Source to Sink

Toward an integrated understanding of the auriferous fluid flow system(s)

Benoît Quesnel, Research Associate

Christophe Scheffer, Research Associate

Georges Beaudoin Carl Guilmette

Crystal LaFlamme Christian Dupuis

New faculty in 2019

Michael Herzog, PhD student

To be recruited, PhD student

Guillaume Raymond, MSc student

To be recruited, MSc student

METAL EARTH

A new Canadian research initiative funded by Canada First Research Excellence Fund.

CANADA FIRST RESEARCH EXCELLENCE FUND

Canada

UNIVERSITÉ LAVAL

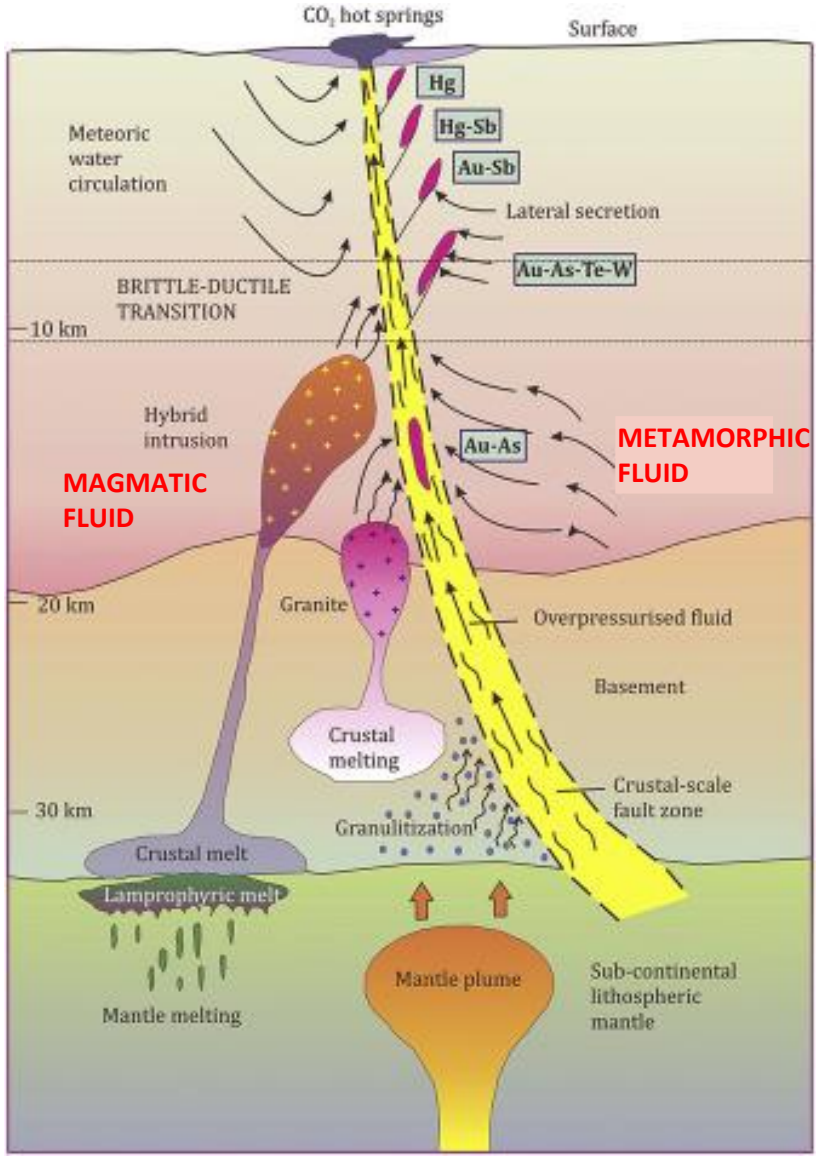
E4m CENTRE DE RECHERCHE SUR LA GÉOLOGIE ET L'INGÉNIERIE DES RESSOURCES MINÉRALES

Laurentian University / Université Laurentienne

HARQUAIL SCHOOL OF EARTH SCIENCES / ÉCOLE DES SCIENCES DE LA TERRE

MERC Mineral Exploration Research Centre

What Controls Gold Endowment?



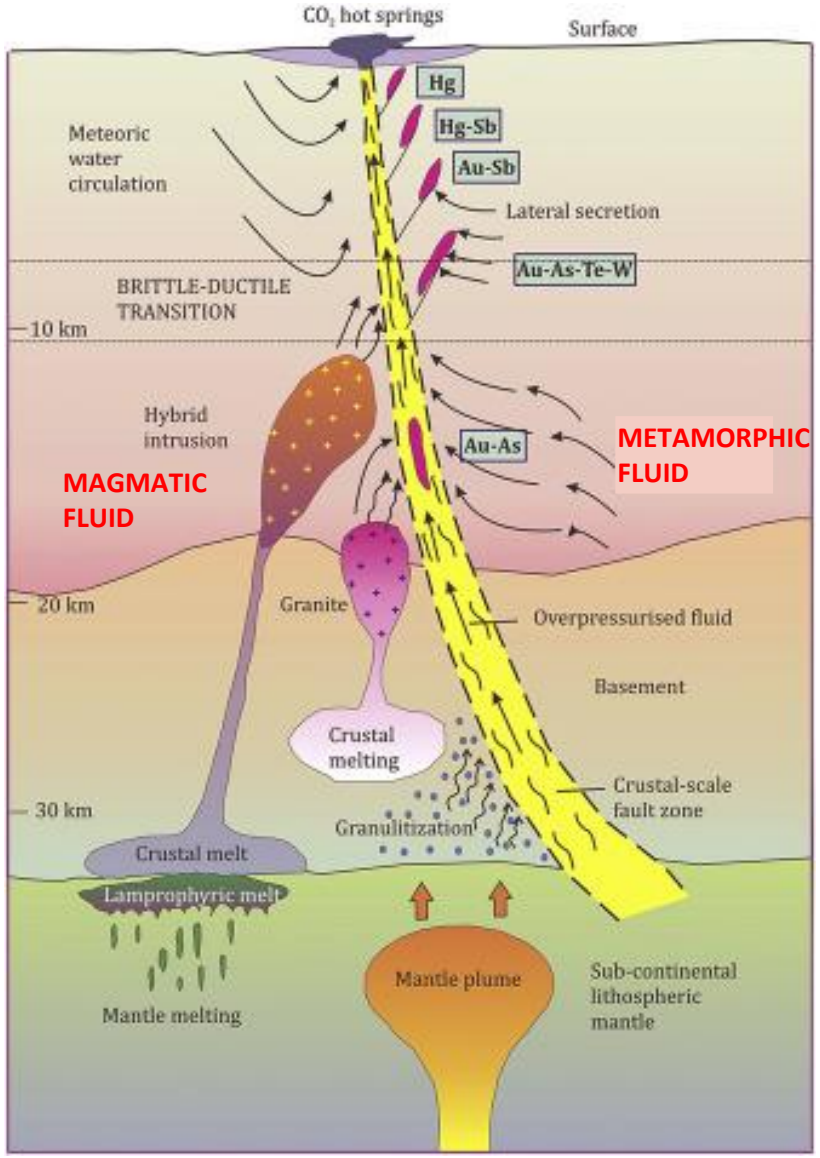
After Groves and Santosh (2016)

SOURCE(S)

- What are the source(s) of fluid(s) and volatiles?
  - What are the geological processes driving fluid release?
- What are the source(s) of Gold? (collab. with Iain Pitcairn, UStockholm)
  - What is the mobility of Au and related elements associated to geological processes.

METAL EARTH

What Controls Gold Endowment?



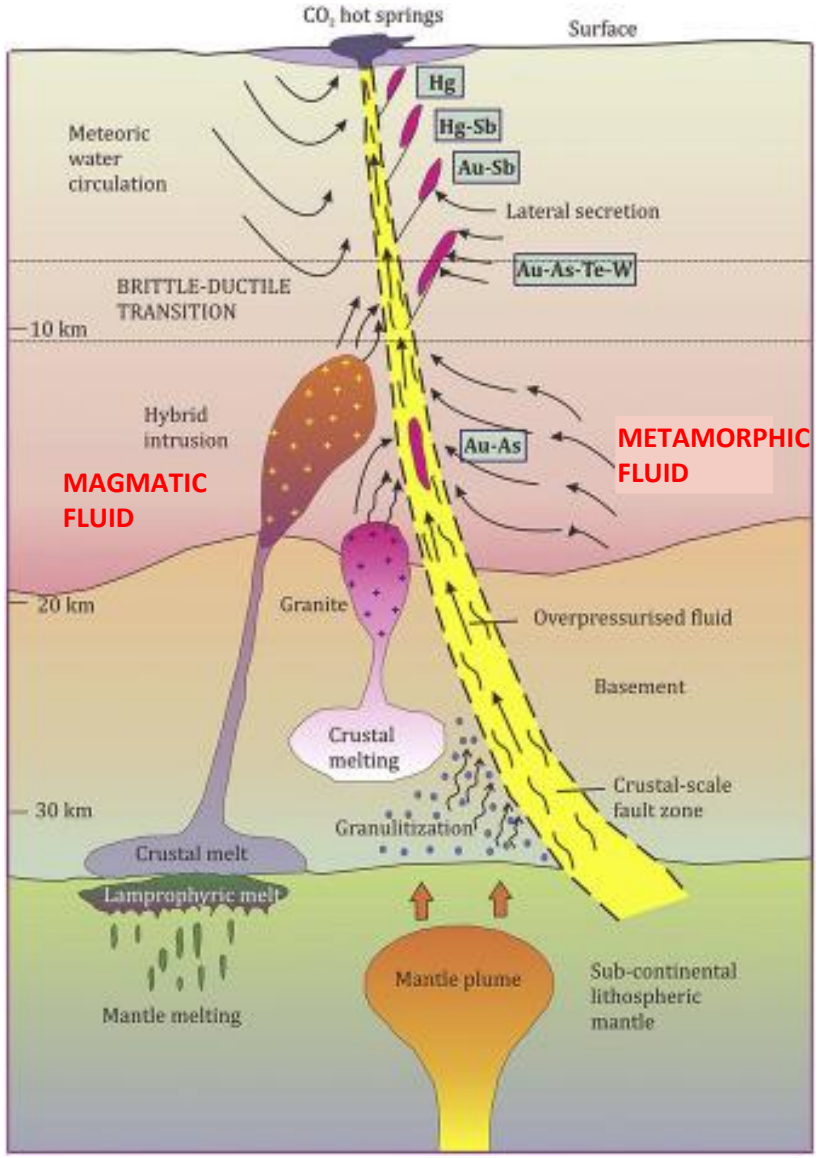
After Groves and Santosh (2016)

SINK

- What mechanisms cause gold endowment?
  - What are the parameters (T, P, fO_2, fS_2, pH) driving destabilization of gold-carrying complexes?
- What are the fluid flow conditions to form a deposit?
  - What differences in fluid-rock reactions are important for gold mineralization?

METAL EARTH

What Controls Gold Endowment?



Uprising auriferous fluid(s)

After Groves and Santosh (2016)

TIMING

- SOURCE(S)
  - What is the timing of fluid generation?
    - What is the corresponding geodynamic setting?
- SINK
  - What is the timing of gold mineralization?
    - Is gold mineralization a result of successive hydrothermal fluid events?

METAL EARTH

STRATEGY

TO COMPARE ENDOWED AND LESS ENDOWED AREAS AT DIFFERENT SCALES

- SUPERIOR SCALE (x100km)
- TRANSECT SCALE (x10km)
- DEPOSIT SCALE (x1km)

The Wabigoon Subprovince: a less endowed endmember

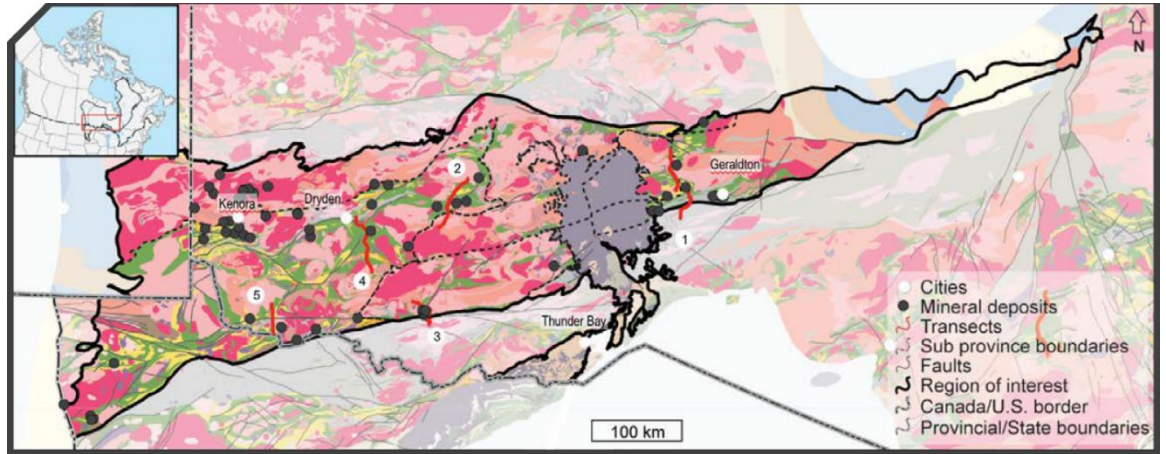


Figure 5: Geological compilation of the Wabigoon Subprovince with locations of the transects. 1. Geraldton-Onaman, 2. Sturgeon River, 3. Atikokan, 4. Dryden-Stormy, 5. Rainy River

The Abitibi Subprovince: an endowed endmember

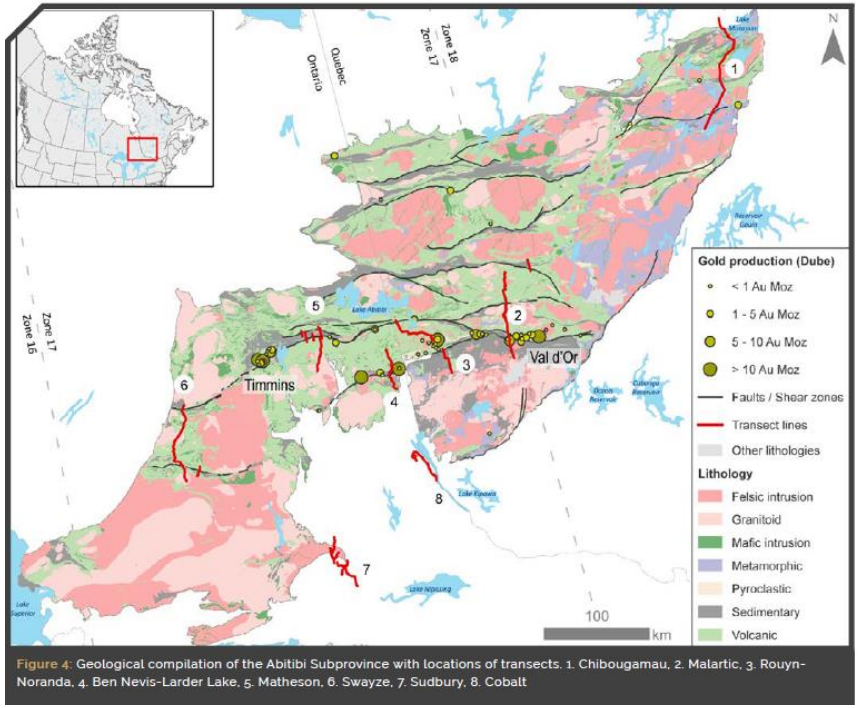


Figure 4: Geological compilation of the Abitibi Subprovince with locations of transects. 1. Chibougamau, 2. Malartic, 3. Rouyn-Noranda, 4. Ben Nevis-Larder Lake, 5. Matheson, 6. Swayze, 7. Sudbury, 8. Cobalt

METAL EARTH

Work Plan 2019-2020

- The Fluid Window (PhD#1)
  - Transect- to regional-scale
  - Composition, volume and timing of fluid generation from relevant metasedimentary packages

- Regional Isotopic Survey (RA)
  - Transect- to regional-scale
  - Isotopic fluid composition variation at superior scale

- Mapping / Modeling Fluid Flow (MSc#1)
  - Deposit-scale
  - Mechanisms of gold endowment; H, O, C, S

SOURCE → SINK

- The Source of Gold (In collaboration with Iain Pitcairn UStockholm)
  - Pontiac and Opinaca (metasediment) / Abitibi and La Grande (volcano-plutonic)
  - Mobilization of Au and related elements and associated geological processes

- Sulfur DNA of Fluids (PhD#2)
  - Transect- to regional-scale
  - Source of fluid(s) and volatiles (S); timing of mineralization

- Mapping physical properties of Hydrothermal Alteration (MSc#2)
  - Deposit-scale
  - Hydrothermal alteration halo mapping

METAL EARTH

The Fluid Window:
Modeling the composition, volume and timing of fluid generation from metasediments

- Both the Abitibi (endowed) and Wabigoon (less endowed) share a tectonic boundary with metasedimentary provinces

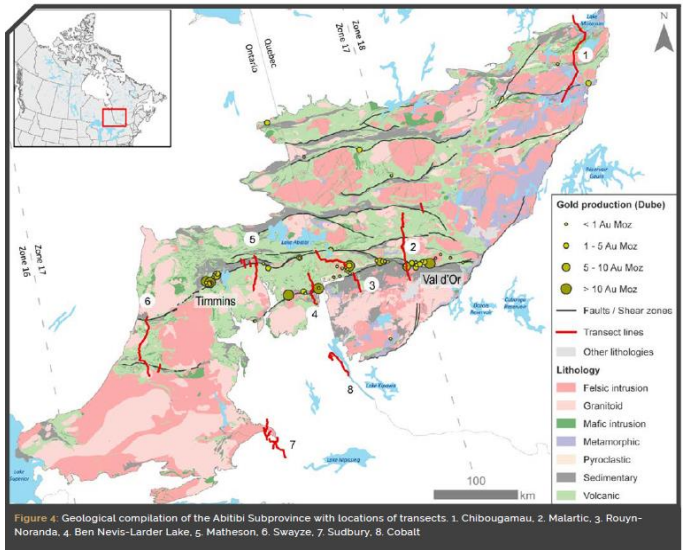


Figure 4: Geological compilation of the Abitibi Subprovince with locations of transects. 1. Chibougamau, 2. Malartic, 3. Rouyn-Noranda, 4. Ben Nevis-Larder Lake, 5. Matheson, 6. Swayze, 7. Sudbury, 8. Cobalt

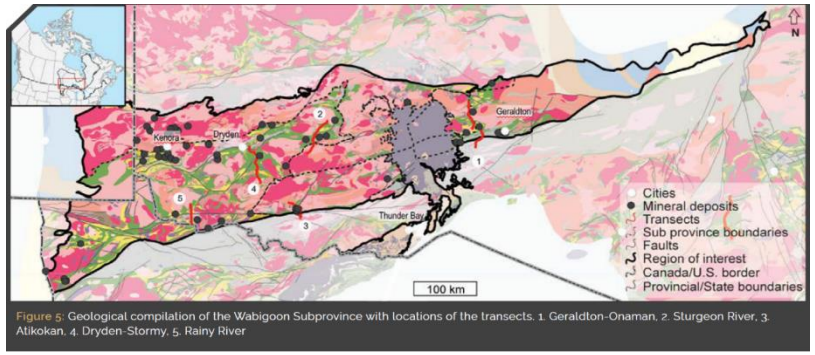
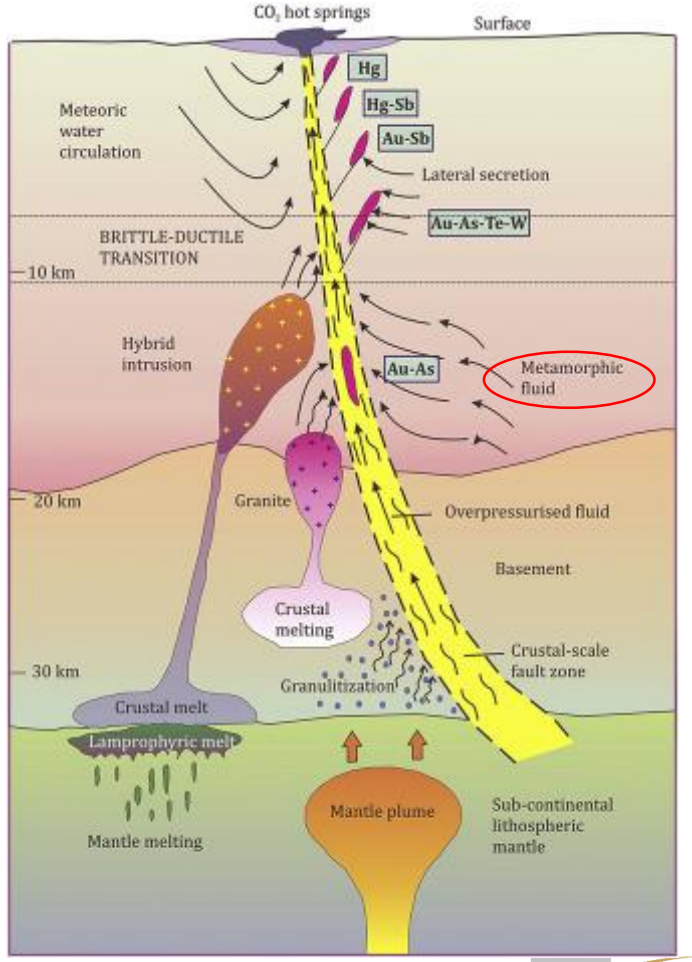


Figure 5: Geological compilation of the Wabigoon Subprovince with locations of the transects. 1. Geraldton-Onaman, 2. Sturgeon River, 3. Atikokan, 4. Dryden-Stormy, 5. Rainy River

Did fluids generated by metasediments contribute to gold endowment?



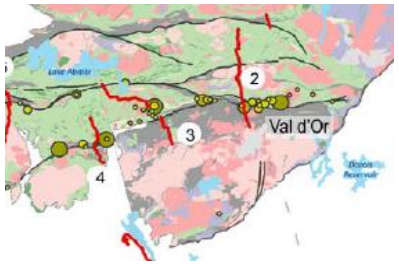
After Groves and Santosh (2016)

METAL EARTH

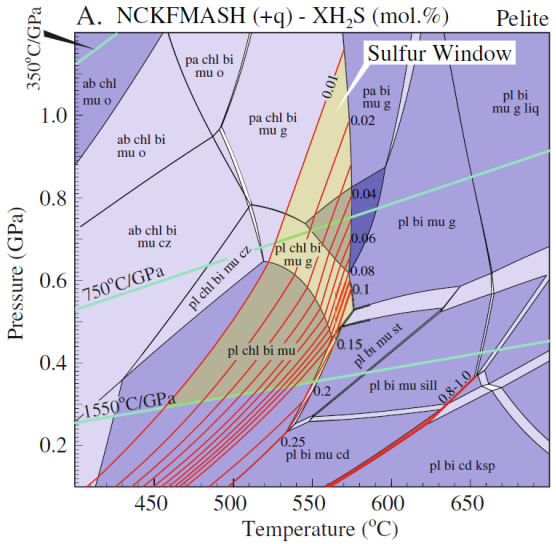
The Fluid Window:
Modeling the composition, volume and timing of fluid generation from metasediments (PhD #1)

Ph.D. 1 : Fluid Generation in the Pontiac

Student: To be recruited
Supervision: Carl Guilmette
Co-supervision: C. Laflamme and G. Beaudoin
Collaborators: T. Jørgensen, I. Pitcairn (Ustockolm), M. Smit (UBC), M. Hamilton? (UofT)



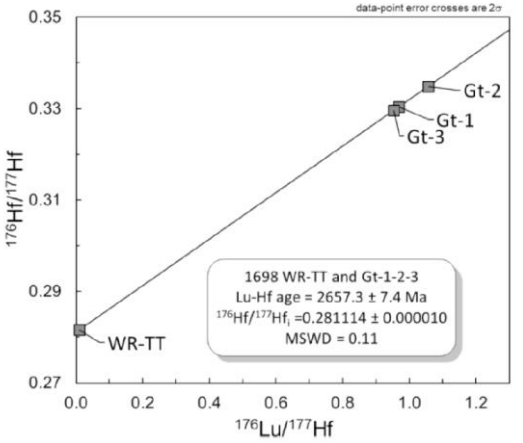
- How much fluid is released during chlorite breakdown, muscovite breakdown, biotite breakdown in the Pontiac?



After Tomkins (2010): P-T pseudosections for typical pelitic bulk compositions showing the sulfur liberation P-T windows

- What is the composition of the fluid released during phylosilicate breakdown?
  - Stable isotopes (C, O, H, S)
    - Mineral-Fluid Fractionation @ $T_{breakdown}$
  - Trace elements
    - Mineral chemistry
    - WR background content across isograds
    - Solubility @ $T_{breakdown}$

- When did the Pontiac release fluids?
  - Prograde minerals
    - U-Pb on Monazite (mu breakdown?)
    - Lu-Hf on Garnet (chl breakdown)
    - U-Pb on zircon (melt crystallization)



- Can these fluid pulses be traced to Au deposits?
  - Link with PhD Michael Herzog
  - Link with RA Regional isotopic survey

METAL EARTH

The Fluid Window:
Modeling the composition, volume and timing of fluid generation from metasediments (PhD #1)

What about other metasedimentary belts?

- Were fluids generated at the same Time, Conditions, Composition in:
  - The Quetico?
  - Successor Basins?

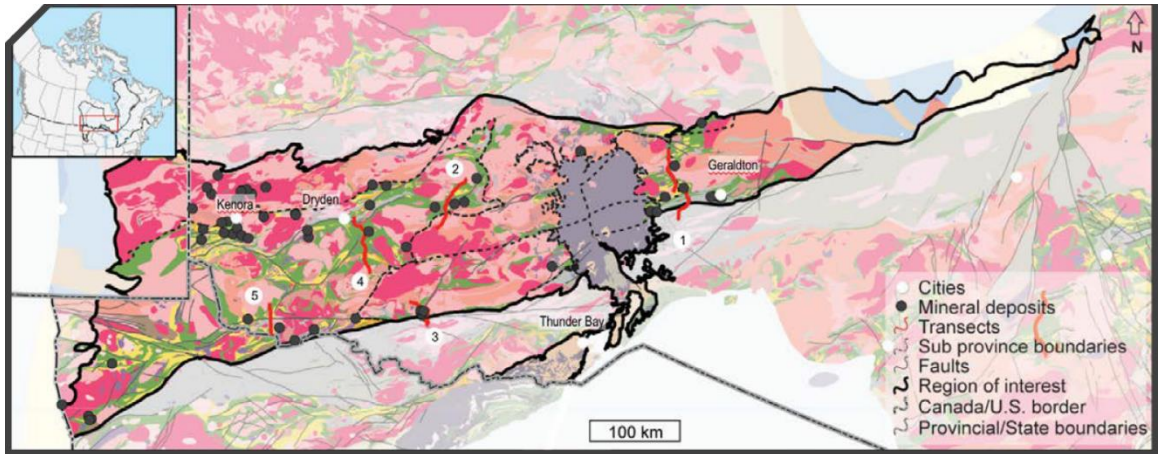


Figure 5: Geological compilation of the Wabigoon Subprovince with locations of the transects. 1. Geraldton-Onaman, 2. Sturgeon River, 3. Atikokan, 4. Dryden-Stormy, 5. Rainy River

What about other hydrated rocks?

- Basalts may also be a source (e.g. Tomkins 2010)
  - Could we get similar information for fluids released from metabasalts?

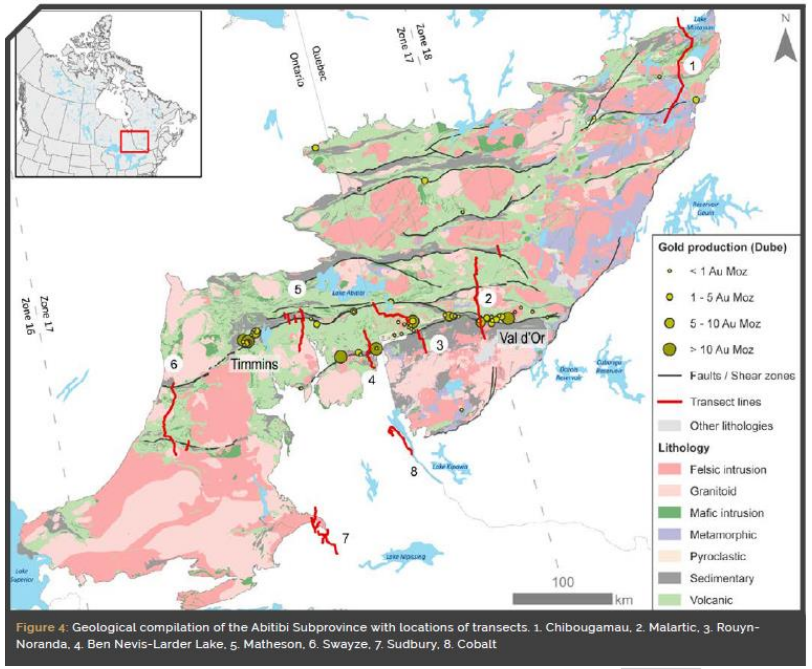


Figure 4: Geological compilation of the Abitibi Subprovince with locations of transects. 1. Chibougamau, 2. Malartic, 3. Rouyn-Noranda, 4. Ben Nevis-Larder Lake, 5. Matheson, 6. Swayze, 7. Sudbury, 8. Cobalt

METAL EARTH

Regional Isotopic Survey (RA)

B. Quesnel, C. Scheffer, G. Beaudoin

Collaborators: X. Zhou, T. Jørgensen, K. Rubingh, Z. Tóth, B. Frieman, C. M. John (Imperial College London)

Is it possible to identify different isotopic trends between both subprovinces?

- Build a stable isotope ($\delta^{18}O$, δD, $\delta^{13}C$, Δ_{47}) database for fluids at the origin of different types of mineralization in various geological contexts
- What are the best areas to perform smaller scale studies in collaboration with transect teams?

The Wabigoon Subprovince: a less endowed endmember

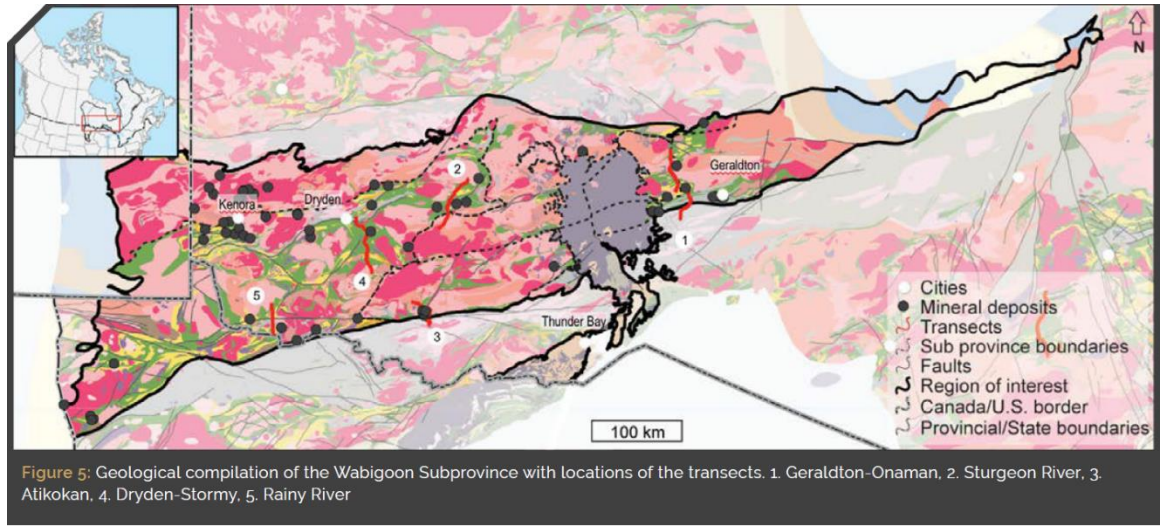


Figure 5: Geological compilation of the Wabigoon Subprovince with locations of the transects. 1. Geraldton-Onaman, 2. Sturgeon River, 3. Atikokan, 4. Dryden-Stormy, 5. Rainy River

The Abitibi Subprovince: an endowed endmember

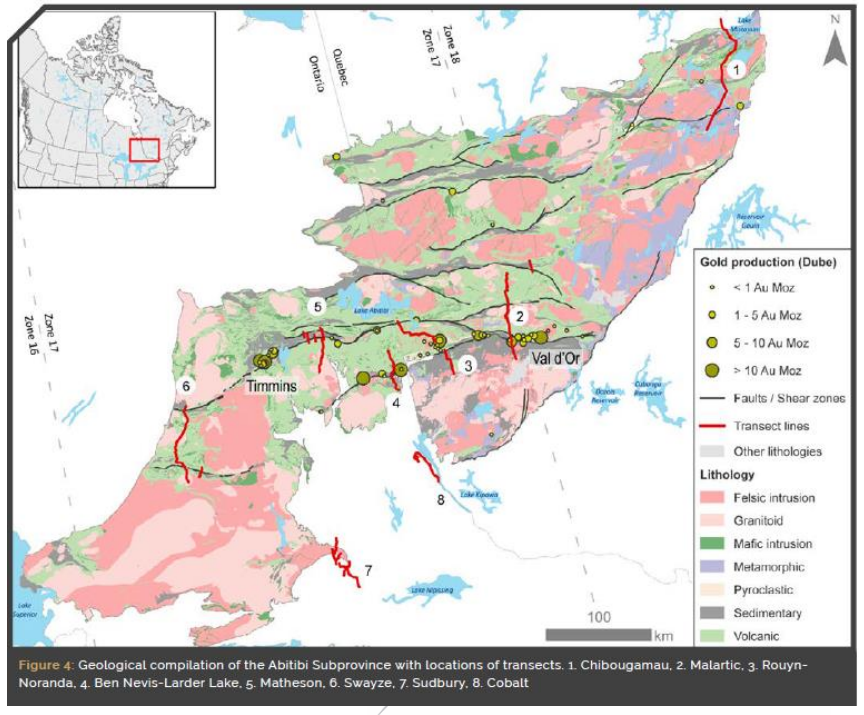


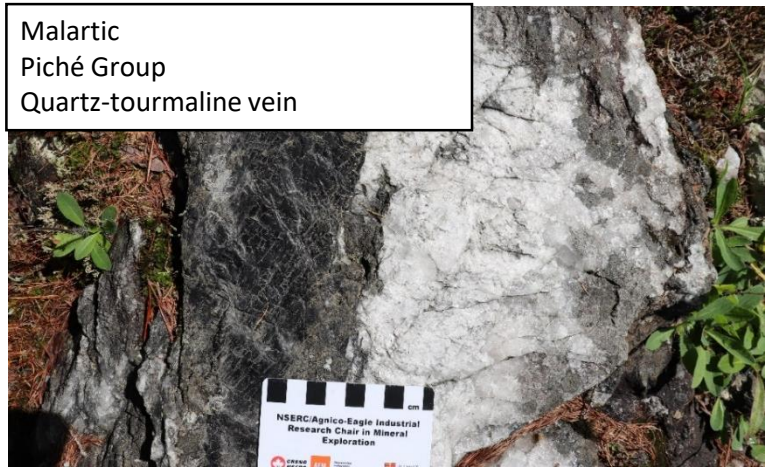
Figure 4: Geological compilation of the Abitibi Subprovince with locations of transects. 1. Chibougamau, 2. Malartic, 3. Rouyn-Noranda, 4. Ben Nevis-Larder Lake, 5. Matheson, 6. Swayze, 7. Sudbury, 8. Cobalt

Regional Isotopic Survey (RA)

2018

- Abitibi subprovince
  - 3 transects sampled (Malartic, Rouyn-Noranda, Larder Lake)
  - 114 vein samples to be analyzed (120 Qz, 36 Cb, 7 Tur, 2 Bt; mineral separates prepared)

Malartic
Piché Group
Quartz-tourmaline vein



- Wabigoon subprovince
  - 2 transects sampled (Geraldton-Onaman, Dryden-Stormy)
  - 40 veins to be analyzed (47 Qz, 20 Cb, 2 Ep; mineral separates in prep.)

Dryden
10 km north from the Wabigoon fault
Quartz vein crosscutted by tension gashes

Regional Isotopic Survey (RA)

Summer 2019

- Abitibi subprovince
  - Chibougamau (Pierre Bedeaux and Lucie Mathieu)
  - Cobalt (Shawna White)?

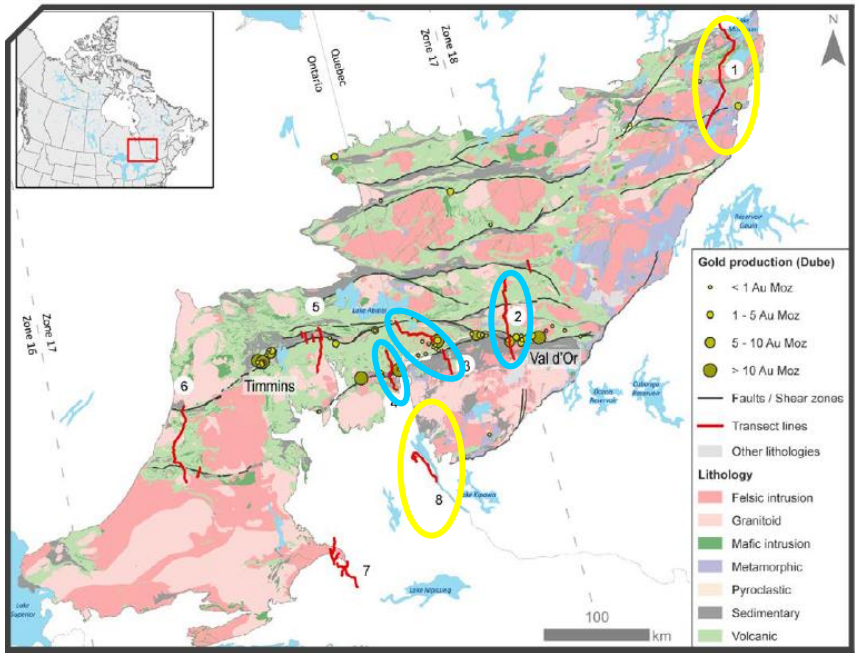


Figure 4: Geological compilation of the Abitibi Subprovince with locations of transects. 1. Chibougamau, 2. Malartic, 3. Rouyn-Noranda, 4. Ben Nevis-Larder Lake, 5. Matheson, 6. Swayze, 7. Sudbury, 8. Cobalt

2019

2018

- Wabigoon subprovince
  - Sturgeon River?
  - Atikokan?
  - Rainy River?

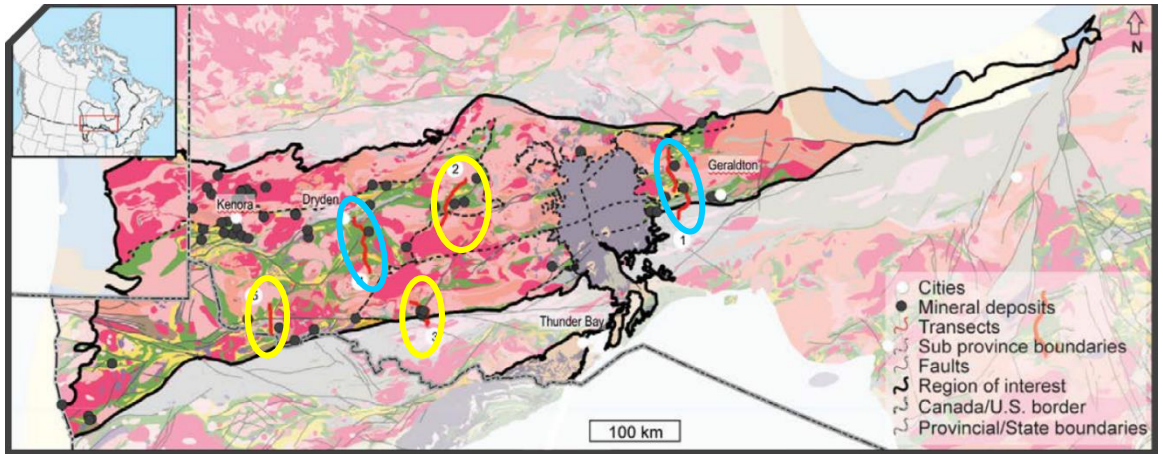
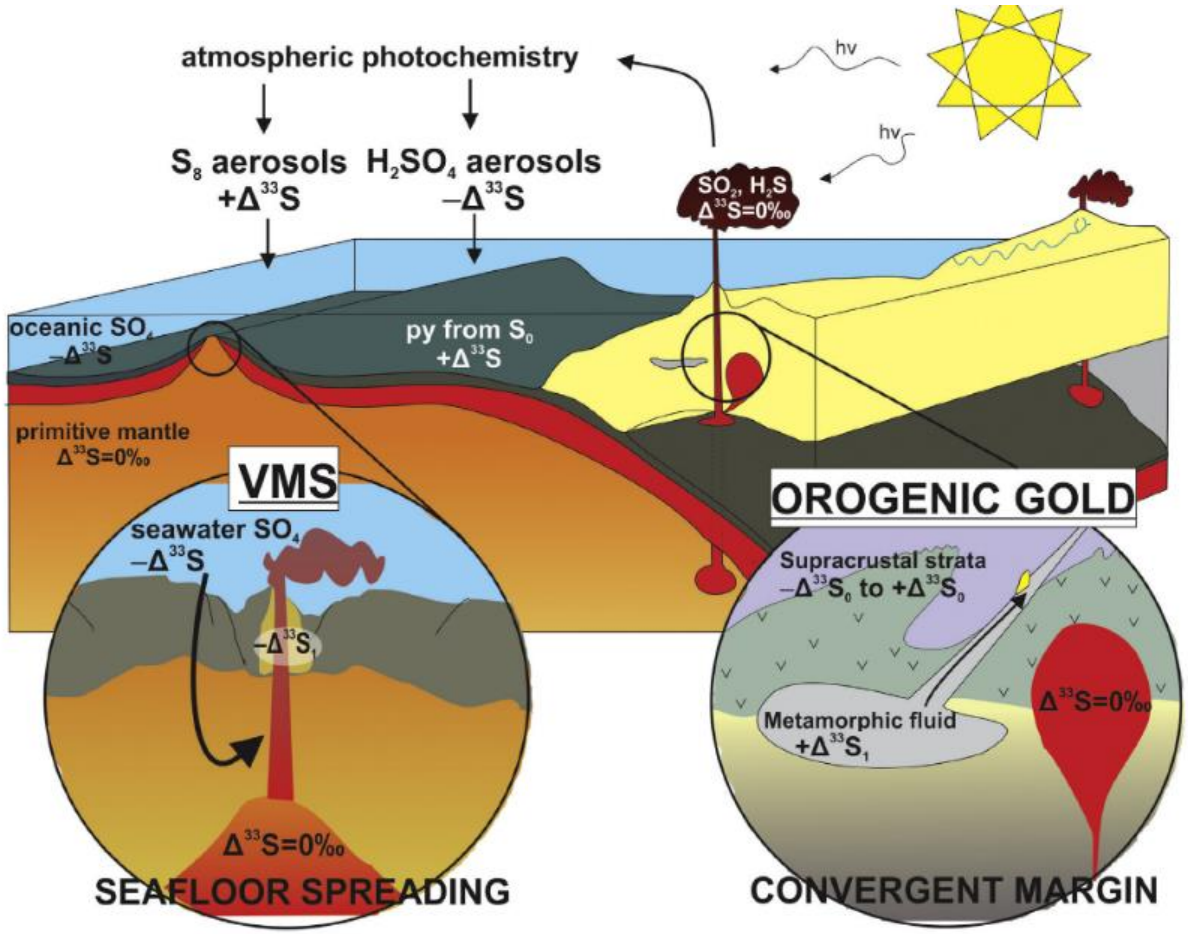


Figure 5: Geological compilation of the Wabigoon Subprovince with locations of the transects. 1. Geraldton-Onaman, 2. Sturgeon River, 3. Atikokan, 4. Dryden-Stormy, 5. Rainy River

Sulfur DNA



LaFlamme et al. 2018

Multiple sulfur isotopes

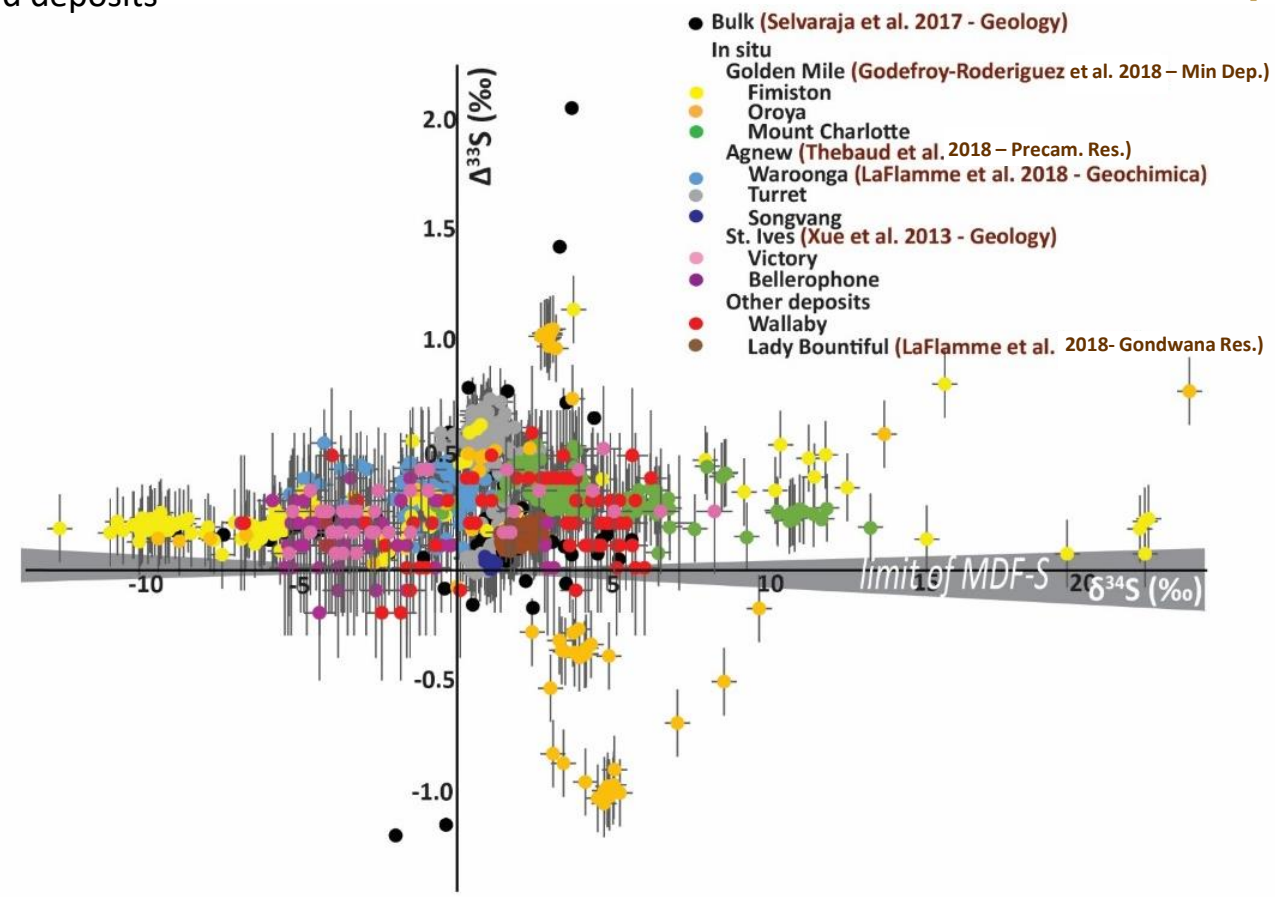
- $\Delta^{33}S$ composition of gold-associated sulfide in Archean orogenic gold deposit can help to decipher the source of sulfur (transporting ligand) in auriferous fluid
- MIF signature ($\Delta^{33}S \neq 0‰$) of sulfide in the deposit indicate incorporation of sediments as source of sulfur, whereas MDF signature ($\Delta^{33}S \approx 0‰$) may indicate a magmatic source.

METAL EARTH

Sulfur DNA:
Yilgarn Craton, Australia

Yilgarn Craton

Gold deposits



LaFlamme et al. 2018 Gondwana Research

New findings:

- Archean sediments form part of sulfur reservoir (**ubiquitous +$\Delta^{33}S$ in most Au deposits**)
- Sulfur reservoir very similar across an entire craton at 2.6 Ga (**$\Delta^{33}S$ = +0.1 to +0.5‰**)
- At camp scale, $\Delta^{33}S$ is not constant and could be related to different fluid pulses/hydrothermal events

Can we further refine these observations at camp scale to investigate specific fluid pulses/hydrothermal events?

METAL EARTH

Gold endowment: monitoring fluid composition through multiple hydrothermal pulses (PhD #2)

Supervision: C. LaFlamme

Co-supervision: G. Beaudoin

Collaborators: X. Zhou, S. Hagemann and N. Thébaud (Centre for Exploration Targeting- Yilgarn2020 project), Chris McFarlane

Develop an understanding of gold endowment in both space and time

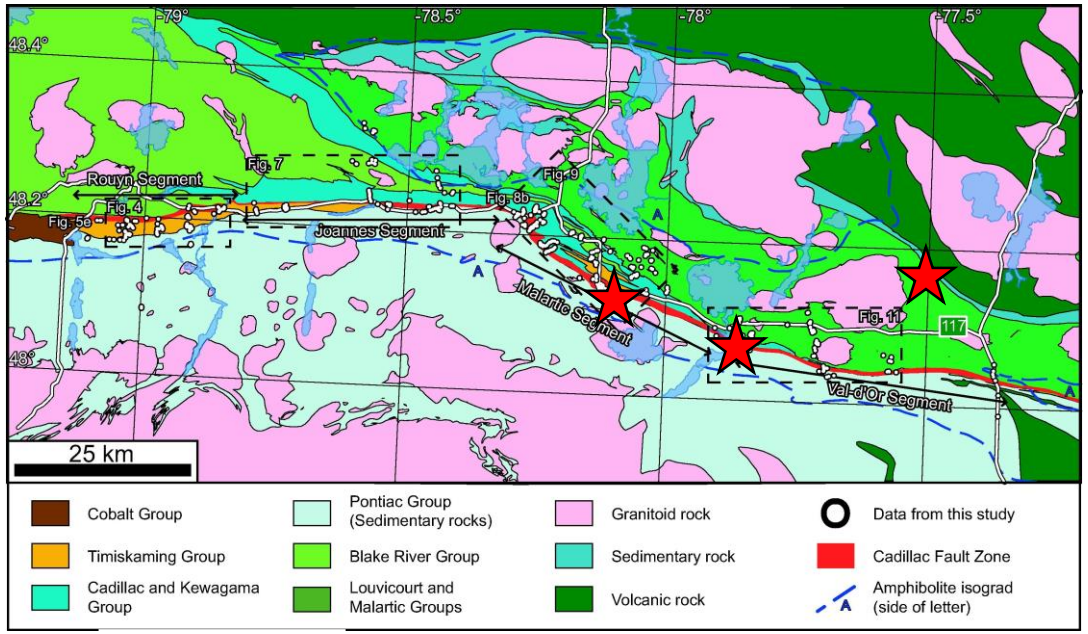
- Build a framework for ore vectoring criteria at the camp-scale
- Improve understanding of aurifeous fluids from source to sink
- Inform on geodynamic setting during the Neoarchean
  - Link to PhD #1: C. Guilmette
  - Link to work completed in Yilgarn Craton
- Refine understanding of evolution of hydrothermal events during Archean crust formation/recycling event

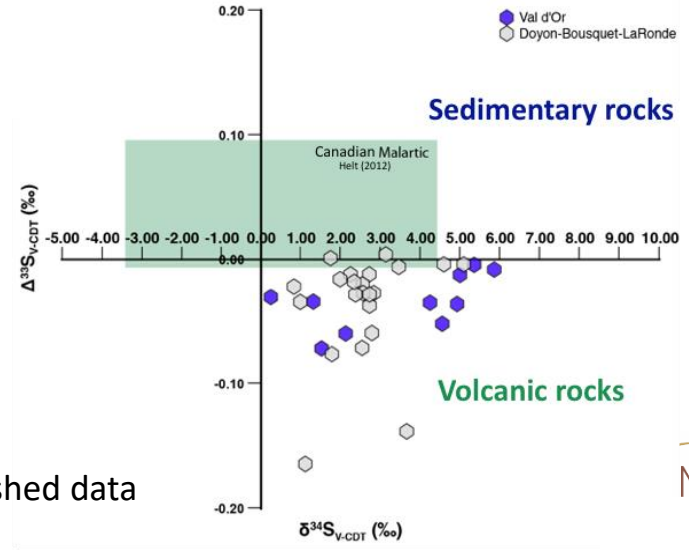
Michael Herzog (PhD student)

METAL EARTH

Gold endowment: monitoring fluid composition through multiple hydrothermal pulses (PhD #2)

- Methods:
  - Detailed lithological/structural observation of core, open pits and underground drives in the Val d'Or region
  - Describe and *integrate hydrothermal events at transect-scale*
  - Define paragenetic sequence and host rock alteration in each hydrothermal event
  - Complete *multiple sulfur isotopes through paragenetic sequence* in auriferous and non-auriferous hydrothermal events at each deposit
  - Complete in situ U-Pb geochronology of accessory minerals associated with gold (e.g. xenotime)





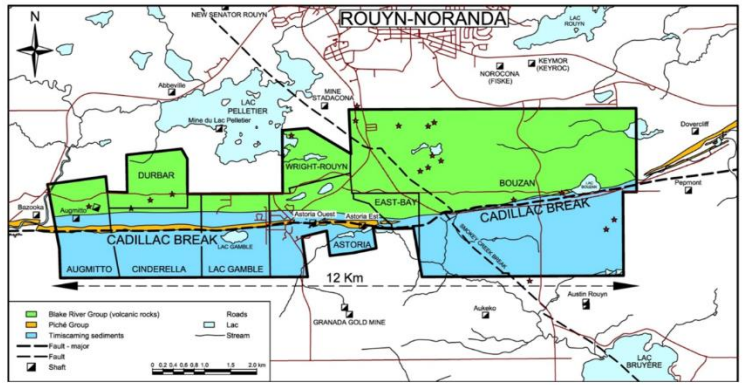
Preliminary work: Helt, unpublished MSc, Beaudoin, unpublished data

METAL EARTH

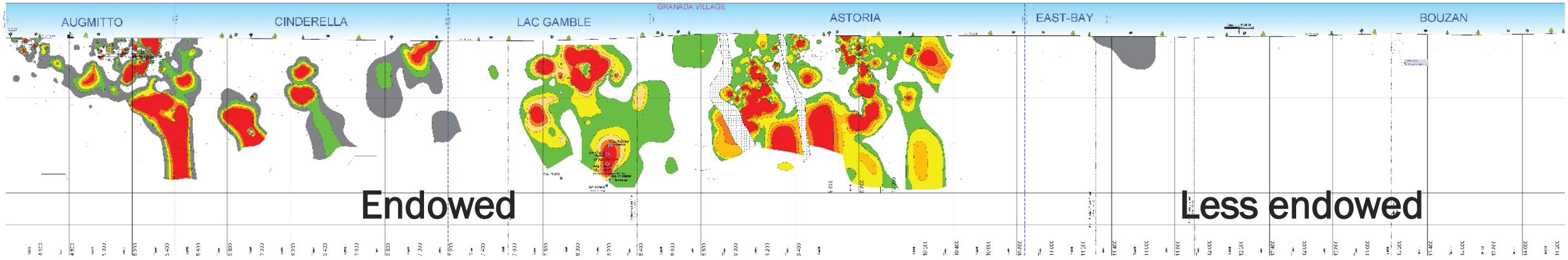
Augmitto-Bouzan: Mapping / Modeling Fluid Flow and Hydrothermal Alteration

The Augmitto-Bouzan segment (Rouyn-Noranda transect)

- 12 km drilled segment along the Larder Lake Cadillac deformation zone ⟶ Access to core library
- Geological background very well constrained (i.e Pierre Bedeaux PhD thesis, 2018 and reference herein) ⟶ detailed fluid study makes sense



Simplified geological map of Yorbeau Resources Inc. property



GRADE-THICKNESS (g/t/m)
> 25
> 20
> 15
> 10
> 5
Drillholes

METAL EARTH

Augmitto-Bouzan: Mapping / Modeling Fluid Flow and Hydrothermal Alteration

Mapping / Modeling Fluid Flow

M.Sc. #1

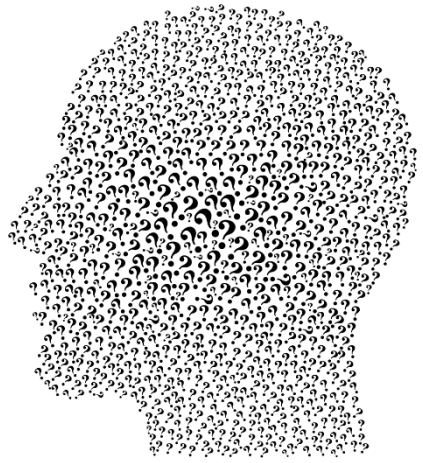
- Supervision: G. Beaudoin
- Co-supervision: C. Laflamme
- Collaboration: T. Jørgensen, G. Riverin and B. Chapon from Yorbeau Resources Inc., C. M. John (Imperial College London)

Guillaume Raymond

Physical Properties of Hydrothermal Alteration Halo

M.Sc. #2

- Supervision: C. Dupuis
- Co-supervision: R. Smith
- Collaboration: M. Naghizadeh, T. Jorgensen, G. Riverin and B. Chapon from Yorbeau Resources Inc.



To be recruited

METAL EARTH

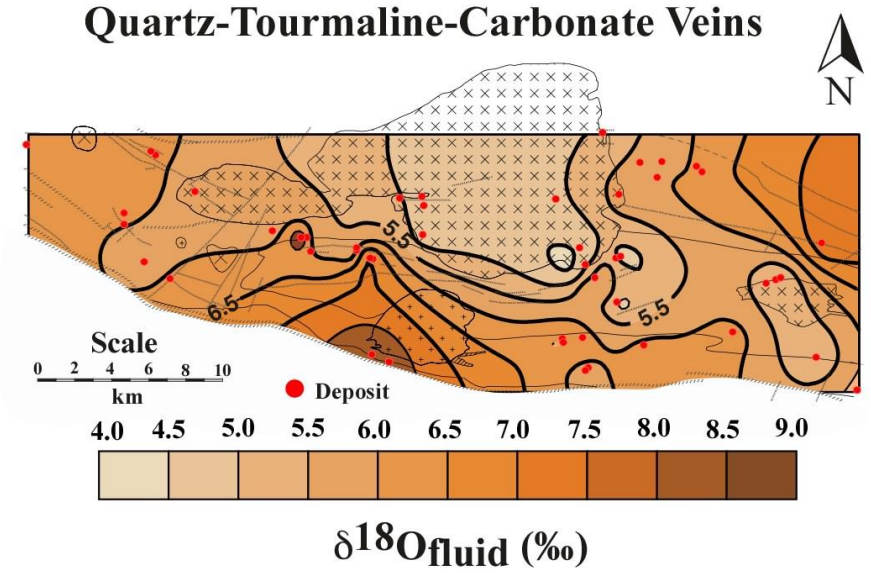
Spatial variation of fluid flow along the Augmitto-Bouzan segment (MSc #1)

What parameters drive gold over-concentration mechanisms?

- Destabilization of gold-carrying complexes can result from fluid thermochemistry variations including:
  - Temperature decrease
  - Increasing fluid-rock interaction (decreasing fluid flow)
  - Fluid source variation and/or fluid mixing

- Do spatial variations of fluid circulation conditions mimic the erratic distribution of gold mineralization?

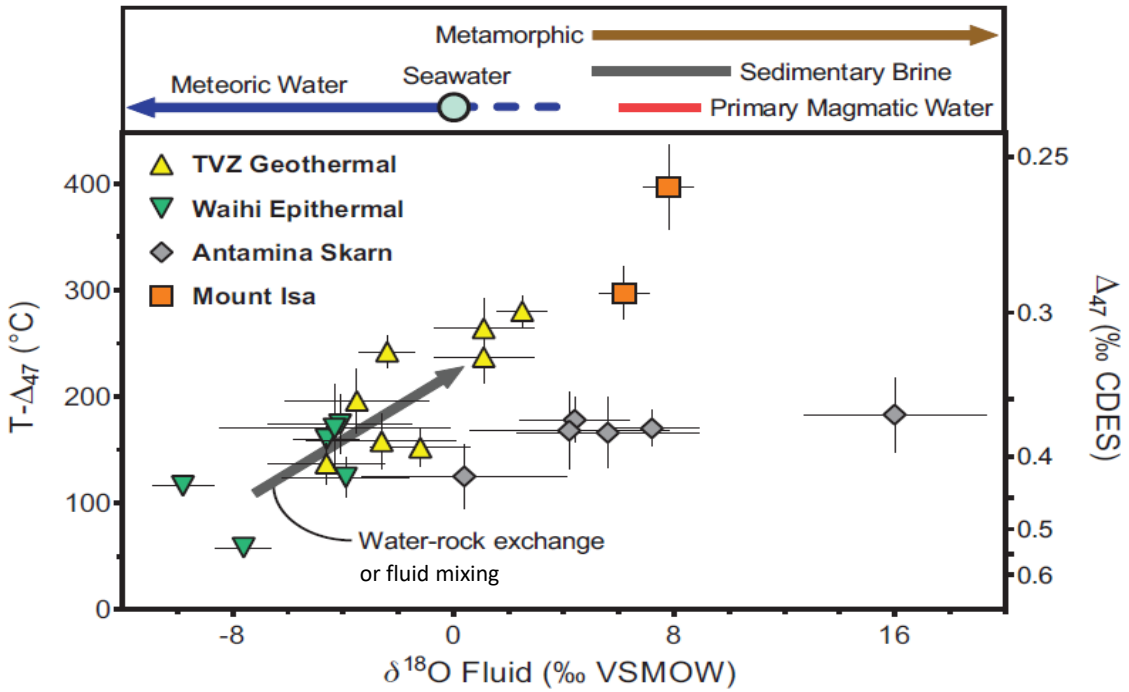
- Stables isotopes ($\delta^{18}O$, δD, $\delta^{13}C$, Δ_{47}) are powerful tools to monitor fluid modification



Beaudoin & Pitre (2005): Val-d'Or vein field oxygen isotope composition of hydrothermal fluids

METAL EARTH

Spatial variation of fluid flow along the Augmitto-Bouzan segment (MSc #1)



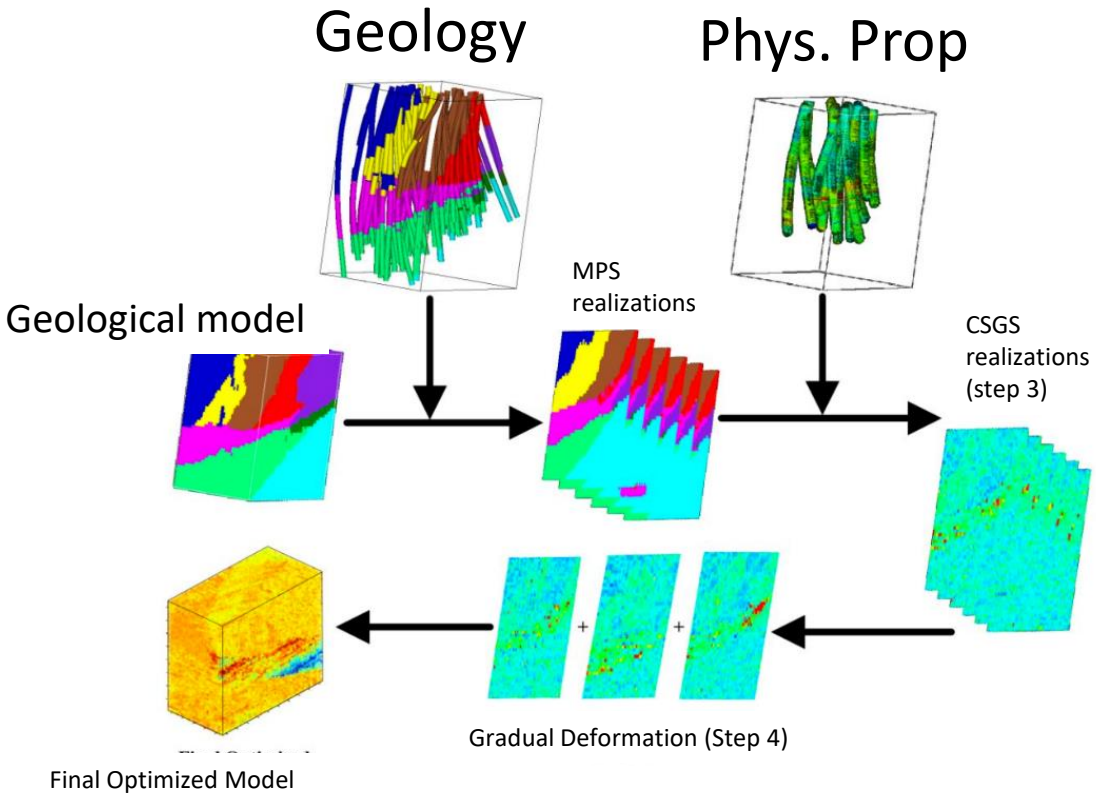
After Mering et al. (2018): Calculated fluid $\delta^{18}O$ plotted against calibrated temperatures (left vertical axis) and observed (Δ_{47} values (right vertical axis)

- Vein paragenetic sequence and host rock alteration
  - Petrography
- Fluid temperature spatial variation
  - Stable isotope paleothermometers
- Fluid source – mixing spatial variation
  - Fluid stable isotope composition
- Fluid-rock interaction spatial variation
  - Stable isotopic mass balance
- 3D Fluid flow modeling
  - Hydrogeosphere software

METAL EARTH

Physical properties of hydrothermal alteration halo along the Augmitto-Bouzan segment (MSc #2)

Do gold bearing formations have specific physical properties?



Tirdad et al. (2019)

- Field acquisition
  - Spectral Gamma
  - Magnetic Susceptibility
  - Full-Waveform Sonic
  - Electrical conductivity
  - Induced Polarization

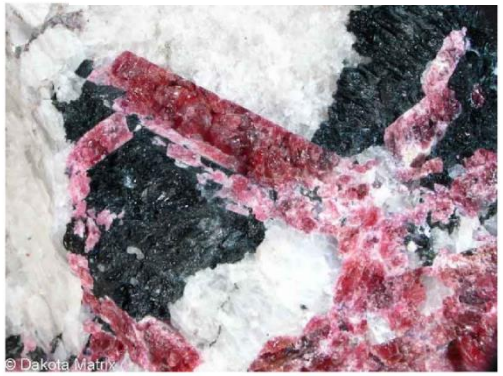
- Investigate signature of formations and lithologies
- Investigate the potential of automated classification algorithms to assist 3D-model building
- Investigate the potential to map fluid flow and hydrothermal alteration (Physical Prop.)

METAL EARTH

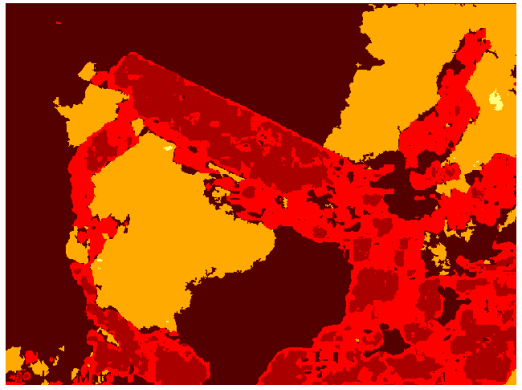
Physical properties of gold bearing formations along the Augmitto-Bouzan segment (MSc #2)

Can vein types be automatically recognized and quantified by an Optical Televiewer (OTV) survey ?

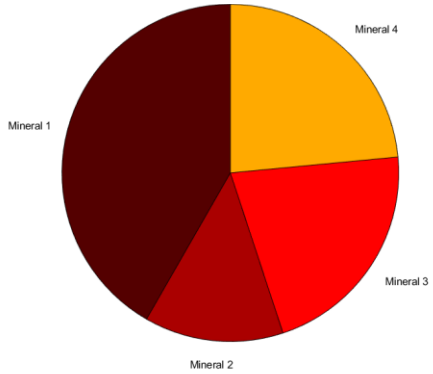
The original image



The mineral map

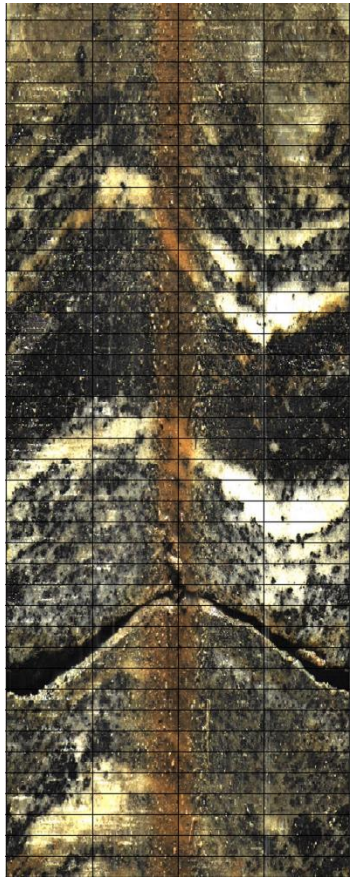


The respective percentage of the minerals in the mineral map



- Investigate the capacity to recognize the nature of veins and veinlets
- Determine the spatial variability of frequency for each type of vein (Link to MSc G. Raymond)
- Build a structural database for each type of veins (Link to MSc G. Raymond)

OTV image



METAL EARTH

Collaboration with transect teams 2019

HOW CAN WE HELP?

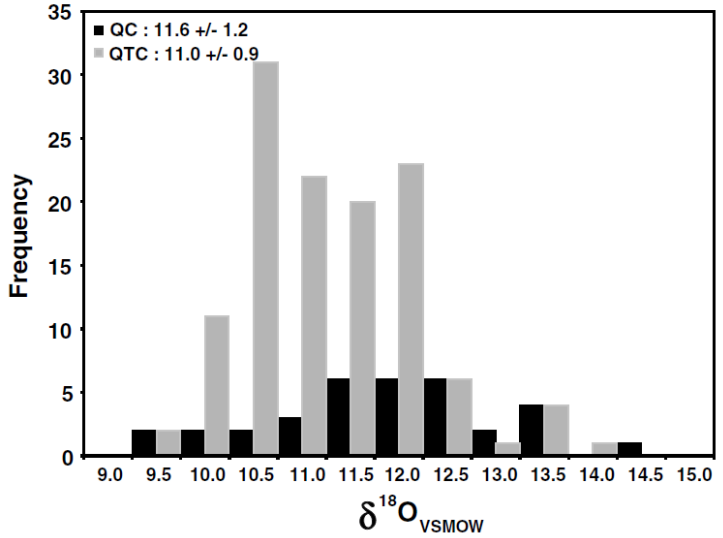
- Our skills
  - Stable isotopes
    - Oxygen stable isotope composition in silicates (C. Scheffer, B. Quesnel, G.Beaudoin)
    - Multiple sulfur isotopes composition of sulfide minerals (C. Laflamme)
  - Boreholes geophysical measurements
    - Borehole surveys + cal. (C. Dupuis)
    - Borehole Interp. (C. Dupuis)
  - Geochemistry
    - Elemental mapping
- Our Lab facilities
  - Stable isotopes
    - Oxygen extraction vacuum line
    - LA-QQQ-ICP-MS (installation end 2019)
  - Drillholes geophysical measurements
    - 300 and 1000 m winches
    - SGR, ELOG, IP, OTV, FWS, MAG, VSP, BHR
  - Geochemistry
    - μXRF

METAL EARTH

Oxygen extraction line for $\delta^{18}O$ (rock and minerals)

Christophe Scheffer, RA in charge of oxygen extraction line

Histogram of $\delta^{18}O$ values for the quartz-carbonate (QC) and quartz-tourmaline-carbonate (QTC) vein from the Val d'Or vein field. Beaudoin & Pitre (2005)



METAL EARTH

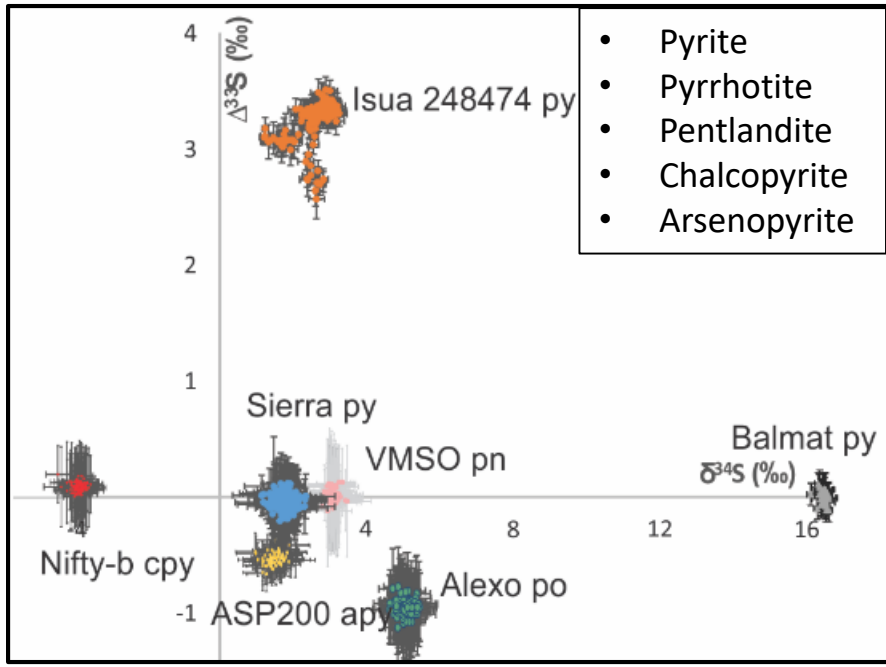
LA-QQQ-ICPMS Laboratory: A focus on multiple sulfur isotopes (installation end 2019)

MOU Université Laval - University of Western Australia
strong link to UWA-SIMS

Reference Material

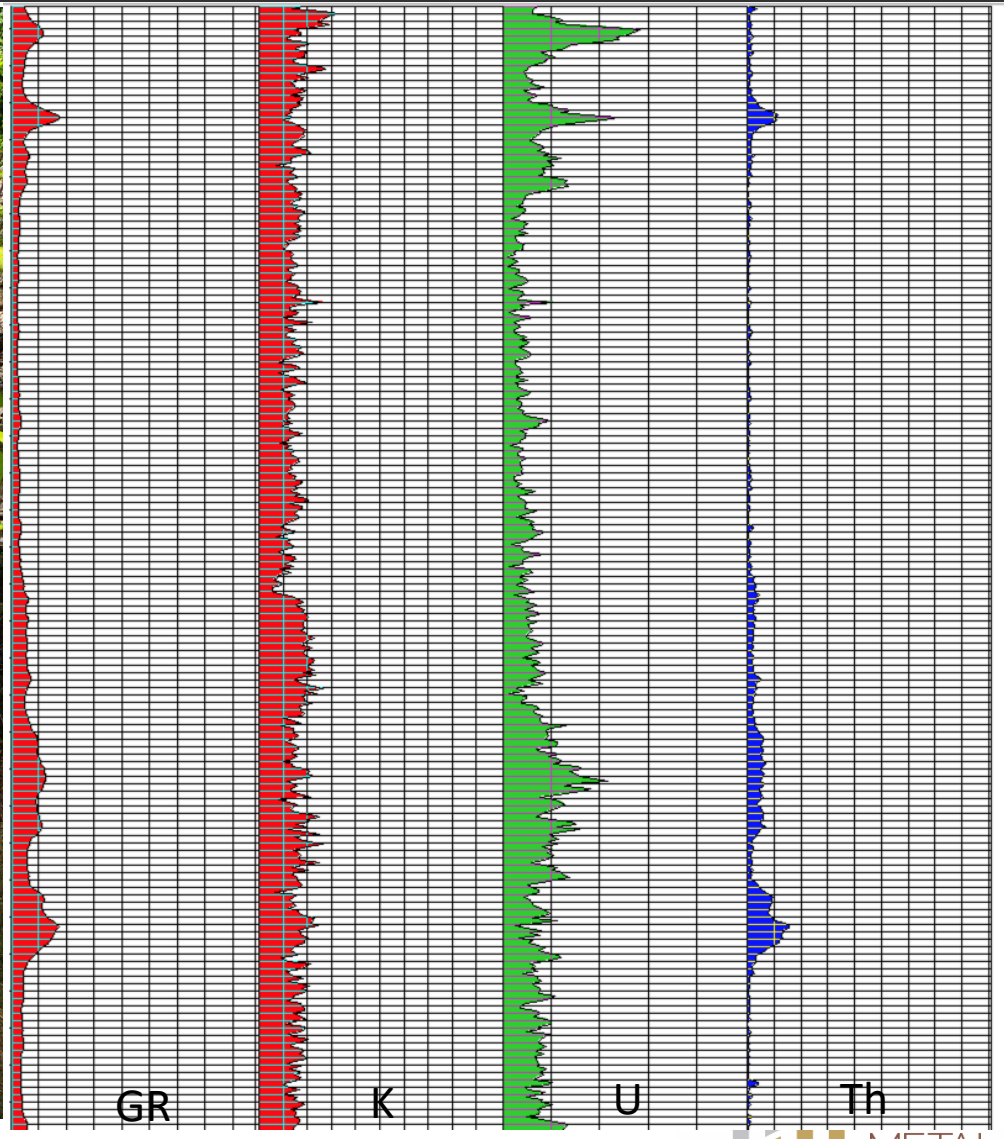
LaFlamme et al. 2016 Chemical Geology
LaFlamme et al. 2018 Geochimica

- Pyrite
- Pyrrhotite
- Pentlandite
- Chalcopyrite
- Arsenopyrite



INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

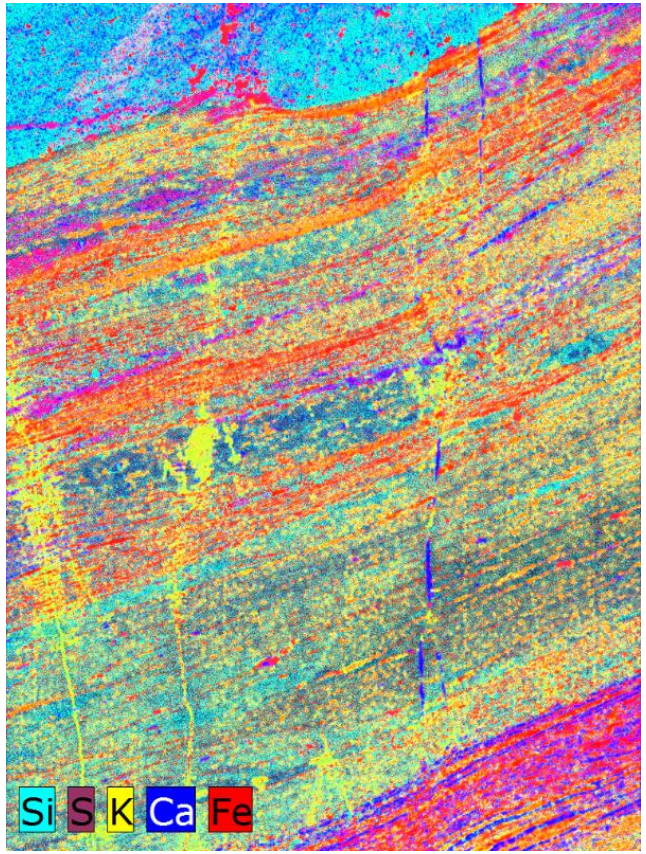
Boreholes geophysical measurements



INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

METAL EARTH

Micro X-ray Fluorescence Spectroscopy: M4 Tornado

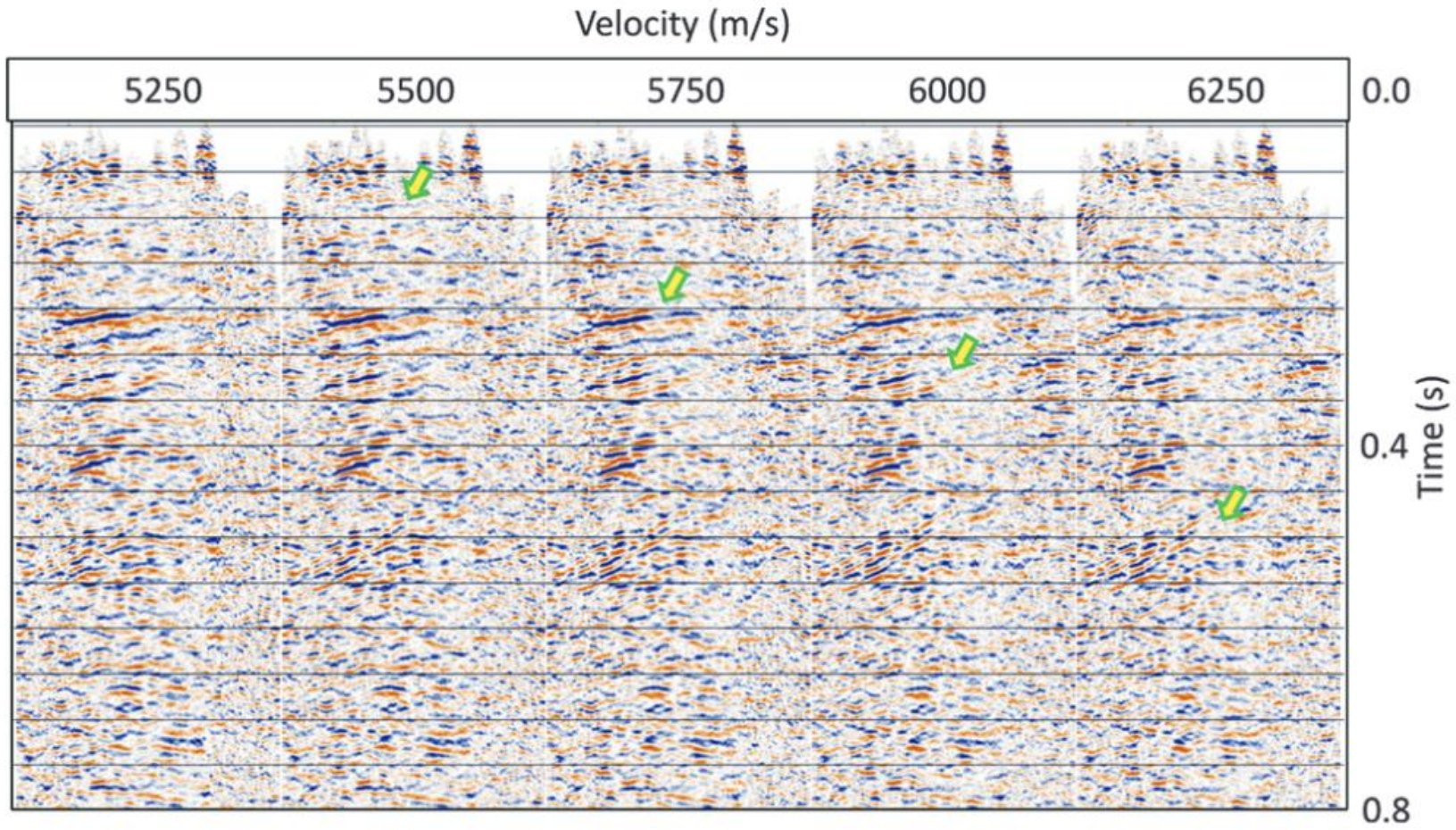


Thin section elemental map

METAL EARTH

MSc project #3: Improving focus and interpretation through petrophysics

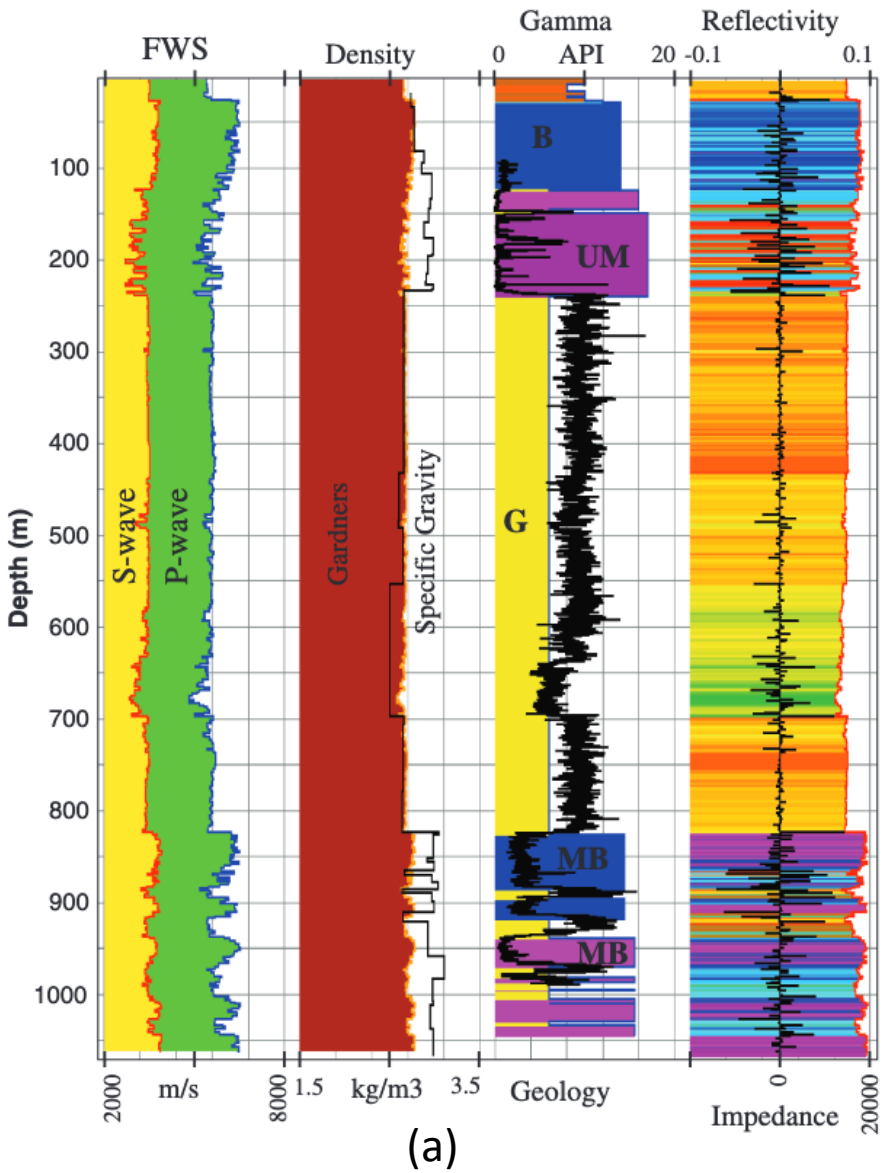
Can we validate our interpretation of a transect and improve our geophysical models ?



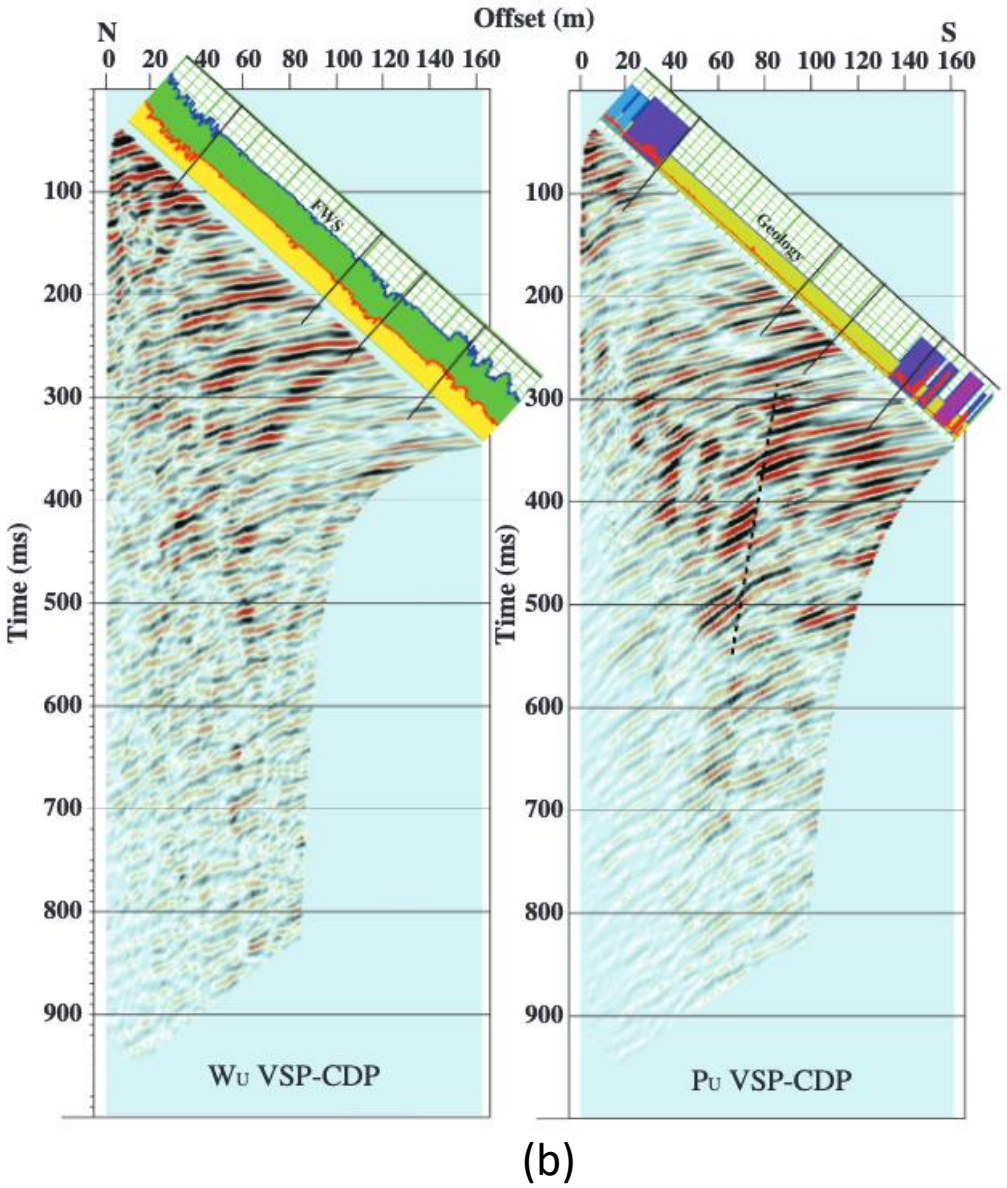
Kambalda – Constant Velocity Stacks
Urosevic et al. (2012)

METAL EARTH

MSc project #3: Improving focus and interpretation through petrophysics



(a)



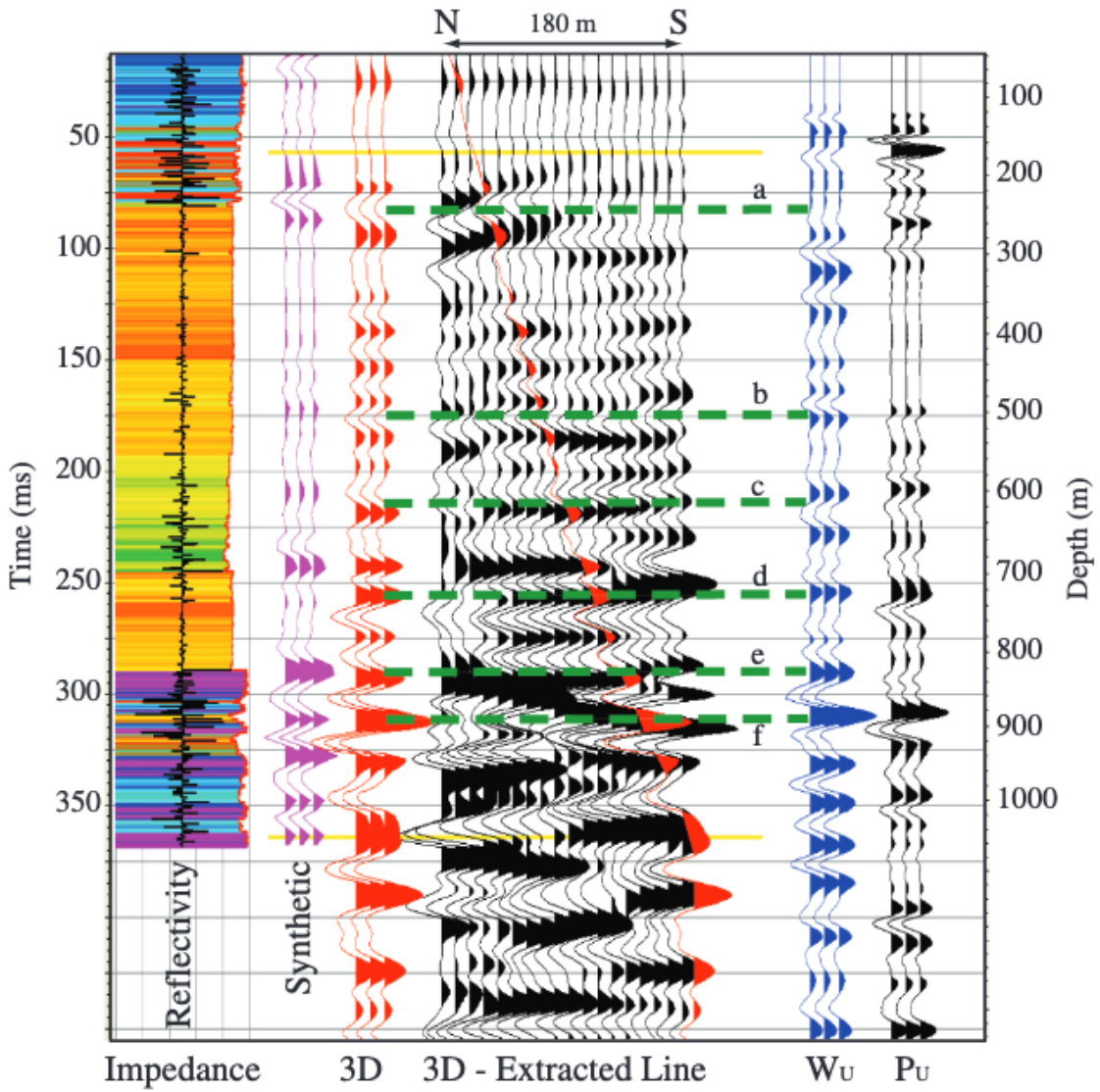
(b)

(a) Physical Prop.
(b) VSP data

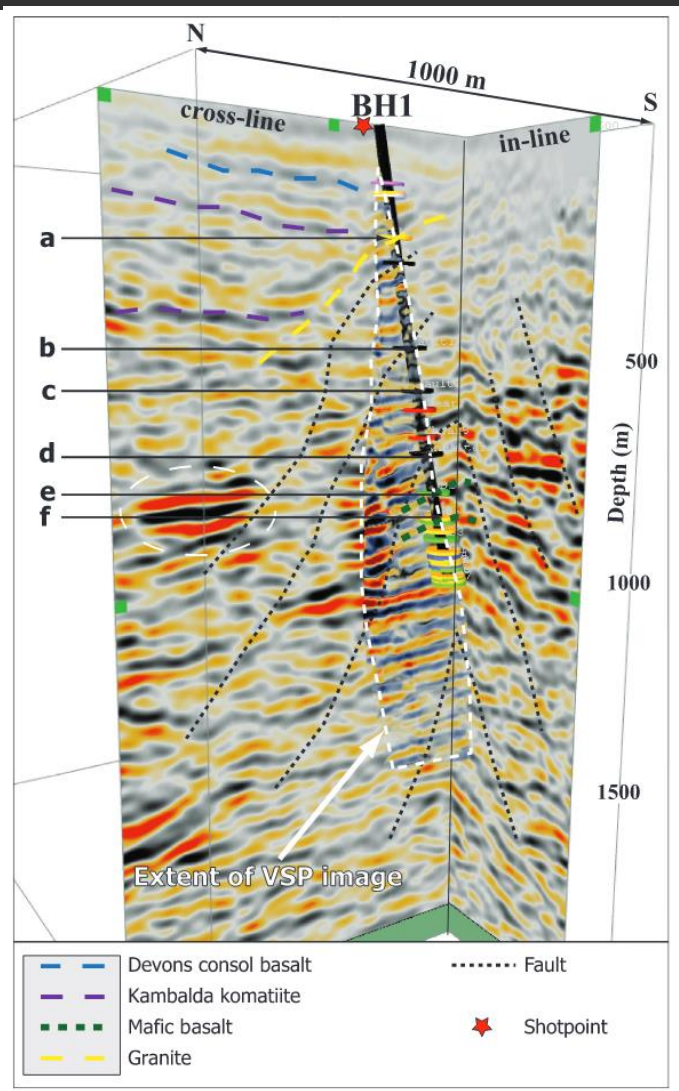
Greenwood et al. 2012

METAL EARTH

MSc project #3: Improving focus and interpretation through petrophysics



(a)

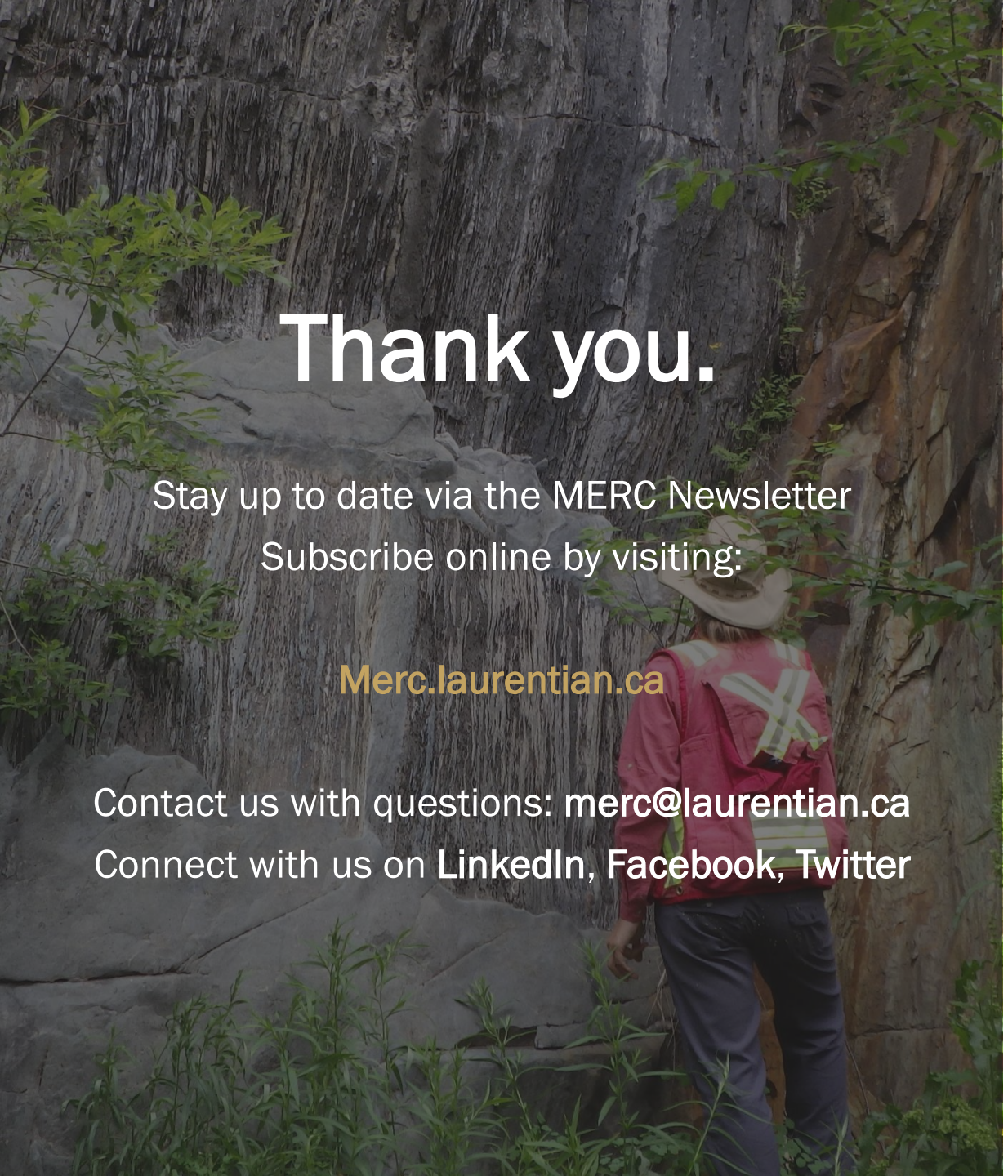


(b)

(a) Modelled vs Measured
(b) VSP in 3D Seis. Volume

Greenwood et al. 2012

METAL EARTH



Thank you.

Stay up to date via the MERC Newsletter
Subscribe online by visiting:

Merc.laurentian.ca

Contact us with questions: **merc@laurentian.ca**
Connect with us on **LinkedIn, Facebook, Twitter**

METAL EARTH

A new Canadian research initiative funded by Canada First Research Excellence Fund.

CANADA FIRST RESEARCH EXCELLENCE FUND

Canada

UNIVERSITÉ LAVAL

E4m CENTRE DE RECHERCHE SUR LA GÉOLOGIE ET L'INGÉNIERIE DES RESSOURCES MINÉRALES

Laurentian University
Université Laurentienne

HARQUAIL SCHOOL OF EARTH SCIENCES
ÉCOLE DES SCIENCES DE LA TERRE

MERC
Mineral Exploration Research Centre