Tectono-magmatic evolution of the Abitibi greenstone belt: importance for Cu-Au and Au magmatic-hydrothermal systems

Lucie MATHIEU
Université du Québec à Chicoutimi (UQAC), Chicoutimi, Québec, Canada

Many thanks to many collaborators and students

Mitacs
CRSNG NSERC
Fonds de recherche Nature et technologies Québec

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METAL EARTH

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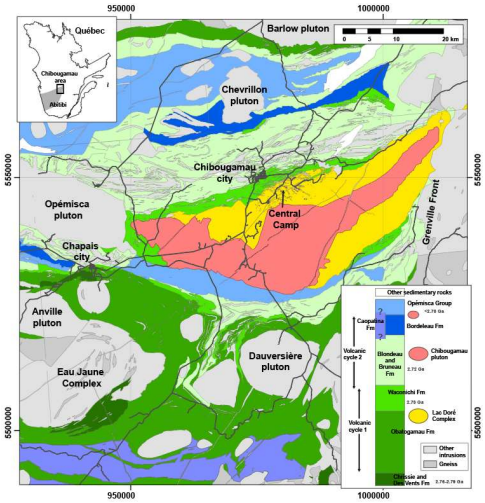
Great team – thank you!



Postdoc – Transect: **Pierre Bedeaux** (completed)

Completed MSc – transect projects: **Adrien Boucher, Marie Kieffer, Julien Huguet, Yousouf A. Youssoufou**

Transect projects – PhD in progress: **Alexandre Crépon, Adrien Boucher**

Thematic projects (Abitibi-Wabigoon): **Patrik Berthoty** (PhD), **Théo Hassen Ali** (PhD), **Taylor Wasuita** (MSc)

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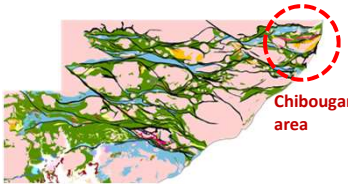
Additional projects

- **Baptiste Madon** (MSc) – fO_2 of syntectonic magmas
- **Nesrine Mokchah** (MSc) – V-magnetite of LDC
- **Esther Bou** (PhD) – sanukitoid magmatism
- **Catherine Gavaris** (MSc) – Mythril metallogeny

Introduction



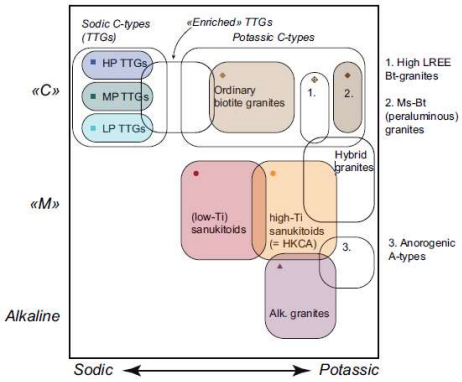
Abitibi Subprovince

Archean magmatism

- Synvolcanic period (TTG suites, tholeiitic, …)
  - >2790 to ~2710 Ma (north)
  - 2730 to 2695 Ma (south)
- Syntectonic period (alkaline magmatism, …)
  - 2701 to 2690 Ma (north)
  - 2695 to 2650 Ma (south)

Magmatic-hydrothermal systems

- Porphyry-style of mineralisation
- IRGS – intrusion-related gold systems



Moyen (2019) - *Geological Society London*

Introduction

Understanding magmatic-hydrothermal systems

Motivations

- Provide a scientific basis to exploration models
- Implications for the tectonomagmatic evolution of greenstone belts

Hypothesis

- Neoarchean intermediate to felsic magmatism fertilized (Au, Cu, …) the upper crust

Method

- Igneous petrology

Introduction

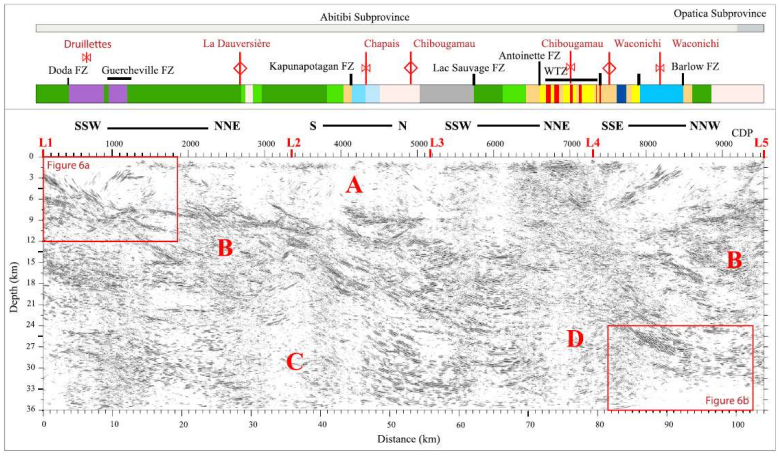
Understanding Archean magmatic-hydrothermal systems, it's also:

- Geodynamic setting
- Partial melting conditions (P, T, %)
- Magmatic system (volume, duration)
- Characteristics of the differentiation process
- Shallow intrusive system (emplacement depth? Duration? Degassing conditions?)
- Mineralizing systems (characteristic of the fluid, volume, host rock composition and structure)

Multi-scale projects

- Large-scale (geodynamic setting, magmatic system)
- Intermediate scale (magma intrusion)
- Local scale (intrusive phase, hydrothermal system)

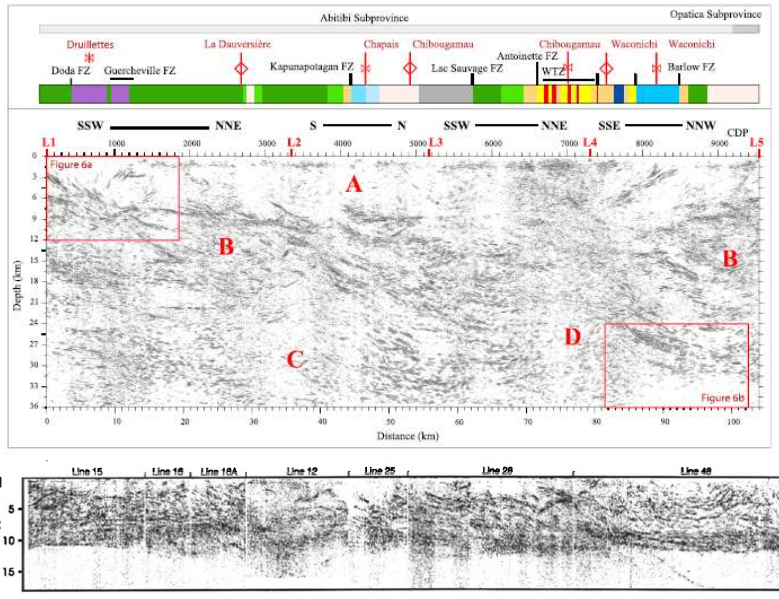
The Chibougamau transect



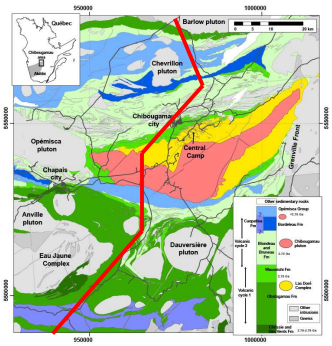
Mathieu et al. (2020) - *Tectonics*

Seismic reflection

Metal Earth seismic surveys – **regional R1** and high-resolution R2 (*Cheraghi et al., 2018; Naghizadeh et al., 2019*).



- R1 – 113 km long, 4 segments
- A – upper-crust
- B – mid-crust
- C – lower-crust
- D – parallel to stratigraphy

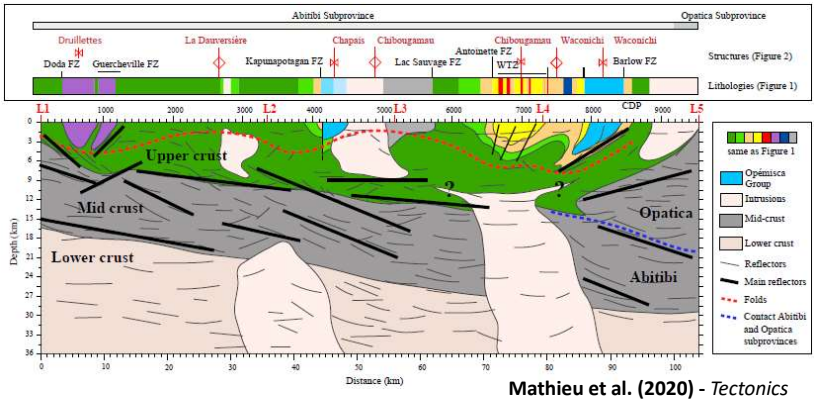


Lithoprobe - Abitibi
(*Calvert and Ludden 1999*)

Seismic reflection

Multi-scale projects

- Large-scale (geodynamic setting, magmatic system)
- Intermediate scale (magma intrusion)
- Local scale (intrusive phase, hydrothermal system)

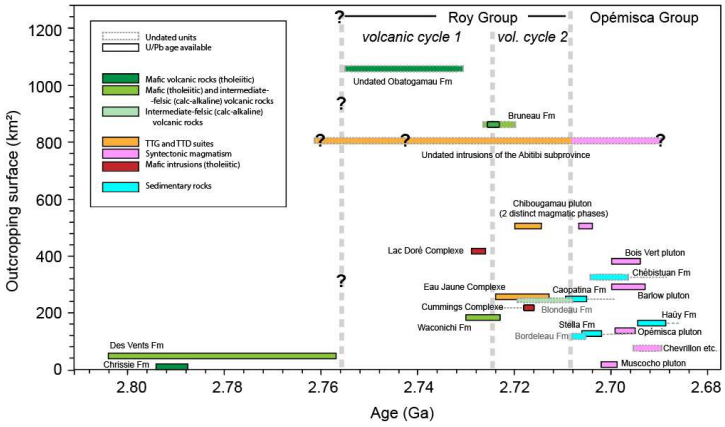


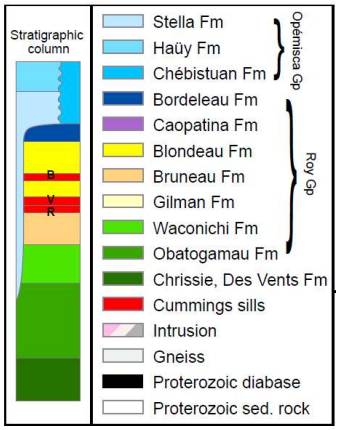
Chibougamau profile (seismic reflection)

Mathieu et al. (2020) - *Tectonics*

Chibougamau transect

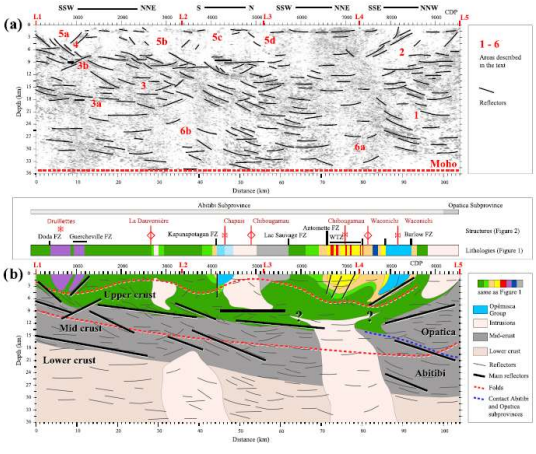
1. Tholeitic (TH) magma – basalts and Lac Doré Complex
2. 'Calc-alkaline' magmas – felsic flows (anatexis?) + TH
3. TTG 'pulse'?
4. Sedimentary basin and K-bearing magmatism

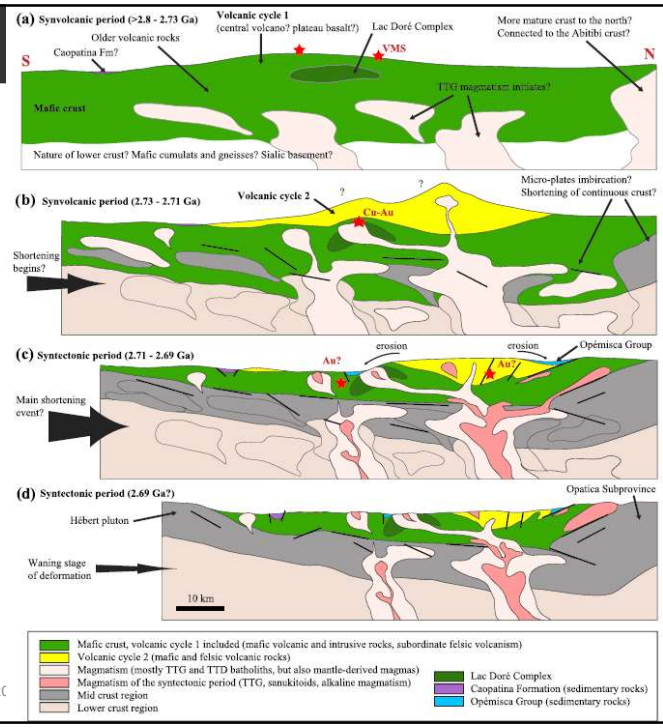




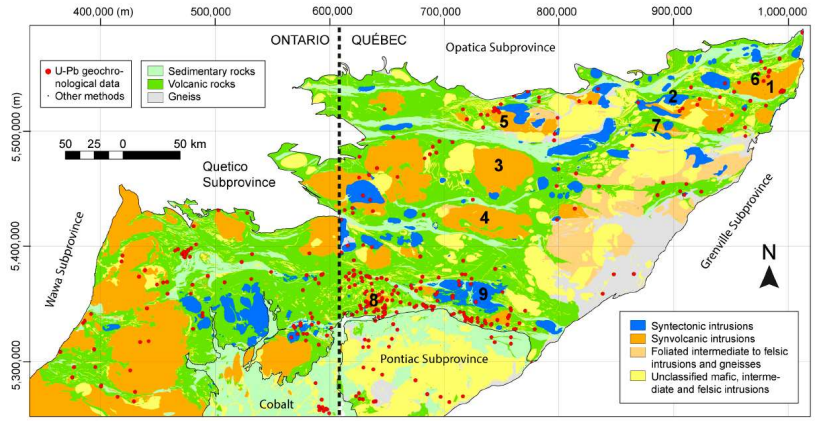
Geodynamic evolution

Partial melting of hot ambient upper mantle (Herzberg et al., 2010; Herzberg & Rudnick, 2012)



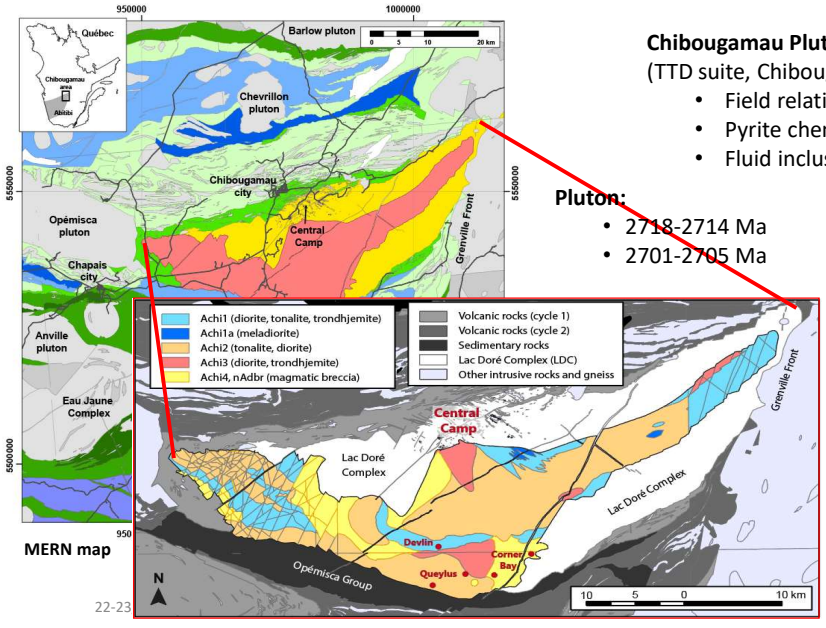


Synvolcanic magmatism in the Abitibi greenstone belt



Mathieu et al. (2020) - *Minerals*

The Chibougamau pluton

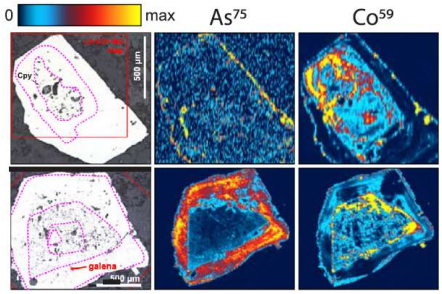


Chibougamau Pluton (ca. 2715 Ma)
(TTD suite, Chibougamau area)

- Field relationships: intermineral dykes, alteration, …
- Pyrite chemistry – magmatic fluid signature
- Fluid inclusions (in progress)

Pluton:

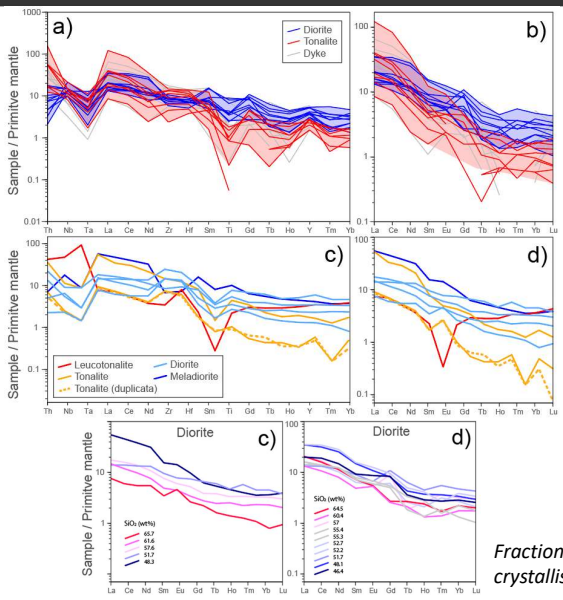
- 2718-2714 Ma
- 2701-2705 Ma



Mathieu (2019) – Ore Geology Reviews

Mathieu and Racicot (2019) - *MDPI Minerals*

Petrogenesis of the Chibougamau pluton



Fractional crystallisation

Chibougamau pluton (polyphased)

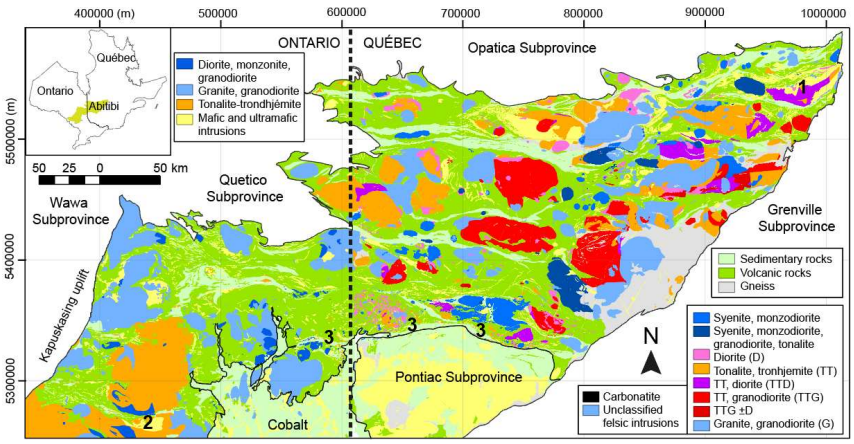
- **Tonalite phase**
  - Typical TTG magmatism (deep partial melting of hydrated and enriched basalt)
- **Diorite phase**
  - Mantle component at the source?

Mathieu and Racicot (2019) - *MDPI Minerals*

Petrogenesis

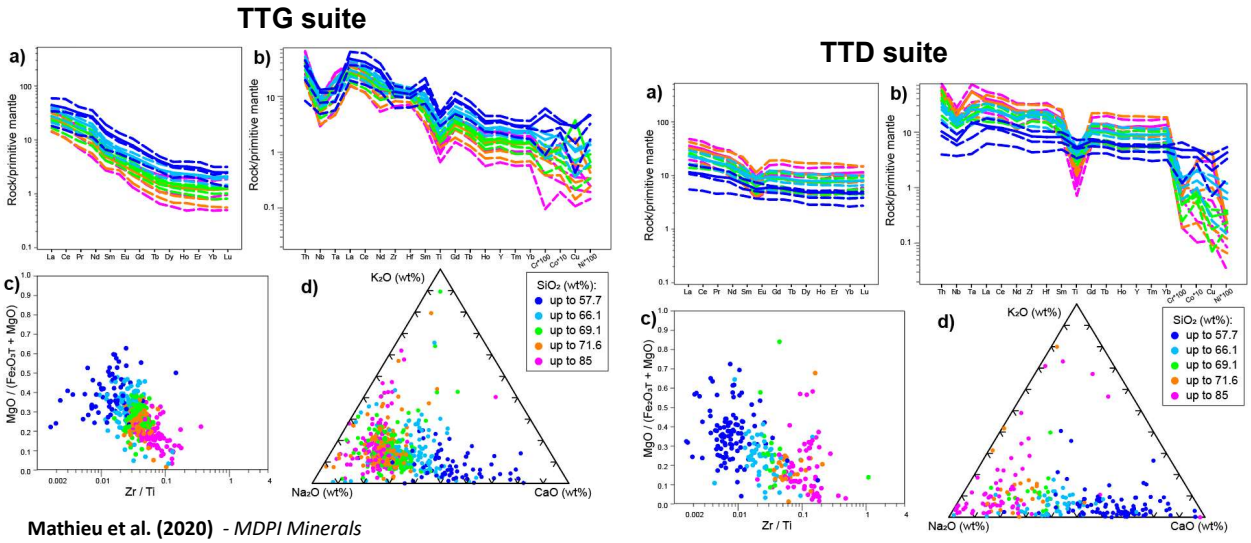
Challenges surrounding petrogenesis, e.g., synvolcanic period:

- TTG – Tonalite-Trondhjemite-Granodiorite
- TTD – Tonalite-Trondhjemite-Diorite



Mathieu et al. (2020) - *MDPI Minerals*

Petrogenesis



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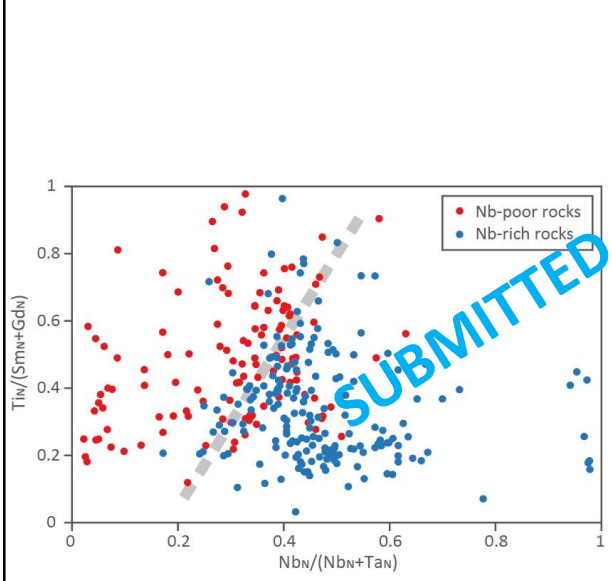
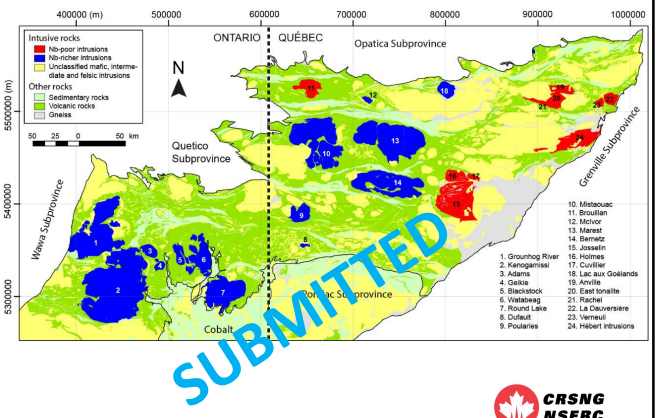
Petrogenesis





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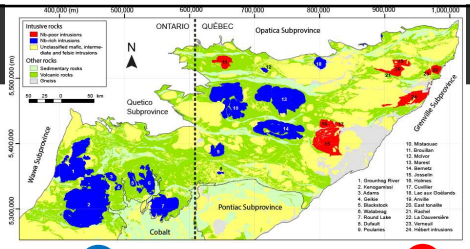
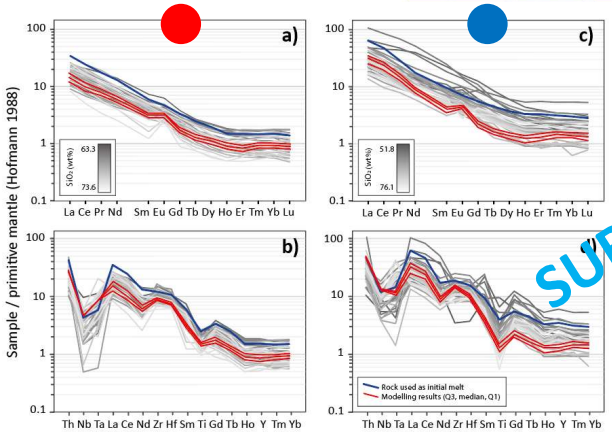
Mathieu (submitted 2021) - *Geology*

Petrogenesis

Mathieu (submitted 2021) - *J. of Petrology*

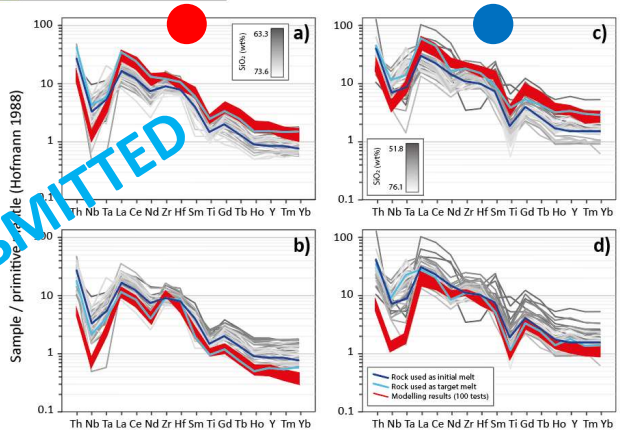


FC model



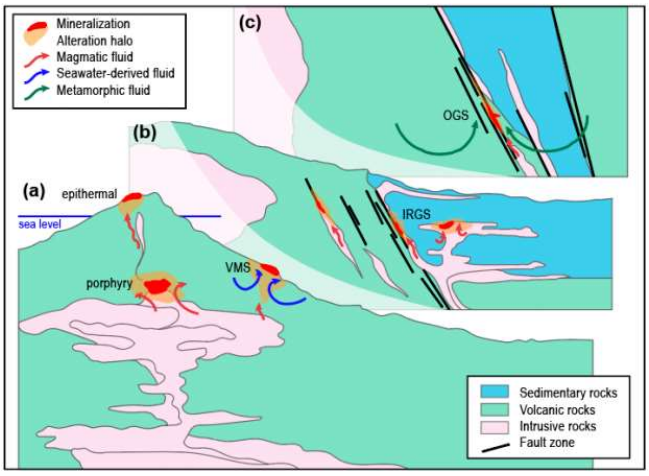
Holmes pluton **Marest batholith**

Mush model



SUBMITTED

Holmes pluton **Marest batholith**



Mathieu (2021) – *MDPI Minerals*

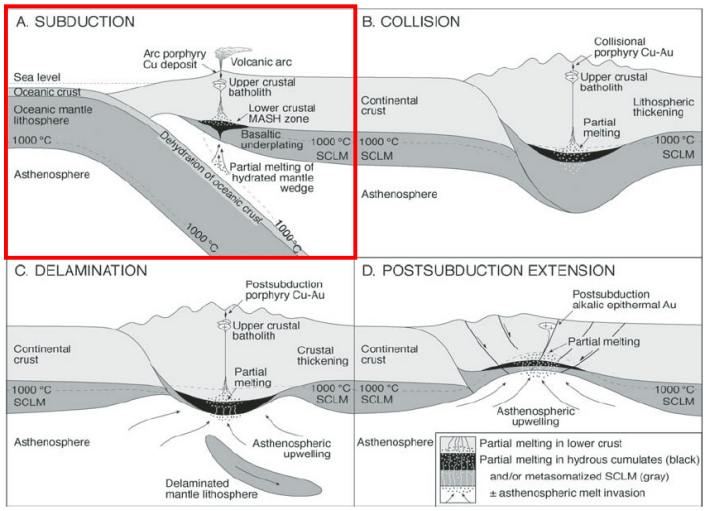
Porphyries in the Abitibi greenstone belt

Porphyry mineralization

Many questions

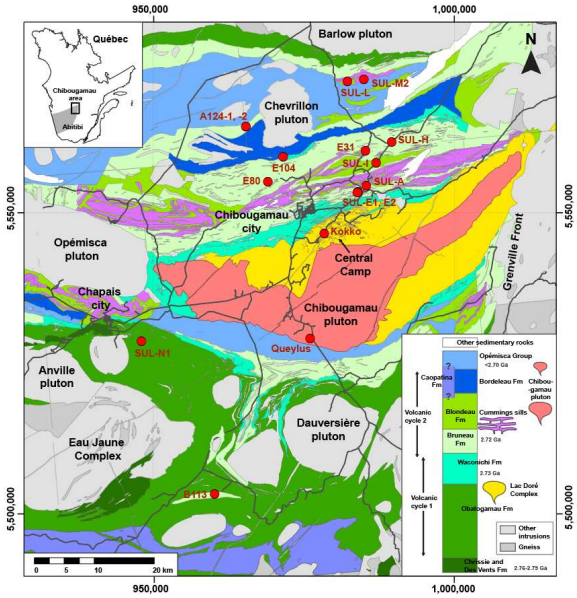
Porphyry-style of mineralisation?

- They don't look like porphyry deposits (too small, …)
- No oxidised magma in the Archean
- Preservation issues



Richards (2009) - *Geology*

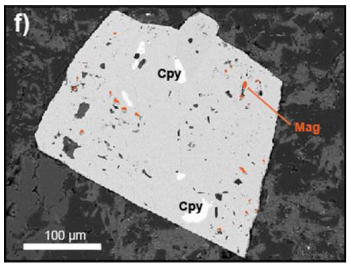
Is it a magmatic-hydrothermal system?



Pyrites from magmatic-hydrothermal systems compared to pyrites from other environments

Magmatic fluid signature:

- Elevated **Te**;
- High **Bi**/Cu, Bi/Te, and/or Bi/Pb ratios.

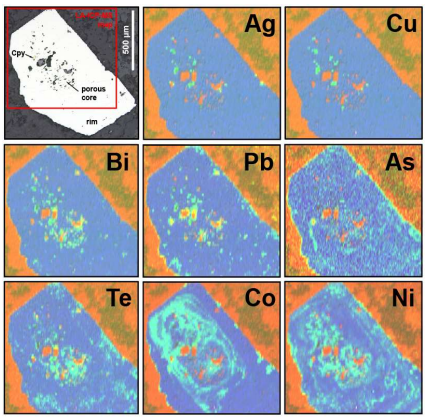


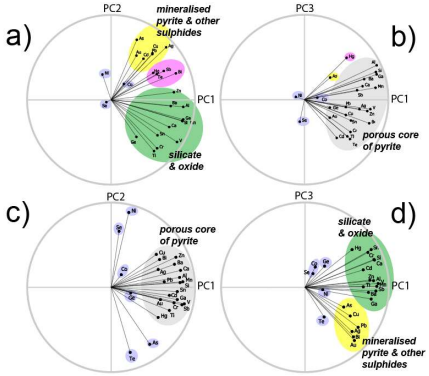
Mathieu (2019) – *Ore Geology Reviews*

Is it a magmatic-hydrothermal system?

Central Camp Cu-Au porphyry system

Porphyry-style Cu-Au deposits (breccia, intermineral dykes, K alteration, hydrothermal magnetite, …) *(Pilote et al. 1998, 2006)*



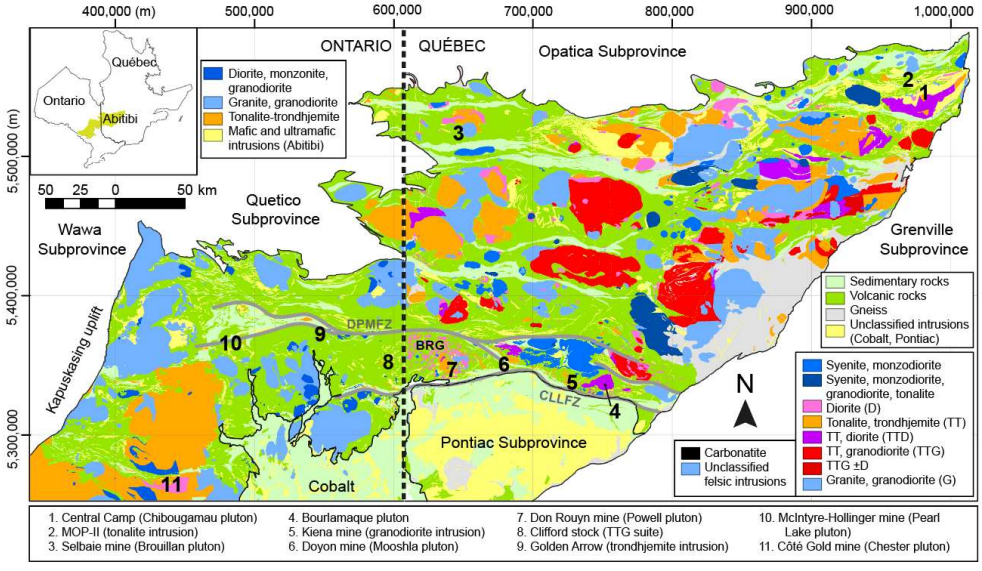


Time-slice data sets

Gourcerol et al. (2018) - *Mineralium Deposita*

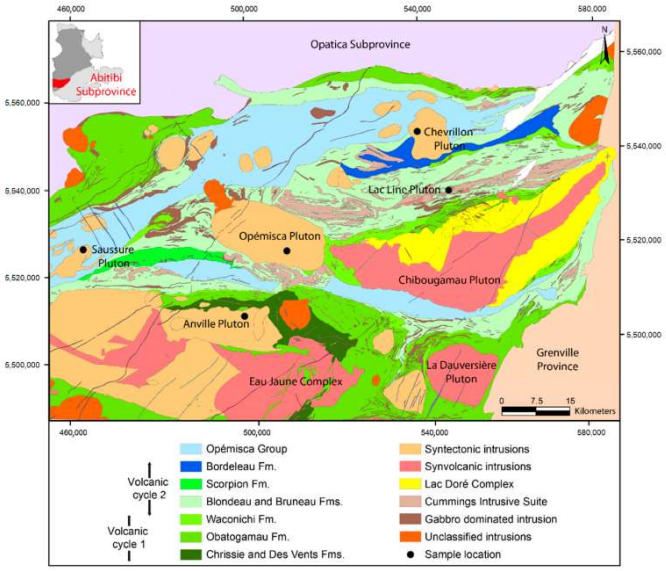
Mathieu and Racicot (2019) - *MDPI Minerals*

Porphyry systems



Mathieu (2021) - *Minerals*

Physico-chemical parameters

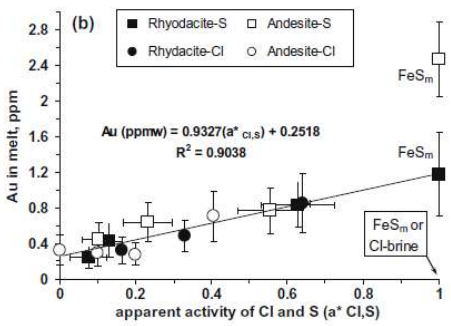


Madon et al. (2020) - *Minerals*

Introduction

Magmas and mineralization

- Au-solubility – S and fO_2 (sulfide/sulfate), magma composition (mafic magmas are S-richer)



Botcharnikov et al. (2010) - *Geochimica et Cosmochimica Acta*

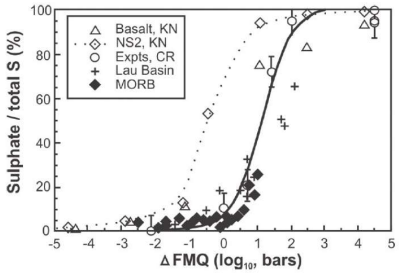


Figure 7. Sulphate as a function of $f(O_2)$, relative to the FMQ buffer (after Carroll and Webster 1994). Open triangles represent tholeiitic basalt synthesized at 1 atm, 1250°C and known $f(O_2)$; open diamonds denote Na_2O•3SiO_2 melts synthesized at 1 atm and controlled $f(O_2)$ and $f(S_2)$; open circles with error bars denote hydrous andesitic to dacitic melts synthesized at 1 to 2.9 kb and 920° to 1025°C. Crosses and filled diamonds correspond to submarine basaltic to andesitic glasses with determined $f(O_2)$ from measured Fe^{3+}/Fe^{2+}.

Yang (2012) - *Geoscience Canada*

Introduction

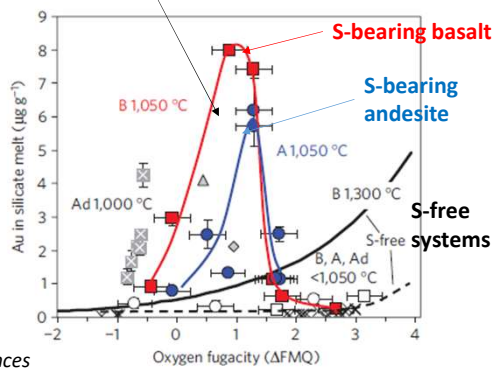
S^{6+} - Sulfate
S^{4+} - Sulfite
S^{0} - Elemental
S^{2-} - Sulfide

Increasing oxygen fugacity (fO_2)

(effective partial pressure of oxygen, reactivity of O_2 in a system)

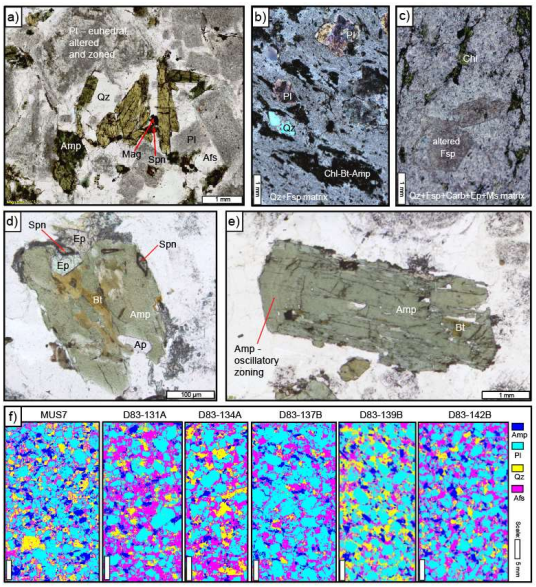
fO_2 and fS_2
How much Au, S, etc. in Neoarchean magmatic systems?
(how much Au, etc. at the source?)

S^{2-} controls Au solubility



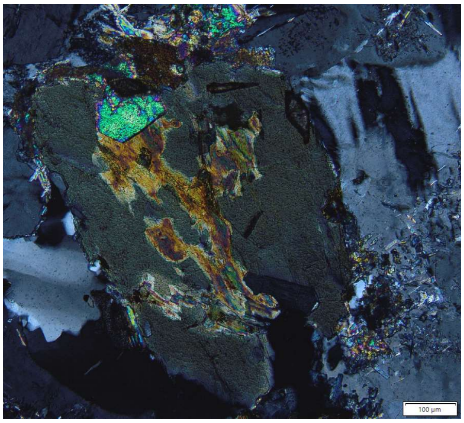
Botcharnikov et al. (2011) - *Nature Geosciences*

Differentiation, emplacement depth



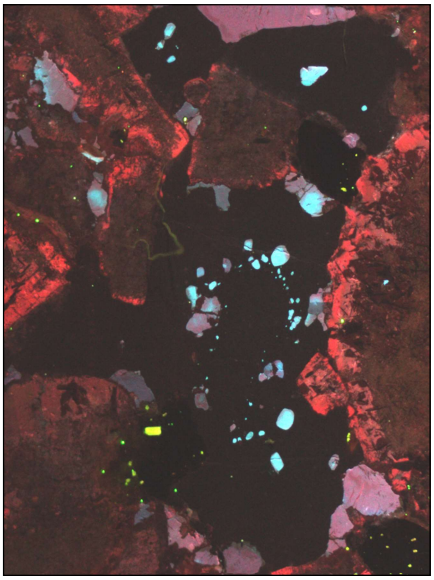
Muscocho Pluton (ca. 2700 Ma)

- Granodiorite
- Chibougamau area, Abitibi greenstone belt

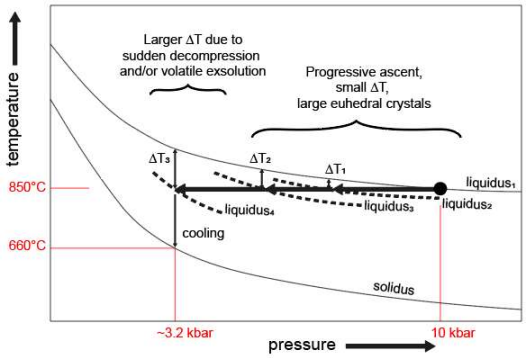


Mathieu et al. (2020) - *Ore Geology Reviews*

Differentiation, emplacement depth

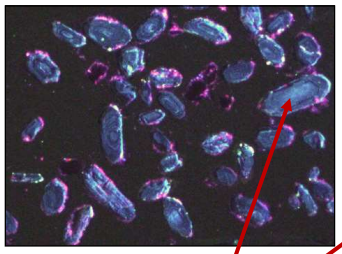


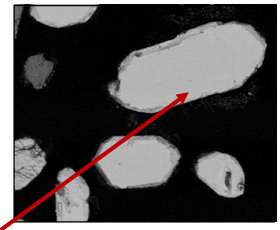
Conclusion: degassing occurred at depth - too deep for an efficient magmatic-hydrothermal mineralizing system?



Mathieu et al. (2020) - *Ore Geology Reviews*

Physico-chemical parameters

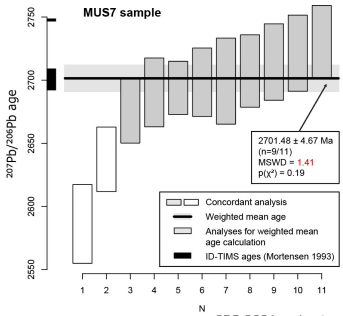




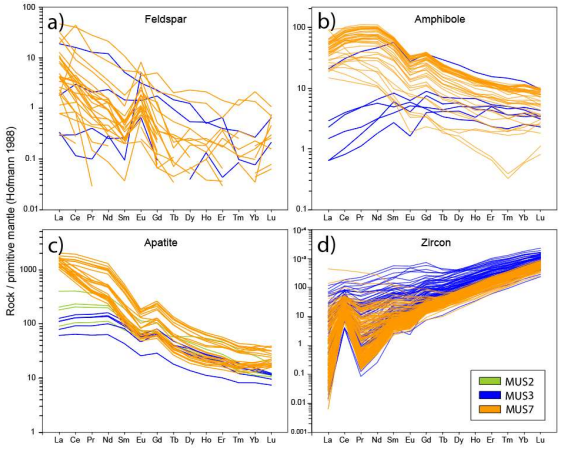
Cathodoluminescence (UQAC)

LA-ICP-MS analyses (LabMaTer, UQAC)

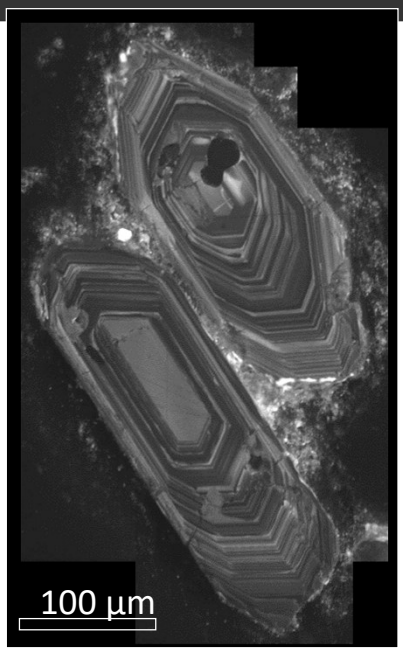
Mathieu et al. (2020) - *Ore Geology Reviews*



Alteration!



Physico-chemical parameters – fO_2



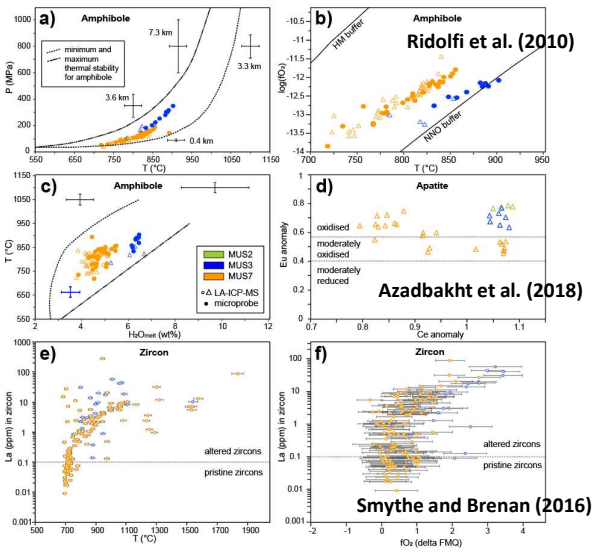
Smythe and Brenan (2016) - *EPSL*

Applied to the Muscocho pluton:

- $aSiO_2$ = 1 (quartz)
- $aTiO_2$ = 0.58 (titanite, etc.)
- Melt composition: whole rock analysis used as a proxy
- Melt composition (H_2O): estimated using amphibole chemistry (Ridolfi et al. 2010)
- Temperature: Ti-in-zircon
- fO_2: REE-content of zircon (Smythe and Brenan 2016)

La Dauversière Pluton (work in progress)

Physico-chemical parameters



Ridolfi et al. (2010)

Azadbakht et al. (2018)

Smythe and Brenan (2016)

Mathieu et al. (2020) - *Ore Geology Reviews*

Muscocho Pluton (ca. 2700 Ma)

- Slow ascent, progressive crystallisation
- Fluid-rich (H_2O)
- S-content?
- fO_2 not optimal (what about at the source?)

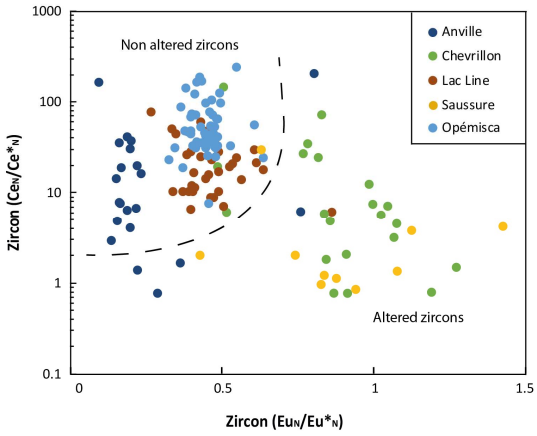
ZIRCON, APATITE, AMPHIBOLE

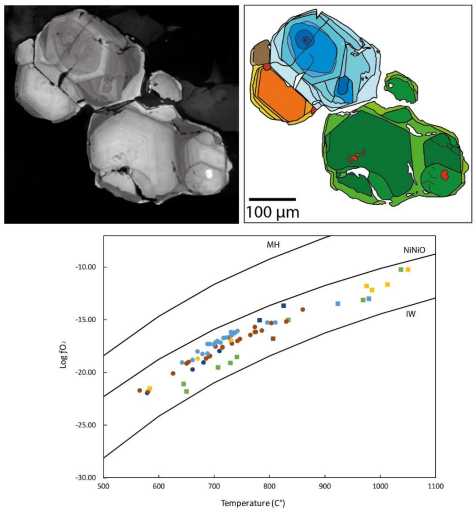
CRSNG NSERC

METAL EARTH

Physico-chemical parameters – fO_2

Intrusions of the synvolcanic and syntectonic periods (Chibougamau area)





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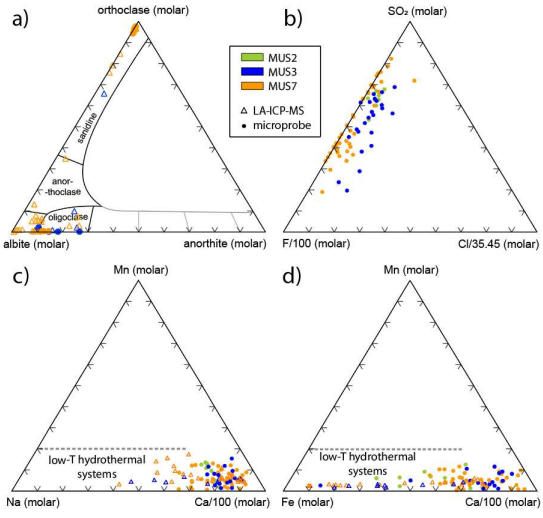
Physico-chemical parameters – S-content



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Empirical partitioning of S between apatite and rhyolititc/andesitic melts (**Parat et al. 2011**)

$$S_{apatite} = 0.0629 * lnS_{melt} + 0.4513$$

Apatite-melt pratitioning model (**Li and Hermann 2017**)

$$Cl_{melt} = \frac{X_{Cl}^{ap}}{X_{OH}^{ap}} \frac{1}{Kd_{Cl-OH}^{ap-me}} * 10.79$$

Results, for the Chibougamau area:

- 10 to 100 ppm S in the melt
- ~0.1 wt% Cl in the melt

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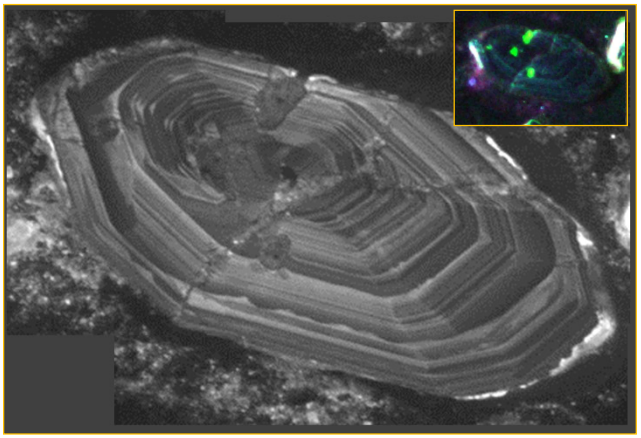
Physico-chemical parameters - timing



La Dauversière Pluton (work in progress)

- U/Pb isotopic system (1-2 Ma resolution)
- Growth rate of zircon? Evolving physico-chemical parameters?

petrochronometer

Conclusions

Understanding Archean magmatic hydrothermal systems

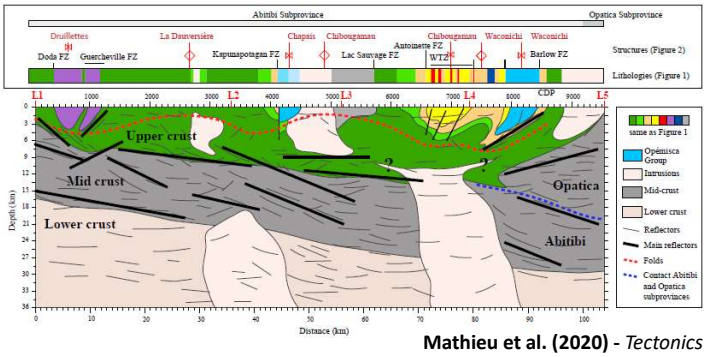
- Geodynamic setting
- Partial melting conditions (P, T, %)
- Magmatic system (volume, duration)
- Characteristics of the differentiation process
- Shallow intrusive system (emplacement depth? Duration? Degassing conditions?)
- Mineralizing systems (characteristic of the fluid, volume, host rock composition and structure)

2. Quantification

- Volume of magmatic system?
- [Au], [S]? (source, intrusive phase)
- Volume of fluid?
- DURATION (magmatism, degassing)

1. Multi-scale projects

- Large-scale (geodynamic setting, magmatic system)
- Intermediate scale (magma intrusion)
- Local scale (intrusive phase, hydrothermal system)



Mathieu et al. (2020) - *Tectonics*


Thank you for your attention
Questions?
Lucie Mathieu
(lucie1.mathieu@uqac.ca)
https://luciemathieugeology.squarespace.com/
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