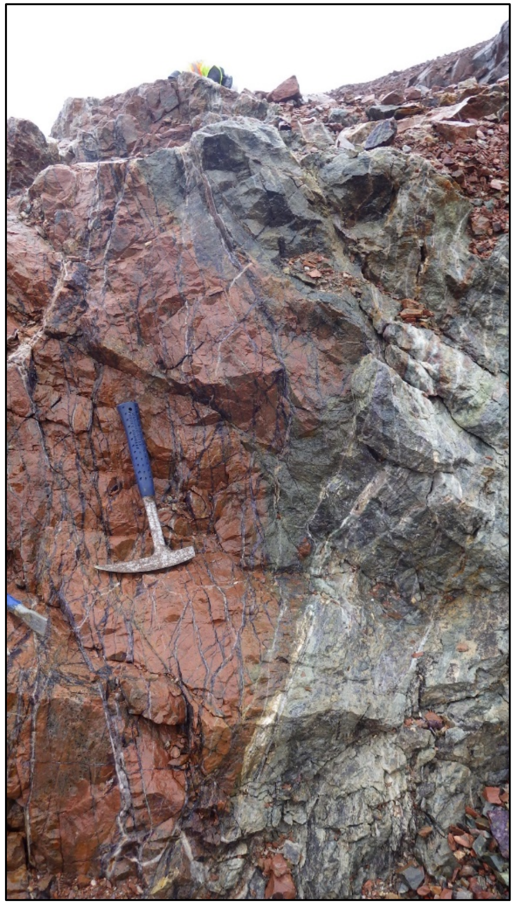
Earlier phase of SLG (age of main phase 374 +/-1.2 Ma)

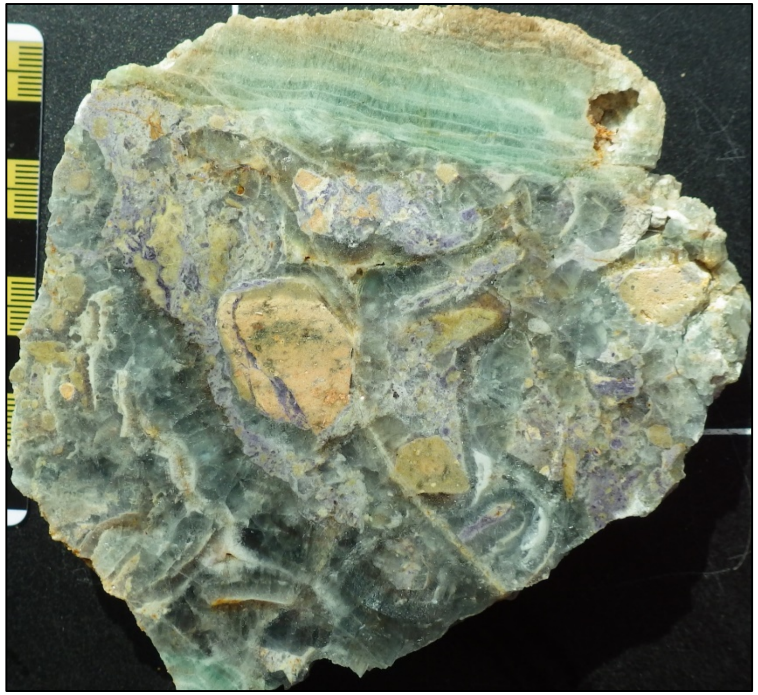
Rhyolite separated early during ascent of granitic magma, possibly due to a pressure drop, and intruded at shallower levels where it cooled faster



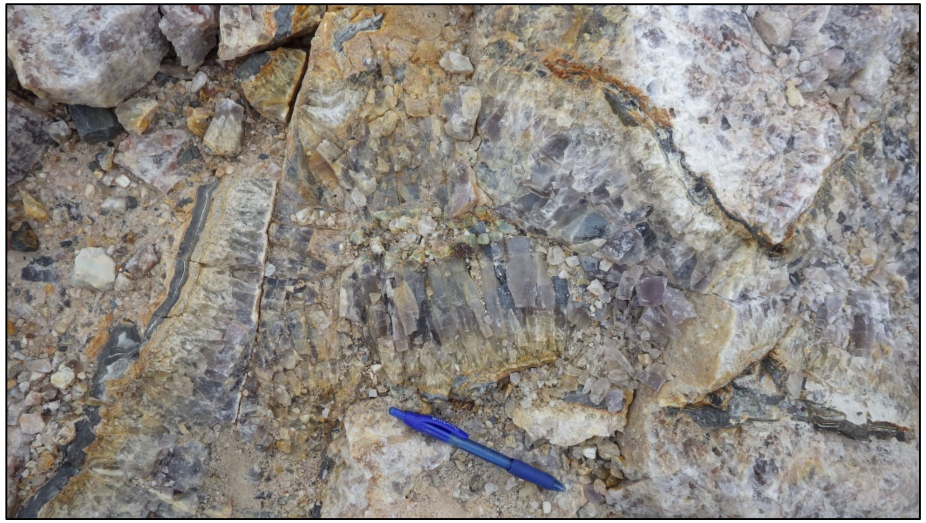


Structure of the deposit





Faulted contacts with mineralization
Horizontal slicken-sides indicate strike-slip faulting
Several phases of fluorite, typically brecciated, with later phases cementing earlier phases
Brittle conditions with high fluid pressure
Local extensional zones host high-grade mineralization



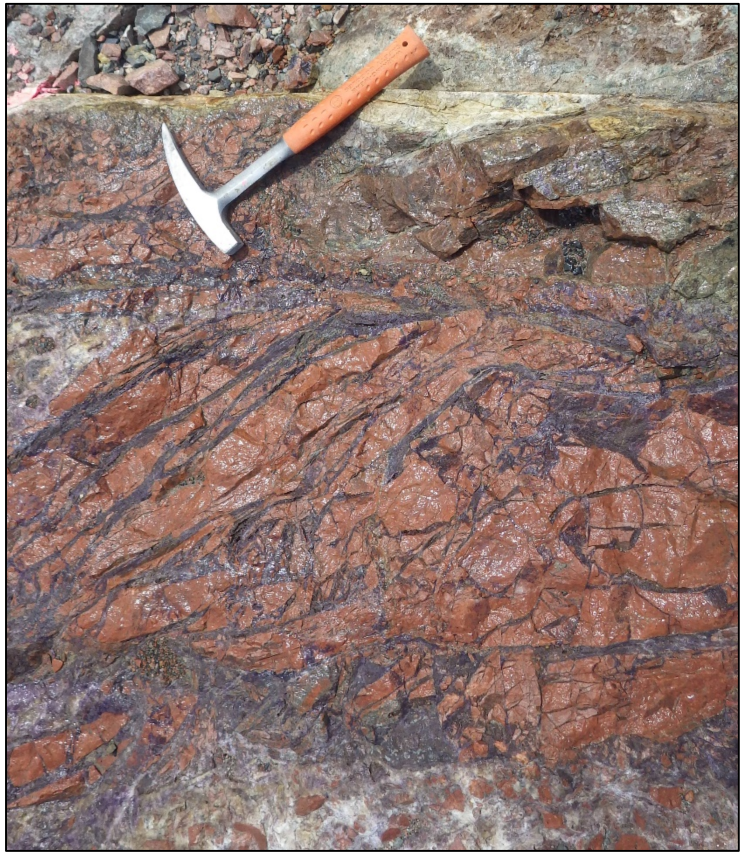
Fluorite mineralization was according to "fault-valve model" (Sibson et al., 1988):

1. Pre-failure: fluid pressure build-up below fault zone
2. Seismogenic fault failure: fluid pressure exceeds lithostatic pressure leading to fault reactivation and creating fracture permeability
3. Post-failure discharge: drainage of the fluid leading to mineral deposition
4. Self-sealing: hydrothermal deposition seals the fracture
5. Repetition of cycle

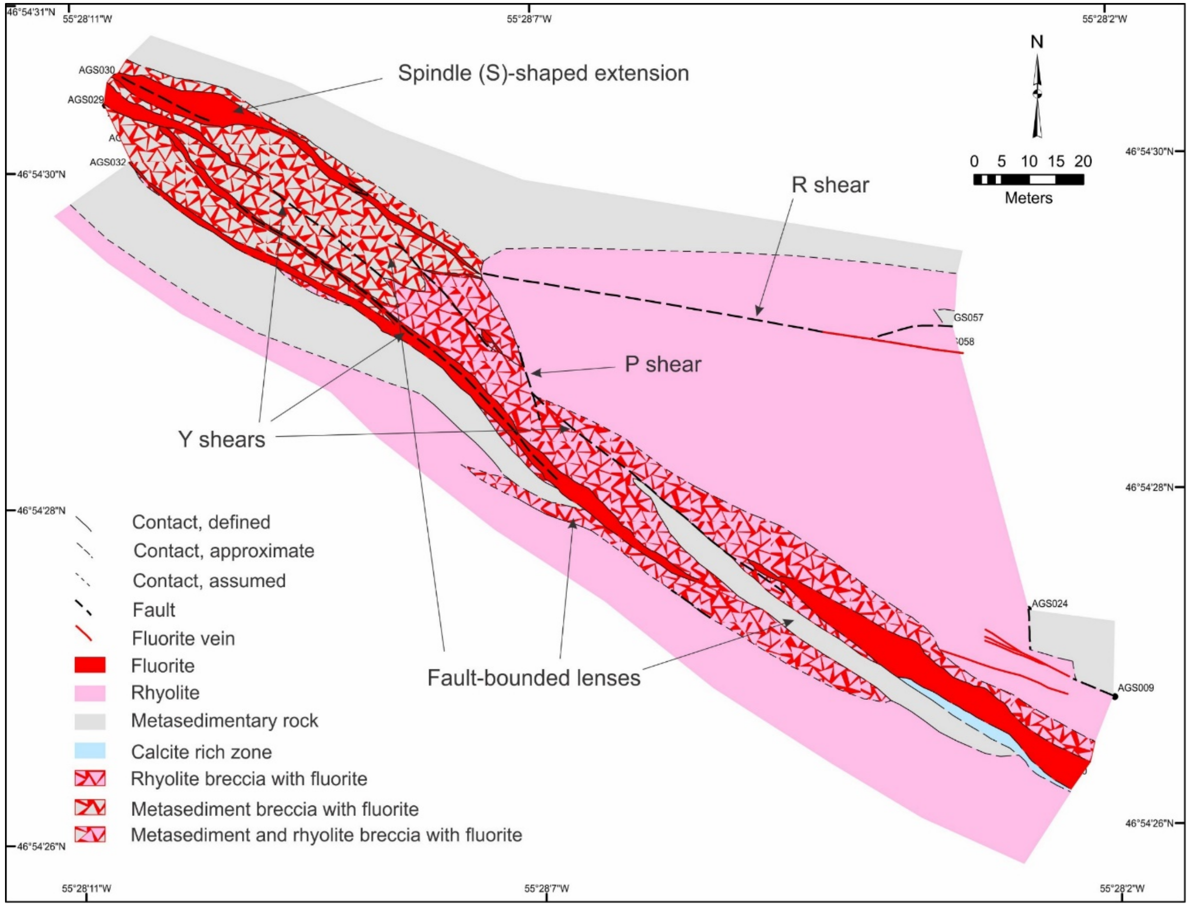
Structure of the deposit

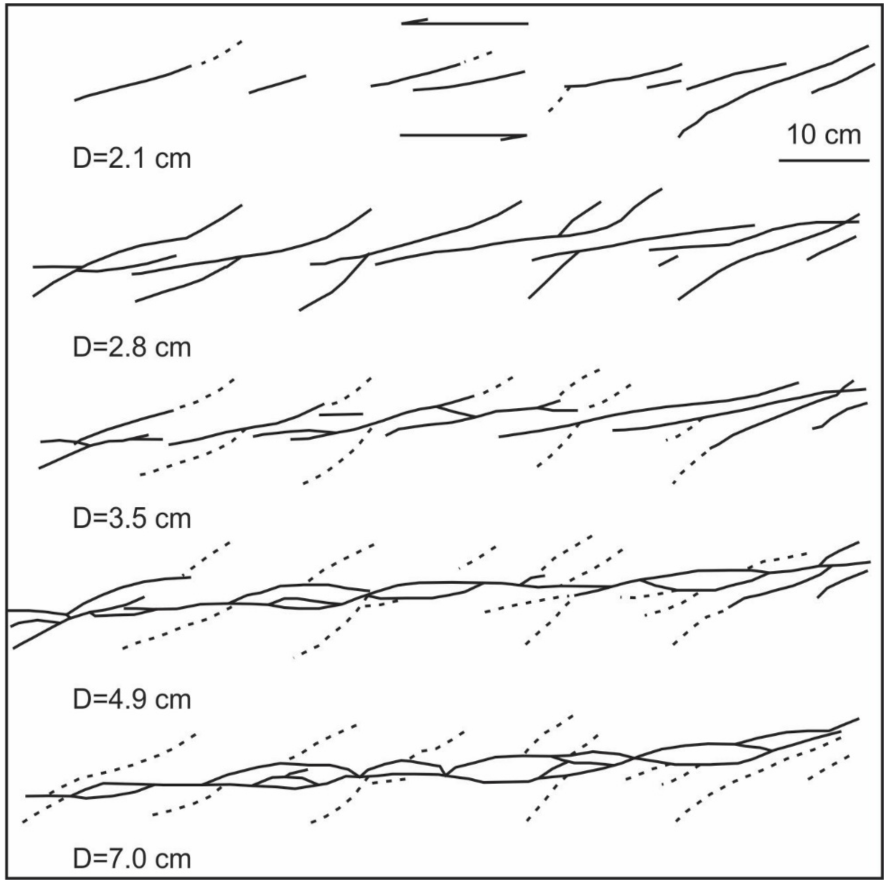
Sinistral movement suggested by :

- sigmoidal tension gashes
- sinistral displacement of earlier veins
- drag folding in locally ductile zones
- direction of R shears
- S-shaped extension



Structure of the deposit

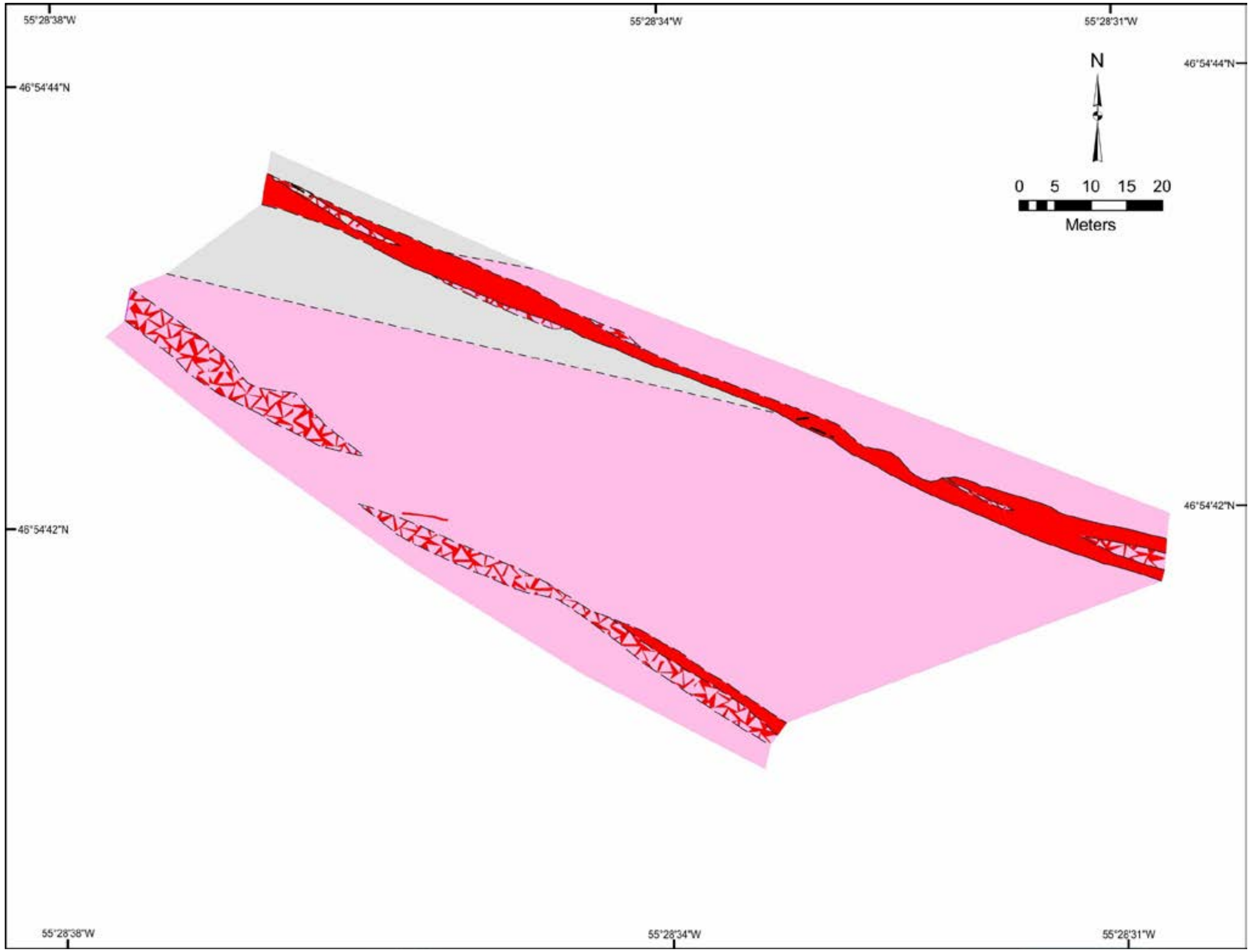


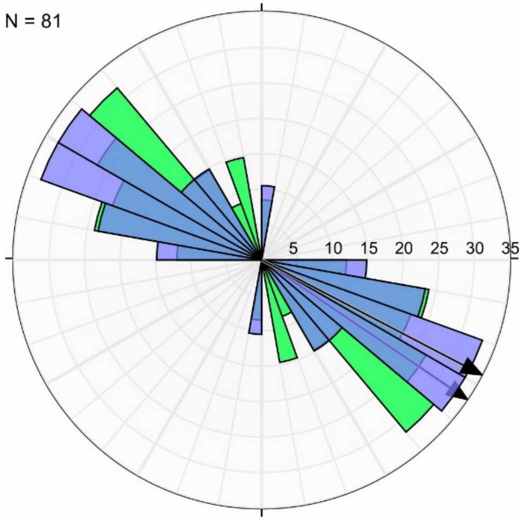


Fault-bounded lenses typical of well developed strike-slip faults (Dooley and Schreurs, 2012; Naylor et al., 1986):

- R shears, gradually swinging into direction of main movement
- P shears
- R and P shears link together and form a series of fault-bounded lenses
- Movement taken up by Y shears (parallel to main movement)
- New R shears develop with continued movement

Structure of the deposit





Orientation of North Vein is slightly different

Narrow, but very high grade, suggesting early extension?

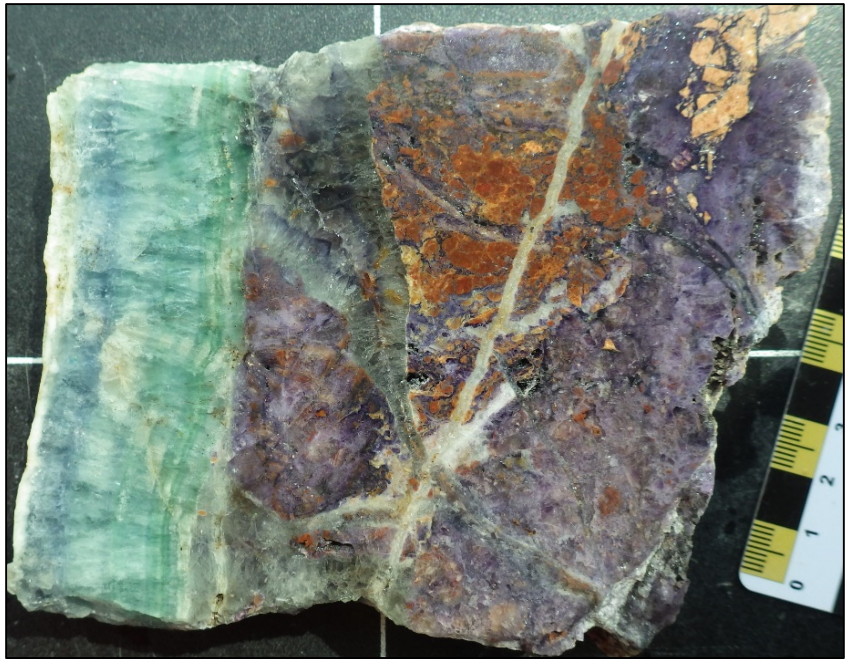
Extensional zones may have been controlled by change in lithology

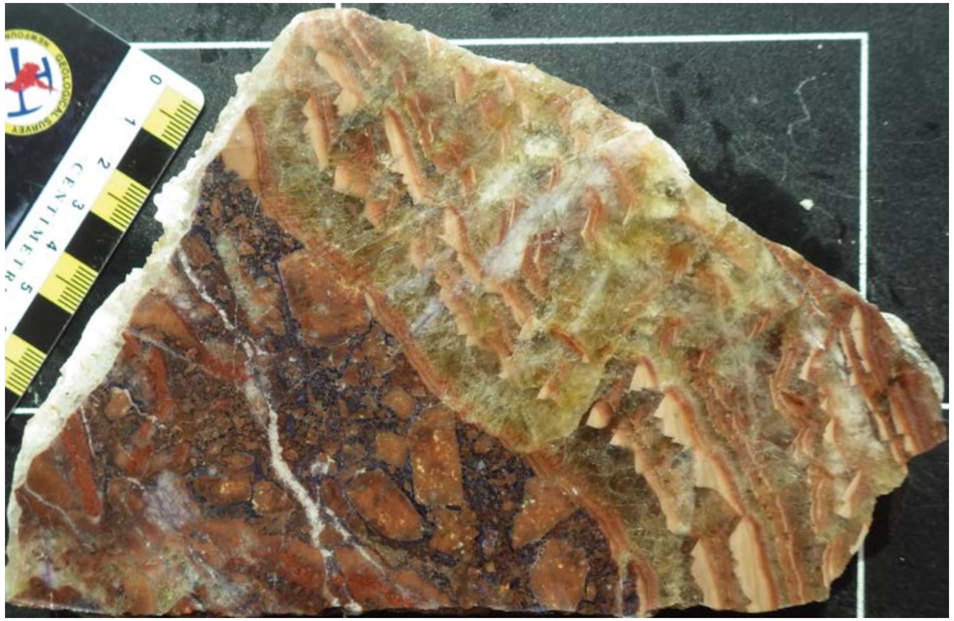
Updated paragenetic sequence

Stage	Phase		Description
Early stage	1	Brecciation of host rocks	Brecciated, weakly- to strongly-altered sedimentary rocks and rhyolite in a quartz-rich matrix.
	2	Purple fluorite stockwork and/or hydrothermal breccia	Purple fluorite and quartz forming stockwork veins and hydrothermal breccia with clasts of host rocks. *
	3a	Banded, fine-grained fluorite and/or yellow, coarse-grained fluorite	Finely banded, fine-grained fluorite and/or coarse-grained yellow fluorite.
	3b	Hematite-fluorite-quartz	Hematite with quartz and fluorite.
Main stage	4	Reddish grey fluorite	Massive, coarse-grained, grey, transparent fluorite, locally slightly reddish or pink.
	5	Fine-grained banded sulphides	Composed of sphalerite and galena.
	6	Grey elongated fluorite	Massive, grey fluorite with elongated crystals up to 20 cm in length.
Late stage	7	Green, blue and white, coarse-grained fluorite	Alternating layers of coarse-grained green, blue and white fluorite with disseminated sphalerite and galena.
	8	Clear or blue, cubic fluorite	Clear or blue cubic fluorite occurs filling vugs.
	9a	Blastonite	Breccia composed of fragments of previous phases in a matrix composed of quartz and fine-grained fluorite.
	9b	Late quartz	Quartz vein stockwork and vug filling.
	10	Pyrite and chalcopyrite	Pyrite and chalcopyrite crystals in quartz lined vugs.

*Variable amounts of calcite occur locally with fluorite in all phases.

Early Stage



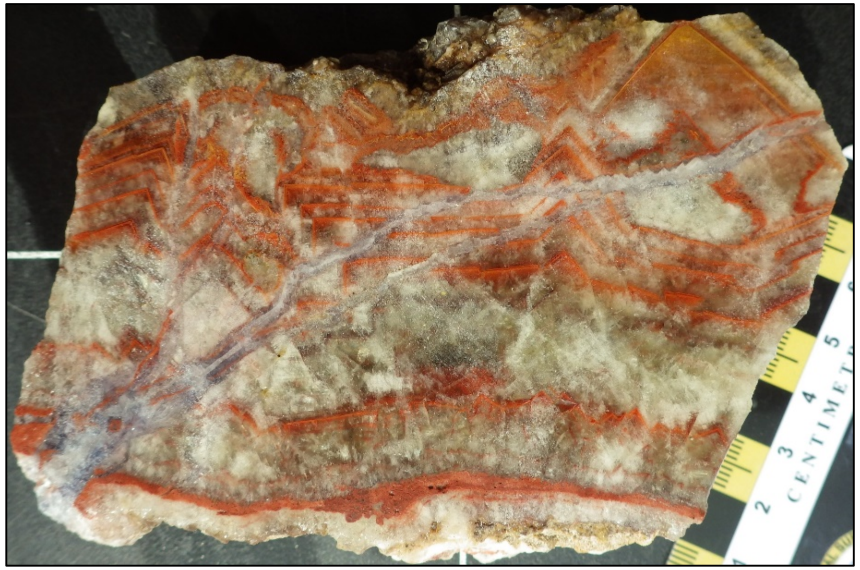


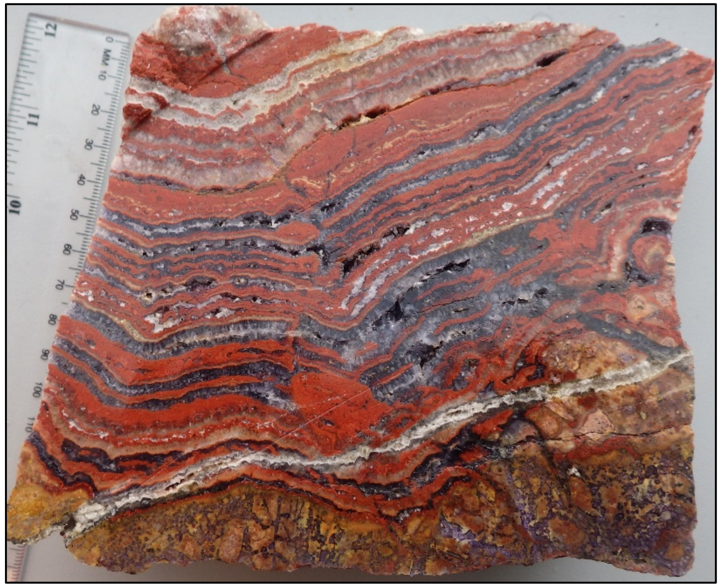
Barren breccia

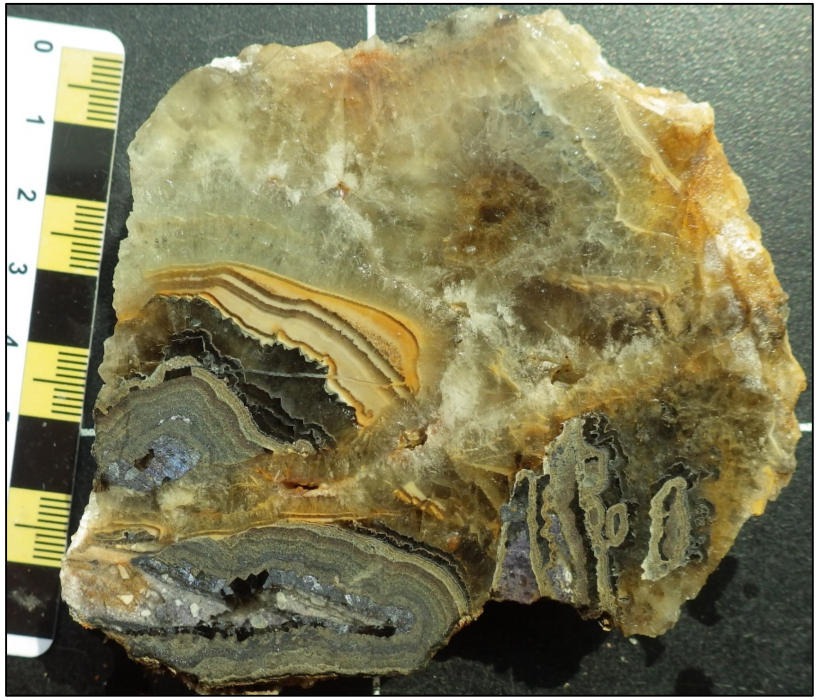
Purple fluorite

Banded fine-grained fluorite and yellow coarse-grained

Hematite-fluorite-quartz

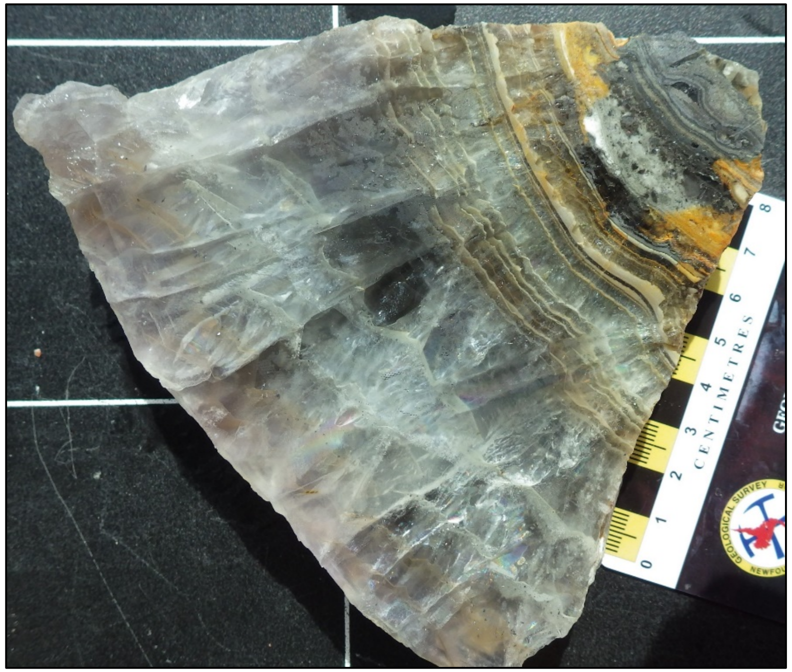






Main Stage

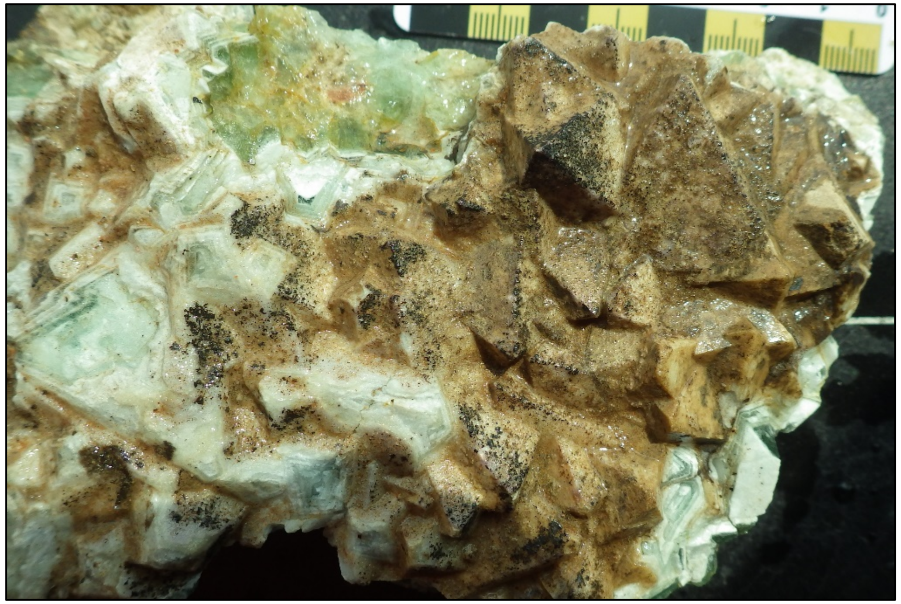
Fine-grained banded sulphides



Reddish grey fluorite

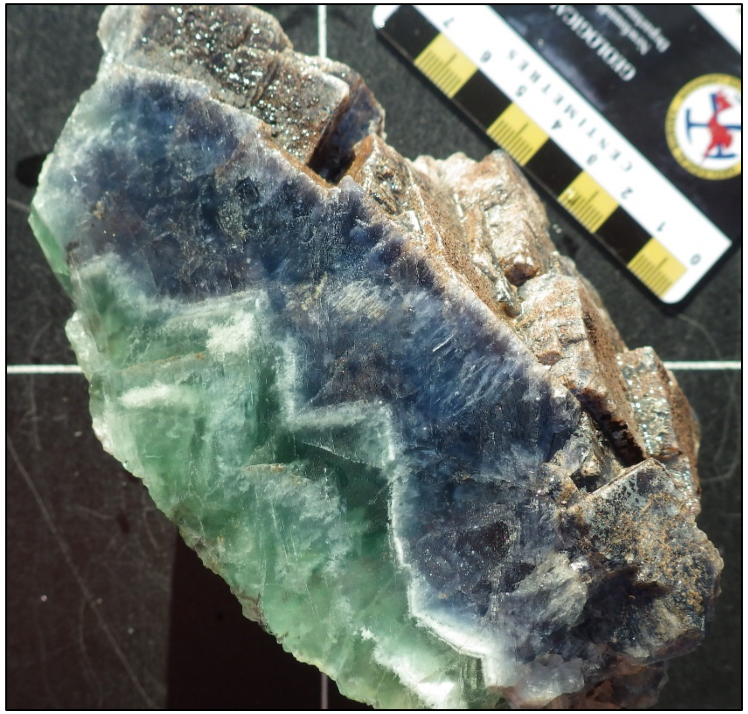
Elongated grey fluorite

Late Stage

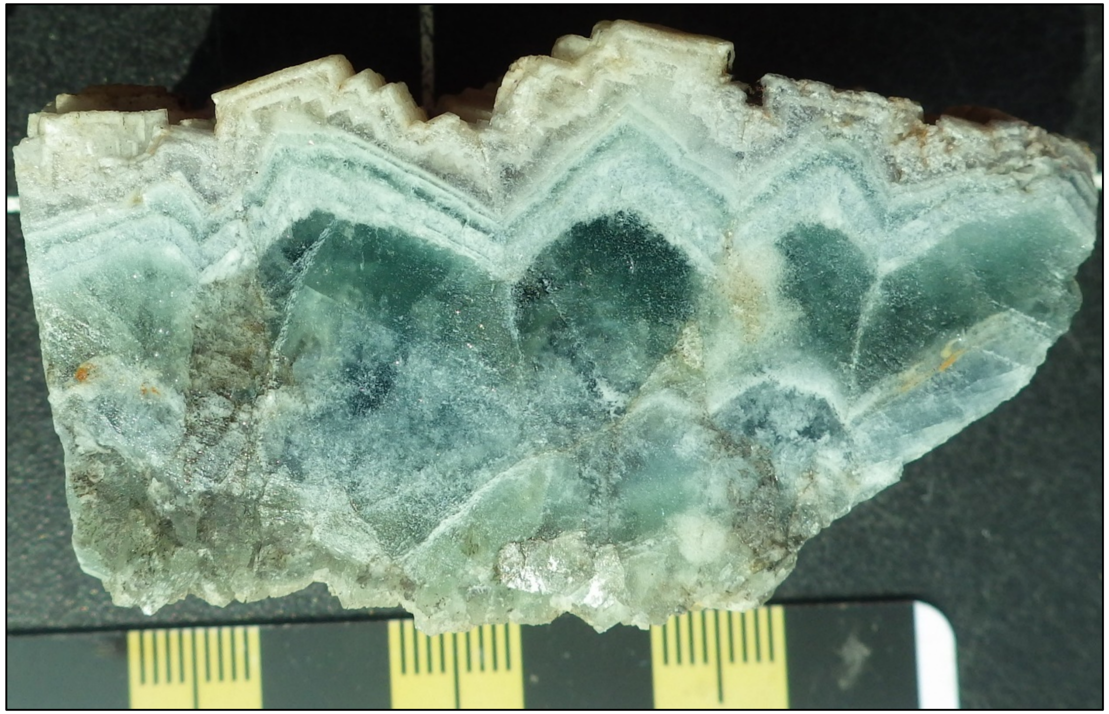


Green fluorite (octahedral)

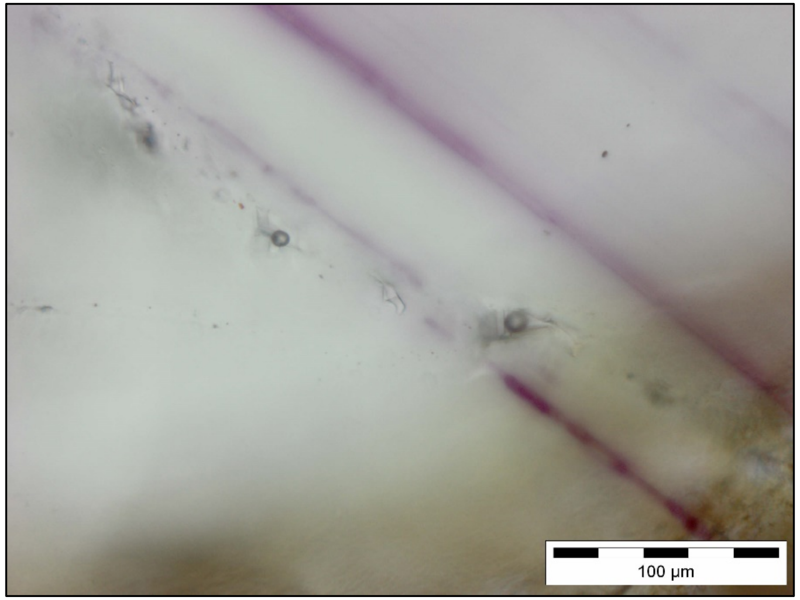
Late quartz

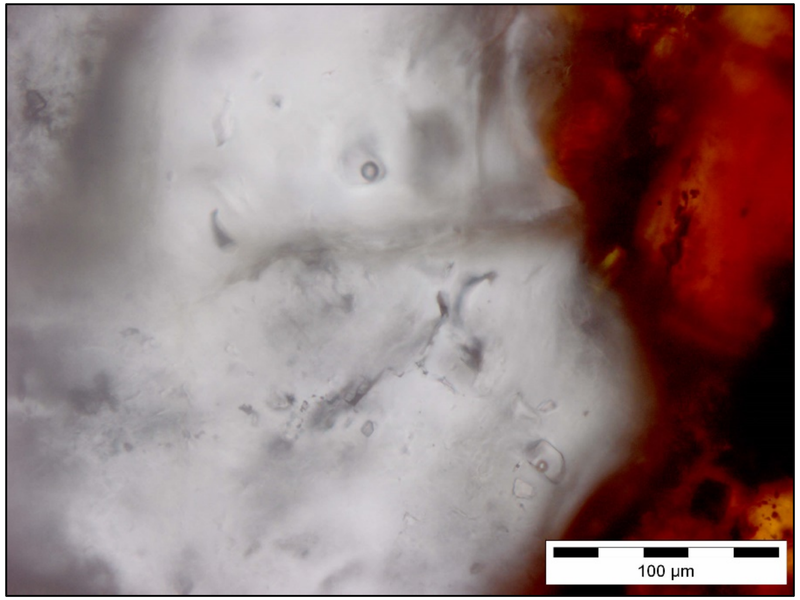


Cubic fluorite (clear or blue)



Fluid Inclusion Analysis



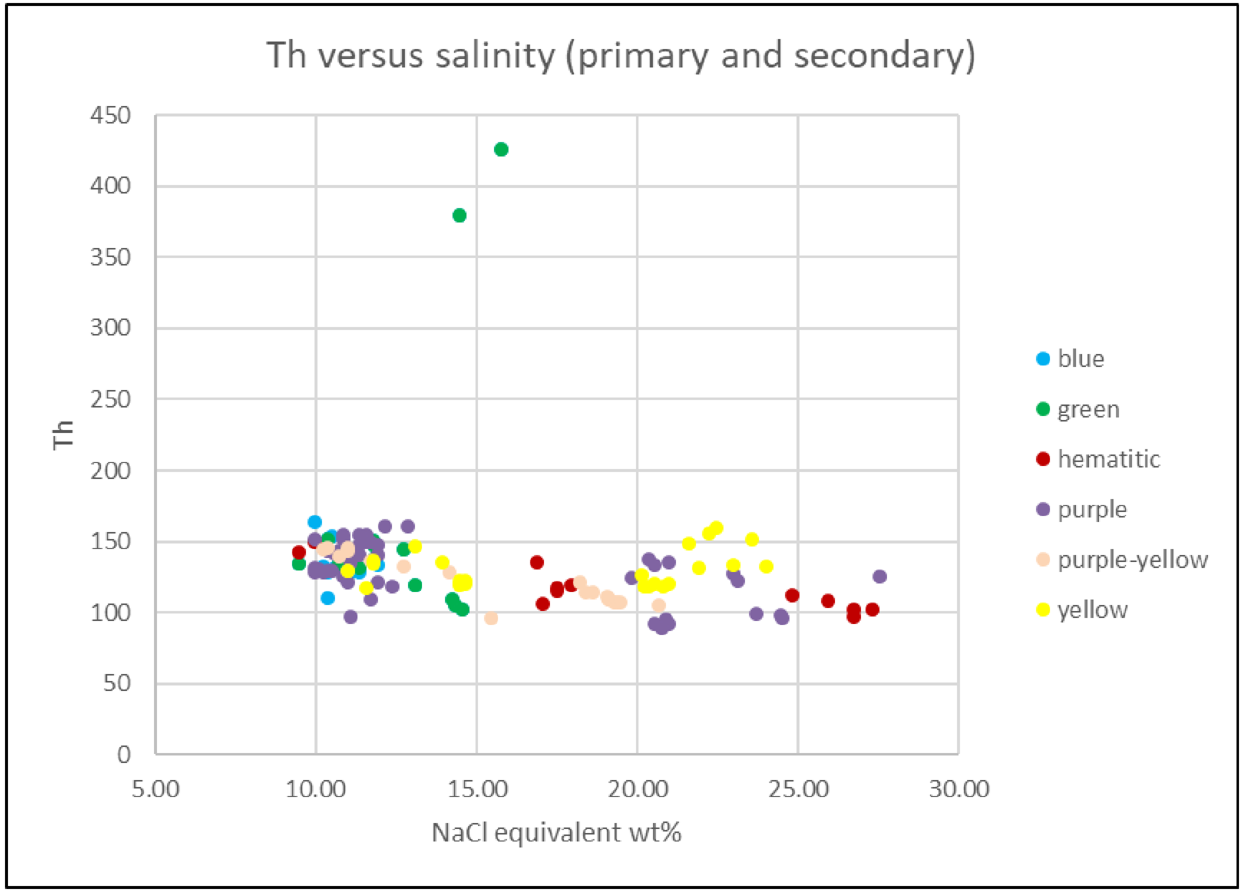


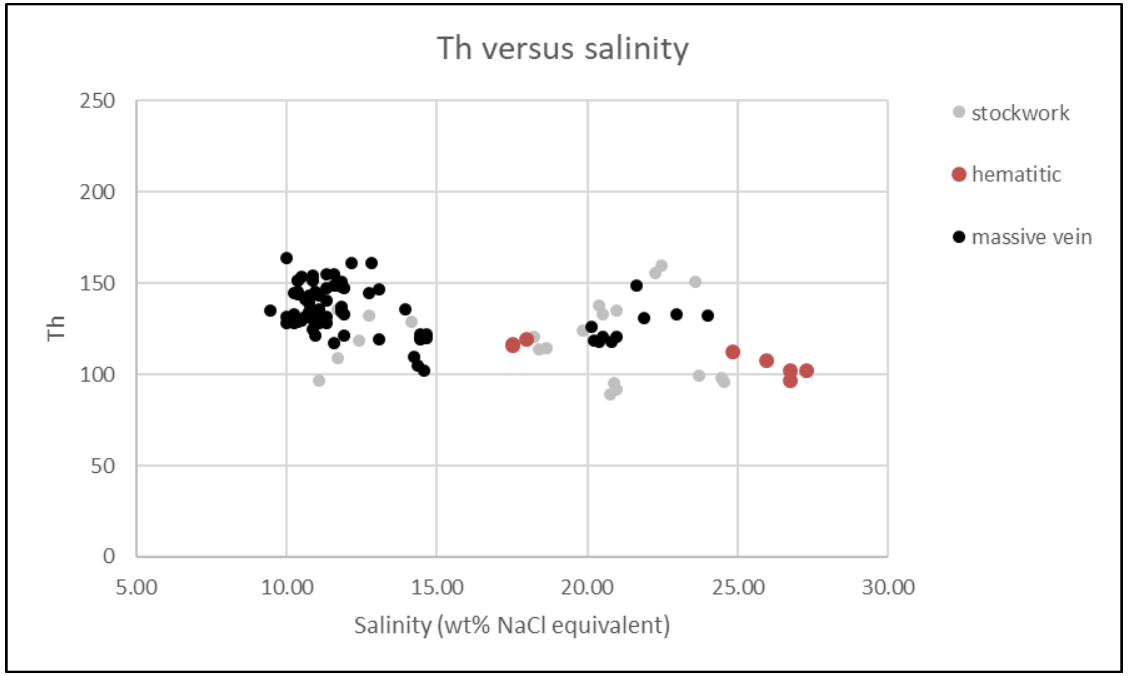
Sample Number	Location	Description
204A02	Grebes Nest Pit	stockwork purple fluorite with calcite cut by yellow fluorite
205A01	Grebes Nest Pit	coarse-grained, massive, purple and yellow fluorite vein (at least 9 cm wide)
209A01	Grebes Nest Pit	purple and minor hematitic fluorite in 3-4 cm wide stockwork veins
211A05	Grebes Nest Pit	green fluorite with minor hematitic layers in calcite-rich breccia
212A01	Grebes Nest Pit	purple fluorite stockwork and hydrothermal breccia, cut by black calcite and yellow fluorite
214A01	Open cut Pit	coarse-grained, green fluorite and sphalerite vein in rhyolite
240A01	Centre Pit	purple and blue fluorite vein (more than 5 cm wide) in rhyolite

Two-phase liquid-vapour inclusions

Liquid-vapour ratio 0.75 to 0.9

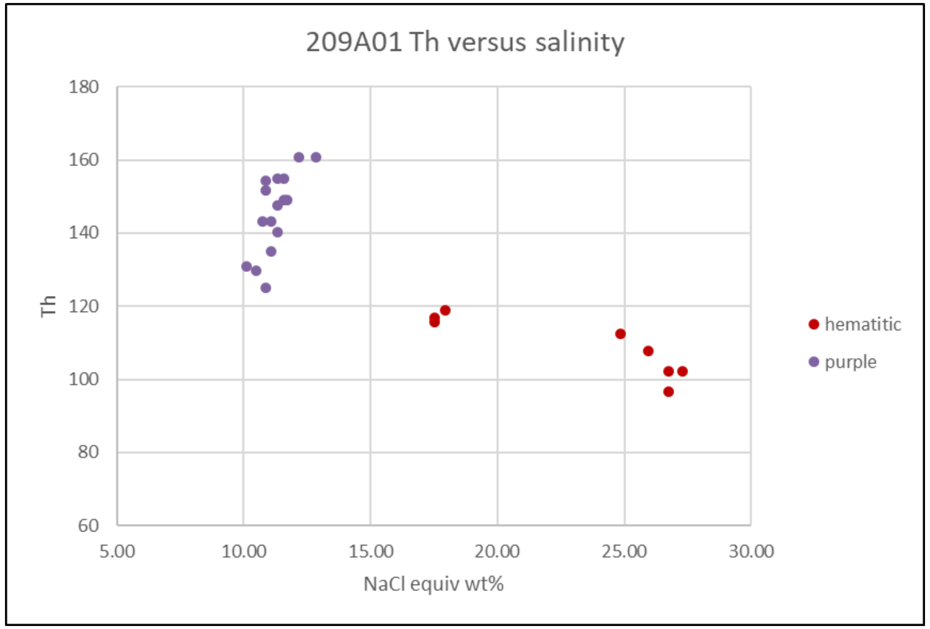
Fluid Inclusion Analysis

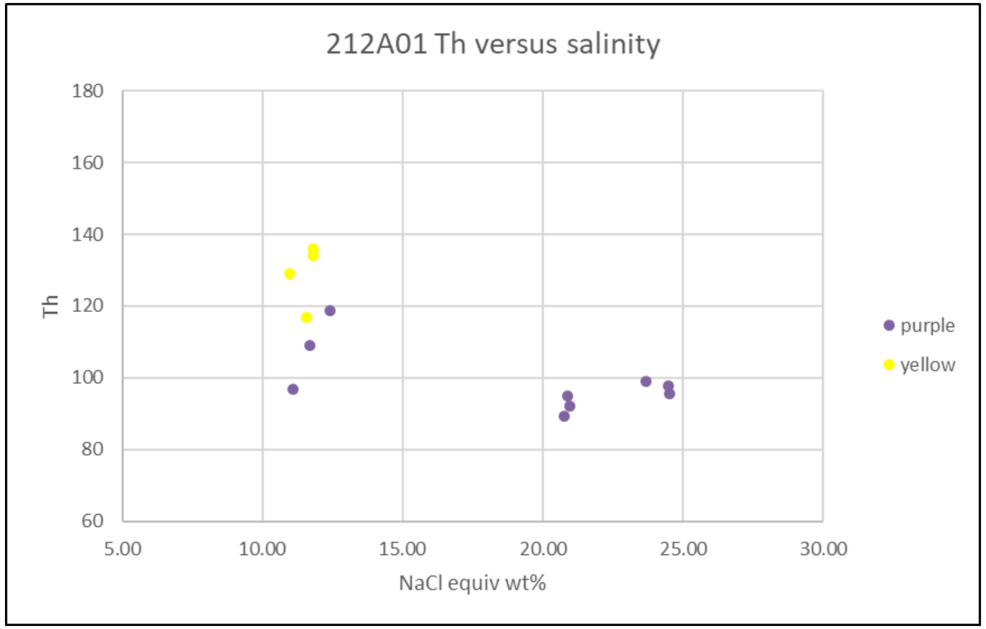


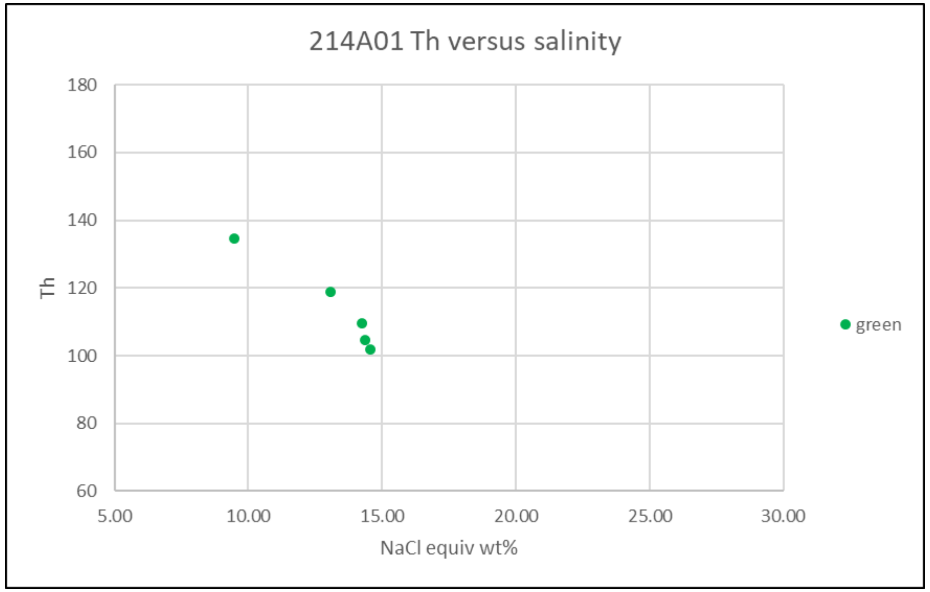


Overall trend from high salinity and lower Th and low salinity and slightly higher Th
Trend varies with both colour and texture of fluorite
Generally, earlier fluorite is high salinity, later fluorite is low salinity

Fluid Inclusion Analysis







Trend is even more noticeable within some of the individual samples

Trend indicates mixing of high salinity magmatic and low salinity meteoric liquid (trend "A" from Strong et al., 1984 and Collins, 1992)

Genetic Implications

Preliminary sequence of events that led to fluorite mineralization in the AGS area:

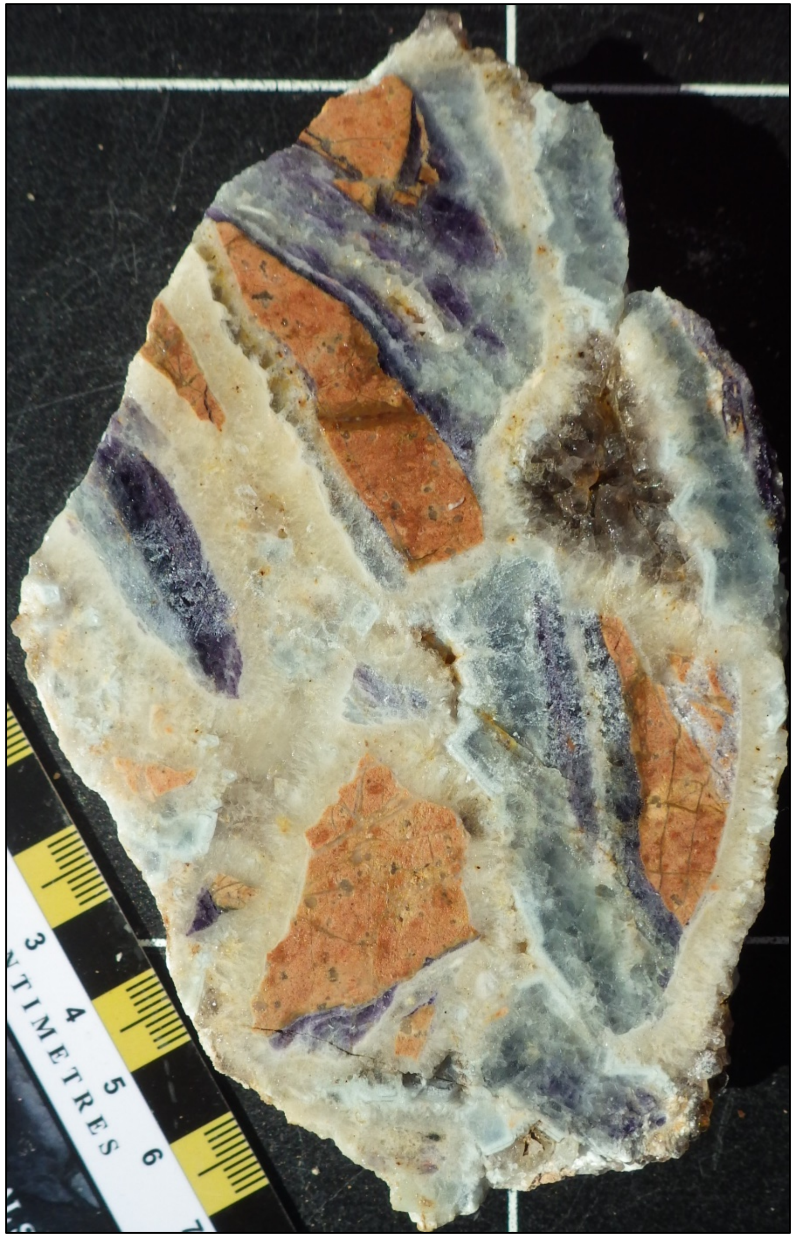
1. Deposition of sedimentary rocks
2. Faulting in the sediments (later reactivated)
3. Emplacement of rhyolite sills
4. Emplacement of the underlying granite

Faulting in sediments prior to the emplacement of SLG was probably crucial in preventing ponding of the mineralizing fluids in the granite and providing channels for the fluids to migrate upwards.

Repeated movement along the fault allowed for multiple phases of fluorite deposition under dominantly brittle conditions ("fault-valve model" by Sibson et al., 1988).

Fluids from the rhyolite may have provided mineralization following the intrusion of the rhyolite, but subsequent intrusion of the main phase of the SLG probably resulted in the main influx of mineralizing fluids.

Fluid inclusion indicates mixing of high salinity magmatic and low salinity meteoric fluids.



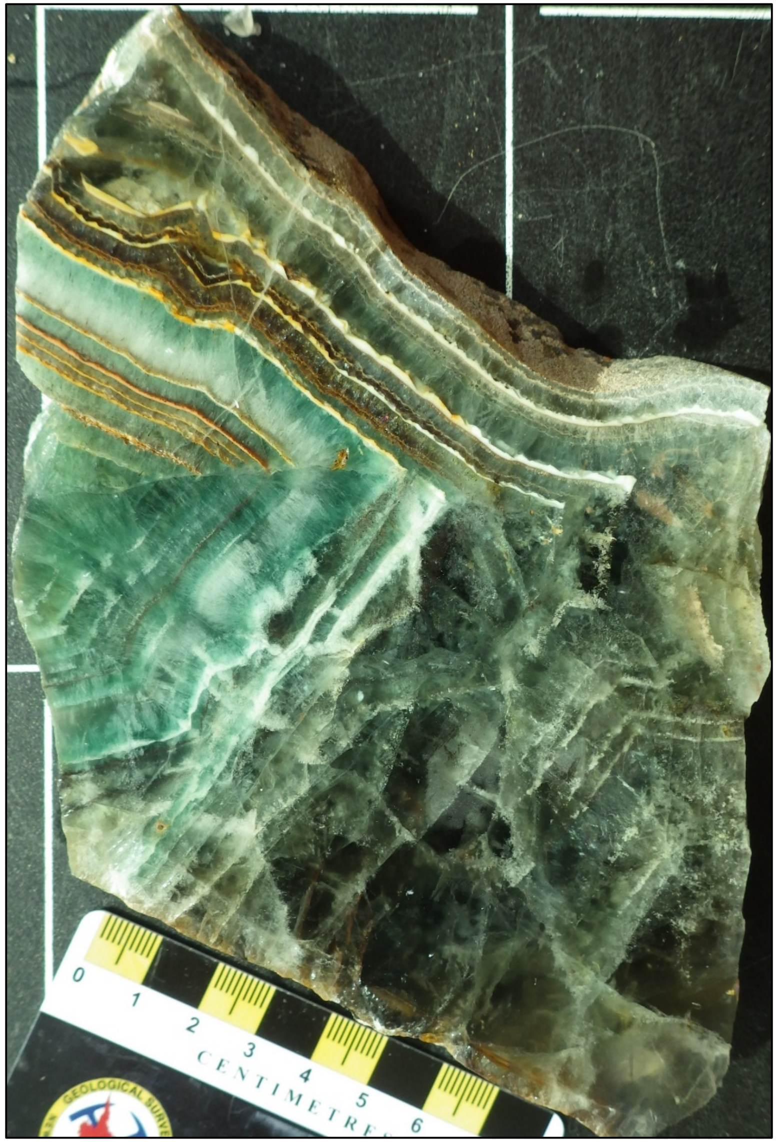
Further Research

Additional fluid inclusion analysis to include phases not analyzed yet (main stage)

REE and trace element geochemistry of fluorites (BSc thesis)

Pb isotope analysis of galena from AGS and some granite-hosted veins (BSc thesis)

Petrology of the SLG (geochemistry, petrography) to investigate regional variations, different phases of the SLG, late- and post-magmatic processes



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