2023-24

ANNUAL **REPORT**

MERC

Mineral Exploration Research Centre
at the HARQUAIL School of Earth Sciences

IN THIS REPORT

MERC

Metal Earth

WATCH NOW!
Metal Earth - Benefits to Canada

About us

Laurentian University's Mineral Exploration Research Centre (MERC) in Sudbury, Ontario, Canada, conducts and promotes global, collaborative, lab- and field-based research on mineral deposits, exploration, and targeting.

MERC hosts internationally recognized projects and researchers from academia, industry and government. Together, faculty members, research scientists, and graduate students focus on mineral deposits, Precambrian geology, and exploration methodology and targeting. MERC also leads the Metal Earth project, one of the world's largest public geoscience projects.

We promote an integrated approach to undergraduate and graduate studies through applied research, education, and HQP training that is designed to:

- solve mineral exploration and mining challenges
- fill knowledge gaps and promote the advancement of geological and exploration education
- supply the sector with a qualified workforce.

As part of Laurentian University's Harquail School of Earth Sciences, MERC is a recognized source of research and geologic expertise. MERC plays a critical role in the training and development of highly qualified personnel for key positions in the mining and minerals industry, academia, and government.

LaurentianUniversity
UniversitéLaurentienne
HARQUAIL School of Earth Sciences École des sciences de la Terre
Canada's Mining University

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Metal Earth - Building Research Capacity

Message from TAMMY **EGER**

Vice-President, Research, Laurentian University

Metal Earth: $104M, the largest university-led geoscience research project in the world

As Laurentian University's Vice-President, Research, I am proud to share this Annual Report, which highlights significant research contributions and achievements that affirm Laurentian University, the Harquail School of Earth Sciences (HES), and the Mineral Exploration Research Centre (MERC) as global leaders in geoscience research.

As a small and primarily undergraduate university, Laurentian is a leader among its Canadian peers in research intensity and income. The projects in this report demonstrate the strength and significance of our geoscience research outputs, which are supported by government and industry partners and are guided by outstanding faculty, staff, and students.

According to a 2024 ranking by Research Infosource Inc., Laurentian ranks number one in Ontario in faculty research intensity ($154K per faculty) and total sponsored research income ($31.4M) among primarily undergraduate universities. Viewed nationally, that's second in research intensity and third in research income. These rankings offer a comparative snapshot of the research opportunities that faculty, students, and staff have at Laurentian.

With funding from the Canada First Research Excellence Fund, MERC leads the Metal Earth project, the largest university-led publicly funded geoscience research project in the world. It's also the largest research project led by Laurentian University and is a testament to Laurentian's expertise in geoscience research and teaching through MERC and HES.

As it nears completion, Metal Earth will leave an invaluable legacy of publicly available data, high-impact publications, and new analytical methods. It has also attracted, retained, and trained highly qualified professionals from diverse backgrounds who will continue to support Laurentian and Canada's place as a world leader in geoscience research.

I look forward to celebrating their future achievements.

Thank you, merci, miigwetch

VIEW OR DOWNLOAD
Research Infosource. (2024, December 9.) Canada's Top 50 Research Universities: Analysis.
https://researchinfosource.com/cil/2024/top-50-research-universities/analysis

CANADA'S TOP 50 RESEARCH UNIVERSITIES 2024 RESEARCH Infosource Inc.

WATCH NOW!
About Metal Earth (2021)

Message from ROSS **SHERLOCK**

MERC and Metal Earth Director

I'm pleased to present this Annual Report, a summary of our 2023-24 Mineral Exploration Research Centre (MERC) and Metal Earth research activities.

Our Annual Report highlights the results and progress of researchers, students, faculty, and staff at Laurentian University and our partners located across Canada and around the world. Our research partnerships benefit from support and collaboration with government agencies, industry, geological surveys, other universities, and research institutes.

This report includes public data releases, peer-reviewed publications, and discoveries made during and after the end of the official reporting period (March 31, 2024). Every year, MERC and its collaborators continue to:

- deliver scientific breakthroughs
- publish high-impact open-access journal articles
- create and strengthen partnerships with industry, government, and academic institutions
- prepare public data releases
- organize global events
- host international collaborations.

Canada's Metal Earth project, the largest university-led geoscience project in the world, is in its ninth year. Since inception, the project has collected, processed, and released massive amounts of data across over a dozen transects. This publicly available data and research-backed interpretation advance Canadian mineral exploration and investment opportunities. They also provide geological insights and proven techniques that may be applied in other parts of the world. Laurentian leads Metal Earth with research groups at partner universities. The project's primary funding comes from the Canada First Research Excellence Fund.

As Metal Earth nears completion, we look forward to sharing our collective research results and celebrating the milestones achieved on scientific, academic, and personal levels. This project and its people have advanced our understanding of the fundamental processes that result in differential metal endowment, improving mineral exploration targeting and success.

As industry and government look to further invest in exploration to meet global demand, MERC focuses on developing partnerships, projects, and research that advances geoscience. It's inspiring work, and I am pleased to share it with you as we look forward to 2025.

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Equinox Gold Corp.

Exiro Minerals

GFG Resources

Glencore Canada - Sudbury Integrated Nickel Operations

Gold Fields

International Explorers and Prospectors Inc. (IEP)

KGHM

McEwen Mining

Melkior Resources Inc.

Noble Mineral Exploration Inc.

SRK Consulting

Transition Metals Corp.

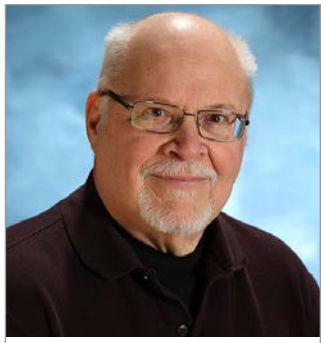
Vale Canada Limited

Wesdome Gold Mines Ltd.

MERC PEOPLE

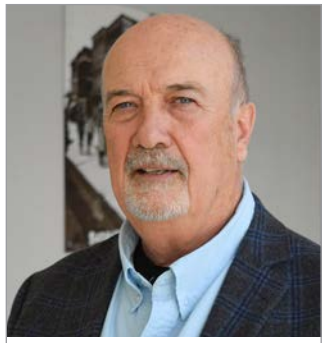
Administration

Ross Sherlock
MERC and Metal Earth Director, Chair in Exploration Targeting



John Ayer
MERC Associate Director, Adjunct Professor

Bruno Lafrance
Metal Earth Associate Director, Professor of Structural Geology



Harold Gibson
Founding Director, Metal Earth; Professor Emeritus, Volcanology and Ore Deposits

Natalie Lafleur-Roy
Finance and Operations Administrative Manager

Courtney Folz
Project and Board Officer

Lynn Bulloch
Communications Manager

Ryan O'Donnell
Research Equity, Diversity, and Inclusion (EDI) Advisor for the Office of Research Services and Metal Earth

MERC PEOPLE

Research Staff


Ademola Adetunji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Taus Jørgensen


Jeffrey Marsh


Ahmad Reza Mokhtari


Mostafa Naghizadeh

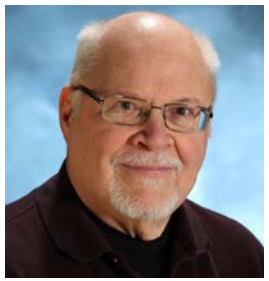

Jack Simmons


Jacob Strong


Gyorgyi Tuba


Rajesh Vayavur

Technical Experts


John Ayer


Eric Grunsky


Jeff Harris


François Robert

MERC PEOPLE

Graduate Students - PhD


Sandra Baurier Aymat


Wieland Boehme


Thomas Gemmell (OGS)


Klaus Kuster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Kristine Nymoen


Dustin Peters


Adrian Rehm


Eric Roots


Henning Seibel


Jonathan Sutton


Mehdi Tavakoli


Lianna Vice (OGS)

MERC PEOPLE

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Margaret (Maggie) Laverge

Anastasiia Mashkova

Taylor Mugford

Samuel Edem Kodzo Tetteh

Technical Staff

Pouran Behnia
GIS Specialist

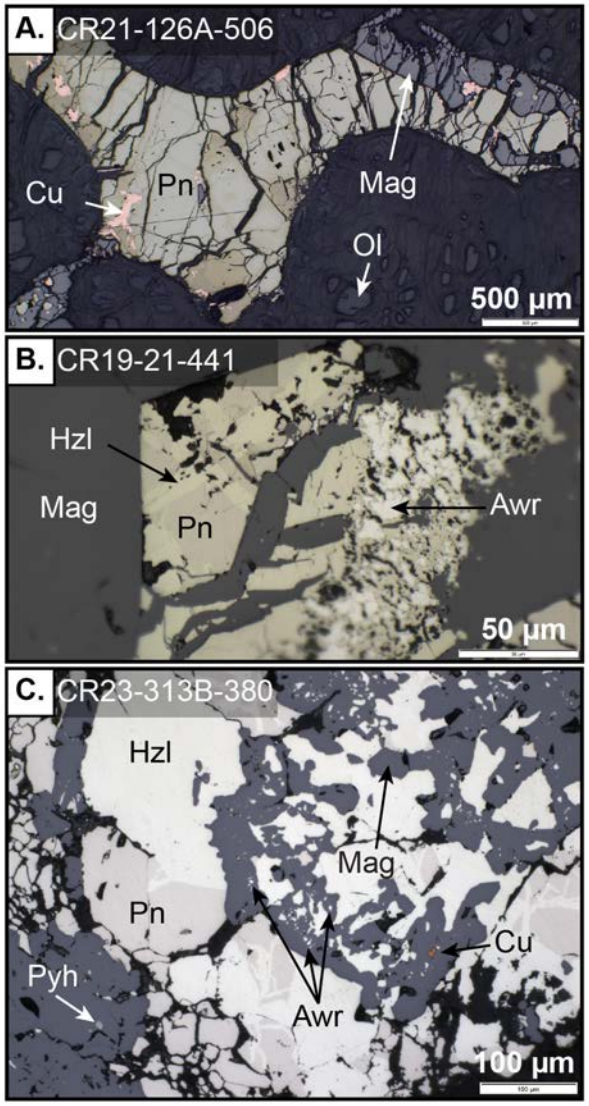
Laboratory Staff

Kirk Ross
Laboratory Manager

Alyne Lalonde
SEM Lab Technician

Nature and controls on Ni, Co, and PGE mineralization - Crawford intrusive complex

Dr. Pedro Jugo, Laurentian University



The 2704 ± 0.88 Ma Crawford Ni-Co-(PGE) deposit, located 50 km north of Timmins, Ontario, is the subject of Nathan Carter's MSc thesis in collaboration with the Canada Nickel Company (CNC).

The deposit is hosted within a mafic-ultramafic intrusion emplaced within volcanic rocks of the Stoughton-Roquemaure assemblage in the Abitibi greenstone belt. Nickel mineralization predominantly occurs in the dunitic portion of the intrusion as disseminated to patchy net-textures consisting of pentlandite (Pn), heazlewoodite (Hzl), and awaruite (Awr).

The intrusion exhibits various stages of serpentinization, and the primary goal of the project was to characterize the effects of serpentinization on Ni mineralization and to derive mineralogical and geochemical parameters that could guide the identification and evaluation of analogous deposits in the district and elsewhere.

Detailed petrographic and mineralogical analyses were conducted using optical microscopy and SEM-EDS, supplemented by electron probe microanalysis (EPMA) for a subset of samples.

Field and petrographic observations showed that serpentinization is complete near the local faults and decreases away from the faults. This variation in the degree of serpentinization captures the evolution of the changes in mineralogy in the system. Based on textures and using mineral chemistry from EPMA, it is shown that during the serpentinization process, the magmatic Ni-bearing minerals, consisting of Ni-rich forsteritic olivine (Fo88 with 2,600 ± 400 ppm Ni) and pentlandite ($Fe_{4.6}Ni_{4.1}S_8$), were transformed into heazlewoodite (Ni_3S_2) and awaruite ($Ni_{2.5}Fe$), increasing the Ni:S ratio in the sulfides from roughly 1:2 in Pn to 3:2 in Hzl (awaruite contains no S).

Using simplified compositions for clarity, parts of this process can be represented by the reaction: $Fe_{4.5}Ni_{4.5}S_8 + 20H_2O + 6H_2 = 5Fe_3O_4 + 3Ni_3Fe + 3Ni_3S_2 + 26H_2S$ with magnetite (Fe_3O_4) and H_2S(aq) as products of the reaction not previously mentioned; whereas the H_2(aq) on the reactants side is a product of the serpentinization of olivine.

Reflected light images of the effect of serpentinization on pentlandite. A) Pentlandite-magnetite-native Cu assemblage in a weakly serpentinized sample that still contains primary olivine (Ol); B) Coexistence of the three important Ni-bearing minerals (Pn, Hzl, Awr) in a sample with the intermediate degree of serpentinization. C) Example from a heavily serpentinized sample showing the Ni-bearing phases (Pn, Hzl, Awr), native Cu, pyrrhotite and abundant secondary magnetite.

In addition, some samples contained copper-bearing minerals, ranging from primary chalcopyrite, to secondary chalcocite, digenite, and bornite, to native Cu. Although Cu is not of economic interest at Crawford, its presence indicates that oxygen and sulfur fugacities (fO2 and fS2) were low enough to stabilize Cu as native metal instead of a sulfide or oxide.

In summary, the Crawford mafic-ultramafic intrusion is an example of progressive serpentinization of ultramafic rocks, ranging from moderate degrees in distal regions to complete serpentinization near local faults. This process alters mineral assemblages and enhances nickel recoverability by transforming magmatic Ni-bearing phases, such as forsteritic olivine and pentlandite, into secondary minerals with higher nickel tenor, such as heazlewoodite and awaruite. The presence of native Cu highlights the extreme reduction within the system during serpentinization. These findings provide valuable criteria for identifying and evaluating similar nickel deposits in the Abitibi greenstone belt and elsewhere.

MSc student Nathan Carter presented his project at the 2024 PDAC-SEG Student Minerals Colloquium in Toronto. His project is nearing completion, and he plans to defend his MSc thesis in early 2025.

(L-R) Dr. Steve Piercey presents Nathan Carter with his award for 2nd place, MSc category, PDAC-SEG Student Minerals Colloquium, Toronto, March 2024. Source: Lynn Bulloch

VIEW OR DOWNLOAD
Carter, N., Jugo, P. (2024, March 3-6) Mineralogical, textural, and geochemical parameters of the Ni-Co-(PGE) Crawford Deposit, Abitibi greenstone belt, Superior Province, Ontario, Canada [Conference Poster]. PDAC-SEG Student Minerals Colloquium, Toronto, Ontario, Canada.
https://merc.laurentian.ca/sites/default/files/carter_pdac_2024_final.pdf

Gold Candle

Dr. Györgyi Tuba, Laurentian University

Progress

Acting as an embedded researcher at Gold Candle Ltd., I have conducted and participated in several grassroots and brownfield projects for the company, including:

- Geochemistry: handling and processing the geochemical database, lithogeochemical classification, vectoring using alteration and mineralization indices.
- Stratigraphy and geochronology: identification and interpretation of specific lithologies in regional exploration program; designing sampling campaign for lithogeochemistry and geochronology
- Metallurgy: participating in designing and sampling for metallurgical testing,
- Interpretation of results.
- Hyperspectral imaging: interpretation of pilot program results.

Highlights

All projects and tasks carried out as an embedded researcher were to the direct benefit of the company, thus, by extension, to the mineral industry.

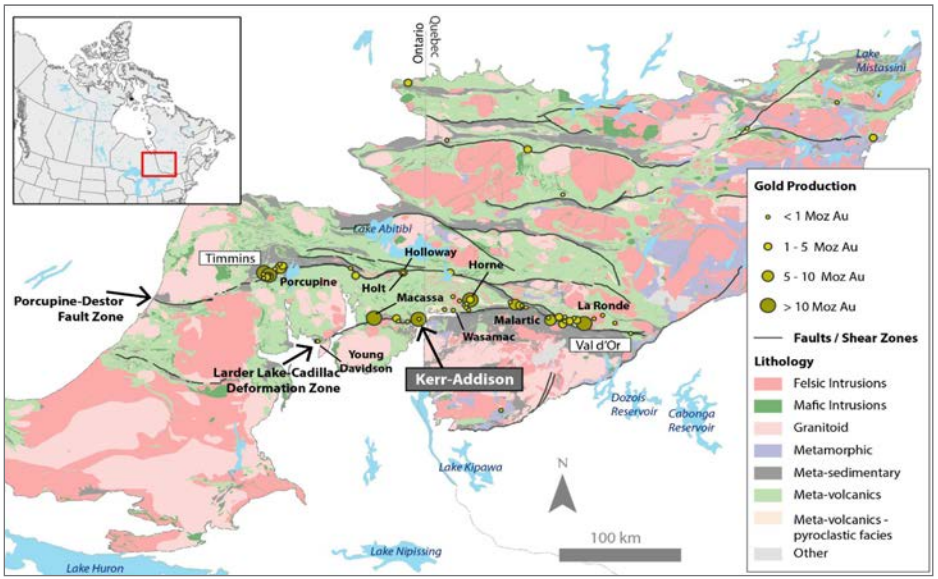
Future Work

The project itself is finished, but the scientific findings in some of the above-mentioned fields warrant further follow-up as academic projects.

A study around the base-metal mineralization potential of the Larder Lake group will likely take place in the following period. It will involve geochronology, lithogeochemistry, geochemistry and stratigraphic reconstruction of a previously untested area and a newly discovered base metal mineralization east of the Kerr-Addison deposit.

Anticipated Outcomes

Results are incorporated into the company's exploration strategy and methodology.



The geology of the Abitibi greenstone belt (after Thurston et al., 2008) with the location of the Kerr-Addison deposit (Gold Candle Ltd.).

VIEW OR DOWNLOAD
Tuba, G. (2024, October 28-31). Who let the gold out? A generalized model for hydrothermal fluid evolution and gold mineralization in orogenic gold deposits [Conference presentation]. Xplor, Montreal, Quebec, Canada.
https://merc.laurentian.ca/sites/default/files/xplor_2024_workshop_gyorgyi_tuba_edit_for_pdf.pdf

Structural Controls on Gold Mineralization on the Great Bear Property, Red Lake, ON

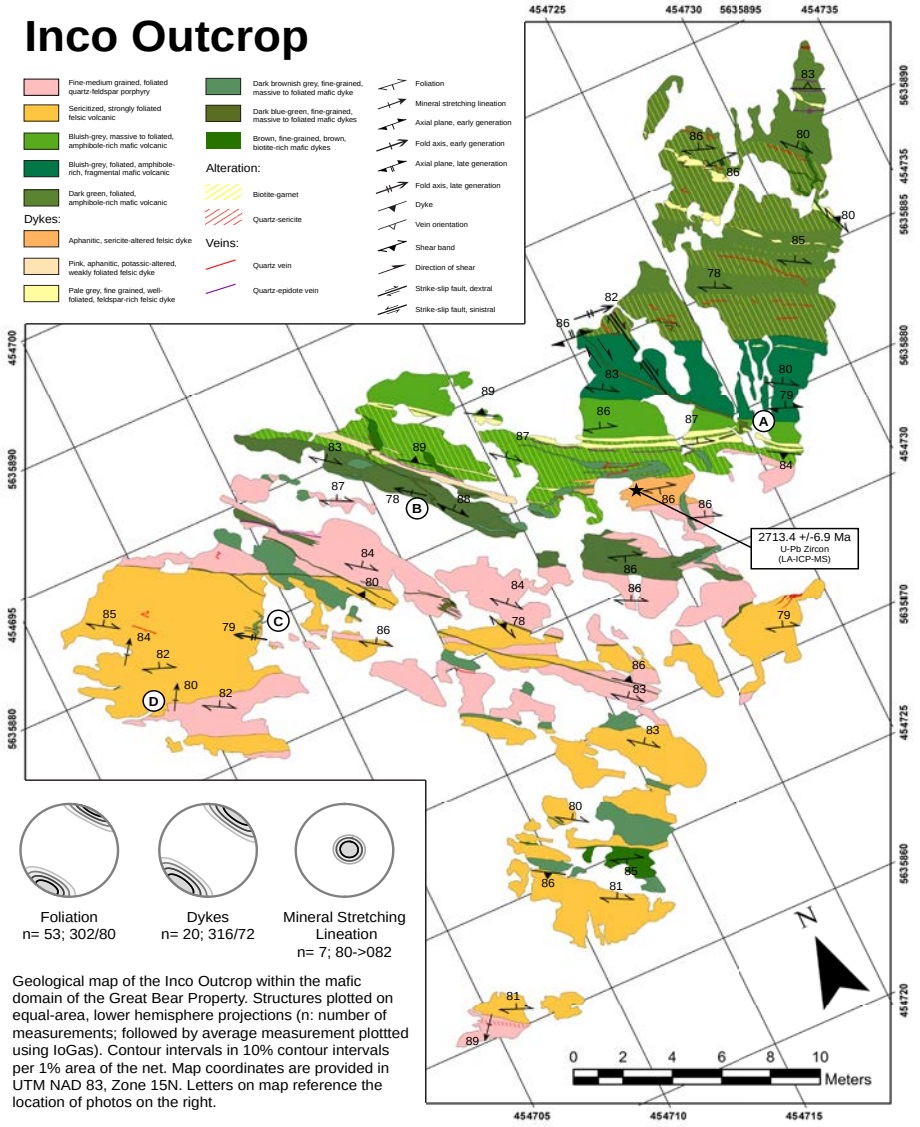
Dr. Bruno Lafrance and Dr. Ross Sherlock, Laurentian University

Discovered in 2017, the Great Bear Deposit, located 25 km south of Red Lake, Ontario, is estimated to contain 6.64 Moz of gold. It is considered one of the largest recent gold discoveries in Canada but remains poorly understood due to limited research. While the plunge of the ore shoot was established through extensive drilling, the structural controls on mineralization were not well understood. Maggie Laverge has made this the focus of her MSc thesis.

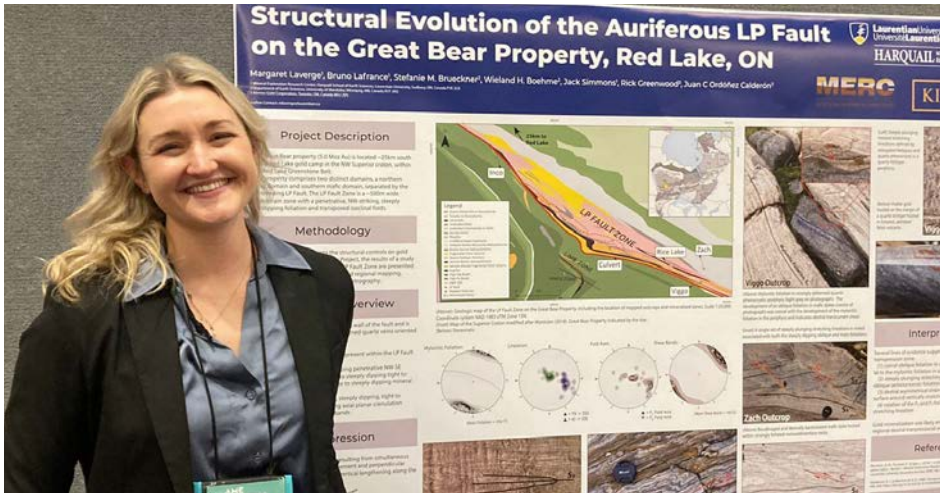
Work began by establishing the structural evolution of the deposit, which had not been previously understood. During the first field season, Maggie aimed to complete this foundational analysis, using the following season to address unresolved questions and determine the timing of gold mineralization. Due to limited significant outcrop, Maggie combined detailed outcrop maps of the few available strippings and outcrops on the property with drill core logging and U-Pb geochronology. In 2023 and 2024, she produced nine detailed maps at 1:2,000–1:4,000 scales and conducted regional mapping at a 1:20,000 scale. She also logged 14 drillholes and collected 10 samples for zircon U-Pb dating.

Through detailed outcrop mapping, two generations of deformation were identified, which represent a continuous, long-lived dextral transpressional regime evolving from pure to simple shear dominant. Drill core observations revealed that gold-bearing quartz-carbonate veins were deformed and often transposed by early isoclinal folding. This suggests that mineralization likely predates deformation, a hypothesis currently being confirmed through petrography.

U-Pb dating of zircons was conducted at Laurentian University using LA-ICP-MS. Analysis of an intensely deformed and mineralized quartz-feldspar porphyry in the felsic domain yielded an age of 2711.6 ± 2.1 Ma, indicating the deposit is contemporaneous with the St. Joseph's Plutonic Suite of the Birch-Uchi Subprovince and younger than the Confederation Assemblage, which was previously assumed. Regional D2 deformation in the Red Lake Greenstone Belt is constrained to 2723–2712 ± 2 Ma, suggesting deformation at the Great Bear Deposit corresponds to regional D3 deformation.



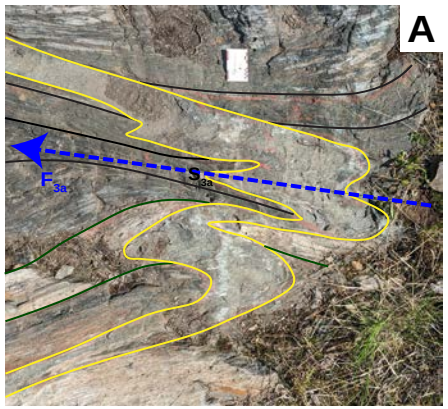
Geological map of the Inco Outcrop within the mafic domain of the Great Bear Property. Structures plotted on equal-area, lower hemisphere projections (n: number of measurements; followed by average measurement plottted using IoGas). Contour intervals in 10% contour intervals per 1% area of the net. Map coordinates are provided in UTM NAD 83, Zone 15N. Letters on map reference the location of photos on the right.



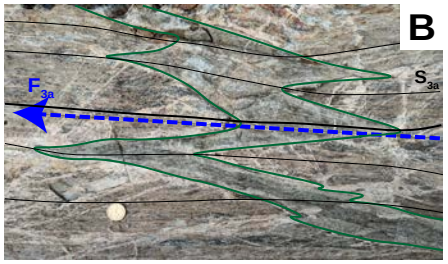
MSc student Maggie Laverge with her 2nd place poster at AME Roundup, January 2024.

Dating of two late, weakly deformed granitic dykes intruding strongly foliated mafics in the property's northwest yielded ages of 2694.9 ± 3.8 Ma and 2691 ± 6 Ma, representing an approximate minimum age for deformation. These ages also constrain the timing of gold mineralization. Additionally, dating of an aphanitic felsic dyke at the Inco Outcrop provided a minimum age for the mafic domain, yielding an age of 2713.4 ± 6.9 Ma.

As mineralization has not been observed at surface, samples of mineralized drill core were collected for petrographic analysis in the summer of 2024. These were examined using an optical microscope and scanning electron microscope (SEM) to identify microstructures hosting or remobilizing gold mineralization. Preliminary results support the hypothesis that gold mineralization predates deformation on the property. This work is ongoing.

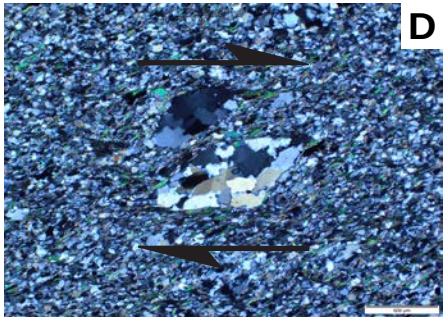


A) A fine grained mafic dyke (outlined in yellow) intrudes into a foliated mafic volcanic and is subsequently tightly folded by early generation folding (blue arrow). Later shearing results in the rotation of foliation (black lines) around this body.



B) Chevron folding (fold axis represented by blue arrow) of a mafic dyke (outlined in green) within a foliated mafic volcanic. The regional foliation (black lines) is present in both the host rock and mafic dyke.

C) Mafic dyke within a sericitized, strongly foliated felsic volcanic. The mafic dyke and it's internal foliation is folded, and the foliation within the surrounding host rock (indicated by black form lines) is dextrally rotated into the folded dyke.



D) Microphotograph of a sample of quartz-feldspar porphyry in which recrystallized quartz phenocrysts are asymmetrical, indicating dextral shear. Muscovite is deflected around the phenocrysts.

Highlights

- 2024 PDAC-SEG Student Minerals Colloquium 3rd place winner, MSc category
- 2024 AME Roundup 2nd place winner, student poster competition
- 2024 Society of Economic Geologists Canada Foundation, Inc. (SEGCF) Graduate Student Fellowship
- 2023-2024 Laurentian SEG Chapter secretary; organized student field trip to Chile
- 2024 PDAC-SEG Student Minerals Colloquium co-organizer

VIEW OR DOWNLOAD

Laverge, M., Lafrance, B., Brueckner, S., Boheme, W., Simmons, J., Greenwood, R., & Ordóñez Calderón, J.C., (2024, March 3-6). Structural Evolution of the Auriferous LP Fault on the Great Bear Property, Red Lake, ON [Conference poster]. PDAC-SEG Student Minerals Colloquium, Toronto, Ontario, Canada.
https://merc.laurentian.ca/sites/default/files/pdacposter2024_ml_compressed.pdf

Characterization of mineralogy, geochemistry, and gold remobilization processes at the Great Bear deposit, Red Lake, ON

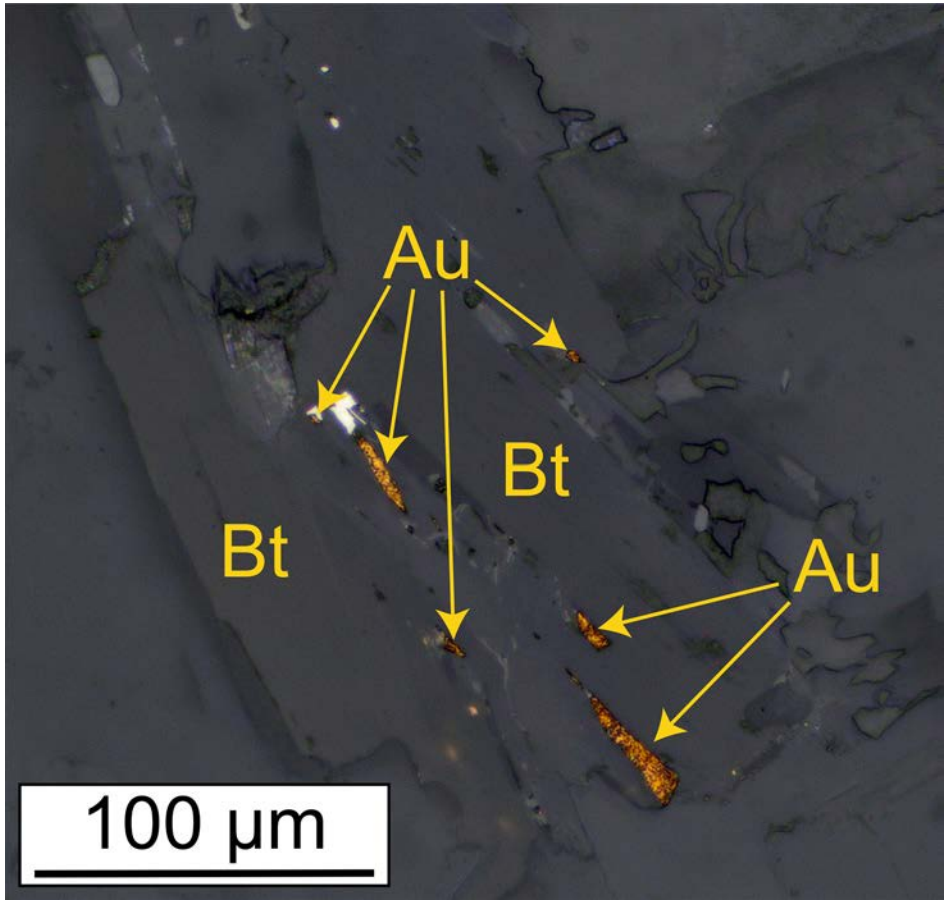
Dr. Stefanie Brueckner, Laurentian University

The Great Bear deposit lies approximately 25 km southeast of the town of Red Lake and the historic Red Lake mine trend. It contains multiple mineralized zones. However, the main zone, the LP Zone, was only discovered in 2019. The Great Bear deposit contains various mafic to felsic volcanic and metasedimentary lithologies. Despite a current resource estimate of 6.6. Moz and grades locally exceeding 20 g/t Au, very little research has been conducted on this deposit. The aim of this research is to identify geochemical patterns surrounding high-grade gold mineralization, constrain mineralization and remobilization processes, and constrain the influence of deformation and metamorphism on gold mineralization.

Progress

PhD student Wieland Boehme conducted fieldwork in 2023 and 2024.This focused on the mineralization hosted by felsic volcanic and metasedimentary rocks in the LP Zone (2023) and mineralization hosted by mafic volcanic rocks in the southwestern part of the deposit (mafic domain, 2024). Both field seasons focused on core logging and sampling representative drill cores from each mineralized zone.

Petrography (transmitted and reflected light microscopy) and SEM (including EDS mapping) analysis have been done on thin sections collected from the mineralization in the LP Zone. An initial analysis of lithogeochemical data provided by Kinross has been conducted. These have been accompanied by initial and ongoing interpretation of all observations.



Reflected light image of gold specks intergrown with biotite. Source: W. Boehme.

Future Work

- Petrography on thin sections collected from the mineralization in the mafic domain
- Additional SEM (including EDS mapping) analysis of thin sections from the LP Zone
- EPMA and LA-ICP-MS analysis of sulfides, gold, and Bi-Te minerals to obtain their mineral chemistry
- EBSD analysis of quartz and sulfides to constrain deformation mechanisms and the influence of deformation on gold mineralization
- SEM analysis (including EDS mapping) of thin sections from the mafic domain
- Fieldwork summer 2025 focussing on core logging and sampling
- Synthesis and interpretation of observations (on-going)

Highlights

Wieland Boehme presented his research at two conferences in poster sessions.

1) Central Canada Mineral Exploration Convention (CCMEC), Winnipeg, November 2023: "Characterizing the Host Lithology and Ore Mineralogy of Gold Mineralization along the LP Fault Zone within the Great Bear Deposit, Ontario"
2) Goldschmidt Conference, Chicago, August 2024: "Mineralogical and textural characterization of the gold mineralization in the LP Zone of the Great Bear Deposit, Ontario, Canada"

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Boehme, W. et al. (2023) Mineralogical and textural characterization of the gold mineralization in the LP Zone of the Great Bear Deposit, Ontario, Canada [Abstract from Goldschmidt Subsession 5eP1, August 20, 2024].
https://conf.goldschmidt.info/goldschmidt/2024/meetingapp.cgi/Paper/22976

Tracking metamorphic P-T-t-fluid evolution across Kinross Gold's Great Bear Deposit

Dr. Doug Tinkham, Laurentian University

The Great Bear deposit lies within a belt of Archean metavolcanic and metasedimentary rocks in the Uchi Subprovince south of Red Lake. It hosts Au mineralization associated with a regional deformation zone. Amphibolite and greenschist facies metamorphic assemblages are developed in the host rocks that contain shear zones and structures that host the Au mineralization, and understanding the metamorphic history in terms of P-T-t-fluid (pressure-temperature-time-fluid) conditions are of interest.

The main objectives of this research project are to constrain the number of metamorphic events, the spatial variability of P-T-t-fluid conditions, determine whether significant dehydration and decarbonation reactions occurred at temperatures high enough to mobilize Au in favourable rock types and determine if there are metamorphic discontinuities across major structures.

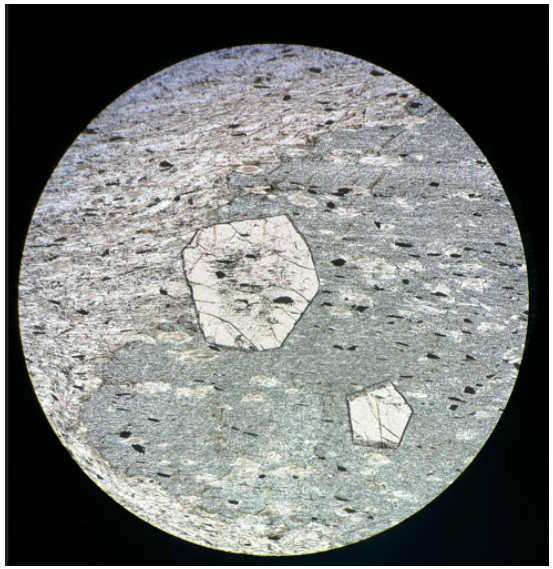
Core photo of andalusite schist with a ~1cm grain of staurolite displaying penetration twinning. Source: J. Belanger.

The initial thesis fieldwork started in May 2024 by MSc student Joleen Belanger. Joleen logged and sampled portions of 24 drill holes across the property to investigate metamorphic mineral assemblages and reactions to understand not only the variability of P-T conditions of metamorphism across the property but, more importantly, to understand the reaction histories that bear on metamorphic fluid production, and how these might temporally relate to deformation fabric development and potential hydrothermal alteration.

Laboratory and analytical work are underway (petrography, micro-XRF, SEM/microprobe, and whole rock geochemistry) and will be followed by phase equilibria modelling of observed assemblages and reactions and metamorphic geochronology.

This research is part of a large collaborative project run under MERC. It is funded by Kinross and an NSERC Alliance grant awarded to Stephanie Brueckner, Bruno Lafrance, and Doug Tinkham.

Non-polarized thin section scan of andalusite schist. Staurolite, andalusite, and garnet are observed co-existing in the same compositional layer, and exhibit intergrowth textures. Source: J. Belanger.



Photomicrograph of previous thin section scan of andalusite schist viewed at 5x magnification. The sample contains coarse-grained andalusite that grew around garnet grains displaying an Si that is parallel to Se. Souce: J. Belanger.

Blue Star Gold Corp., Ulu Gold Project

Dr. Ross Sherlock and Dr. Bruno Lafrance, Laurentian University

The Ulu Gold project is the focus of Evan Hall's MSc thesis with MERC and the Harquail School of Earth Sciences, conducted in partnership with Blue Star Gold Corp. and Mitacs.

Situated in the relatively underexplored High Lake greenstone belt, approximately 525 km NNE of Yellowknife in the Kitikmeot region of western Nunavut, the Ulu Gold Project represents a significant high-grade gold resource. This study aims to address the need for a better understanding of the geology of the deposit.

MSc student Evan Hall (second from left) and exploration team at Blue Star Gold Corp.'s Ulu Gold Project, Kitikmeot region, Nunavut, summer 2023. Source: Evan Hall.

The Ulu deposit is hosted in amphibolite-grade mafic volcanic rocks within a major fold structure and has experienced multiple phases of deformation. However, compared to most orogenic gold systems, the deposit shows atypical features, notably the lack of pervasive carbonate alteration and no clear association with a dominant belt-scale structural feature.

The primary objectives of this research are to resolve the controls on mineralization by examining the structural, lithostratigraphic, and stratigraphic factors influencing the deposit and to develop a genetic model for its formation. The findings from this study will contribute insights into the formation of gold deposits in the High Lake greenstone belt and enhance the broader understanding of gold deposits in higher-grade metamorphic terranes globally.

Two seasons of fieldwork have been completed, during which samples were collected for petrographic characterization of lithological units and the ore zone, analysis of mineralization-controlling features, whole rock geochemistry, alteration assemblage mineral chemistry, and samples for U-Pb dating. The integration of these datasets will generate a model to guide current and future exploration efforts in the region and address a critical knowledge gap in economic geology.

MSc student Evan Hall (left) and a fellow exploration geologist inspecting strongly deformed and folded volcanic strata, Ulu Gold Project, Kitikmeot region, Nunavut, summer 2023. Source: Evan Hall.

Haile Epithermal Deposit, South Carolina

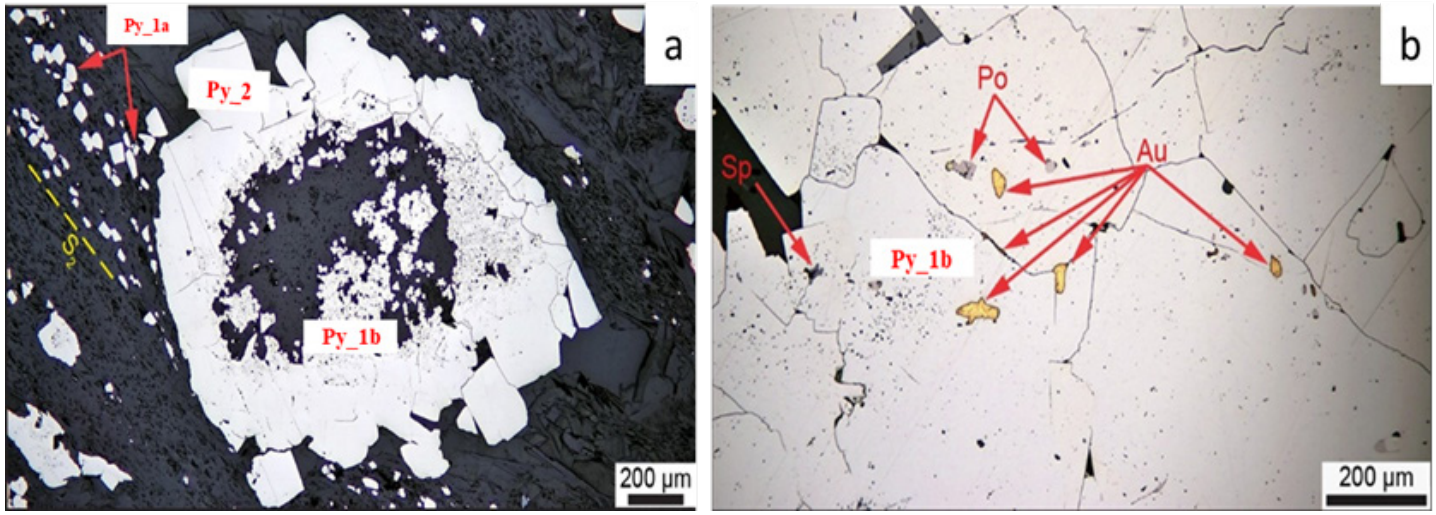
Dr. Stefanie Brueckner, Laurentian University

Robert K. Amissah is completing his MSc in Geology with a research focus on the impacts of metamorphism and deformation on the Neo-Proterozoic Haile Epithermal Deposit in South Carolina, United States.

The greenschist metamorphosed and deformed Carolina terrane, which forms part of the Appalachian orogen, hosts several hydrothermal gold deposits, including the high-tonnage, low-grade epithermal Haile deposit. The complex orogenic history and related deformation in the area have led to open questions about the source of gold.

Although Os-Re age dating of the mineralization supports a syngenetic origin of gold, constraining a likely remobilization process resulting from metamorphism and deformation during the Taconian orogeny is lacking and unexplained.

In this research, pyrite, which is the dominant ore phase and known proxy to gold mineralization at Haile, is analyzed using petrographic and advanced micro-analytical techniques (SEM, SIMS, EBSD, LA-ICP-MS) to understand how gold was remobilized and what role metamorphism and deformation played.



Reflected light images of pyrite (a) earlier pyrite (Py_1a, Py_1b), latest pyrite (Py_2) (b) brittle deformed pyrite with inclusions of gold, pyrrhotite and sphalerite. Source: R. K. Amissah.

Ultimately, this project aims to determine how effective pyrite can be as an exploration tool, especially in metamorphosed deposits.

External funding sources for this research are Pretivm Resources & NSERC.

Progress

All micro-analytical work has been completed, including

- petrographic and SEM work on pyrite samples to characterize ore assemblages and the various textures
- EPMA to study the major and minor element composition of pyrite
- EBSD to understand the microstructural relationships of the observed pyrite textures
- SIMS to understand the possible sources of sulfur in pyrite
- interpreting LA-ICP-MS spots and elemental maps to understand the trace element relationships and composition in pyrite

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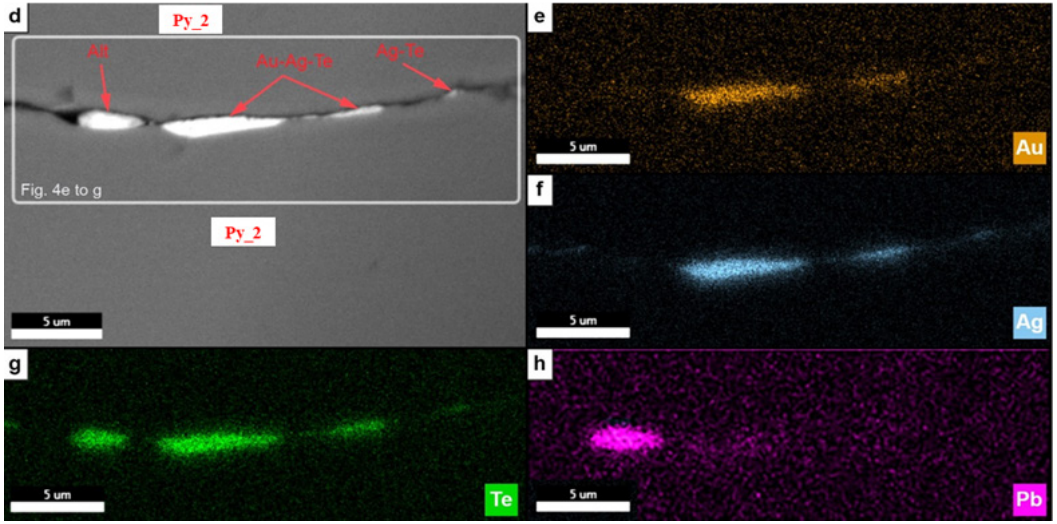
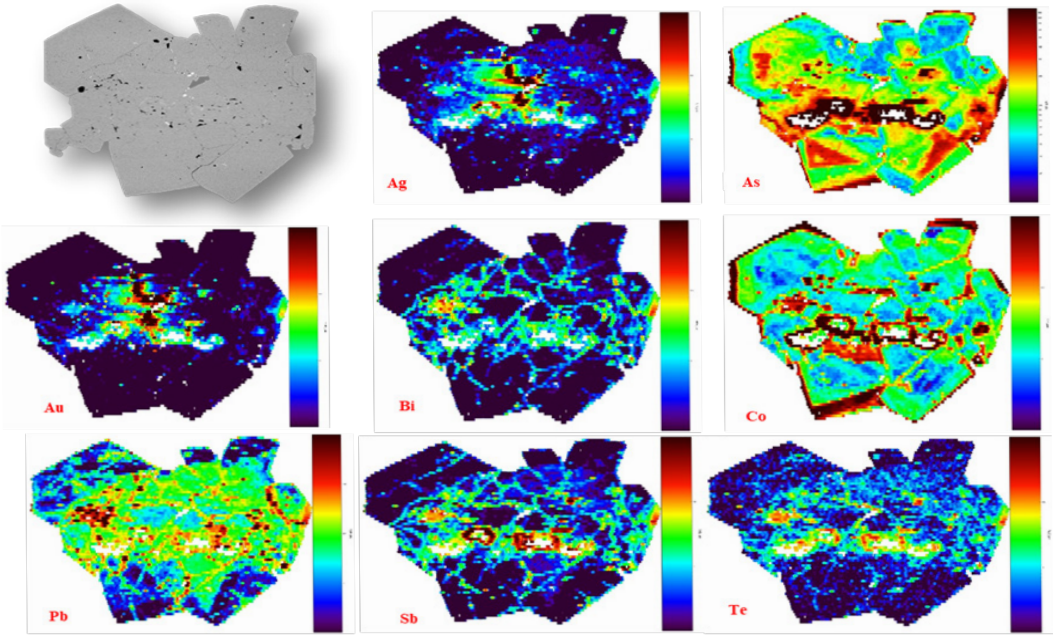
Amissah, Robert K. (2024, August 21). Ore textures and pyrite chemistry of the metamorphosed Haile epithermal deposit, South Carolina [Oral presentation]. Goldshmidt 2024. Chicago, Illinois, United States. https://conf.goldschmidt.info/goldschmidt/2024/meetingapp.cgi/Paper/21270



BSE image, (a) and corresponding EDS elemental maps, (e-h) showing gold occurring as a telluride phase between adjacent Py_2 grains. Source: R. K. Amissah.



LA-ICP-MS elemental map showing the concentrations of gold, silver, arsenic and LMCE in pyrite. Source: R. K. Amissah.

Implications

The pyrite textures observed show evidence of deformation in the form of brittle cracks and annealing with gold occurring as inclusions in cracks and in between adjacent pyrite grains.

Results suggest precious metals formed during the deposition of metasedimentary and metavolcanic host rocks in the Neoproterozoic.

However, orogenic activities during the Ordovician-Silurian resulted in the remobilization of syngenetic gold:

- mainly, by metamorphic hydrothermal fluids liberating gold from earlier pyrite and;
- locally, low melting point chalcophile elements (LMCE) scavenging gold during metamorphism and depositing them in structurally favourable sites.

Pyrite as a potential tool for exploration in deformed and metamorphosed terranes, must be utilized cautiously to achieve the best results.

Future Work

- Comprehensive review and collation of all data from various micro-analytical works (SEM, SIMS, EBSD, LA-ICP-MS) to better understand what processes caused remobilization of gold
- Thesis is on-course to be completed and submitted to the graduate school in early winter 2025
- Manuscript for peer-reviewed publication is underway

Highlights

- Ronald E. Seavoy SEG Student Foundation Field Trip; Volcanic-Hosted Epithermal Precious Metal Deposits of the Walker Lane Trend, SW Nevada, 2023
- 2nd Place, MSc Level, Vale Poster Session, Central Canada Mineral Exploration Convention 2023.
- Oral Presentation at Goldschmidt, Chicago, August, 2024

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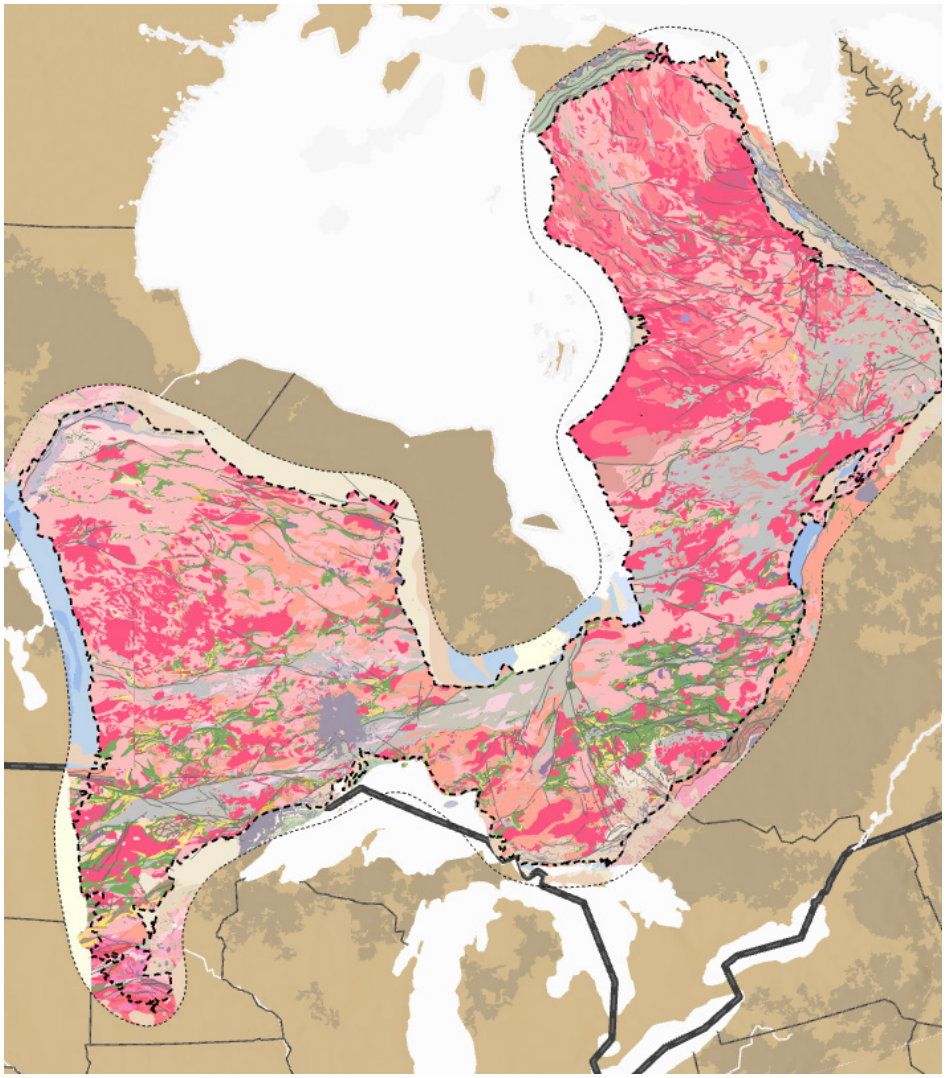
Metal Earth YouTube Playlist

METAL EARTH

Transforming our understanding of Earth's early evolution and processes that result in differential metal endowment



Metal Earth is a Canadian $104 million applied R&D program led by Laurentian University.

The project is transforming our understanding of the genesis of base and precious metal deposits during Earth's evolution. It will make Canada a world leader in metal endowment research and a world-class innovator through open-source delivery of new knowledge and the implementation of new technology.

With funding from the Canada First Research Excellence Fund and additional federal, provincial, and industry partners, this initiative is a strategic consortium of outstanding researchers from academia and allied Canadian and international research centres, government, and industry.

Core goals and objectives

Fundamental Science

- Transform our understanding of Earth's early evolution and processes that govern differential metal endowment.
- Improve the science for targeting and finding new orebodies.

Applied Innovation and Commercialization

- Cement Canada's position as a global leader in mineral exploration research through open-source delivery of new knowledge and the development of transformative technologies targeted at increasing exploration success.
- Improve training of quality young geoscientists for the mineral industry.

Canada

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SIGNATURE **PUBLICATIONS**

The following are 15 peer-reviewed journal publications that reflect the breadth and global relevance of Metal Earth's research progress in 2023-24.

Behnia, P., Harris, J., Liu, H. M., Naghizadeh, M., & Roots, E. A. (2023). Random forest classification for volcanogenic massive sulfide mineralization in the Rouyn-Noranda Area, Quebec. Ore Geology Reviews, 161. https://doi.org/10.1016/j.oregeorev.2023.105612

Behnia, P., Harris, J., Sherlock, R., Naghizadeh, M., & Vayavur, R. (2023). Mineral Prospectivity Mapping for Orogenic Gold Mineralization in the Rainy River Area, Wabigoon Subprovince. Minerals, 13(10), 1267. https://doi.org/10.3390/min13101267

Della Justina, F., & Smith, R. S. (2024). Using gravity data uncertainties in forward modeling to estimate uncertainties in model parameters: A case history in estimating the dip and the dip uncertainty of the Porcupine Destor Fault. Geophysics, 89(3), B229-B240. https://doi.org/10.1190/geo2023-0202.1

Fassbender, M. L., Hannington, M., Baxter, A. T., Diekrup, D., Stewart, M., & Brandl, P. A. (2024). Geochemical Signatures of Mafic Volcanic Rocks in Modern Oceanic Settings and Implications for Archean Mafic Magmatism. Economic Geology, 119(2), 445-470. https://doi.org/10.5382/econgeo.5044

Godet, A., Guilmette, C., Marsh, J. H., Rottier, B., Tinkham, D., Malta, I. S., Rehm, A., Hamilton, M. A., Ribeiro, D., Beaudoin, G., & Jorgensen, T. R. C. (2023). Origin, nature, and evolution of the northern Pontiac subprovince, Canada: Insights from the intrusive record. Precambrian Research, 396. https://doi.org/10.1016/j.precamres.2023.107169

Jegen, A., Dannowski, A., Schnabel, M., Barckhausen, U., Brandl, P. A., Riedel, M., Beniest, A., Heyde, I., Hannington, M. D., Sandhu, A., Werner, R., & Kopp, H. (2023). Extension Dynamics of the Northern Fonualei Rift and Spreading Center and the Southern Mangatolu Triple Junction in the Lau Basin at 16°S. Geochemistry Geophysics Geosystems, 24(4). https://doi.org/10.1029/2022GC010550

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Liu, H. M., Harris, J., Sherlock, R., Behnia, P., Grunsky, E., Naghizadeh, M., Rubingh, K., Tuba, G., Roots, E., & Hill, G. (2023). Mineral prospectivity mapping using machine learning techniques for gold exploration in the Larder Lake area, Ontario, Canada. Journal of Geochemical Exploration, 253. https://doi.org/10.1016/j.gexplo.2023.107279

Montsion, R. M., Perrouty, S., Lindsay, M. D., Jessell, M. W., & Sherlock, R. (2024). Development and application of feature-engineered geological layers for ranking magmatic, volcanogenic, and orogenic system components in Archean greenstone belts. Geoscience Frontiers, 15(2). https://doi.org/10.1016/j.gsf.2023.101759

Schofield, M. D., Lafrance, B., Gibson, H. L., Poulsen, K. H., Scheffer, C., Quesnel, B., Beaudoin, G., & Hamilton, M. A. (2024). Discriminating Superimposed Alteration Associated with Epigenetic Base and Precious Metal Vein Systems in the Rouyn-Noranda Mining District, Quebec; Implications for Exploration in Ancient Volcanic Districts. Economic Geology, 119(3), 617-641. https://doi.org/10.5382/econgeo.5063

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Snyder, D. B., & Thurston, P. C. (2024). A North Caribou superterrane in the Superior craton, North America. Precambrian Research, 403. https://doi.org/10.1016/j.precamres.2024.107329

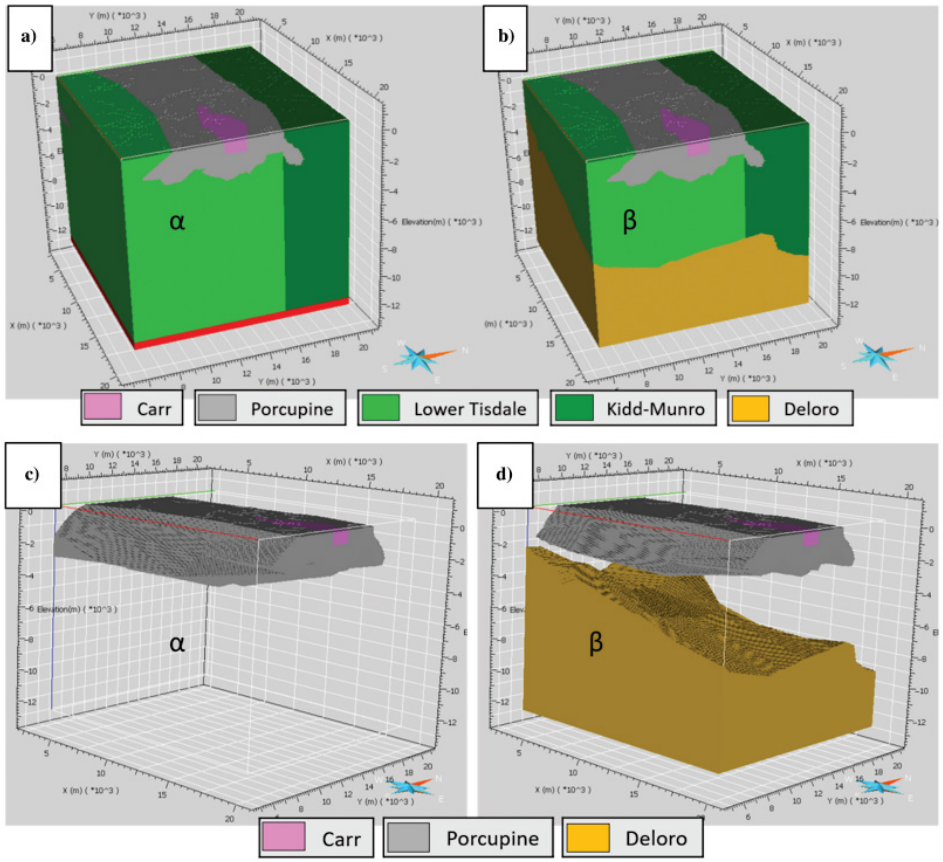
Strong, J. W. D., Mulder, J. A., Cawood, P. A., Cruden, A. R., & Nebel, O. (2023). Isotope evidence for Archean accordion-tectonics in the Superior Province. Precambrian Research, 393. https://doi.org/10.1016/j.precamres.2023.107096

Tamosauskas, M., Ma, C., Haugaard, R., Lodge, R. W. D., Sherlock, R., Hamilton, M., & Marsh, J. (2024). Formation of a late-orogenic conglomeratic sequence in the Neoarchean western Wabigoon terrane, Superior craton. Precambrian Research, 406(107394). https://doi.org/10.1016/j.precamres.2024.107394

Vite-Sánchez, O., Ross, P.-S., and Mercier-Langevin, P., (2024). Mafic to intermediate volcanic rocks of the Blake River Group, Abitibi greenstone belt, Canada: Geochemistry, petrogenesis and relation with VMS deposits. Precambrian Research, 404(107331). https://doi.org/10.1016/j.precamres.2024.107331

Geophysics in the Metal Earth Project

Dr. Richard Smith, Laurentian University; and Dr. Christian Dupuis, Université Laval



Three-dimensional models generated from the 2D modeling sections. (a) Model α and (b) model β. Both these models are viewed from the east-southeast. The Tisdale and Kidd-Munro have been removed from the same models in (c and d) to show the variation in the thickness of the Porcupine and the Deloro from east to west, this time viewed from the southeast. The relevant geologic legends are shown at the bottom. The red layer at the bottom of (a) is the midcrustal layer with a density of 2.67 g/cm3.
Source: Della Justina et al, 2024: https://doi.org/10.1190/geo2023-0523.1

Progress

PhD student Yasaman Nemati is assessing hydrothermal gold deposits' petrophysical characteristics using borehole geophysical data gathered from 7 boreholes in Rouyn Noranda. The findings indicate a strong correlation between petrophysical characteristics and geochemistry data.

Employing the mass balance method, her work demonstrates that areas gaining K+ exhibit an increase in gamma-ray values. At the same time, regions with carbonate alteration showed a gain in Ca2+, resulting in decreased density. Furthermore, areas likely corresponding to the alteration of magnetite from the komatiite by hydrothermal fluids to form pyrite and arsenopyrite and to precipitate gold could be identified, as this type of alteration coincides with variations in magnetic susceptibility, resistivity, density, velocity, and IP responses measured downhole.

Further analysis of electrical logs revealed significant differences in the resistivity of altered rocks compared to less-altered rocks. Optical televiewer logs and core images illustrated that this discrepancy is attributed to the increased presence of quartz veins in altered sections. Moreover, it was observed that less-altered sections exhibited erratic behaviour in IP logs, whereas altered sections displayed relatively constant IP values.

Furthermore, an in-depth examination of the relationship between hydrothermal alteration and sonic and SP logs demonstrated that sonic logs exhibited higher values in more altered sections, primarily due to the presence of quartz veins. Conversely, SP values were elevated in less altered sections owing to the presence of sulfides.

In the latest phase of her project, Yasaman has built a 3D mathematical model of the electrical tool in the borehole environment. This model focuses on the influence of veins, fractures and the geometry of the normal resistivity tool. The completion of this model has revealed intriguing revelations, elucidating how vein

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Christopher Mancuso/Richard Smith: *Integrated imaging of the Sturgeon greenstone belt*

characteristics such as thickness, radius, conductivity, and angle impact normal resistivity measurements. Using this model, we investigate the effects of multiple veins and complex fracture systems. Continuous comparison with actual measurements enhances comprehension, leading to nuanced insights into the interplay between geological features and geophysical tools.

Building this tool resulted in significant delays in establishing the correct model. After a full year of work, the model is now functional and generating the results that allow us to proceed.

Saeid Cheraghi was working on a manuscript addressing the heterogeneity and scaling behaviour of crystalline rocks, comparing examples from the Abitibi and Wabigoon subprovinces. This paper was 60% complete when his contract expired. If time permits, he will complete it.

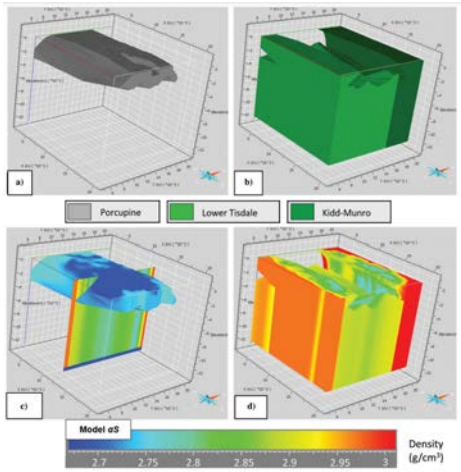
In another research project, Saeid was working on applying machine learning to seismic attribute data. However, this project was incomplete and required more data for training purposes, so it is less likely to be completed.

Rajesh Vayavur is continuing his work on 3-D potential-field inverse modelling of Metal Earth transect, working on Cobalt in 2024. Results are incorporated into the interpretations described elsewhere.

Independent of this work, Rajesh completed 3D-constrained modelling on the Chicobi transect to show the utility of density constraints. Exploration Geophysics published this work in August 2023.

Rajesh is continuing to unravel the upper-crustal architecture of the Eastern Sudbury basin by 3D integration of various geological and geophysical datasets. This work is part of an NSERC-CRD grant in collaboration with Vale and Glencore companies. Rajesh presented his results at a meeting with Vale in April 2023 and at a Metal Earth workshop in March 2023. A paper on this topic is being prepared.

In addition, Rajesh has also performed 3D depth-to-basement geometry inverse modelling using gravity data to constrain the topography of the base of the Sudbury impact crater around seismic line 182. The final inverted surface dips southwards from the North Range of the Sudbury basin, as expected, but also identifies an anticline, which is not apparent on the seismic reflection section. The inverted density surface complements the seismic reflection section and helps trace the seismic reflector in areas of low signal-to-noise ratio. The results were presented at the GAC-MAC 2023 conference as an oral presentation.

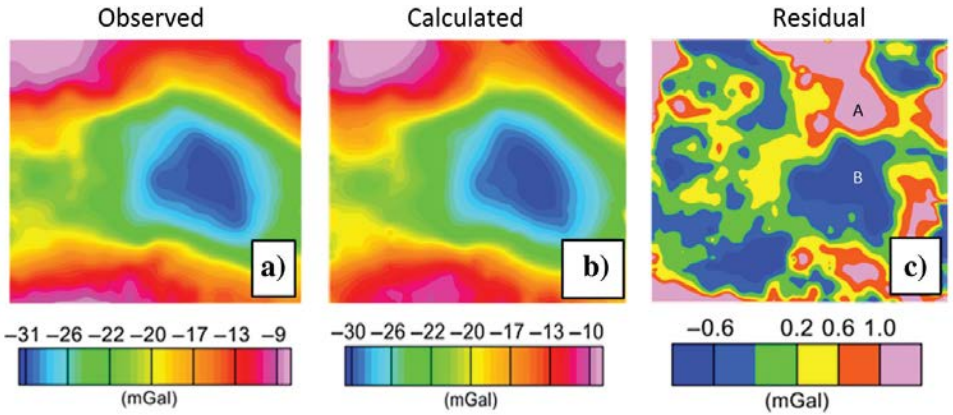


Left: Model αS. (a) The volume classified as the Porcupine assemblage and (c) the density variation in this assemblage and within a north-south section around this assemblage. The blue layer represents 2.67 g/cm3 , the density of the midcrustal layer below 12.5 km. (b) The volume designated as the Lower Tisdale (light green) and Kidd-Munro (dark green) assemblages and (d) the density variations within these units. This perspective view is from the southeast.

Source: https://doi.org/10.1190/geo2023-0523.1

Below: (a) The observed data grid, (b) the calculated data grid, and (c) the residual data grid from the model βS. The calculated data grid and residual data grids are computed only at the gravity station locations.

Source: https://doi.org/10.1190/geo2023-0523.1



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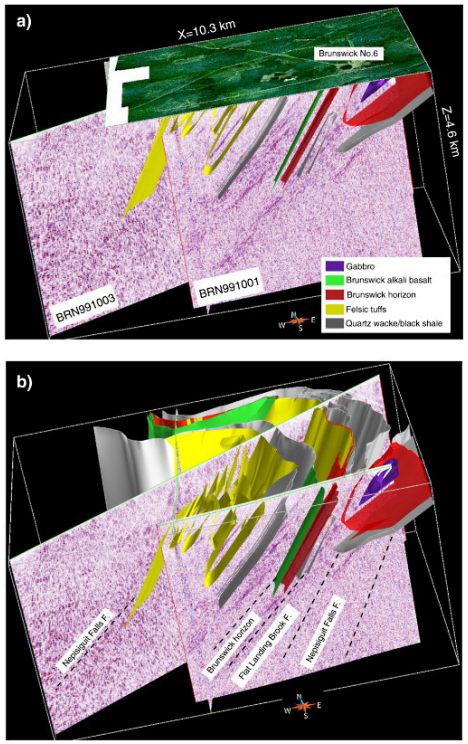
Fabiano Della Justina, et al; A case history using gravity data to validate alternate interpretations of the material below a deep seismic reflector in the Matheson area of Ontario, Canada. Geophysics 2024; https://doi.org/10.1190/geo2023-0523.1

VIEW OR DOWNLOAD
Eshaghi, E., et al. (2023). Density and magnetic susceptibility of major rock types within the Abitibi greenstone belt: a compilation with examples of its use in constraining inversion. Exploration Geophysics, 54(6), 647–669. https://doi.org/10.1080/08123985.2023.2236154



(a) and (b) three-dimensional integration of the migrated seismic sections with the available 3D geologic model of the Brunswick No. 6 area (courtesy of Xstrata Zinc). The Brunswick horizon is shown in red color only for presentation purpose. Source: https://doi.org/10.1016/j.tecto.2011.04.011

The Metal Earth project has acquired an extensive MT data set in the Slave Craton to image and understand the Hope Bay Greenstone belt. Ademola Adetunji undertook the processing of this data. Ademola has also been working on two papers, primarily geophysical content, that are close to publication. The manuscript describing the interpretation of the Metal Earth MT data for the Chibougamau transect is in the final stages of geological inputs and will be submitted for publication. An article that describes the large-scale tectonic structures and history associated with the world-class Timmins gold deposits, based on insights from Metal Earth's Timmins broadband MT data, was submitted to the Journal of Geophysical Research – Solid Earth during the reporting period. The paper's title is "Multi-scale distribution of graphite in the Timmins-Porcupine gold-camp, Canada from magnetotelluric and petrophysical studies: implications for metallogenic evolution."

Eric Roots completed his PhD research during the reporting period and graduated in November 2024. In May 2024, Roots published "Constraints on Growth and Stabilization of the Western Superior Craton from Inversion of Magnetotelluric Data" in Tectonics.

A final manuscript that identified anisotropy in the conductivity of the lithospheric mantle is forthcoming.

Graham Hill and Eric Roots have also recently submitted a manuscript that utilizes Coulomb stress modelling of earthquakes on the equivalent of a south-dipping Cadillac-Larder Lake Fault. They observe that the MT signature is consistent with a reverse dip-slip fault and a dextral oblique-slip fault, which is consistent with the structural observations.

Chris Mancuso is a PhD student working on joint inversion of geophysical data in the Western Wabigoon province. He has developed a novel approach to ray tracing which will mitigate extreme heterogenies and velocity inversions typical of highly tectonized mining belts. As part of this approach's proof of concept, he developed a complex synthetic velocity model to serve as a more appropriate benchmark for land-based reflection seismic modelling.

Fabiano Della Justina prepared and submitted three papers from his PhD thesis. One was accepted, and the others are currently undergoing another review.

The geophysics group has been working with Metal Earth's data integration group and has coauthored several papers with them; these are reported elsewhere.

Future Work

This year, Yasaman Nemati plans to submit the results of her work in three separate papers. The working titles of the papers are as follows:

1. Petrophysical Signatures and Mineral Endowment: The Piché Group, Rouyn-Noranda, Quebec
2. Finite Element Modeling of the Borehole Electrical Resistivity Tool to Understand the Effects of Veins
3. Untangling the Effect of Multiple Veins: Understanding the tool geometry effects in vein-dominated deposits.

Quebec KEGS member Circé Malo Lalande (left) presents PhD student Yasaman Nemati (right) with the KEGS Bourse des pionniers de la géophysique québécoise at Québec Mines + Énergie, Québec City, November 2023. Photo: Christian Dupuis.

The draft of the first paper is ready and is under internal review. The results for the second paper are almost ready. We are running the model to finish gathering data for the third paper. Once the modelling is completed, we can start analyzing the data and complete the writing of the last two papers.

Saeid Cheraghi may complete one paper, time permitting.

Rajesh Vayavur completed his Sudbury Basin paper, "Three-dimensional upper crustal architecture of the East range of the Sudbury Basin, Ontario, Canada." It has been submitted to the Canadian Journal of Earth Sciences.

Ademola Adetunji will complete the processing and interpretation of the data from the Slave Craton to understand the similarities and differences between the endowed Hope Bay and Abitibi belts. This will be written up as a paper, and the publication of the other two papers will be completed.

Eric Roots will publish the remaining papers that have come out of his thesis.

Chris Mancuso will use the velocity and density models estimated from trav-el-time inversion. These models will be fused with regional and transect gravity data to make joint physical property models of the Western Wabigoon province. He plans to disseminate the ray tracing geophone correction and surface wave methods and the subsequent joint inversion results in a series of manuscripts and conference presentations in 2024-25.

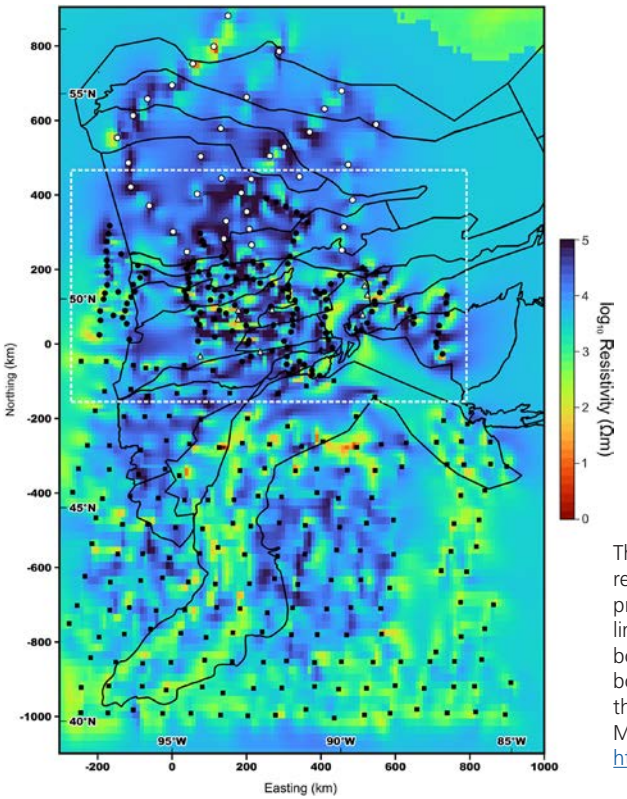
Anticipated Outcomes

The work of Yasaman Nemati on borehole geophysics will provide an understanding of how hydrothermal alterations affect the physical characteristics of mafic and ultramafic rocks. From this, there will be an understanding of the effect of veins and fractures and their associated characteristics (thickness, radius, angle, conductivity) on normal resistivity tool measurements.

This understanding will allow petrophysical logs to be used alone/ or in association with other logs to identify the areas with a higher probability of gold endowment. The geophysical logs will also provide a characterization of the undersurface to aid the inversion and surface geophysical modelling.

Rajesh Vayavur's Sudbury work has helped to understand the upper-crustal architecture of the Eastern Sudbury basin and has shown the importance of 3D integration of various geological and geophysical datasets and 3D constrained modelling for comprehensive subsurface interpretation.

The conductivity structures imaged by Ademola are expected to shed light on the tectonic/geodynamic history and



Thickness-weighted integrated resistivity of the top 20 km of the preferred inverse model. Solid black lines correspond to major terrane boundaries, including subprovince boundaries, the craton edge, and the surface expression of the Mid-Continent Rift. Source: https://doi.org/10.1029/2023TC008110

VIEW OR DOWNLOAD
Roots, E. A., et al (2024). Constraints on growth and stabilization of the western Superior Craton from inversion of magnetotelluric data. Tectonics, 43, e2023TC008110. https://doi.org/10.1029/2023TC008110

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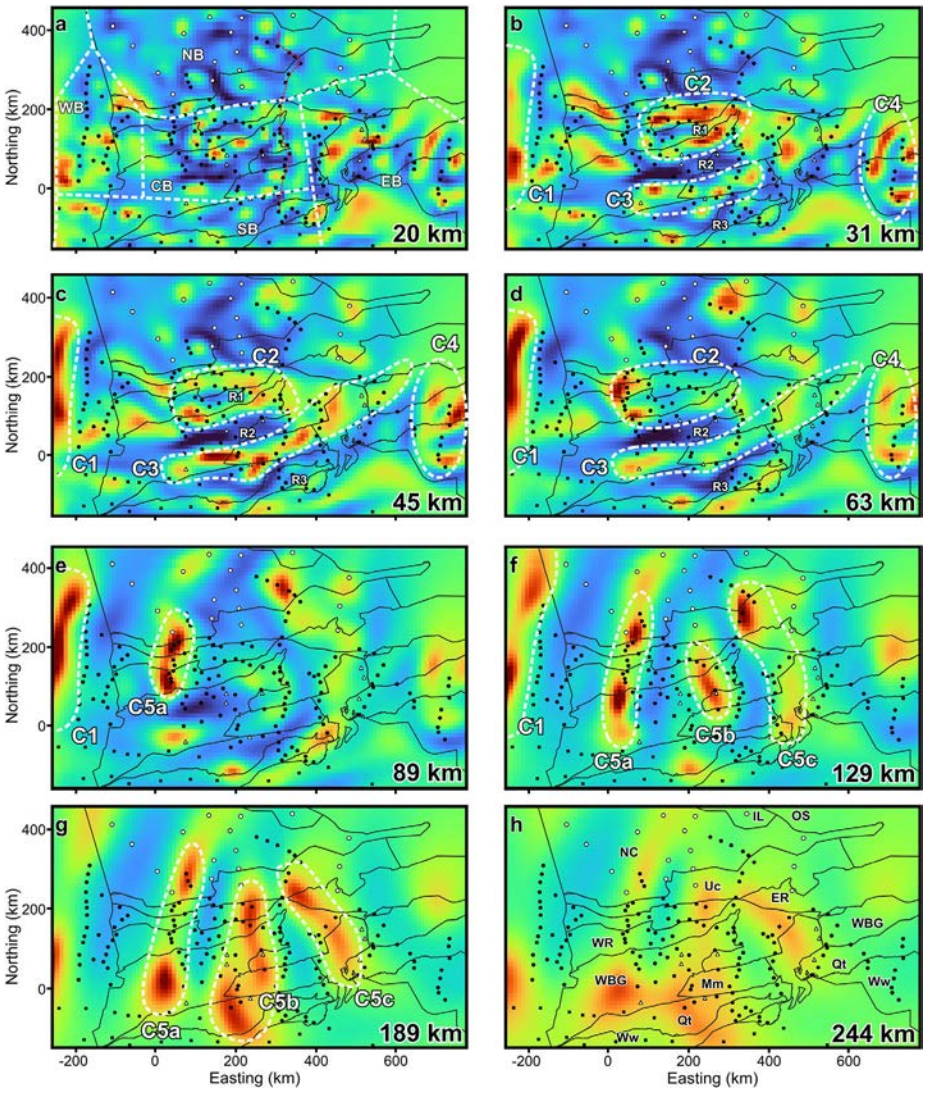
Roots, E. A. (2024). Large-scale resistivity structure of the Superior Craton, Canada (Doctoral dissertation). Laurentian University, Sudbury, Ontario, Canada. https://laurentian.scholaris.ca/handle/10219/4185



Plan view slices at representative depths through the preferred inverse model at depths of (a) 20 km, (b) 31 km, (c) 45 km, (d) 63 km, (e) 89 km, (f) 129 km, (g) 189 km, and (h) 244 km. the red dashed line corresponds to Lithoprobe seismic line 1. White dashed lines in (b)–(h) highlight the features discussed in the text. Source: https://doi.org/10.1029/2023TC008110

fluid pathways that can be used to construct the source-to-sink history of mineral deposits or the lack thereof.

The work of Eric Roots indicates deep electrical anisotropy within the lithosphere of the western Superior, which has implications on its geodynamic history as well as on processes of cratonic construction and modification globally. Similarities found between the broad crustal conductivity structures between the metal-endowed southeastern Superior and non-endowed western Superior also have implications on our understanding of the lithospheric mineralization system model and the critical factors affecting differential metal endowment within Archean terranes.

Implications

The results of the borehole project show that the measurement of physical properties and, therefore, geophysical data can be affected by the geometry of the instruments used. This is an important insight when trying to build models that explain larger-scale datasets. This work confirmed that measurements that appeared erroneous on the different channels of the normal resistivity tools are associated with thin resistive structures. Without this insight, modellers may include low resistivity layers in their models that are measurement artefacts. Furthermore, the resistivity alteration index developed this year provides a simple and powerful tool that enables the users to determine, simply from the resistivity data, if the rock mass was host to significant hydrothermal alteration which could have led to mineral enrichment.

Vale invited Rajesh to present his work at one of their exploration meetings. The anticline structure he identified could have brought prospective rocks closer to the surface, where they are easier to mine.

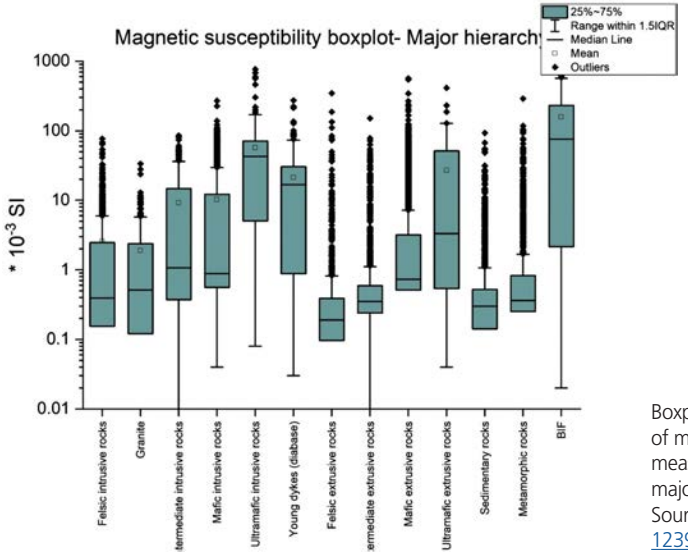
Fabiano's work shows that the Deloro is 8 km deep below the Matheson seismic line and getting shallower to the east, an interpretation that is consistent with the gravity and seismic data. This shows that gravity and seismic data can be used together to make inferences about deep upper-crustal geology.

Eric's work indicates broadly similar electrical structures in the mid- to lower crust within both the western and southeastern Superior Craton. This similarity suggests that deep crustal architecture (as inferred from MT data) is likely one of many factors in determining metal endowment.

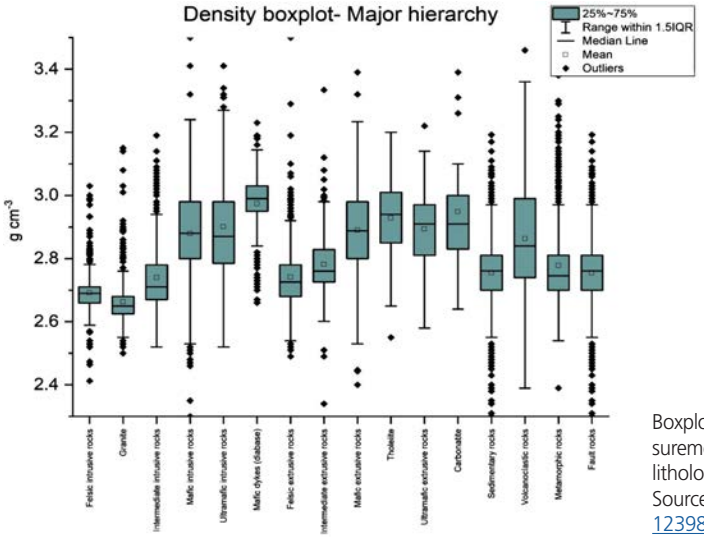
Chris Mancuso's research will provide new methods, which will be evaluated on Metal Earth data and geological contexts.

Highlights

- Yasaman Nemati received the Bourse des pionniers de la géophysique québécoise, KEGS Foundation, November 2023.
- The aim of the borehole logging project undertaken by Yasaman Nemati is to understand how the physical properties of rocks have been altered by hydrothermal processes. We discovered that areas with higher gold content, especially those with visible gold, were often associated with high resistivity. These areas contained complex sets of quartz-carbonate veins. The intricate geometry of resistive bodies in orogenic gold deposits has always posed a challenge in determining how they affect resistivity readings and their relationship to gold endowments. Our findings demonstrate how the presence of single and multiple veins influences these factors. Results also show that physical properties are closely associated with alteration mechanisms and not lithologies. This is an important insight for everyone trying to train artificial intelligence algorithms associated with mining.
- Chris Mancuso was admitted into Queens University as a pre-doctoral fellow with the aim to get assistance with his doctoral research.
- Fabiano Della Justina's presented his results at the Geological Association of Canada meeting in Sudbury, 2023, and received the award for the best student-geophysicist presentation.
- The geophysical results from the Sudbury integration were presented by Rajesh at the 68th ILSG Annual Meeting 2022 and PDAC 2023 conferences. The results were also presented at the Vale PGEN Meeting 2023 and were well received.
- Mostafa Naghizadeh presented the results of active and passive seismic experiments in Larder Lake at the Canadian Society of Exploration Geophysicists conference (Geoconvention) in Calgary in June 2024.
- Mostafa Nagizadeh was invited to present results from the Metal Earth Project at the Society of Exploration Geophysicists 2023 meeting in Texas, USA. Richard Smith was invited to make a presentation in 2024.
- Eric Roots graduated with his PhD in November 2024.



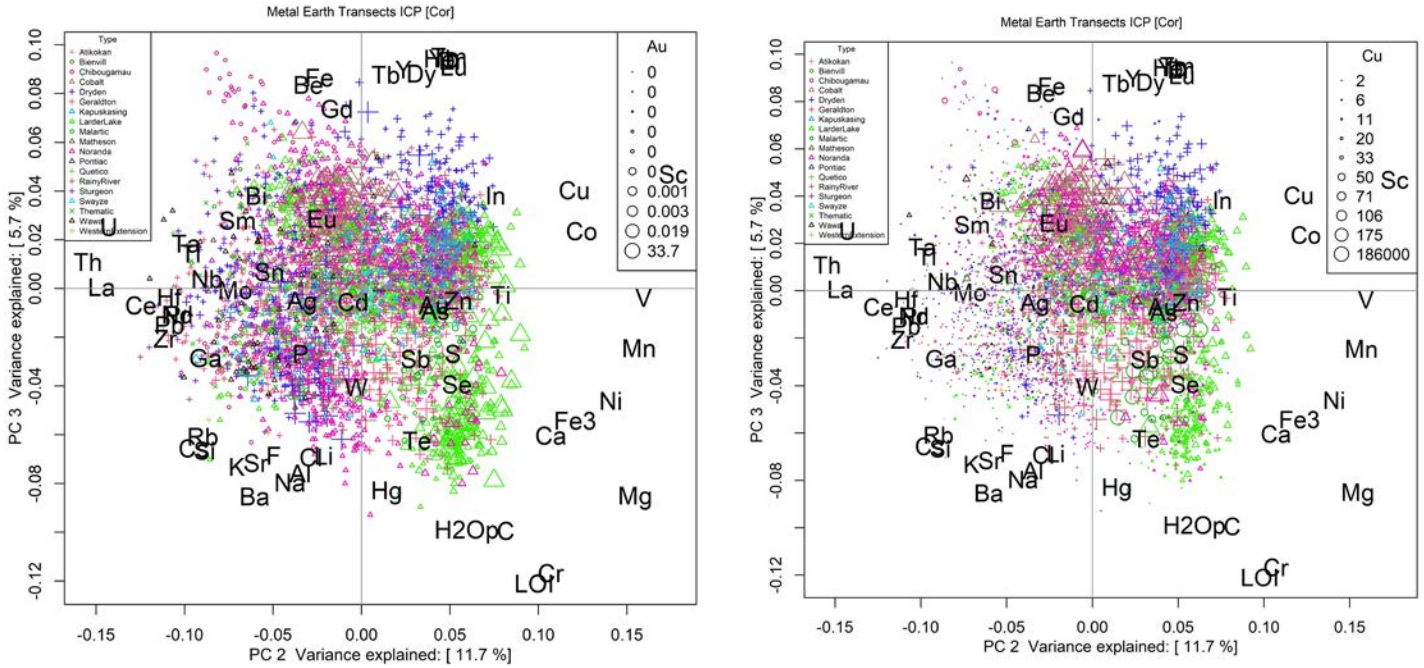
Boxplot analysis of magnetic susceptibility measurements represented by major lithological groups. Source: https://doi.org/10.1080/08123985.2023.2236154



Boxplot analysis of density measurements represented by major lithological groups. Source: https://doi.org/10.1080/08123985.2023.2236154

Lithogeochemistry Compilation and Essential Data Analytics

Dr. Eric Grunsky, Geological Survey of Canada



A preliminary view of the multi-element relationships associated with relative increases in gold and copper over the Metal Earth transects. Source: Eric Grunsky

WATCH NOW!
Jeff Harris: *Data Analytics Review and Mineral Prospectivity results from Geraldton and Dryden*

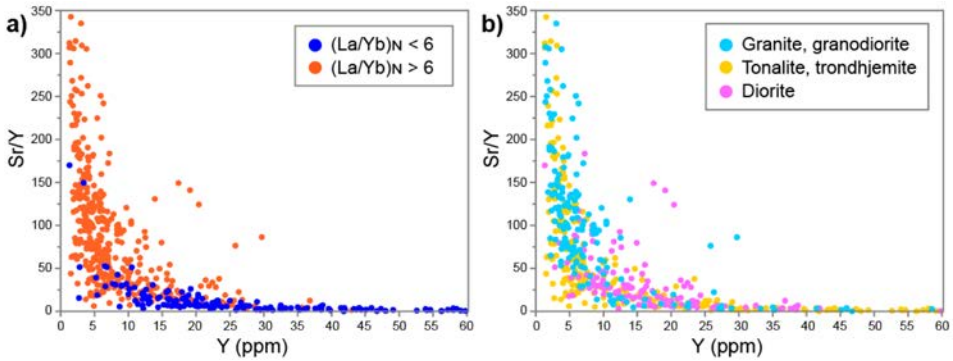
Progress

The Geochemistry Compilation team (Jeff Harris, Lucie Mathieu, Ahmad Reza Mokhtari, Gyorgyi Tuba, Pouran Behnia, Eric Grunsky) are evaluating a dataset of whole-rock geochemistry data collected across the various Metal Earth Transects and compiled from datasets published by the Ontario and Québec geological surveys.

Quality Control / Quality Assurance procedures have been carried out to ensure the integrity of the lithogeochemical database. The group is working to compile the Metal Earth geochemistry datasets into a common database, which will allow for long-term access for future studies.

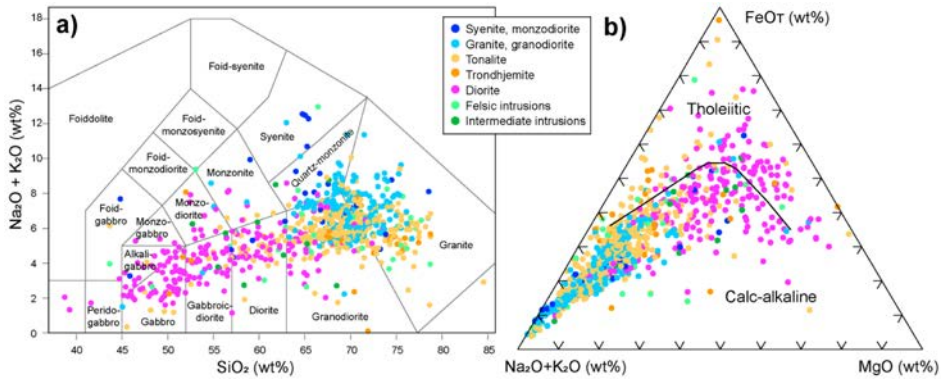
When the database is complete, it will include:

- Analytical data from field samples obtained from transect research
- Certified Reference Material analysis for quality assurance/quality control checking
- Laboratory and blank standards for quality assurance/quality control checking



Chemistry of intermediate-felsic intrusive rocks of the SIGEOM (https://sigeom.mines.gouv.qc.ca) dataset displayed on the Sr/Y vs. Y binary diagram. Only rocks recognized as granite, granodiorite, tonalite, trondhjemite, and diorite in the field, with REE, Y, and Sr analyzed, are displayed (n = 558). Color code corresponds to the HREE content (a) and field-based names (b).

Source: Mathieu et al. (2020)



Chemical composition of intermediate-felsic intrusive rocks of the SIGEOM dataset (n = 840) displayed on (a) the total alkali versus silica (TAS) diagram and (b) the alkali-FeOT-MgO (AFM) ternary diagram. The rocks identified as felsic and intermediate intrusions are fine-grained and could not be classified precisely in the field.

Source: Mathieu et al. (2020)

The QA/QC data confirms generally acceptable results for the analytical procedure by employing Thompson-Howarth and Shewhart control charts. Those who rely on this data should review the analyte type and insights from QA/QC graphs. Concerns exist regarding the concentrations of specific analytes in blank samples. The QA/QC process revealed potential mislabeling for some RM samples, which were subsequently excluded from further QA/QC analysis. These issues will be documented in the database report and acknowledged in future publications utilizing Metal Earth geochemical data.

A geological map has been obtained from Rebecca Montsion's work on geospatial tagging of the Metal Earth geochemical data to the transects.

Ahmad Reza Mokhtari has joined the ME team and is examining the multi-element geochemical data to highlight potential base—and precious-metal mineralization and characterize the geochemistry of the different transects.

Multi-element studies are ongoing in the Larder Lake, Matheson and Geraldton transect areas. Lithogeochemical comparisons within and between the Metal Earth Transects are ongoing.

Future Work

Once the geochemical data and the geospatially tagged geological information are integrated, the following will occur:

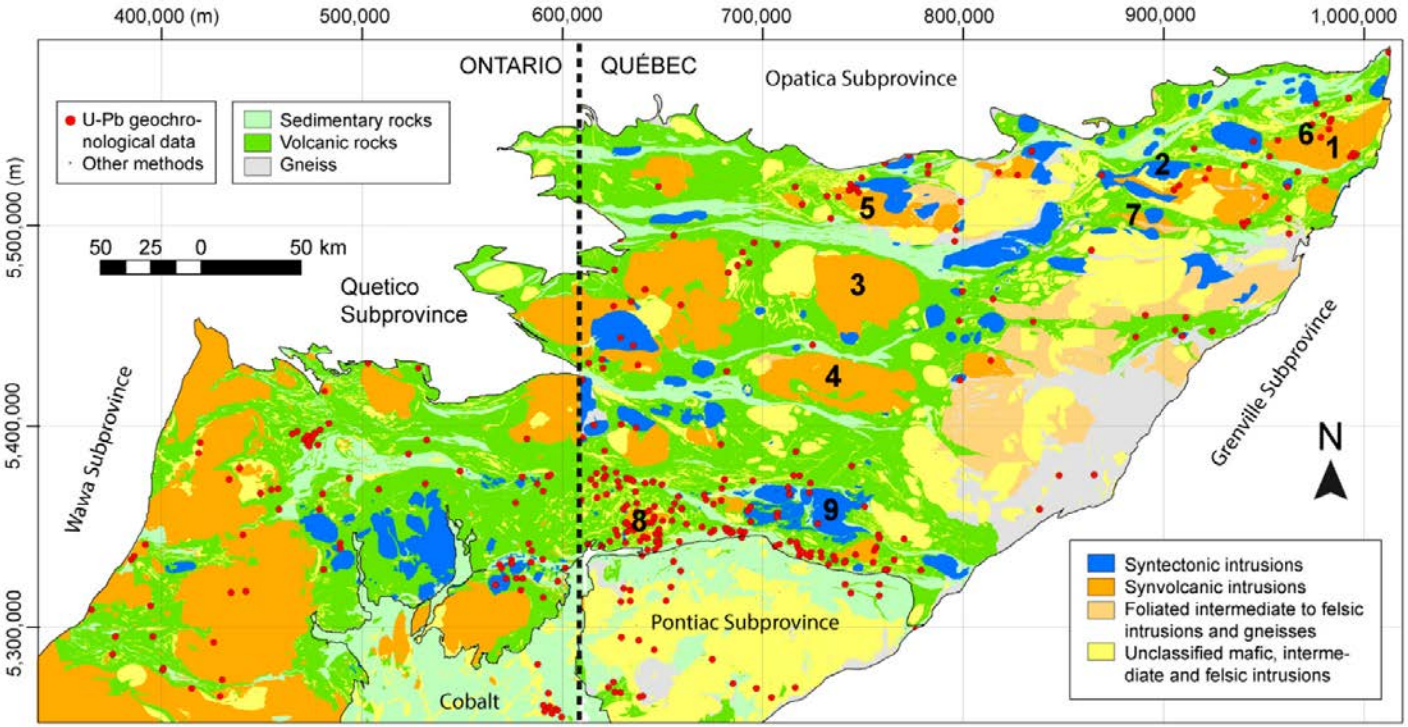
1) Characterization of the geochemistry of the transects using multivariate statistical methods will highlight geochemical similarities/differences within and between them.
2) Studying transect geochemistry to identify specific geological features to highlight information on Archean crustal formation and geodynamic processes. Element ratios and statistical analysis will be applied.

Anticipated Outcomes

- Geochemical characterization of all Metal Earth transects
- Identification of geochemical signatures associated with processes, including crustal formation and mineral resource potential

Implications

- This project consolidates an array of geochemical data collected under the Metal Earth project using consistent laboratory methods.
- The database will provide a legacy standard for aggregating and accessing geochemical data collected from the transects.



Geological map of the Abitibi Subprovince displaying intrusions of the synvolcanic and syntectonic periods. The map is modified from the MERN and OGS dataset, and the projection is UTM NAD83 Zone 17N. Numbers locate the Chibougamau pluton (1), the Ouest granodiorite (2), the Marest (3) and Bernetz (4) batholiths, the Rivière Bell (5), Lac Doré Complex (6), and Opawica River (7) layered intrusions, as well as the Powell, Flavrian and Dufault plutons (8) and the Lacorne pluton (9).
In the legend for geochronological data, 'other methods' refers to Ar/Ar, K/Ar, Sm/Nd, Pb/Pb, and Rb/Sr data (cooling ages, age of peak metamorphism, etc.).
Source: Mathieu, L., Crépon, A., & Kontak, D. J. (2020). Tonalite-dominated magmatism in the Abitibi Subprovince, Canada, and significance for Cu-Au magmatic-hydrothermal systems. Minerals, 10(3), 242. MDPI. https://doi.org/10.3390/min10030242

Highlights

The introduction of methods to characterize multi-element geochemical data and assist in identifying processes for mineral exploration enhancement will benefit the industry.

VIEW OR DOWNLOAD
Mathieu, L., Crépon, A., & Kontak, D. J. (2020). Tonalite-dominated magmatism in the Abitibi Subprovince, Canada, and significance for Cu-Au magmatic-hydrothermal systems. Minerals, 10(3), 242. MDPI
https://doi.org/10.3390/min10030242

WATCH NOW!
Haiming Liu: *Multivariate Statistical Analysis of Lithogeochemical Data of the Larder Lake Area*

Hope Bay

Dr. Rasmus Haugaard, Laurentian University

Geologists from Laurentian University, Agnico Eagle, and Université Laval looking for rocks and minerals of economic importance in the central part of the Hope Bay greenstone belt, August 2023. Source: R. Haugaard.

Progress

A full MT grid coverage of the Hope Bay greenstone belt (NE Slave craton) was carried out during July and August of 2023. Processing of the data set is nearly complete.

During the August 2023 field season, samples of sedimentary rocks and the bounding granitoids of the Hope Bay block were collected. Volcanic rocks were previously sampled.

A set of sedimentary rocks has been sent for thin section, whole rock analytical work, and heavy mineral separation. The granitoid samples have been processed for whole rock analysis and heavy mineral separation. Final U-Pb and Lu-Hf analytical work will be completed at the University of Toronto and the University of Alberta.

Future Work

The final MT data set will be used to interpret the conductive architecture of the Hope Bay greenstone belt and its bounding granitoids. This interpretation should reveal the size and crustal extent

WATCH NOW!
Rasmus Haugaard - *Geoscience studies in the Hope Bay Greenstone belt, presented at the Metal Earth scientific meetings, March 2024, Toronto, Canada.*

of key mineralized structures associated with known deposits, and potentially pave the way for new target sites for future exploration.

The Hope Bay MT survey will also allow for crustal comparison with the Abitibi, which consists of similar rocks, in style and age.

Sedimentary rocks will be interpreted with respect to their source composition, timing of provenance, and how they depositionally and stratigraphically sit in the general volcanic-dominated belt.

Granitoids will be interpreted with respect to their crystallization ages, and an attempt will be made to fingerprint their source of origin in the deeper crust.

Contrasts and similarities in the Lu-Hf systematic between the Hope Bay belt and the rest of the Slave craton, as well as the Abitibi craton, will be carried out.

Anticipated Outcomes

- One MT manuscript addressing the overall conductive architecture of the Hope Bay belt
- One sedimentary rock-focused manuscript addressing the depositional environment and provenance of the clastic rocks.
- One manuscript constraining the timing of the granitoids and addressing the source of origin of the Bathurst Block plutons.

Implications

This work will advance our understanding of the geological processes affecting metal endowment in Archean greenstone belts in multiple cratons.

Highlights

- This is the first craton-scale MT survey in the Hope Bay belt. Results of this survey in the Slave Craton may be used to determine if craton-scale MT studies can provide meaningful results elsewhere.
- Agnico Eagle and its Hope Bay geologic team are collaborating closely with this project. MT and geological architecture interpretations will help the company select areas for future exploration targeting.

Geologists from Agnico Eagle, Université Laval and Metal Earth searching for structures of economic importance in the rocks in the south-central part of the Hope Bay greenstone belt, August 2023. Source: Rasmus Haugaard.

The tundra landscape and Hope Bay greenstone belt, close to the Arctic coast of Nunavut, August 2023. Source: R. Haugaard.

Craton Scale: Overview

Metal Earth PhD candidate Kristine Nymoen presented her research at the 6th International Archean Symposium and joined a pre-conference field trip focused on Australia's Southwest Yilgarn Craton and the ongoing research in this area. Six Metal Earth researchers participated in the July 2023 conference.

Metal Earth has employed a series of transects across all the terranes in the southwestern Superior Province in a bid to understand the contrasting mineral endowment of the Abitibi versus the other terranes of the Superior Province. The transects have used reflection seismic profiles and various magnetotelluric techniques accompanied by geologic mapping to better understand the endowment question.

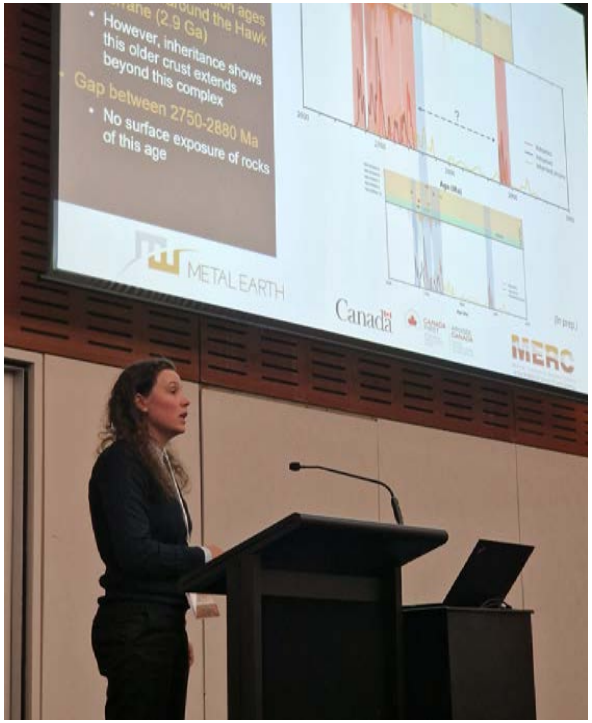
There are gaps in this approach, particularly the poorly accessible North Caribou terrane and Hudson Bay terranes.

In 2023, PDF Jacob Strong began work with Metal Earth. He has completed Lu-Hf mapping of the North Caribou terrane. In addition, he studied a number of zircon xenocrysts and obtained an Eoarchean igneous xenocryst and a very early metamorphic age. Given the fact that these xenocrysts are substantially older than the existing crystallization ages in the Hudson Bay terrane, we decided to re-sample the Minnesota Valley gneisses, which have crystallization ages somewhat comparable to the Hudson Bay terrane with a view to carefully examine the xenocryst population.

In addition, Strong is working on samples from the Winnipeg River terrane, a possible old microcontinental fragment. PhD Student Kristine Nymoen is working on the Wawa terrane. She has submitted a manuscript integrating whole rock geochemistry and Lu-Hf isotopes throughout the terrane. She has data on S isotopes to be published shortly.

Craton Scale: Origin, petrogenesis and architecture of the southern Superior Craton in space and time: Implications for large-scale mineral endowmentg

Dr. Phillips C. Thurston, Laurentian University



Kristine Nymoen presents her research on the Wawa subprovince, Superior Craton, at the 6th International Archean Symposium, Australia, 2023.

Kristine Nymoen studying rocks of the Corrigin Tectonic Zone at Posselts Cutting on a field trip during the 6th International Archean Symposium, Australia, 2023.

Progress

- All analytical work and data processing is complete.
- PhD student Kristine Nymoen submitted a first manuscript, "Crustal evolution and architecture of the Wawa subprovince, Superior Craton: insight from zircon U-Pb-Hf-O isotopes and geochemistry," to *Precambrian Research* (under review)

Future Work

- Complete interpretation of new data and write-up manuscripts.
- Integrate the craton-scale isotopic mapping PhD project results with other Metal Earth research to achieve the project's stated goals.
- Continue to attend and present the PhD research at conferences to share our findings with the research community.

WATCH NOW!
Kristine Nymoen - *Integrating whole-rock geochemistry with isotopic mapping and phase equilibria: crustal architecture of the Wawa subprovince*

VIEW OR DOWNLOAD
Nymoen, K. G., Mole, D. R., Tinkham, D. K., Thurston, P. C., & Stern, R. A. (2023). The evolving crustal architecture of the Wawa Subprovince, Superior Craton. In K. Gessner, T. E. Johnson, M. I. H. Hartnady, & D. Wiemer (Comps.), 6IAS: 6th International Archean Symposium – Abstracts (pp. 66). Geological Survey of Western Australia, Record 2023/8. https://6ias.org/abstract/

Anticipated Outcomes

- This PhD study will enhance our knowledge of the variability of the crustal architecture in the southeastern Superior Craton by using zircon U-Pb geochronology to determine the timing of the formation of felsic crust.
- Using whole-rock and zircon trace element geochemistry to identify geochemical signatures of magmatic processes and geochemical signatures of source rocks and integrating this data with Hf-O and S-isotopes to study the possible age variability of magmatic sources.
- Ultimately, this allows for a better understanding of how crustal architecture may indicate differences in tectonic processes and relate to different metal endowments in the Wawa-Abitibi terrane of the Superior Province.

Implications

This research contributes to understanding how crustal architecture may relate to differential metal endowment between different terranes within Archean cratons through source characterization and tectonomagmatic processes.

Kristine Nymoen teaching undergraduate students how to make good outcrop descriptions, as part of the Field Geology course offered at Laurentian University.

VIEW OR DOWNLOAD
Gibson, H., Thurston, P. C., Ayer, J., & Simmons, J. (2023, July 25–27). A cratonic scale early ensialic successor basin in the Superior Province [Conference presentation]. 6th International Archean Symposium (6IAS), Fremantle, Perth, WA, Australia.

Highlights

- Presented research at the 6th International Archean Symposium and attended the field trip "Redefining Archean Terrane Boundaries: A radical update within the Yilgarn Craton" organized by the Geological Survey of Western Australia (GSWA) in summer 2023
- Participated and presented research from the craton-scale project at a Metal Earth workshop held at the Saskatchewan Geological Open House in fall 2023
- Participated and presented research from the craton-scale project at the Metal Earth workshop "The influences of tectonics and crustal architecture on gold and base metal endowment in Archean terranes compared with modern oceanic arcs" at the Prospectors & Developers Association of Canada (PDAC) convention in Toronto in March 2024
- Held a presentation about the PhD project for the Geological Society of Norway at the Harstad department
- Received travel grant from the Mineralogical Association of Canada (MAC)

VIEW OR DOWNLOAD
Nymoen, K. G., Mole, D. R., Tinkham, D. K., Thurston, P. C., & Stern, R. A. (2023). Integrating whole-rock geochemistry, isotopic mapping and phase equilibria: Implications for architectural controls on mineral systems in Wawa. GAC-MAC-SGA Conference, Geoscience Canada, 50, 105–237. https://doi.org/10.12789/geocanj.2023.50.200

VIEW OR DOWNLOAD
Nymoen, K. et al. Isotopic mapping and its application to understanding craton architecture and localization of mineral systems. (2023) MERC Short Course, Saskatchewan Geological Open House. https://merc.laurentian.ca/sites/default/files/isotopic_project_me_shortcourse_sgoh_nymoen.pdf

Craton Scale: Isotope Mapping Synthesis

Dr. Jacob Strong, Laurentian University

Progress

- Project 1 (main): Completing zircon isotope analysis for NCT.
- Project 2 (secondary): Compilation of geochemical data for the NCT (in prep) for internal use once complete.
- Project 3 (main): Compilation of isotope data from the Superior Province for internal use (ongoing). Synthesis of isotope data compilation with geochemistry and geophysics.
- Project 4 (secondary): (Fig 1 zircon) Oldest zircon in the Superior Province 4.0 – 3.9 Ga (manuscript completed and submitted August 2024, currently under revision November 2024).
- Project 5 (Secondary, external): Chris McFarlane (UNB) and Chris Coueslan, Manitoba Survey samples; U-Pb-Hf-TE investigation of 3.9 – 3.2 Ga Assean Lake detrital zircon (external collab; manuscript undergoing pre-submission revisions).
- Project 6 (main): Investigation of zircon xenocrysts from the 'Southern Province' and Minnesota River Valley terrane. Currently imaging zircon (December 2024).

Future Work

- Isotope analysis ongoing (Completion projected for early 2025)
- Geochemical compilation analysis
- Synthesis of isotope data

Anticipated Outcomes

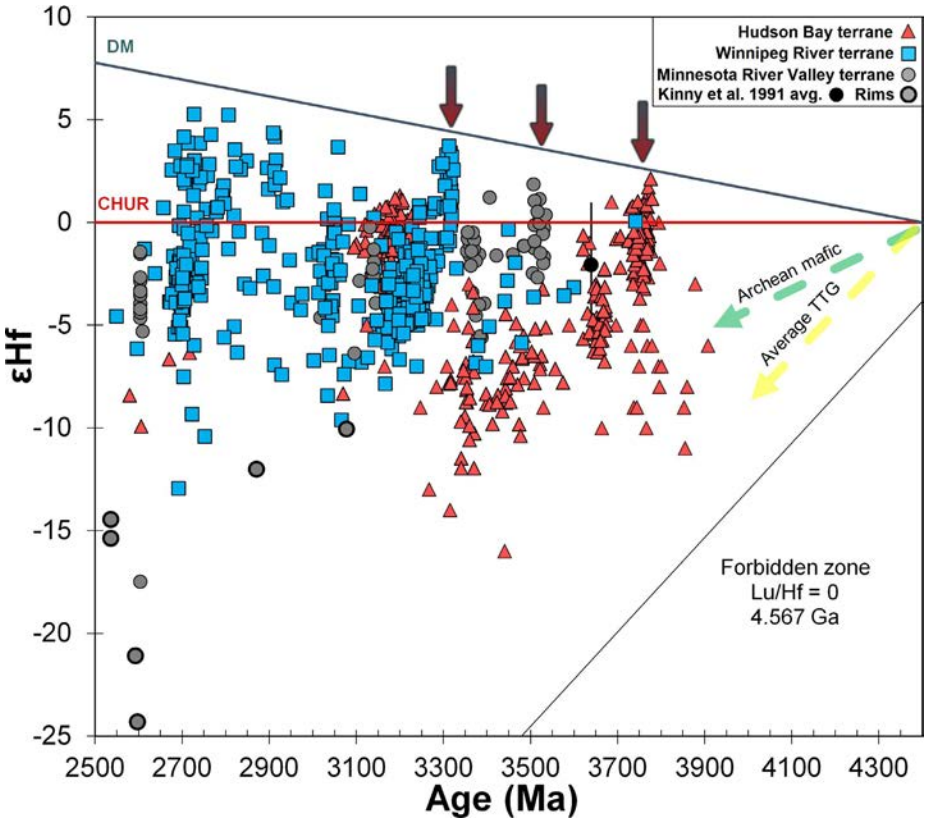
- 4-6 manuscripts

Implications

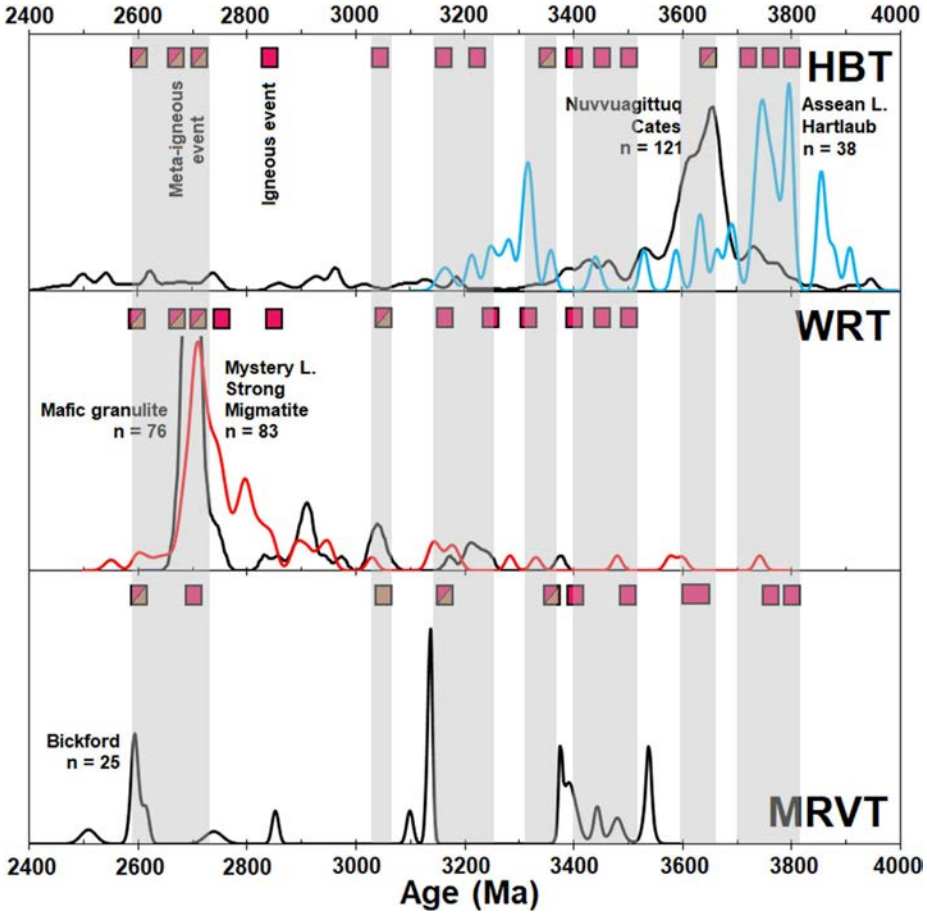
- Impacts our understanding of early earth and Superior Province formation/ evolution
- Impacts our understanding of differential metal endowment between granite-greenstone belts in the Superior Province

WATCH NOW!
Jacob Strong *- Granite-Greenstone terranes throughout Earth's history: Crustal growth by extensional geodynamic scenarios?*

VIEW OR DOWNLOAD
Strong, J. W. D., Cruden, A. R., Cawood, P. A., & Dickin, A. P. (2023). Zircon U-Pb-Hf isotope evidence for juvenile Penokean sources (ca. 1.9 Ga) in the SW Grenville Province. Lithos, 462–463, 107420.



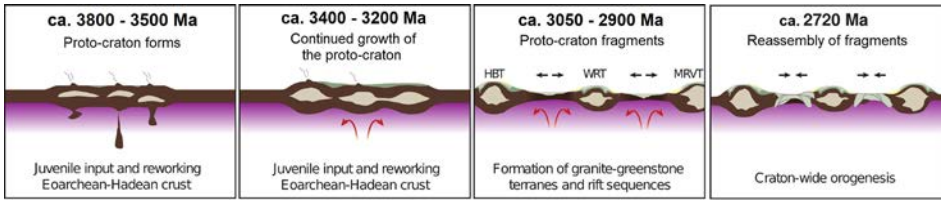
Compilation of new and published in-situ U-Pb-Hf isotope data for igneous and detrital zircon from the Hudson Bay (HBT), Winnipeg River (WRT) and Minnesota River Valley (MRVT) terranes (Hartlaub et al., 2006, Satkoski et al., 2013; O'Neil et al., 2013; Vezinet et al., 2020, Strong et al., 2022a and 2022b). Vertical arrows indicate episodic periods of coeval juvenile growth and crustal reworking during the Eo-Paleoarchean. The green and yellow dashed arrows indicate time-integrated 176Lu/177Hf evolution trajectories of 0.02 for Archean mafic rock (Kemp et al., 2010) and 0.004 for average TTG (Guitreau et al., 2012). Source: Strong et al, Precambrian Research 393, 2023.



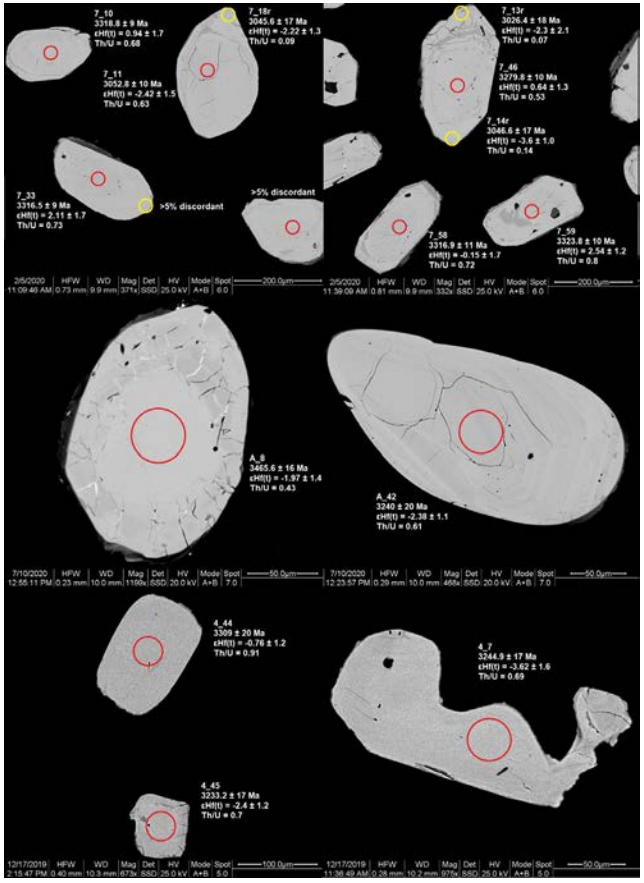
Comparative age chart of detrital zircon probability distributions alongside igneous and meta-igneous zircon growth events for the three plutonic-gneiss terranes. Highlighted bars indicate correlated events discussed in the text. Source: Strong et al, Precambrian Research 393, 2023.

VIEW OR DOWNLOAD
Strong, J. W. D., Mulder, J. A., Cawood, P. A., Cruden, A. R., & Nebel, O. (2023). Isotope evidence for Archean accordion-tectonics in the Superior Province. Precambrian Research, 393, 107096.

VIEW OR DOWNLOAD
Strong, J. W. D., Mulder, J. A., Cawood, P. A., Cruden, A. R., & Nebel, O. (2023). Crustal growth and reworking in the Winnipeg River terrane ca. 3.3–3.25 Ga: Isotope evidence for the survival of an Archean super-craton. Abstract presented at the GAC-MAC Conference, Laurentian University, Harquail School of Earth Sciences.

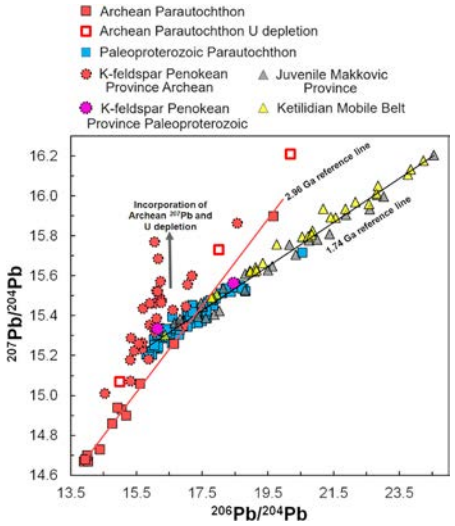


Schematic showing the proposed formation, disaggregation and reassembly of the Superior craton based on geochronologic correlations (IMG_001, IMG_002). Note, arrows depicting extension refer to interpreted disaggregation events discussed in the text. Abbreviations; HBT- Hudson Bay terrane, MRVT-Minnesota River Valley terrane, WRT- Winnipeg River terrane. Source: Strong et al, Precambrian Research 393, 2023.

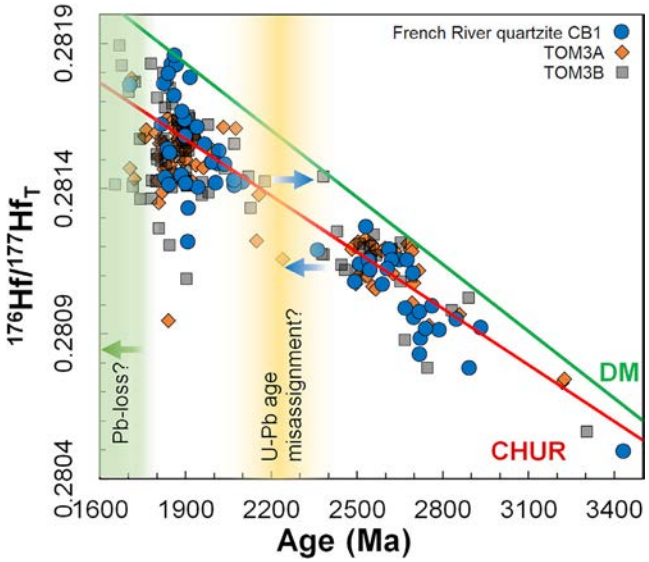


Representative back-scattered electron (BSE) images of zircon from Tannis Lake gneiss 789–30 (7_analysis #), Cedar Lake gneiss AC97-108 (A_analysis #) and 90–405 (4_analysis #).

Source: Strong, J. W. D., Mulder, J. A., Cawood, P. A., Cruden, A. R., & Nebel, O. (2023). Isotope evidence for Archean accordion-tectonics in the Superior Province. Precambrian Research, 393, 107096. https://doi.org/10.1016/j.precamres.2023.107096

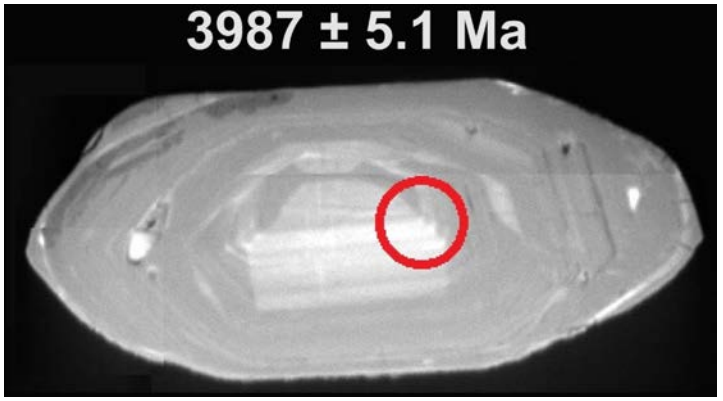


Whole-rock Pb Pb isotope diagram showing a compilation of samples from the Archean Parautochthon, Paleoproterozoic Parautochthon, Makkovik Province and Ketilidian Mobile Belt (Arcuri and Dickin, 2018; Kerr and Fryer, 1994; Kalsbeek and Taylor, 1985), with Pb isotope feldspar analyses from the Penokean Province (Van Wyck and Johnson, 1997).



Hafnium isotope evolution diagram comparing detrital zircon analyses from the French River quartzite CB1 with similar samples, TOM3A and TOM3B, reported by Culshaw et al. (2023). Highlighted bars offer a potential explanation for excess scatter observed in zircon analyses from TOM3A and TOM3B. As indicated by the arrows, horizontal migration of analyses can occur from Pb-loss by recrystallization, metamorphic zircon growth or U Pb age misassignment to Hf isotope compositions.

Source: Strong, J. W. D., Cruden, A. R., Cawood, P. A., & Dickin, A. P. (2023). Zircon U-Pb-Hf isotope evidence for juvenile Penokean sources (ca. 1.9 Ga) in the SW Grenville Province. Lithos, 462–463, 107420. https://doi.org/10.1016/j.lithos.2023.107420



The oldest xenocrystic zircon from the Superior Province, in a sample from the Hudson Bay terrane of Ontario. Source: Jacob Strong.

Highlights

- Identification of the oldest zircon in the Superior Province (4.0 – 3.9 Ga)
- U-Pb-Hf and trace element characterization of 3.85 – 3.2 Ga detrital zircon from Assean Lake (manuscript in preparation, completion by Sept 2024 for co-author comments).
- Acceptance of Jeff Harris's manuscript (JWDS co-author) utilizing current isotope compilation. Submitted to Natural Resources Research.

VIEW OR DOWNLOAD
Strong, J. W. D., & Dickin, A. P. (2021). Neodymium isotope mapping a polygenetic TTG batholith: Failed back-arc rifting in the Central Metasedimentary Belt, southwestern Grenville Province. Canadian Journal of Earth Sciences, 59(2), 251–267.

VIEW OR DOWNLOAD
Nymoen, K. G., Mole, D., Thurston, P. C., Tinkham, D. K., & Stern, R. A. (2023, November 27). Isotopic mapping and its application to understanding craton architecture and localization of mineral systems [Conference presentation]. MERC Short Course, Saskatchewan Geological Open House, Laurentian University, Harquail School of Earth Sciences.

Mineral exploration footprints of crustal-scale deformation zones in Neoarchean greenstone belts, Canada

Dr. Stéphane Perrouty, Laurentian University

Progress

PhD student Theo Lombard is completing EPMA analyses on quartz and pyrite for the samples from the Dryden and Val-d'Or areas:

- WDS and EDS pyrite maps
- CL quartz imaging
- Definition types of quartz textures and pyrite zonations (Ni, Co, As, Pb)

Lombard is completing LA-ICPMS analyses on pyrites from the Dryden and Val-d'Or areas: S33, S34, S36, Fe57, Co59, Ni60, Cu63, Zn66, Zn67, As75, Se82, Se77, Mo95, Ag107, Cd113, Sn116, Sb121, Te125, Au197, Bi209, W182, W184, Pb204, Pb206, Pb207, Pb208.

He has started LA-ICPMS data processing on iolite.

Refining the mass balance calculation based on the MacLean method (Multiple precursor method) using the whole rock geochemistry of the samples from the Dryden area and the Val-d'Or areas:

- highlight main gains and losses related to the footprint of the LLCDZ and the WDZ
- correlation between the elemental changes and the mineralogy observed in the thin sections

Began the comparison compilation between a highly endowed (LLCDZ, Val-d'Or) and a poorly endowed (WDZ, Dryden) Archean deformation zone.

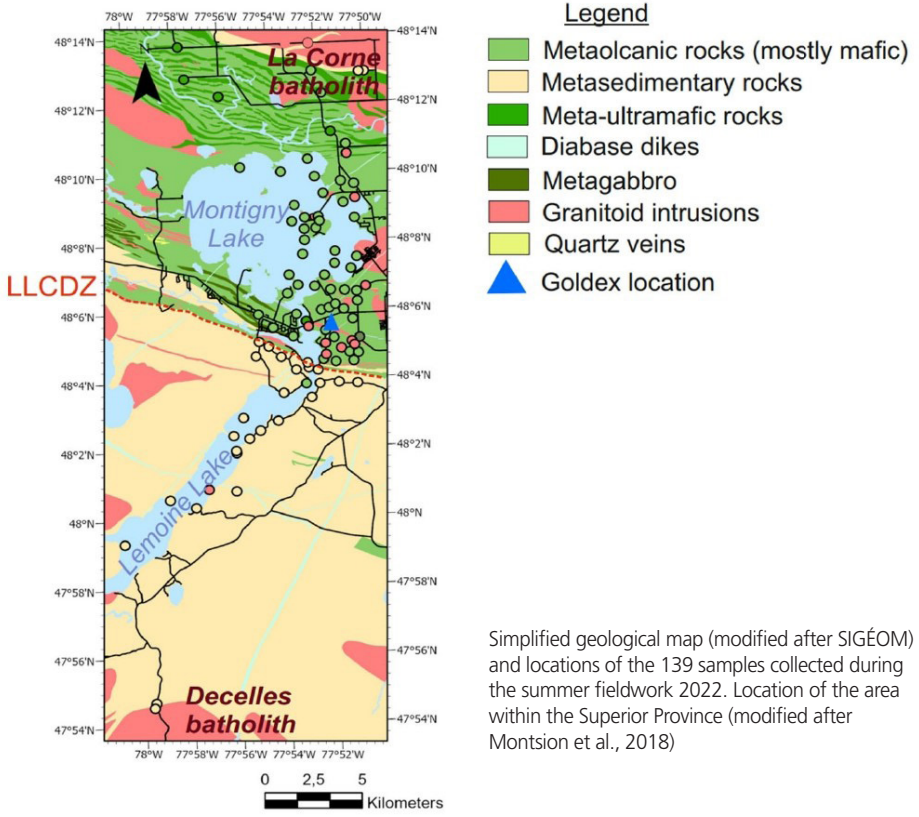
Future Work

Using Principal Component Analysis to group and smooth the data, making the interpretation easier and more relevant:

- Combine the whole rock geochemistry changing factor, the deformation intensity and the alteration type.
- Pyrite chemistry data to try to define a typical signature associated with the presence or the absence of Au.

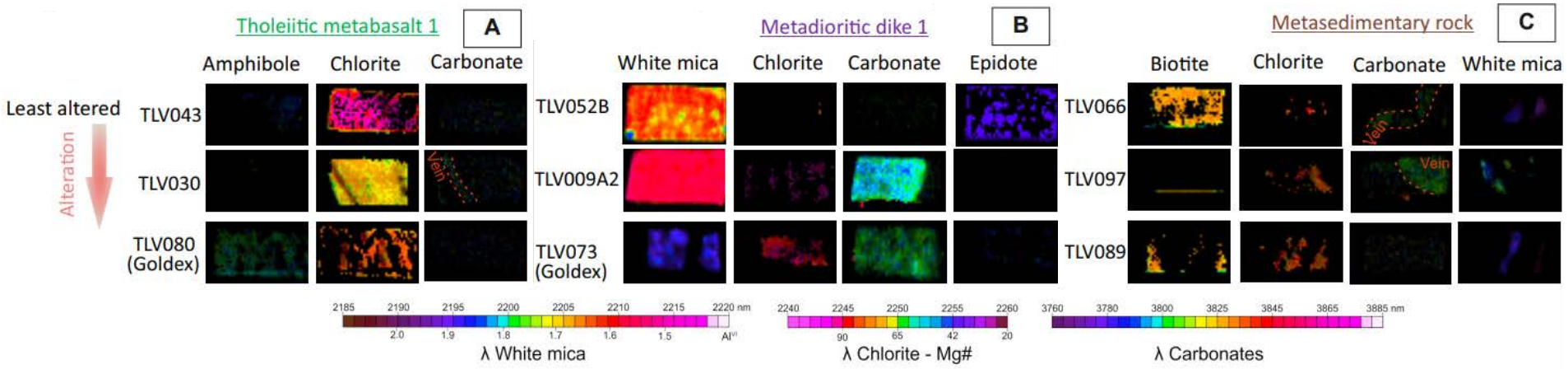
Investigation of quartz mineral chemistry:

- Making thick sections on selected samples
- CL quartz imaging (EPMA)
- LA-ICPMS analyses on quartz



Simplified geological map (modified after SIGÉOM) and locations of the 139 samples collected during the summer fieldwork 2022. Location of the area within the Superior Province (modified after Montsion et al., 2018)

WATCH NOW!
Theo Lombard - *Mineral exploration footprints of crustal-scale deformation zones in Archean greenstone belts: fieldwork resume and first hyperspectral and geochemistry results for the Val-d'Or area*



Processed hyperspectral images of the least altered samples and 2 altered samples for the metadiorite, the metabasalt and the metasedimentary rock. Source: T. Lombard, 2023.

SEM to investigate the presence of sulfate

EPMA analysis on white micas, biotite, chlorite and carbonate minerals to compare and confirm the hyperspectral results and define a better fluid: rock interaction (metamorphic fluid/ magmatic/hydrothermal)

Constrain the temperature formation of the quartz and the pyrite using respectively Ti and Se

(Optional: SIMS analyses to investigate the S isotopes and the source of the sulfur)

Anticipated Outcomes

The project goal is to identify physical and chemical parameters showing the metasomatic halo through sections of major deformation zones in Neoarchean greenstone belts.

It aims to understand physical and chemical parameters at different scales, from the whole rock (deformation intensity, mineralogy, and geochemistry) to the mineral chemistry, by comparing different sections of the deformation zone (endowed or barren) in the Archean greenstone belt.

The main objectives are to:

- Define the elemental gains and losses and mineralogical changes related to fluid-rock interaction during the fluid migration
- Define a temperature gradient associated with the fluid pathway
- Identify quartz and pyrite trace element signatures associated with the fluid pathway
- Identify the key parameters differentiating endowed and barren deformation zones

Globally, this project will:

- Link the footprint of the deformation zone and the gold content
- Provide a better understanding of the process leading to gold endowment
- Provide new exploration tools for targeting enriched deformation zones

Implications

Metal Earth aims to understand the metal endowment process during the

VIEW OR DOWNLOAD
Lombard, T. (2023) - *Structural controls on gold mineralization in Neoarchean greenstone belts, Val-d'Or, Abitibi Greenstone Belt, Canada [Poster presentation]. GAC-MAC-SGA 2023 Conference, Sudbury, Ontario* https://merc.laurentian.ca/sites/default/files/poster_lombard_gac23.pdf

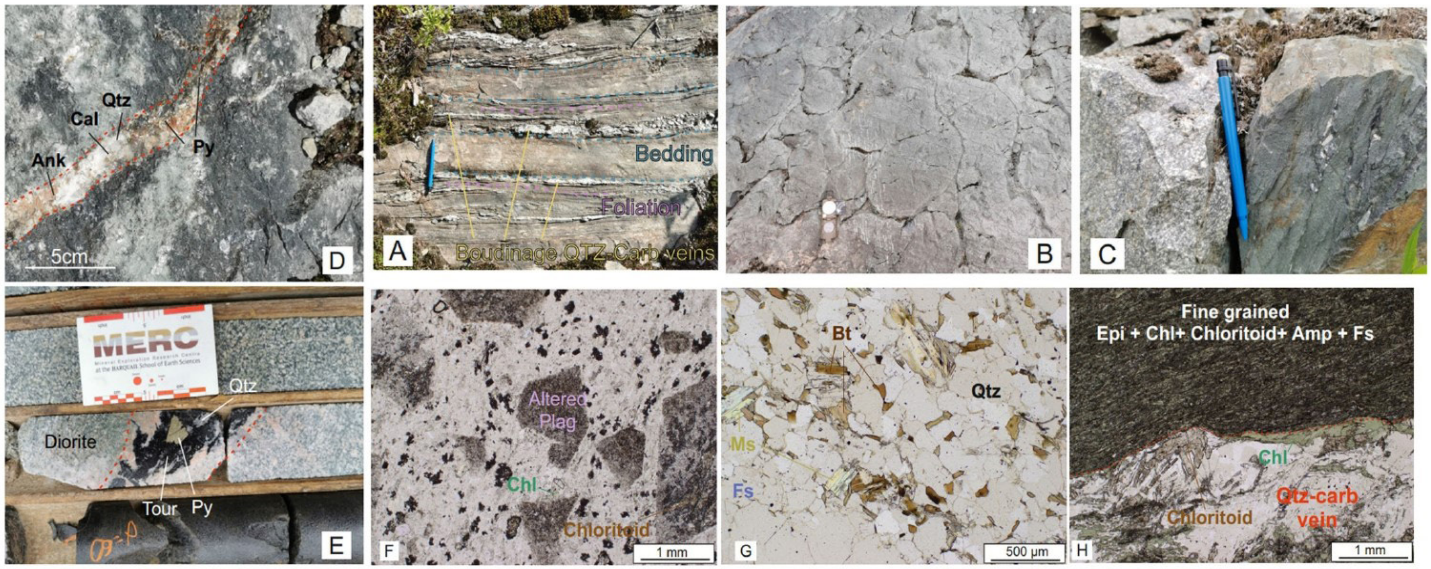
VIEW OR DOWNLOAD
Lombard, T., Perrouty, S., Linnen, R., & Lypaczewski, P. (2023) - *Mineral exploration footprints of crustal-scale deformation zones in Neoarchean greenstone belts, Canada: Fieldwork resume and first hyperspectral and geochemistry results for the Val-d'Or area. In GAC-MAC-SGA 2023 Conference Proceedings (p. 176). Geological Association of Canada, Mineralogical Association of Canada, and Society for Geology Applied to Mineral Deposits. Conference, Sudbury, Ontario* https://journals.lib.unb.ca/index.php/GC/issue/view/2355/59

Precambrian. Orogenic gold deposits represent one of the primary sources of gold worldwide, particularly occurring along deformation zones within Precambrian greenstone belts. It is widely recognized that faults serve as conduits for fluid during the formation of orogenic gold deposits.

This project takes a comprehensive large-scale approach by comparing different sections of major deformation zones—some enriched in gold and others barren—instead of focusing on a specific deposit. The goal is to establish the intensity and sequence of the alteration related to the fluid:rock reaction. It aims to contribute new insights into the metasomatic halo on both sides of major deformation zones at a large scale. Specifically, the study will explore potential temperature gradients, geochemistry variations, and mineral chemistry changes crossing a portion of deformation zones and indicating the presence or absence of a mineralized fluid.

Additionally, the research will endeavour to define exploration tools that utilize parameters influencing gold content, allowing for the differentiation of favourable deformation zones for orogenic gold deposits. Overall, this project aligns well with Metal Earth's objective of examining differences between endowed and less endowed areas and the factors governing metal enrichment.

Collectively, the results are contributing to the elaboration of models for craton disaggregation and assembly in the Neoarchean, providing a precise geodynamic framework to understand the role of regional fluid generation and circulation in gold mineralization.



Macro and micro scale photographs of the main lithologies studied. (A) Metaturbidites from the Pontiac showing the foliation parallel to the bedding. (B) Pillow metabasalt. (C) Metadiortitic intrusion in contact with a mafic volcanic rock.(D) Photograph of a quartz-carbonate (calcite and dolomite)-pyrite veins. (E) Photograph of a quartz-carbonate -tourmaline- pyrite photograph hosted by a diorite from the Goldex mine. (F) Plane polarised photograph of the metadiorite that was crosscut by a mafic volcanic rock. Plagioclase are replaced by epidote, chlorite and chloritoid and minor sericite. The epidote is replaced by cholrite in more altered samples. (G) Plane polarised photograph of the metasedimentary rock. (H) Plane polarised photograph of the metabasalt with a quartz vein at the bottom showing epidotes and chloritoide. Chlorite occurs mostly along the edge of the vein. Source: Lombard, T. (2023). Structural controls on gold mineralization in Neoarchean greenstone belts, Val-d'Or, Abitibi Greenstone Belt, Canada [Poster presentation]. GAC-MAC-SGA 2023 Conference, Sudbury, Ontario. https://merc.laurentian.ca/sites/default/files/poster_lombard_gac23.pdf

Highlights

- Lombard's poster earned the 2023 Keating-Boyle award in the PhD category at GAC-MAC Sudbury in May 2023. In September 2023, he presented his research in a GAC-MAC webinar for the Keating-Boyle Award winner.
- Lombard presented his research at the PDAC-SEG Student Minerals Colloquium (SMC) in Toronto in March 2024.
- Lombard served as vice president of the Laurentian University SEG Student Chapter (2023-2024) and coordinated a trip to Chile in February 2024.

Supracrustal architecture of the eastern Michipicoten greenstone belt, Ontario

Dr. Stéphane Perrouty, Laurentian University and Lianna Vice (Ontario Geological Survey)

Progress

- 2023 mapping of Riggs and Glasgow townships with a full OGS field season, additional targeted mapping of key and interesting locations
- Submission of 2023 samples for thin section preparation
- Published 2023 Summary of Fieldwork
- U-Pb LA-ICPMS analyses for 2022 samples
- Sample preparation and SEM work for 2023 and previous OGS geochronology samples (31 samples)
- Hyperspectral imaging of 800 slabs

Future Work

- 2024 mapping of strategic locations to complete compilation map, Dolson and Echum townships
- Submission of 2023 and 2024 samples for geochemistry
- U-Pb LA-ICPMS for 2023 (and historical) samples
- Lu-Hf LA-ICPMS analyses for select geochronology samples (2022, 2023 and previous)
- Geochemical analyses
- Analyses of hyperspectral data
- Compilation map of the study area, lithological and assemblage
- Better define the regional structural controls on orogenic gold mineralization

WATCH NOW!
Lianna Vice - *Supracrustal architecture of the eastern Michipicoten greenstone belt, Ontario*

VIEW OR DOWNLOAD
Ma, C., Vice, L.E.D., Nagy, C., Adam, Z.V., Shirriff, D., Lafrance, B. and Robichaud, L. 2023. Orogenic and intrusion-related gold deposits of the Michipicoten and Mishibishu greenstone belts in the Wawa region, with an emphasis on their structural timing and setting: A geological guidebook; Geological Association of Canada Mineralogical Association of Canada–Society for Geology Applied to Mineral Deposits, Joint Annual Meeting, Sudbury, Ontario, May 25–27, 2023, Field Trip FT10, Ontario Geological Survey, Open File Report 6398.
https://prd-0420-geoontario-0000-blob-cge0eud7azhvfsf7.z01.azurefd.net/lrc-geology-documents/publication/OFR6398/ofr6398.pdf

Dr. Stéphane Perrouty examining rotated clasts in metaconglomeratic rock in the Michipicoten Greenstone Belt, June 2024. Source: Lianna Vice.

Anticipated Outcomes

- Supracrustal assemblage map of the northeastern Michipicoten greenstone belt, comparing it to adjacent greenstone belts
- Identification of meta-turbidite basin with southern contact bounded by a major deformation zone (Easey Lake DZ)
- Observation of localized conglomeratic horizons within Easey Lake DZ
- Identification of meta-volcano-sedimentary assemblage in Dolson Township bounded by iron formations and gneiss, investigating if it is possibly equivalent to Hawk Assemblage

Implications

The Michipicoten greenstone belt is in a strategic location within a moderately endowed, currently producing greenstone belt. The Easey Lake deformation zone is a possible analogue to the Porcupine-Destor deformation zone as defined by the presence of meta-turbidites north of it, polymictic meta-conglomerates within it and several nearby gold occurrences. This project complements the thematic work on the western extent of the Porcupine-Destor deformation zone. A thorough investigation of supracrustal assemblages and tectonic settings within the Michipicoten greenstone belt will provide insight into the tectonic processes responsible for its growth and further insight into the processes driving the evolution of the Superior craton.

Outcrop on the shore of Dog Lake in the Northeast Michipicoten Greenstone Belt, Manitou Mountain visible in the distance, July 2024. Source: Lianna Vice.

Highlights

- Published Summary of Fieldwork 2023
- Presented talk at GACMAC 2023
- Published guidebook for field trip in collaboration with Chong Ma, Bruno Lafrance, Carl Nagy and others
- Student completed PhD Comprehensive examinations Fall 2023
- Presented at the 2024 Metal Earth Partners meeting in Toronto
- Presented poster at PDAC

VIEW OR DOWNLOAD

Vice, L. E. D., Perrouty, S., & Pelletier, S. G. (2023). Preliminary geology of Riggs and Glasgow townships, Michipicoten greenstone belt, northeastern Ontario. In Ontario Geological Survey (Ed.), Summary of Field Work and Other Activities, 2023 (Open File Report 6405, p. 78). Ontario Geological Survey. www.geologyontario.mines.gov.on.ca/publication/OFR6405.06

VIEW OR DOWNLOAD

Vice, L., Perrouty, S., Robichaud, L., & Walker, J. (2023). Reassessing the supracrustal architecture of the eastern Michipicoten Greenstone Belt, Southern Superior Province, Ontario. In GAC-MAC-SGA 2023 Conference Proceedings (pp. 160). Geological Association of Canada, Mineralogical Association of Canada, and Society for Geology Applied to Mineral Deposits. https://journals.lib.unb.ca/index.php/GC/issue/view/2355/59

Superior Cr-Ni-Cu-PGE Thematic Project

Dr. C. Michael Lesher, Laurentian University

Progress

PhD candidate Klaus Kuster is currently working on finalizing his project titled "Petrogenesis and Metallogenesis of Polymetallic Cr-Ni-Cu-PGE Systems in Superior Province, Canada." This project is also supported by the TGI-6 Program of the Geological Survey of Canada and co-supervised by Dr. Michel Houlé.

The project comprises three components that will integrate the three papers necessary for the completion of this project. They are as follows:

1) A study on the mass-balance problem and the physical-chemical conditions (P-T-X-fO2) for the formation of thick chromite deposits in ultramafic systems
2) A compilation on the distribution and chemical composition of komatiitic rocks across the Superior Province, as they relate to the Cr contents of the parental magmas (and therefore fertility)
3) A study of the potential genetic links between chromite and sulfide mineralization within the same ore systems using type examples in the Superior Province: Shebandowan ON, Ring of Fire ON, Lac des Montagnes QC).

During the period of April 1, 2023, to March 31, 2024, the following work was completed:

- 243 samples analyzed for major and trace elements by ICP-AES and ICP-MS
- 78 samples analyzed for full PGEs (Ir, Os, Pd, Pt, Rh, Ru) + Au by NiS fire-assay ICP-MS
- Chromites in 42 samples (576 spots) analyzed for major and minor elements by EPMA WD-XRES
- Chromites in 20 samples (335 spots) analyzed for trace elements by LA-CIP-MS

WATCH NOW!
Klaus Kuster - *Petrogenesis and Metallogenesis of Co-associated Cr and Ni-Cu-(PGE) mineralization in the Superior Province*

Klaus Kuster mapping the Lac-des-Montagnes ultramafic intrusion, Nemiscau area, James Bay, Quebec.

- Fe-Ni-Cu-Co sulfides in 12 samples (376 spots) analyzed for major and minor elements by EPMA WD-XRES
- Olivines and pyroxenes in 11 samples (174 spots) analyzed for major and minor elements by EPMA WD-XRES
- 28 additional thin sections were prepared and examined to supplement previous petrographic work, adding up to 330 thin sections
- 2,500 additional samples were added to the geochemical database, which now includes 14,000 samples. Interpretation and experimenting with data discrimination (k-means clustering and Principal Component Analysis) is ongoing.
- Re-compilation of experiments used to calibrate the phase equilibria modelling software MELTS and COMAGMAT databases containing only chromite on the liquidus and addition of subsequent crystallizing phase in each experiment, including P-T-X-fO2 conditions, was done. Interpretation is ongoing.

Future Work

- Future work on this PhD project will concentrate on finalizing the remaining steps on all aspects of this work within the context of the geochemical database to begin writing the three manuscripts to be submitted to peer-reviewed journals.

The remaining steps are:

- Interpretation of chromite saturation mechanisms in Chr-Ol systems, and the effects of chromite in sulfide solubility.
- Finish interpreting and discriminate the whole-rock data with the use of k-means clustering and principal component analysis. Prepare the manuscript on the geochemistry of komatiitic rocks in the Superior Province and prepare and organize data in order to publish a GSC open file report with the compilation results.
- Interpretation of the remaining geochemical and mineralogical analytical data (including PGE, EPMA, and LA-ICP-MS) together with petrography and whole-rock geochemistry data.
- Incorporate these results into the database and prepare a manuscript on the petrogenesis and metallogenesis of co-associated chromite and sulfide systems using type examples of the Shebandowan, Ring of Fire and Lac des Montagnes komatiitic intrusions.

Anticipated Outcomes

- Better understanding of the controls on why some mafic-ultramafic magmatic systems contain only Ni-Cu-PGE mineralization (e.g., Abitibi Belt, Ontario-Québec; Yilgarn Block, Western Australia; Cape Smith Belt, New Québec; Thompson Nickel Belt, Manitoba), some contain only Cr mineralization (e.g., Inyala and Railway

Klaus Kuster presenting his research at the Metal Earth scientific meeting in March 2024.

laus Kuster logging core in the Nisk deposit in Nemiscau area, James Bay, Quebec.

Klaus Kuster on his way to conduct field work

Block, Zimbabwe; Ipueira-Medrado, Brazil; Kemi, Finland; Sukinda-Nuasahi, India; most parts of the Stillwater Complex, Montana; most parts of the Bushveld Complex, South Africa), and only a few systems (thus far) contain both significant Cr and significant Ni-Cu-PGE (McFaulds Lake and Shebandowan areas, Ontario; Uitkomst, South Africa; some parts of the Stillwater and Bushveld Complexes)

- Better understanding of the controls on the formation of Cr mineralization in komatiitic magmas and the influence of magma composition (komatiite vs komatiitic basalt vs basalt) and relationship (if any) to particular facies of iron formation

Implications

This work will benefit the mineral industry by developing an exploration model for deposits containing Cr and Ni-Cu-PGE. The model will be used immediately in the McFaulds Lake Greenstone Belt (Ring of Fire area) of northern Ontario but will also apply to the rest of the Superior Province and worldwide.

There is a recently discovered and significant difference in the endowment of the critical metals Cr and Ni (and associated Co) in the Superior Province. In terms of Cr, Bird River – Uchi – Oxford-Stull – La Grande – Eastmain [BUOGE] superdomain >> Shebandowan Belt >> Abitibi Belt. In terms of Ni, Abitibi (albeit dispersed) >> Shebandowan (more concentrated) ~ McFaulds Lake part of the BUOGE superdomain >> other parts of the BUOGE superdomain. Understanding the differences between more- and less-mineralized terranes is a fundamental goal of Metal Earth.

VIEW OR DOWNLOAD

Kuster, K., Lesher, C. M., & Houlé, M. (2023). Spatial and genetic relationships of co-associated Cr and Ni-Cu-(PGE) mineralization in the Esker Intrusive Complex, McFaulds Lake Greenstone Belt, Superior Province, Canada. In GAC-MAC-SGA 2023 Conference Proceedings (p. 167). Geological Association of Canada, Mineralogical Association of Canada, and Society for Geology Applied to Mineral Deposits.
https://journals.lib.unb.ca/index.php/GC/issue/view/2355/9

Highlights

Kuster presented his research, Magmatic Ore Deposits Associated with Mafic-Ultramafic Systems, at a technical session at the GAC-MAC-SGA Sudbury 2023 conference in May. He also presented a poster at the PDAC-SEG Student Minerals Colloquium and the Metal Earth Scientific Meetings in March 2023.

Genesis and Localization of Ni-Cu-(PGE) Mineralization in the North Range of the Sudbury Structure, Ontario, Canada

Dr. C. Michael Lesher, Laurentian University

PhD student Dustin Peters (top row, fourth from left) coordinated Field Trip 3 at GAC-MAC-SGA Sudbury 2023, which examined the Sudbury Impact Structure.

Progress

PhD candidate Dustin Peters is currently working on finalizing his project titled "Genesis and Localization of Ni-Cu-(PGE) Mineralization in the North Range of the Sudbury Structure, Ontario, Canada." This project is supported financially by the Natural Sciences and Engineering Research Council of Canada (NSERC) and Vale Canada Ltd. Collaborative Research and Development Grant CRDPJ-530035 to Michael Lesher, with administrative/logistical support by MERC-Metal Earth.

WATCH NOW!
Mike Lesher - *Magmatic Cr-Ni-Cu-PGE Thematic Projects*

The project comprises three components that will integrate the three papers necessary for the completion of this project. They are as follows:

1. Geochemical variations of the Main Mass along the North Range of the Sudbury Igneous Complex – Implications for the differentiation of impact melt sheets
2. Genesis of Hf-Nd-Pb-S isotopic variations in the Sudbury Igneous Complex – Implications for initial melt sheet characteristics and the origin of Ni-Cu-(PGE) sulfide ore formation
3. Genesis and characterization of Footwall Breccia at the base of the Sudbury Igneous Complex

During the period of April 1, 2023, to March 31, 2024, the following work was completed:

- Core logging of 5 representative contact breccia sequences across the North Range. Sampling of Main Mass Felsic Norite and Mafic Norite, Sublayer Norite, Footwall Breccia, and several footwall rock lithologies (106 samples total)
- Mapping of ~10 km2 area of Levack Gneiss Complex north of Levack Mine. Collection of 20 representative samples for whole-rock geochemical analysis and potential Hf-Nd-Pb isotope analysis
- 91 samples analyzed for major and trace elements by ICP-AES and ICP-MS
- 14 representative Main Mass samples and 4 representative Levack Gneiss Complex samples analyzed for Hf-Nd-Pb isotopes by whole-rock MC-ICP-MS
- Compilation of Hf-Nd-Pb-S isotopic database for the Sudbury Igneous Complex and surrounding footwall rock lithologies (>1500 samples). Data compilation is ongoing.
- Pearce-Element-Ratio analysis of Main Mass whole-rock geochemical database (>2000 samples) to better define the crystallization sequence of impact melt sheet across the North Range
- Testing of new XRF to identify optimal scanning parameters for characterization of contact breccia samples (mainly Sublayer Norite and Footwall Breccia)
- Peters prepared and led two one-day field trips across the Sudbury Structure as part of the 2023 Sudbury GAC-MAC-SGA conference
- Peters also presented his research at the 2023 Sudbury GAC-MAC-SGA conference and at the 2024 International Ni-Cu Symposium in Thunder Bay

VIEW OR DOWNLOAD
Peters, D., Lesher, C. M., & Pattison, E. F. (2023). Petrological and geochemical variations in the main mass along the North Range of the Sudbury Igneous Complex: Insights into initial melt sheet characteristics and its differentiation history. In GAC-MAC-SGA 2023 Conference Proceedings (p. 96). Geological Association of Canada, Mineralogical Association of Canada, and Society for Geology Applied to Mineral Deposits. https://journals.lib.unb.ca/index.php/GC/issue/view/2355/59

VIEW OR DOWNLOAD
Peters, D., Lesher, C. M., & Pattison, E. F. (2023). Impact melt homogeneity in the Sudbury Igneous Complex and relevance for Ni–Cu–(PGE) ore formation. In GAC-MAC-SGA 2023 Conference Proceedings (p. 130). Geological Association of Canada, Mineralogical Association of Canada, and Society for Geology Applied to Mineral Deposits. https://journals.lib.unb.ca/index.php/GC/issue/view/2355/59

Future Work

Peters will finalize the remaining steps and begin writing three manuscripts to be submitted to peer-reviewed journals.

Remaining steps:

- Finalize the interpretation and analysis of the Main Mass whole-rock geochemical database and incorporate MELTS modelling. Prepare a manuscript on the geochemical variations of the Main Mass along the North Range of the Sudbury Igneous Complex and their implications for the differentiation history of impact melt sheets.
- Finish isotope database compilation and data interpretation. Perform isotope mass-balance calculations and prepare a manuscript on Hf-Nd-Pb-S isotopic variations in the Sudbury Igneous Complex and their implications for initial melt sheet characteristics and the origin and formation of Ni-Cu-(PGE) sulfide ores.
- Scanning of representative contact breccia samples (polished slabs and/or polished thin sections) by μXRF to identify unique chemical and textural parameters/characteristics. Prepare manuscript on Footwall Breccia characteristics.

Anticipated Outcomes

1. A better understanding of the initial characteristics and differentiation/crystallization history of the Sudbury impact melt sheet and large terrestrial impact melt sheets in general. The Ni-Cu-(PGE) sulfide ores associated with the Sudbury Igneous Complex formed as a direct result of the impact event, so better understanding the processes involved in the impact melt formation and differentiation will also help to better

understand the origin and formation of the sulfide ores. This will ultimately aid future exploration efforts at Sudbury and help to assess the mineralization potential of other terrestrial impact sites.

2. A second major goal of the project is to develop a useful breccia classification scheme (specifically for Sublayer Norite and Footwall Breccia) that can be used by mining companies to improve core logging routines and to more accurately characterize the various ore-hosting breccias and to better assess the mineralization potential in future exploration campaigns.

Implications

The goals of the Sudbury thematic components of Metal Earth were to 1) characterize the internal and footwall stratigraphy of the eastern side of the Sudbury Structure seismically (R. Nielsen) and 2) better constrain the origin of exotic ultramafic inclusions in mineralized Sublayer Norite and Inclusion-Bearing Quartz Diorite, and their implications for the genesis of the Sudbury Igneous Complex (Y. Wang PhD project). This work expands and complements the latter project by adding additional constraints on the crystallization history of the Main Mass (impact melt) and the formation of underlying mineralized Footwall Breccia. Although the Sudbury Structure was generated by an extraterrestrial bolide impact, the ore-forming process (high-T thermomechanical erosion) at the base of the impact melt sheet appears to have been very similar to that in the dynamic magma conduits (channelized lava flows/sills/dikes) that host other Ni-Cu-PGE deposits. Better-mineralized systems are characterized by high temperatures, high fluxes/amounts of magma, and external sources of S (all deposits) and metals (Sudbury and some other deposits), whereas less-mineralized systems are characterized by lower temperatures, lower fluxes/amounts of magma, and the paucity of external S sources.

VIEW OR DOWNLOAD

Wang, Y., Lesher, C. M., Lightfoot, P. C., Pattison, E. F., & Golightly, J. P. (2023). Genesis of sublayer, footwall breccia, and associated Ni-Cu-platinum group element mineralization in the Sudbury Igneous Complex. Economic Geology, 117(8), 1791–1807. https://doi.org/10.5382/econgeo.4948

Highlights

Publication of field guide for 2023 Sudbury GAC-MAC-SGA conference by Ontario Geological Survey as Open File Report: Peters, D., Baurier Aymat, S., Péloquin, A.S., Gordon, C.A. and Lesher, C.M. 2023. Geological traverse of the Sudbury impact structure and evolution of the impact melt: A geological guidebook; Geological Association of Canada–Mineralogical Association of Canada–Society for Geology Applied to Mineral Deposits, Joint Annual Meeting, Sudbury, Ontario, May 25–27, 2023, Field Trip FT03, Open File Report 6393, 67p.

Presentation of preliminary results at the 2023 Sudbury GAC-MAC-SGA conference:

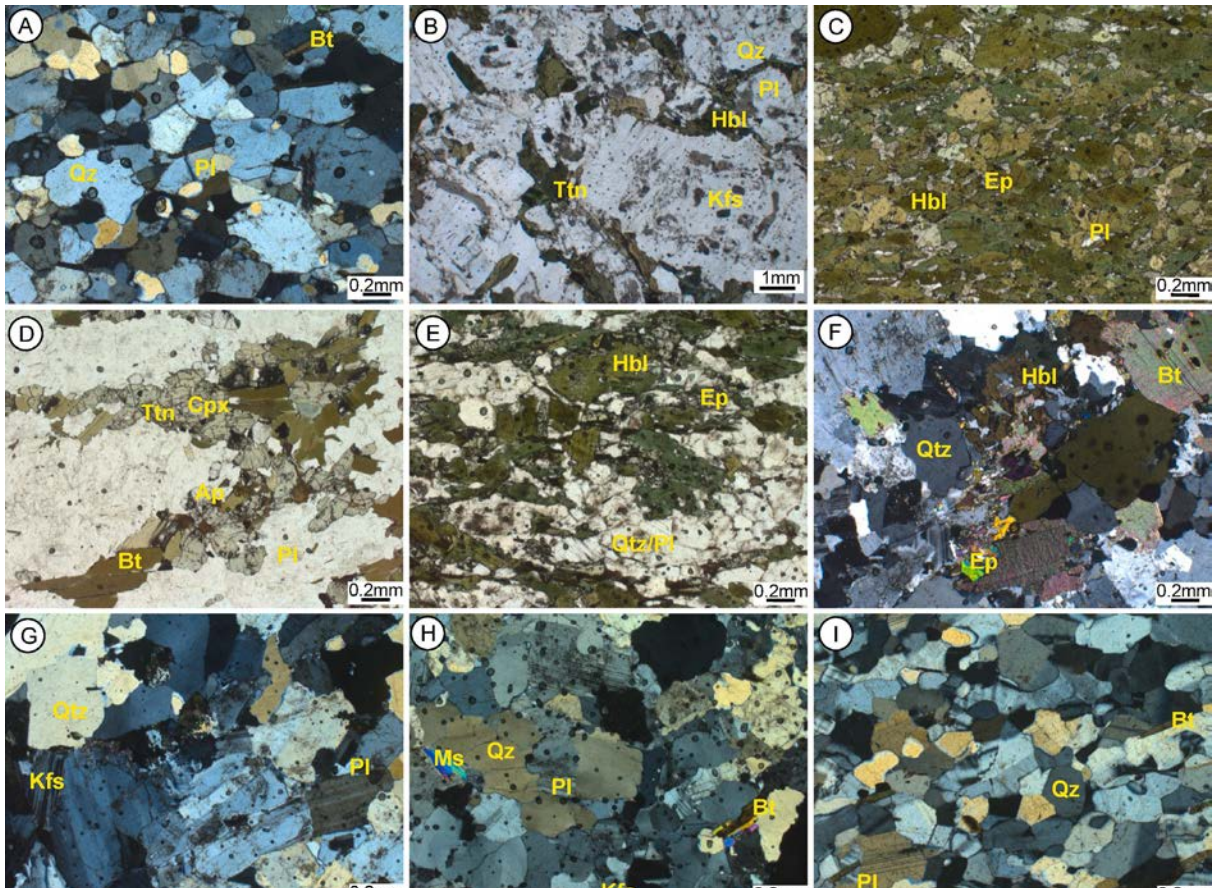
- Peters, D., Lesher, C.M., Pattison, E. 2023. Impact melt homogeneity in the Sudbury Igneous Complex and its relevance for Ni-Cu-(PGE) ore formation; Geological Association of Canada–Mineralogical Association of Canada–Society for Geology Applied to Mineral Deposits, Joint Annual Meeting, Sudbury, Ontario, May 25–27, 2023, Conference abstract and talk
- Peters, D., Lesher, C.M., Pattison, E. 2023. Petrological and geochemical variations in the Main Mass along the North Range of the Sudbury Igneous Complex – insights into initial melt sheet characteristics and its differentiation history; Geological Association of Canada–Mineralogical Association of Canada–Society for Geology Applied to Mineral Deposits, Joint Annual Meeting, Sudbury, Ontario, May 25–27, 2023, Conference abstract and talk

Presentation of preliminary results at the 2024 International Nickel-Copper Symposium in Thunder Bay:

- Peters, D., Lesher, C.M., Pattison, E. 2024. Hf-Nd-Pb-S isotopic evidence for variable impact devolatilization and its relevance for Ni-Cu-(PGE) sulfide ore formation in the Sudbury Igneous Complex; International Ni-Cu Symposium, Thunder Bay, Ontario, August 05–08, 2024, Conference abstract and talk
- Received award for best student presentation

Gold Fluid Window

Dr. Carl Guilmette, Université Laval; and Dr. Douglas Tinkham, Laurentian University



Microphotographs in thin section. a) Tonalite layer of the Opasatica gneiss (#018); b) Phenocrystic granodiorite (Rémigny batholith, #012); c-d-e) amphibolitized gabbro, monzonite, and quartz-monzonite from the Lac Fréchette batholith (#027, #031, and #023 respectively); f) Quartz-monzonite, Lac Fournière pluton (#032); g) Granite, Lac Héva pluton (#047); h-i) Muscovite-biotite- and biotite granite, Decelles batholith (#01 and #07). Abbreviations follow Whitney and Evans, 2010. Source: Godet et al, 2023. Precambrian Research 396.

Progress

This reporting period summarizes the fourth year of the Gold Fluid Window Metal Earth thematic project under the lead of Carl Guilmette and Doug Tinkham. Our research over the year 2023 was primarily performed by five current group members and one previous group member. From this group, Dr. Christiaan Laureijs is a new Research Associate; Dr. Antoine Godet, a former Research Associate; Dr. Marine Jouvent, postdoctoral fellow; and graduate students Adrian Rehm (PhD), Diogo Ribeiro (PhD) and Jeremie Darveau (MSc); and additional collaborators. Besides further data acquisition and fieldwork, the reporting period was dedicated to developing analytical methods that introduced the capability to do in-situ Rb-Sr dating at Université Laval. Through this, our lab is now also well-equipped and ready to acquire high-quality in-situ geochronological data.

Fieldwork:

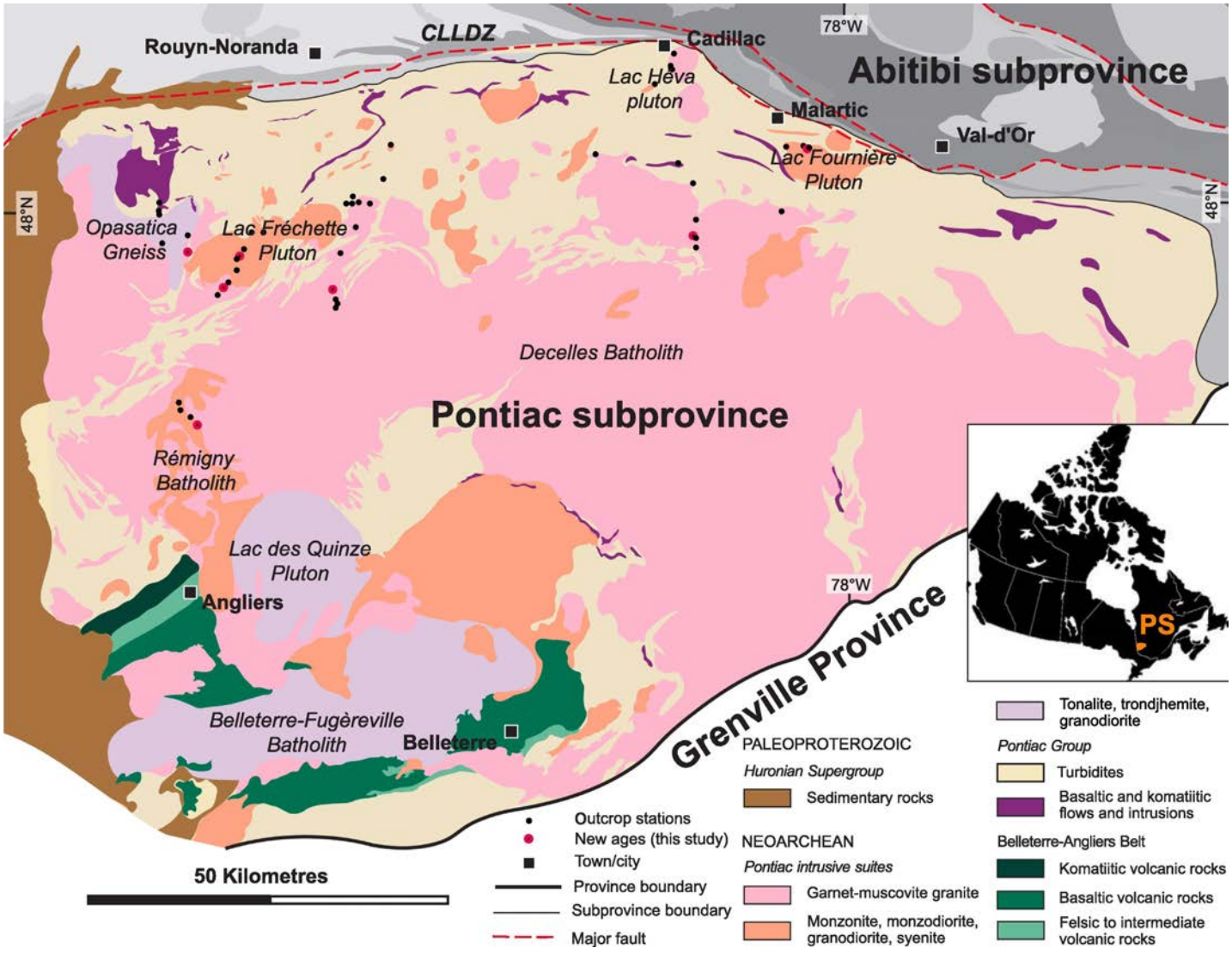
The fourth fieldwork season (Summer 2023) of this project was conducted in Grenville Tectonic Front Zone (GTFZ), Parc de la Vérendyre (Southeast of Val d'Or), Abitibi, Québec, during three weeks in the months of July to August. Key outcrops (157) were described, 156 rock samples were collected, and structural measurements were taken.

WATCH NOW!
Gold Fluid Window - *Updates*

Lab work:

Numerous samples collected in the field in the summer of 2023 were cut, and thin sections were prepared for detailed petrographic description. The lab work can be subdivided into multiple activities and thus different datasets:

- Quantitative elemental mapping on thin sections was performed using in-situ, non-destructive (micro XRF) and destructive (laser ablation (LA) ICP-MS and Electron microprobe at ULaval). From these, major element distribution was investigated by micro XRF and EMPA, and trace elements of single grains and selected textural domains were selected by LA-ICPMS.
- Sulfur stable isotope analysis was performed on whole rock samples (40) by Dr. Guillaume Barré at the Institute de Physique du Globe de Paris (Paris, France) for Diogo Ribeiro. In-situ sulfur isotope analysis was performed on sulfides (27 samples), titanite, rutile and ilmenite (21 samples) at the Université Laval under the lead of Diogo Ribeiro, supervised by Guillaume Barré.
- In terms of geochronology, in-situ Lu-Hf dates of garnet have been produced by our group members (Christiaan Laureijs) and collaborators (Kyle Larson, UBC Okanagan in Kelowna) in the Fipke Laboratory of



Geological map of the northern Pontiac subprovince after the SIGEOM open-source database. Black points indicate the location of the new samples presented in this study. PS refers to Pontiac Subprovince on the map inset. Source: Godet, A., Guilmette, C., Marsh, J. H., Rottier, B., Tinkham, D., Siles Malta, I., Rehm, A., Jørgensen, T. R. C., Hamilton, M. A., Ribeiro, D., & Beaudoin, G. (2023). Origin, nature, and evolution of the northern Pontiac subprovince, Canada: Insights from the intrusive record. Precambrian Research, 396, 107169. https://doi.org/10.1016/j.precamres.2023.107169

Trace Element Research (FiLTER) using a tandem quadrupole ICP-QQQ-MS connected to a laser ablation system. Four biotite samples have also been dated by in-situ Rb-Sr in Kelowna by Christiaan Laureijs, supervised and trained by Drs. Kyle Larson and Mark Button. Subsequently, in November and December 2023, our group successfully produced the first in-situ Rb-Sr biotite age data at ULaval (currently 12 dated samples in total).

Modelling:

In addition to analytical work, phase equilibria modelling was performed on selected samples from the Pontiac and Quetico subprovinces to quantify P-T-t-X paths and fluid dehydration reactions performed by Adrian Rehm and Marine Jouvent.

Dissemination:

Interpretations of the outcomes of the activities mentioned above were presented at the 2023 GAC-MAC Conference in Sudbury by Carl Guilmette, Diogo Ribeiro and Adrian Rehm. Diogo Ribeiro also attended the SEG Biannual Meeting in Zurich. At the 2023 Québec Mines+Energie conference our group was well represented by poster presentations from Antoine Godet, Marine Jouvent, Christiaan Laureijs, Diogo Ribeiro and Jeremie Darveau. Here, preliminary results from the field and geochemical datasets of new samples and method development were presented and discussed as completed and planned research aims. Carl Guilmette gave a project overview talk at the Metal Earth Partners Meeting in Quebec City in October. Then, the whole group presented their results at the March 2024 Annual Meeting in Toronto.

Future Work

The general objectives set for the next period/year are to complement the existing sample collection with key samples that are needed for regional and craton-scale studies in tectonometamorphism, plutonism and fluid production. Hence, we are focusing on acquiring LA-ICPMS analyses on datable accessory phases from metasedimentary, metabasite and granitoid samples from the Abitibi and Pontiac subprovinces and fill the gaps in the Grenville Tectonic Front Zone to constrain the timing of metamorphism and igneous crystallization of selected bodies.

The group is planning to conduct detailed fieldwork on the tectonic structures in the Pontiac. The goal will be to better understand and constrain the role of these structures related to tectonic activity and fluid movement. To investigate this, we plan to map key structures and take oriented samples in the field. After detailed petrography, we plan to apply various in-situ geochemical and crystallographic analytical methods such as EBSD, SEM imaging, micro-XRF, EMPA and LA-ICPMS to quantify major and trace elements. Further, we plan to apply various low-temperature in-situ geochronometers for hydrous phases such as Rb-Sr in biotite with potentially K-Ca in hornblende for brittle fluid conductive structures and high-temperature geochronometers such as Rb-Sr in feldspar and Lu-Hf in garnet and U-Pb zircon to date ductile deformation in metamorphic rocks that involves partial melting. Detailed fabric analysis of oriented samples will provide constraints on shear sense, shear temperature and involved mechanisms. A new post-doc, Taylor Ducharme, will join the team in June to lead this project.

Further, samples for in-situ zircon and monazite U-Pb ages from the GFTZ have been submitted to Dr. Kirk Ross (Laurentian University, Sudbury, Canada). Garnet fractions from the La Ronde mine have been submitted to Dr. Matthijs Smit (UBC, Vancouver) for high-precision Lu-Hf dating by ID MC ICPMS.

Regarding modelling work, we continue to pursue phase equilibria modelling to quantify the P-T-t paths with existing and new samples from the GFTZ and the La Ronde mine.

We are also in the process of initiating and publishing several research papers for the coming year. These pieces of research will include new geochronological datasets, development in-situ radiometric dating, and new trace element and isotopic data, which will then be synthesized into regional studies of metamorphism in the Grenville Front Tectonic Zone and in the Pontiac, Abitibi, Quetico, and Opinaca subprovinces. These studies will also be complemented by the modelling of metamorphic conditions (P-T-t-x-D) and fluid-generating processes to understand the origin of mineralizing fluids.

VIEW OR DOWNLOAD

Godet, A., Guilmette, C., Marsh, J. H., Rottier, B., Tinkham, D., Siles Malta, I., Rehm, A., Jørgensen, T. R. C., Hamilton, M. A., Ribeiro, D., & Beaudoin, G. (2023). Origin, nature, and evolution of the northern Pontiac subprovince, Canada: Insights from the intrusive record. Precambrian Research, 396, 107169
https://doi.org/10.1016/j.precamres.2023.107169

Anticipated Outcomes

Our group will generate a new understanding of the metamorphic and tectono-thermal evolution of the Quetico, Pontiac and Opinaca basins, as well as the Abitibi greenstone belt and the bounding, deeper exposure of those subprovinces in the Grenville Front Tectonic Zone. These areas are considered key litho-tectonic domains that record the final stages of the assembly of the Superior Craton, during which most orogenic gold deposits were formed. The project will provide quantitative data that advances our knowledge of the pressure, temperature, time, rock and fluid chemistry and deformation history of the belts. This fundamental data set will contribute to our understanding of craton disaggregation and assembly in the Neoarchean and provide a precise geodynamic framework to understand the role of regional fluid generation and circulation in gold mineralization.

Implications

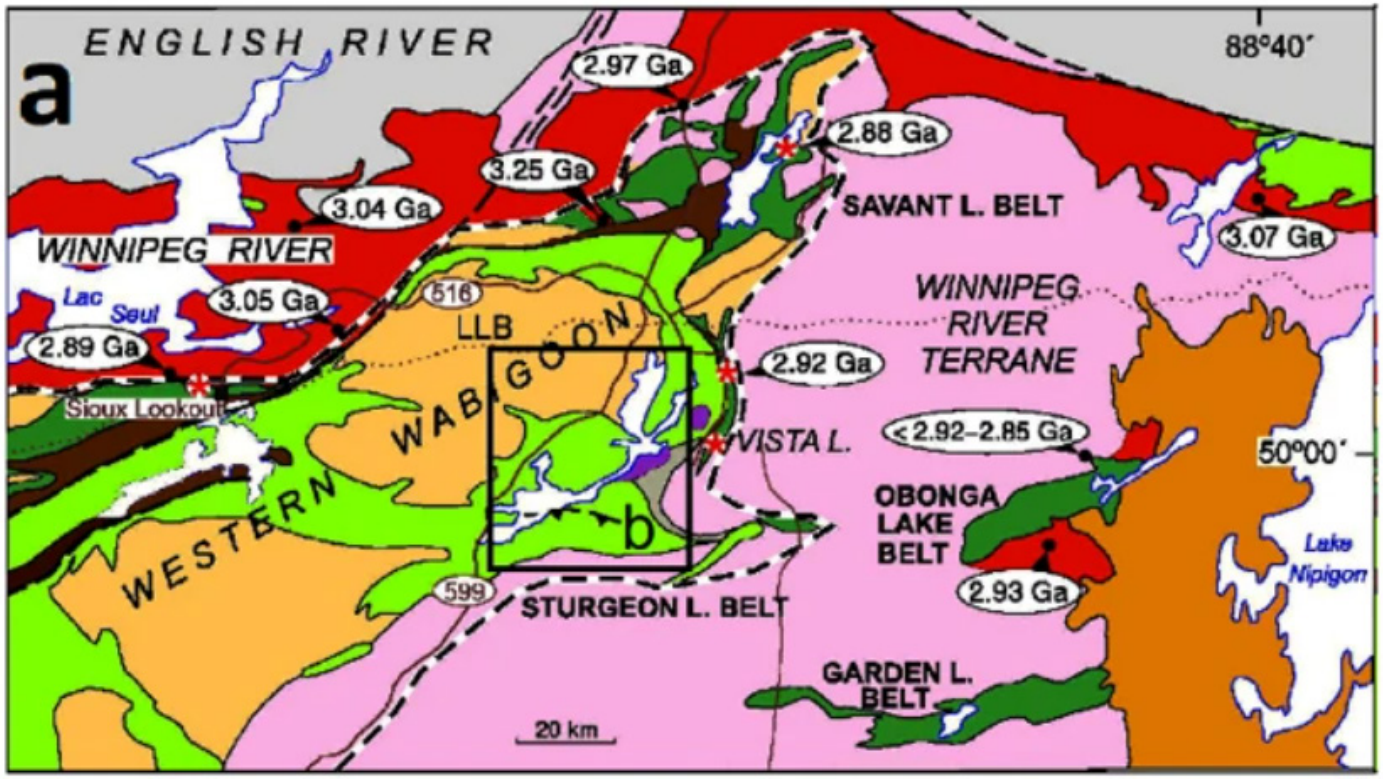
The project is contributing to the goals of Metal Earth by addressing fundamental knowledge gaps on the potential relationship between metamorphic processes and associated fluid generation on gold endowment in the Superior Province. This research provides a new perspective on the metamorphic evolution of key litho-tectonic domains that record the final stages of the assembly of the Superior Craton, a period during which most orogenic gold deposits were formed. The new data tests first, whether the Quetico, Pontiac, Opinaca, and Ashuanipi had similar or differing depositional and tectonic-metamorphic evolutions and second, how this may have affected differential endowment in the neighbouring structures and subprovinces (e.g. CLLFZ in the Abitibi). In sum, the results contribute to the precision of models for craton disaggregation and assembly in the Neoarchean. This provides a more comprehensible geodynamic framework to understand the role of regional fluid generation and circulation in gold mineralization and potentially new fields, isotopes, and chemical indicators for targeting those deposits.

Highlights

- Christiaan Laureijs was appointed in September 2023 to start working on implementing in-situ radiometric dating methods (Rb-Sr and Lu-Hf). These methods will contribute to the timing of (poly)metamorphic history and fluid/rock interaction processes that could relate to the formation of ore deposits.
- Antoine Godet left the group to start a new position as a Research Scientist at Natural Resources Canada in Québec City. However, he was appointed an Adjunct Professor at the Université Laval and still collaborates on projects of the Gold Fluid Window research group.
- Successful fieldwork was conducted in the Grenville Front Tectonic Zone, near the Pontiac and Abitibi subprovinces.
- First in-situ radiometric Rb-Sr isochron (biotite) produced at the Université Laval in December 2023.
- We congratulate Diogo Ribeiro on winning the Best Student Oral Presentation award at the Biannual SGA 2023, held in Zurich, Switzerland.
- Further, the expertise of our group was demanded for numerous reviews of manuscripts and supervision of graduate students.

Data Analytics

Dr. Jeff Harris, Laurentian University



Regional setting of the Winnipeg River and western Wabigoon terranes, western superior province. Source: Parsa, M., Harris, J., & Sherlock, R. (2023). Improving mineral prospectivity model generalization: An example from orogenic gold mineralization of the Sturgeon Lake Transect, Ontario, Canada. Mathematical Geosciences, 55(5), 943–961. https://doi.org/10.1007/s11004-022-10038-6

Progress

- 2 papers submitted; to *Ore Geology Reviews* and *Economic Geology*
- 1 MSc thesis paper submitted to *Ore Geology Reviews*
- 1 new project initiated: Compilation, correction and analysis of Metal Earth geochemical databases to analyze the difference between geochemistry of the Abitibi and Wabigoon subprovinces
- Recruited Ahmad Reza Mokhtari, a research scientist from Iran, to work on a new geochemical project and other data analytics projects
- Ongoing production of 3D Leapfrog models for each Metal Earth transect
- Uploading of all Metal Earth data for delivery to public and industry

WATCH NOW!
Jeff Harris - *A study of faults using the Random Forest machine learning algorithm, presented at the Metal Earth scientific meetings, March 2023.*

Future Work

- Initiate a study of the spatial relationship between gold mines and MT conductive zones over the Superior Province
- Continue and finalize the web delivery system
- Continue work on the new geochemical project

Anticipated Outcomes

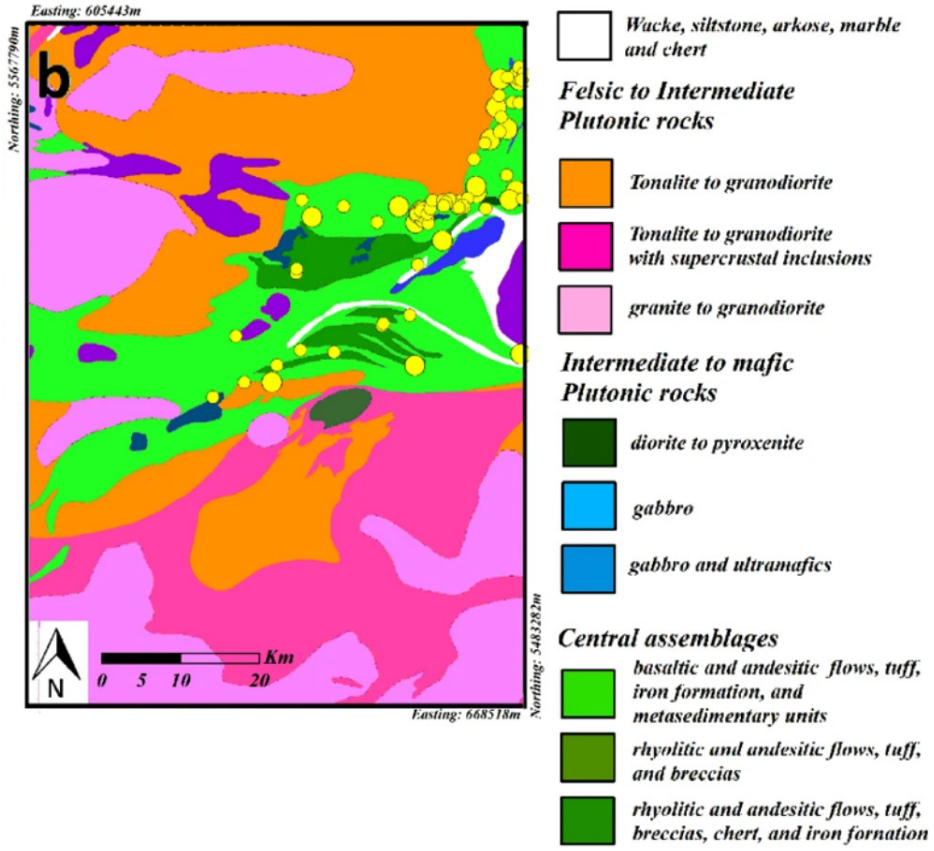
- Three papers in peer-reviewed journals are forthcoming:
  1. Orogenic Gold Mineral Prospectivity Mapping (MPM) of the Geraldton Area, Ontario (Harris et al)
  2. Mineral Prospectivity Mapping (MPM) and differential metal endowment between two greenstone belts in the Canadian Superior craton (Harris et al)
  3. A Comprehensive Analysis of the Geological Features Influencing the Probability of Gold Discovery in the Larder Lake Region Using Advanced Machine Learning Algorithms (Trivedi)

Implications

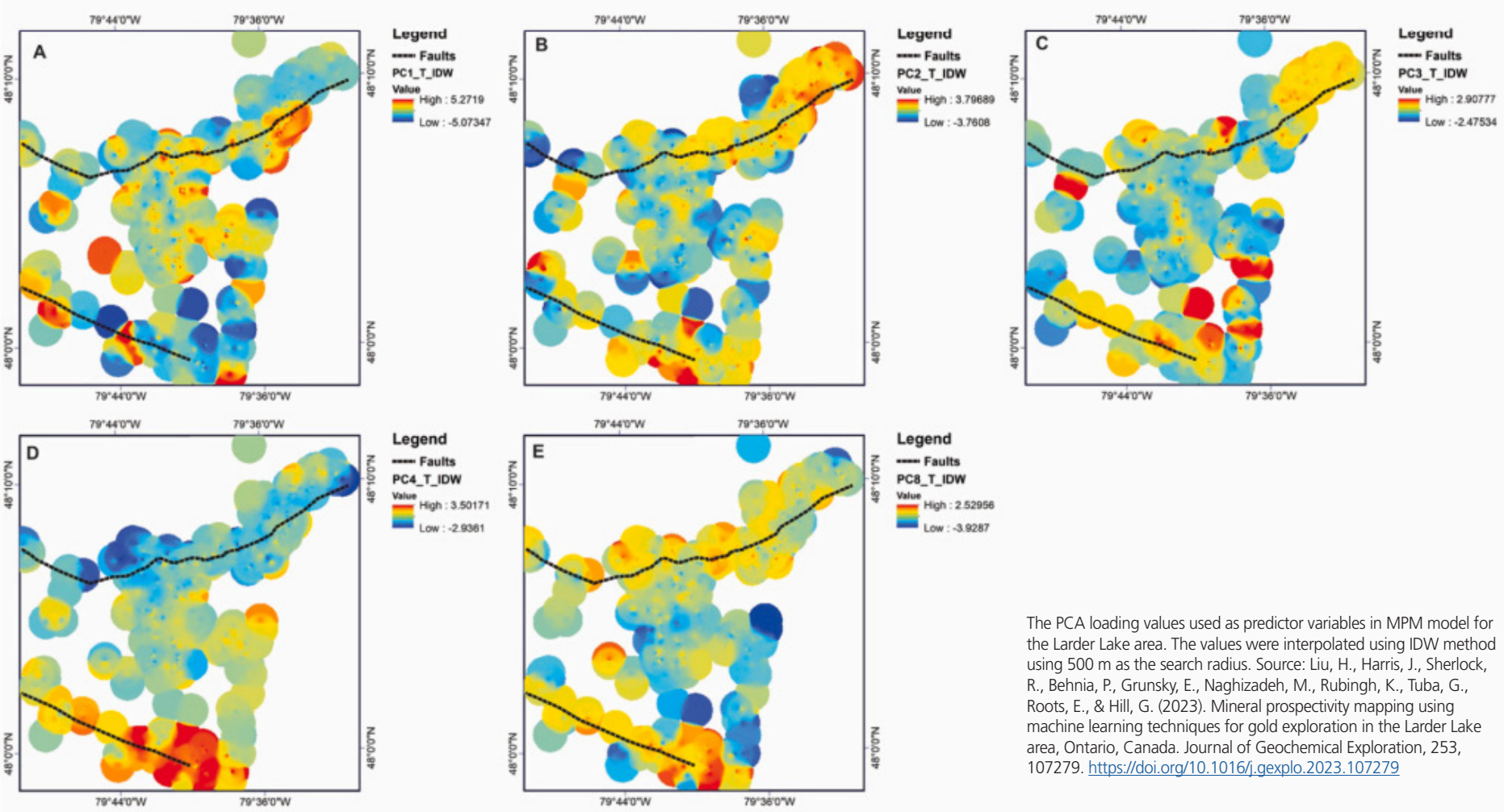
- Provided methodological papers on how to produce Mineral Prospectivity Maps (MPMs) for each Metal Earth transect – this will aid exploration endeavours over all transects
- New paper discussing differences between fertile and non-fertile greenstone belts – this will aid exploration efforts in all transects – this is the main question addressed by the Metal Earth project

VIEW OR DOWNLOAD
Liu, H., Harris, J., Sherlock, R., Behnia, P., Grunsky, E., Naghizadeh, M., Rubingh, K., Tuba, G., Roots, E., & Hill, G. (2023). Mineral prospectivity mapping using machine learning techniques for gold exploration in the Larder Lake area, Ontario, Canada. Journal of Geochemical Exploration, 253, 107279.
https://doi.org/10.1016/j.gexplo.2023.107279

VIEW OR DOWNLOAD
Behnia, P., Harris, J., Sherlock, R., Naghizadeh, M., & Vayavur, R. (2023). Mineral prospectivity mapping for orogenic gold mineralization in the Rainy River area, Wabigoon Subprovince. Minerals, 13(10), 1267.
https://doi.org/10.3390/min13101267



Simplified bedrock map of the study area in the regional setting map on previous page, (modified after Sanborn-Barrie and Skulski 2005). Large and small yellow circles are gold deposits and occurrences, respectively. Source: Parsa, M. et al, 2023. Mathematical Geosciences, 55 (5).



The PCA loading values used as predictor variables in MPM model for the Larder Lake area. The values were interpolated using IDW method using 500 m as the search radius. Source: Liu, H., Harris, J., Sherlock, R., Behnia, P., Grunsky, E., Naghizadeh, M., Rubingh, K., Tuba, G., Roots, E., & Hill, G. (2023). Mineral prospectivity mapping using machine learning techniques for gold exploration in the Larder Lake area, Ontario, Canada. Journal of Geochemical Exploration, 253, 107279. https://doi.org/10.1016/j.gexplo.2023.107279

Highlights

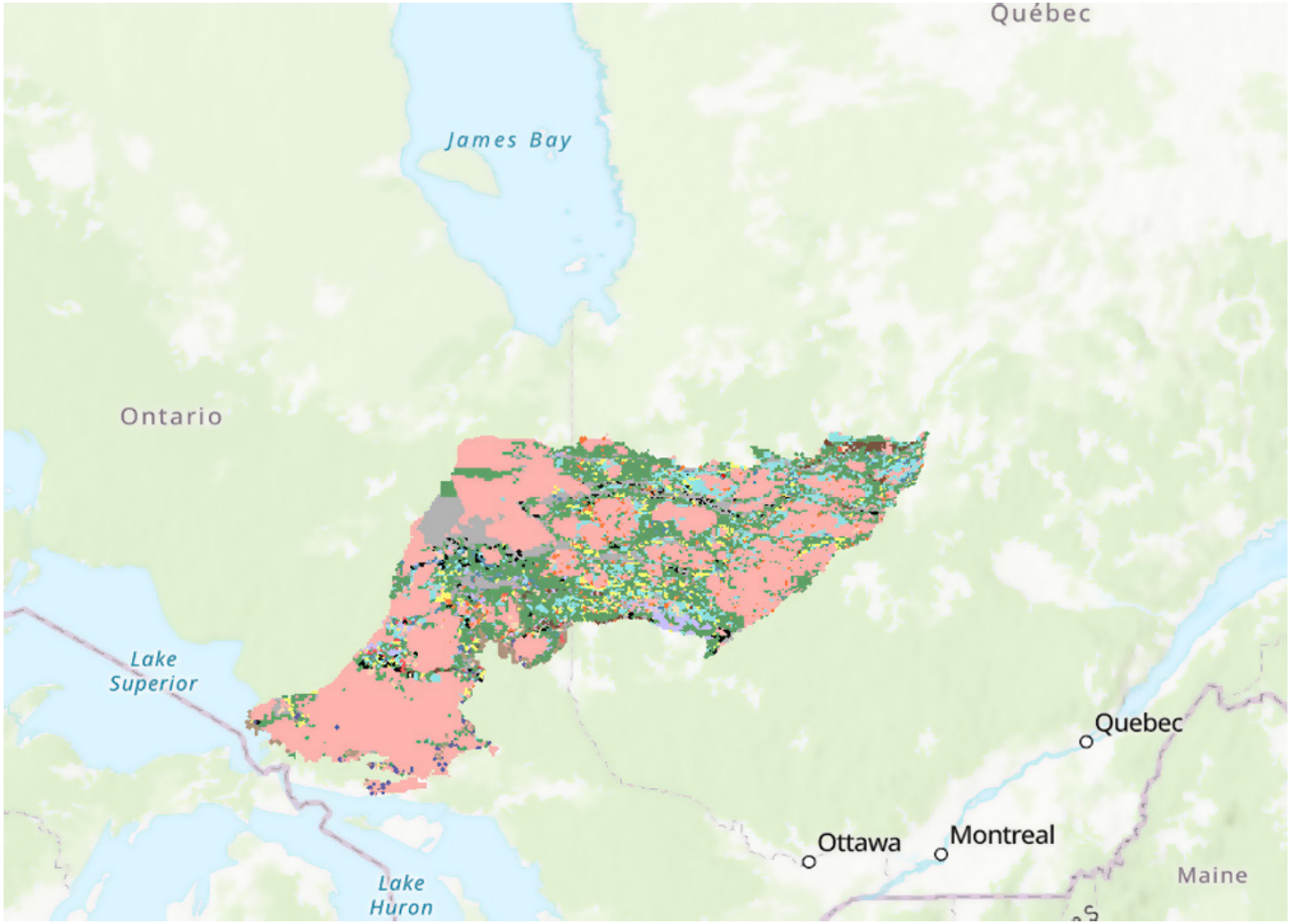
- New paper discussing reasons for differences between well-endowed and less endowed greenstone belts (primary problem to be addressed by Metal Earth Project – offering a breakthrough for mineral exploration in the Superior Province)
- New hire for data analytics project (Mokhtari)
- Mihir Trivedi defended his MSc thesis and submitted a paper on his research to a scientific journal
- Completed a web-based delivery system for release of all Metal Earth geoscience data

VIEW OR DOWNLOAD

Behnia, P, Harris, J., Liu, H., Jørgensen, T. R. C., Naghizadeh, M., & Roots, E. A. (2023). Random forest classification for volcanogenic massive sulfide mineralization in the Rouyn-Noranda Area, Quebec. Ore Geology Reviews, 161, 105612. https://doi.org/10.1016/j.oregeorev.2023.105612

Controls on VMS endowment during the evolution and assembly of Greenstone Belts: Assemblage-level compilation and reconstruction of the Abitibi Greenstone belt

Dr. Taus Jørgensen, Laurentian Universityy



Progress

Preliminary versions of the lithological and assemblage compilations within the Abitibi Greenstone Belt (AGB) were made available to other Metal Earth researchers.

This project has utilized the compilations to quantify geological attributes within the volcanic assemblages of the AGB. These derivative data were used in quantitative analysis to investigate the differential VMS endowment in the AGB and better understand the relationship between major structures and VMS deposits, including Au-rich VMS.

The Metal Earth Abitibi Lithological Compilation (MEALC) is a map product constructed predominantly from compilations and maps produced by the Ontario Geological Survey (OGS) and the Ministère des Ressources naturelles et des Forêts (MRNF). The MEALC has a unified legend that allows for a continuous lithological map across provincial boundaries. The MEALC largely maintains metadata from the reference material to enable users to modify the compilation to serve their needs. Source: https://metalearth.geohub.laurentian.ca/maps/a4d00bd64b-b94466a34ee215df8024f9/explore?location=48.360004%2C-80.002589%2C7.51

Future Work

The preliminary compilations are under internal review with a version provided on the MERC website. Refined versions will be published with a companion paper that utilizes them to interrogate differential VMS endowment in the Abitibi Greenstone Belt and compare them to modern analogues/VMS settings.

Anticipated Outcomes

This work will improve the VMS model, mainly based on deposit-to-district-scale research, as the current model does not address why geologically similar volcanic centres, assemblages within greenstone belts, or greenstone belts have variable VMS endowment.

The differential base and precious metal endowment of assemblages within the Abitibi greenstone belt and between greenstone belts suggest fundamental differences in assemblage-scale tectonic, magmatic, and crust-mantle processes that impact metal endowment during greenstone belt construction. This research will improve our understanding of these fundamental controls on VMS endowment and provide new insights into Archean tectonics and metallogeny.

Implications

The thematic research will address differential VMS endowment at the assemblage to greenstone belt scales through three integrated and complementary projects that will provide a quantitative comparison, using defined geological attributes, of volcanic assemblages in the well but variably VMS-endowed Abitibi greenstone belt, with comparisons to the less endowed greenstone belts. It builds on and compliments Metal Earth's Transect, Craton and Metal Ocean research.

VIEW OR DOWNLOAD
Jørgensen, T. R. C. (2024, October 29). Assessing differential VMS endowment in the Abitibi Greenstone Belt: Insights from the Noranda Camp and Abitibi-wide assemblage and lithological compilations [Short course presentation]. Short Course: New Insights into Crustal-Scale Influences on Gold and Base Metal Endowment in the Archean Superior Province, Laurentian University, Sudbury, Ontario, Canada.https://merc.laurentian.ca/sites/default/files/aemq_explor_2024_sc_trcj_20241029.pdf

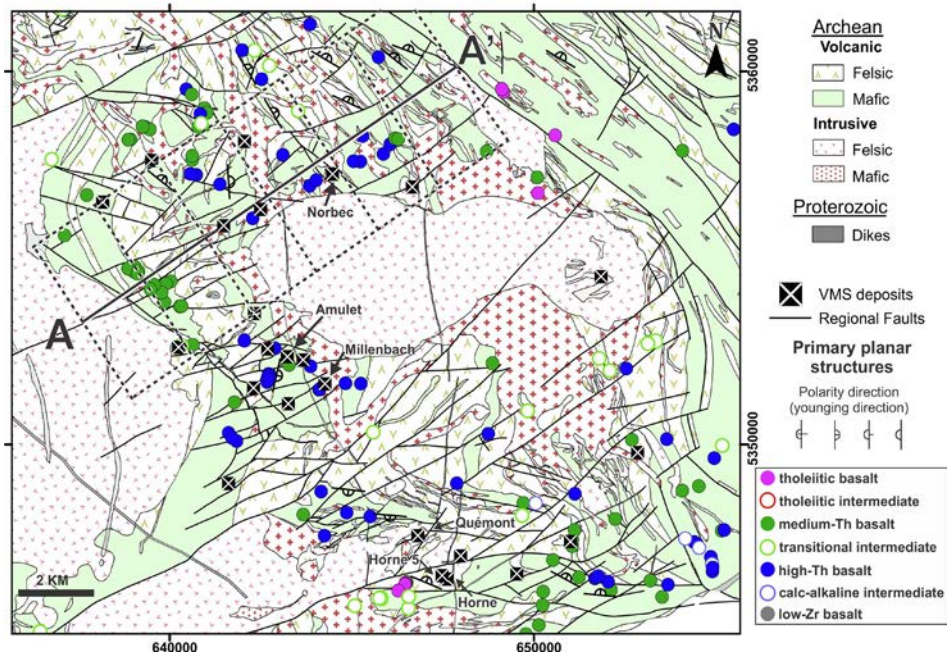
Highlights

- Assemblage-level and lithological compilations of the Abitibi greenstone belt in the provinces of Quebec and Ontario will be useful to companies conducting exploration in these areas. They can serve as a fundamental geological dataset for mineral prospectivity and data analytics research.
- The Metal Earth Abitibi Lithological Compilation (MEALC) is available here: https://metalearth.geohub.laurentian.ca/maps/a4d00bd64b-b94466a34ee215df8024f9/explore?location=48.360004%2C-80.002589%2C7.51

WATCH NOW!
Taus R. C. Jorgensen - *Assemblage-level compilation of the Abitibi Greenstone Belt and its use in assessing differential VMS endowment, Metal Earth scientific meetings, Toronto, March 2024.*

Petrogenetic Evolution of the Abitibi Greenstone Belt

Dr. Pierre Simon-Ross, Institut national de la recherche scientifique



Simplified geological map of the Noranda camp portion of the BRG, showing the geochemical profile A-A' and the distribution of the mafic to intermediate geochemical groups. Geology simplified from SIGEOM (2022). All geochemical data within the dotted rectangle are projected in the central continuous line to observe the geochemical variations across the volcanic sequence as shown in image on the next page.
Source: Vite-Sanchez, O. et al, 2024.

WATCH NOW!
Octavio Vite-Sanchez - *Geochemistry and Petrogenesis of volcanic rocks from the Blake River versus Stoughton-Roquemaure assemblages, Abitibi Greenstone Belt: implication for VMS endowment, Metal Earth scientific meetings, March 1, 2024, Toronto ,Canada.*

WATCH NOW!
Isaac S. Malta - *P-T-t- deformation-fluid evolution of the pontiac metasedimentary subprovince (Superior craton) and its impl;ications for orogenic gold mineralization, Metal Earth scientific meetings, March 1, 2024, Toronto, Canada.*

Progress

Volcanogenic massive sulfide (VMS) deposits are Cu-Zn-Au-Ag (±Pb) deposits that form on the seafloor. Some areas of the Precambrian Shield of Canada are more fertile than others for VMS deposits, but we do not fully understand why.

The long-term goal of subproject 1b is to compare variably VMS-endowed volcanic assemblages within the Abitibi Greenstone Belt (AGB), focusing on geochemistry and petrogenetic evolution. By combining our results with those of subproject 1a (which will compile other assemblage-scale attributes, including volumes of volcanic products and area-age relationships), we aim to identify the unique combinations of geological events or conditions that correlate with regional VMS endowment.

During the period of April 1, 2023, to March 31, 2024, the following work has been completed by PhD Student Octavio Vite-Sanchez at INRS:

- The classification, grouping, and petrogenetic modelling was completed for the highly endowed Blake River Group and published in Precambrian Research.
- The equivalent work on the poorly endowed Stoughton-Roquemaure assemblage is complete, and Octavio has started to write that paper, which will feature magma mixing models in addition to the usual fractional crystallization and assimilation models in the Magma Chamber Simulator (MCS)

A new postdoc, Kieran Iles, arrived at INRS in the fall of 2023, and he has started to work on the geochemistry and petrogenesis of the well-endowed Deloro assemblage (which includes the Matagami VMS district):

- The first few months were devoted to familiarization with the Abibiti geology, the geochemical software (IOGAS) and a compilation update
- Geochemical groupings are now done for the Deloro and petrogenetic modelling is partly done (fractional crystallisation and assimilation models in MSC)

Future Work

Octavio will finish the Stoughton-Roquemaure paper and then move on to his final paper, which will be a comparison between the Blake River and Stoughton-Roquemaure assemblages, with implications for VMS fertility

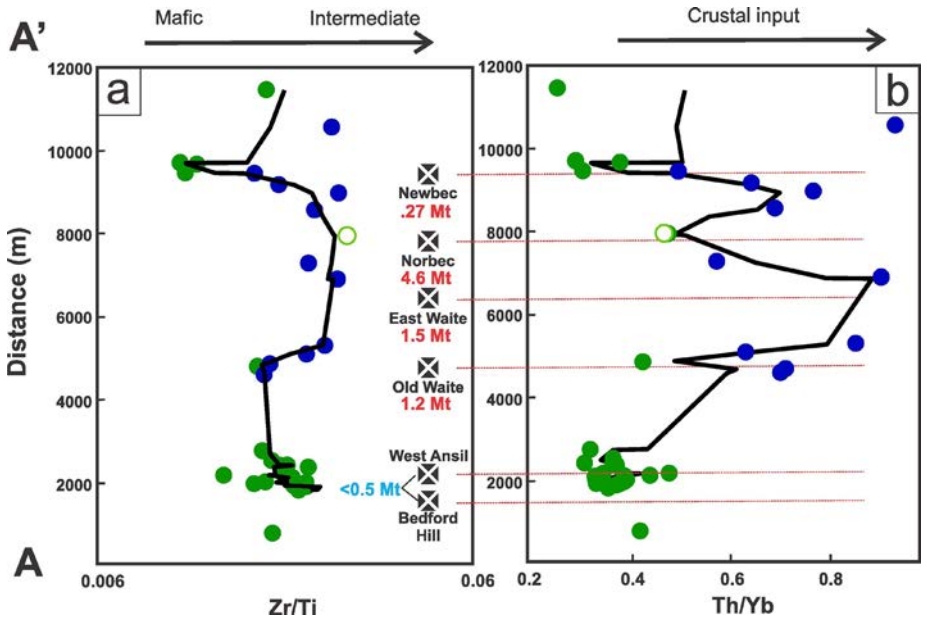
- Octavio will submit and defend his PhD thesis
- Kieran will finish work on the Deloro assemblage this year, potentially including partial melting models for the crust and mantle, submit a paper about that, and move on to other assemblages
- At the end of the project, there will be a complete synthesis of the geochemistry and petrogenesis of volcanic rocks in the Abitibi and how that relates to VMS fertility over time and space. This will lead to a better understanding of the processes responsible for differential VMS endowment during the evolution of greenstone belts.

Anticipated Outcomes

VMS project 1, including subproject 1b, will improve our understanding of the constructional history of the Abitibi greenstone belt. We will compare the composition of well-endowed and poorly endowed volcanic assemblages, interpret the petrological differences between them, and identify which factors might control both the petrology and the VMS fertility. We aim to identify the unique combinations of geological events or conditions that correlate with regional VMS endowment.

Implications

An overarching goal of Metal Earth is to resolve the processes responsible for differential metal endowment during the evolution and construction of Archean greenstone belts. The VMS thematic projects address differential VMS endowment at the assemblage to greenstone belt scales. This fills a knowledge gap and may result in a step-change in understanding the processes responsible for differential VMS endowment. It will also facilitate comparisons with the western Pacific Ocean (e.g., Lau basin).



Geochemical profile A-A' in the Noranda formation (see image on previous page). (a) Magma fractionation is based on the ratio Zr/Ti (ppm/ppm). (b) Crustal assimilation based on the ratio Th/Yb (ppm/ppm). Total mine production are marked in bold red while estimated resources in bold blue. (For references, description, and interpretation of the references to colour in this figure legend, the reader is referred to the web version of the source article.) Source: Vite-Sánchez, O., Ross, P.-S., & Mercier-Langevin, P. (2024). Mafic to intermediate volcanic rocks of the Blake River Group, Abitibi greenstone belt, Canada: Geochemistry, petrogenesis and relation with VMS deposits. Precambrian Research, 404, 107331. https://doi.org/10.1016/j.precamres.2024.107331

Highlights

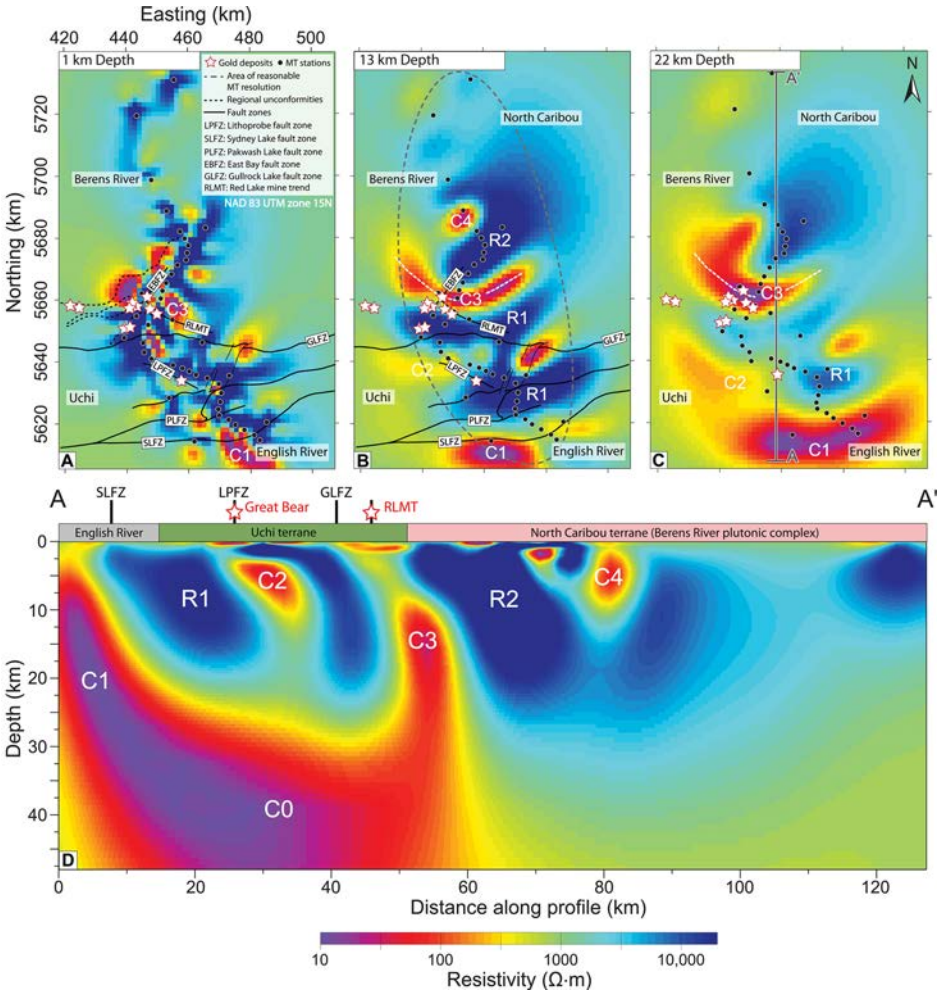
A paper was published in Precambrian Research: Mafic to intermediate volcanic rocks of the Blake River Group, Abitibi greenstone belt, Canada: Geochemistry, petrogenesis and relation with VMS deposits.

VIEW OR DOWNLOAD
Vite-Sánchez, O., Ross, P.-S., & Mercier-Langevin, P. (2024). Mafic to intermediate volcanic rocks of the Blake River Group, Abitibi greenstone belt, Canada: Geochemistry, petrogenesis and relation with VMS deposits. Precambrian Research, 404, 107331.
https://www.sciencedirect.com/science/article/pii/S0301926824000445?via%3Dihub

WATCH NOW!
Georges Beaudoin - *Source to Sink: Stable isotopes (H, O) and 3D fluid flow modeling constraints on gold endowment along the Augmitto-Bouzan orogenic gold deposit (Abitibi subprovince, Quebec), and future work, Metal Earth scientific meetings, March 1st, 2024, Toronto, Canada.*

Crust-Mantle Processes Responsible for VMS Endowment during the evolution of Archean Greenstone Belts: Nature of Assemblage Boundaries

Dr. Jack Simmons, Laurentian University



Progress

- As the basis for characterizing the nature and temporal evolution of the metasedimentary subprovinces of the Superior Craton, this project has so far involved:
- The compilation and standardization of all published U-Pb detrital zircon from across the North American Craton, including the Superior Craton.
- Sampling of metasedimentary deposit sequences preserved across the Abitibi subprovince for detrital zircon analysis.
- Core logging of a newly discovered gold-endowed metasedimentary and metavolcanic sequence (Great Bear deposit) in the Red Lake Greenstone Belt of the Uchi subprovince (collaboration with Great Bear Resources/Kinross).
- ID-TIMS of zircon from two felsic porphyries sampled from the Great Bear property.
- LA-ICPMS of detrital zircon from three metasedimentary rocks sampled from the Great Bear property.
- LA-ICPMS of detrital zircon from metasedimentary rocks sampled from the Abitibi subprovince.
- Preparation of a research paper on the Great Bear gold deposit.

(A–C) Resistivity model showing horizontal slices at upper-crustal (A), mid-crustal (B), and lower-crustal (C) depths. MT—magnetotelluric. (D) Cross section extracted from the three-dimensional model along the line A-A′ indicated in panel C. Black dots show the MT locations and white stars show Au deposits. R1–R2 and C0–C4 are resistive and conductive features, respectively. Coordinate system abbreviations: NAD 83—North American Datum of 1983; UTM—Universal Transverse Mercator. Source: Adetunji, A. Q., Launay, G., Ferguson, I. J., Simmons, J. M., Ma, C., Ayer, J., & Lafrance, B. (2023). Crustal conductivity footprint of the orogenic gold district in the Red Lake greenstone belt, western Superior craton, Canada. Geology, 51(4). Geological Society of America. https://doi.org/10.1130/G50660.1

- Development of a geophysical atlas with standardized Metal Earth seismic and MT sections.

Future Work

The data required to facilitate the anticipated outcomes (stated below) has been collected and analyzed. Future work will entail writing papers and developing a database of geochronology data compiled from existing publications.

Anticipated Outcomes

The results from this project will be presented to industry partners and at scientific conferences. In addition, one book will be published by Laurentian University in collaboration with Canadian Science Publishing and at least three papers will be submitted to leading scientific journals for publication.

Book: A Metal Earth atlas of seismic reflection and magnetotelluric transects across the Superior Province (submitted to Canadian Science Publishing).

Paper 1: A gold-endowed Archean lava dome associated with a crustal-scale fault: constraints from the structurally-controlled Great Bear gold deposit, Red Lake greenstone belt, Superior craton, Canada (ready for submission to Economic Geology).

Paper 2: Detrital zircon: a reliable paleotectonic indicator for Archean protocontinents? (in preparation).

Paper 3: The detrital zircon record of Laurentia (in preparation).

Database: Standardised U-Pb detrital zircon data for metasedimentary samples from across the North American Craton (in preparation)

Paper 4: Revised stratigraphic framework for the Archean Red Lake Greenstone Belt.

Implications

In the context of Objective 1 of Metal Earth's core research goals, new stratigraphic, geochemical and isotopic data collected as part of Paper 1 from the newly discovered Great Bear gold deposit will help test existing models for gold mineralisation in the Red Lake Greenstone Belt. This research could also lead to new exploration targets across the Uchi Subprovince.

Detrital zircon geochronology data compiled from existing publications as part of this project will ultimately be developed into a database, complimenting an existing geochronology database that was developed by Meek et al. (2020) under the auspices of Metal Earth's R & D project. This will contribute to Objective 2 of Metal Earth's core research goals.

Highlights

- Co-author on a paper that was recently submitted to the journal 'Solid Earth' titled 'Trans-crustal geophysical responses beneath the supergiant Timmins-Porcupine orogenic gold camp, Canada'.
- Co-author on a field guide published by the Ontario Geological Survey titled 'Discovering the Abitibi Gold Belt: A Geological Guidebook'.

WATCH NOW!
Jack Simmons - *Detrital zircon insights into sedimentation and crustal growth across Laurentia, Metal Earth scientific meetings, February 29th, 2024 Toronto, Canada*

VIEW OR DOWNLOAD
Adetunji, A. Q., Launay, G., Ferguson, I. J., Simmons, J. M., Ma, C., Ayer, J., & Lafrance, B. (2023). Crustal conductivity footprint of the orogenic gold district in the Red Lake greenstone belt, western Superior craton, Canada. Geology, 51(4). Geological Society of America.
https://doi.org/10.1130/G50660.1

Influence of magma residency and crust maturity on VMS endowment

Dr. Stephen J. Piercey, Memorial University

Postdoctoral fellow Sarah Speight presented a research update at the Metal Earth scientific meetings in Toronto on February 29, 2024.

Progress

- Personnel change in September 2023: Dr. Sarah Speight is the postdoctoral fellow.
- Several group meetings have occurred to discuss timelines and objectives for the research, as well as collaborating with Priyal Daya (Ph. D. candidate) and Dr. Jacob Hanley regarding the VMS Thematic project.
- Review of previously collected data and preliminary review of the zircon mineral chemistry data.
- Participated in the Metal Earth meeting in Quebec City (October 2023) and presented a research update entitled "Zircon mineral chemistry of the AGB: Preliminary results and implications for crustal residence and assimilation."
- Hired and began working with a new RA at Memorial University (Dorota Pietruska) to assist with and expedite data collection in 2024.
- Sample selection for batch #2 of data collection and travel to Halifax, NS, for in-person work with Priyal Daya and Dr. Hanley.
- Participated in the PDAC Metal Earth meeting in Toronto (March 2024) and presented a research update entitled "Lu-Hf characteristics of zircon from the Abitibi greenstone belt."
- Created a working "Master Sample" file that includes data from previous and current data collection.

WATCH NOW!
Sarah Speight - *Lu-Hf isotopic characteristics of zircons from the Abitibi greenstone belt; Metal Earth scientific meetings, February 2024, Toronto.*

Future Work

- Travel to Memorial University for second batch of zircon analysis and apatite grains (occurring as inclusions in zircon and/or apatite from mineral separates)
- Final selection of samples for the last batch of data collection.
- Ongoing SEM-BSE and CL imaging of zircons with accompanying EMPA.
- LA-ICP-MS analysis of zircons for U-Pb, trace elements, and Lu-Hf.
- Manuscript outlining and planning.
- Synthesis work with Project #1 and #3 of the VMS Thematic Project.

Anticipated Outcomes

- Studying the zircons with inherited ages due to entrainment during pluton emplacement may give indications of the underlying crustal architecture and crust-mantle interactions. Lu-Hf isotopes will help determine the nature of magma reservoirs present during the construction of the Abitibi greenstone belt. This work may assist with improving targets during exploration programs by understanding the processes related to differential endowment at the assemblage and greenstone belt scale.

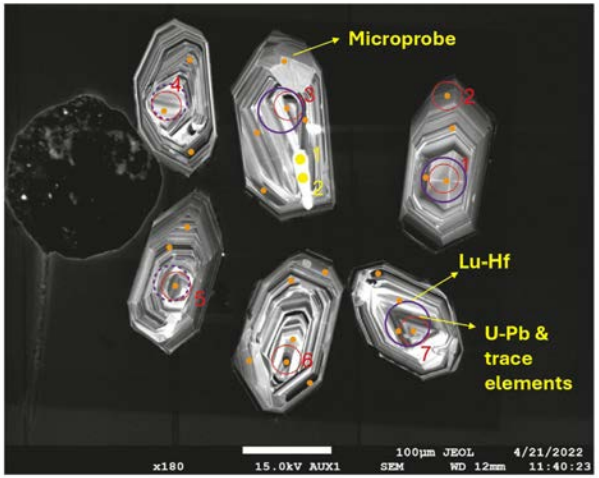
Implications

- Focusing on understanding the processes related to magma formation, fractionation, and metal fertility during the Archean should lead to a deeper understanding of VMS metal endowment and the formation of deposits.

Highlights

Presentation of results and working hypotheses at two Metal Earth meetings.

WATCH NOW!
Stephen J Piercey - *Volcanogenic Massive Sulfide (VMS) Deposits: New Ideas and Future Research Directions. MDD Webinar, 2023 Duncan R. Derry Medal winner, November 2023.*

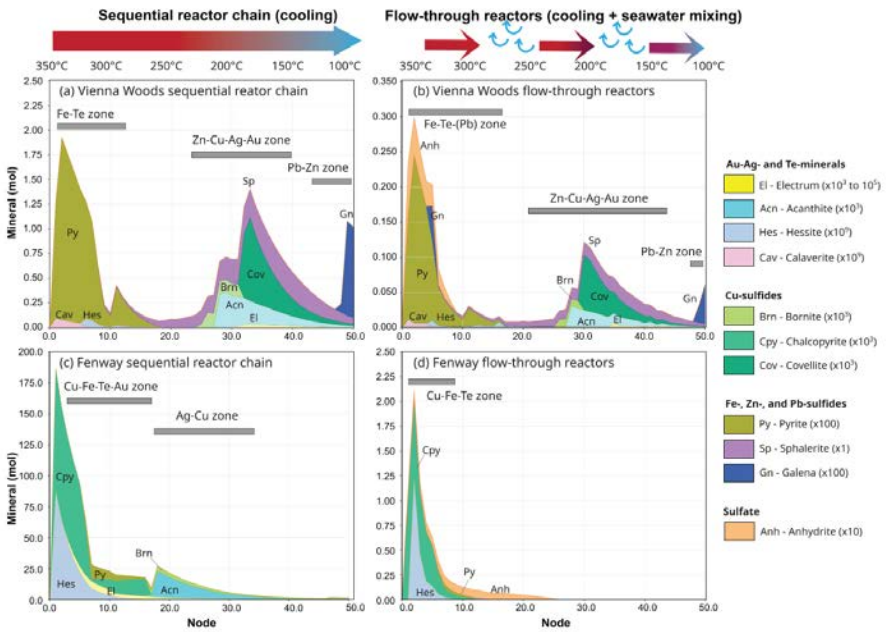


Methods (presented at GAC-MAC-SGA 2023) include: cathodoluminescence imaging (left); microprobe analysis of trace elements for internal standardization; initial LA-ICP-MS analysis for U-Pb; and secondary LA-ICP-MS for Lu-Hf isotopic and trace element data. Source: S. Speight.

Dr. Sarah Speight conducting laboratory work. Source: S. Speight.

Crust-mantle processes responsible for VMS endowment
Trace metal constraints on the setting and source of metals

Dr. Mark Hannington and Dr. David Diekrup



Simulated 1-D reactive transport models showing sequential reactor chain cooling and flow-through reactors with cooling and seawater mixing models. a, b) Simulated mineralogy of cooled Vienna Woods vent fluid showing the development of a high-temperature Fe-Te–rich zone >300°C and a Zn-Cu-Ag-Au–rich zone at low temperature between 100° and 250°C. c, d) Simulated mineralogy of cooled Fenway vent fluid showing the development of a Cu-Fe-Te-(Au)–rich zone between 250° and 350°C and a low-temperature Ag ± Cu zone. Multipliers were added to improve illustration of mineral zoning. Source: Hurtig et al, 2024.

VIEW OR DOWNLOAD

Hurtig, N. C., Gysi, A. P., Monecke, T., Petersen, S., & Hannington, M. D. (2024). Tellurium transport and enrichment in volcanogenic massive sulfide deposits: Numerical simulations of vent fluids and comparison to modern sea-floor sulfides. Economic Geology, 119(4), 829–851. https://doi.org/10.5382/econgeo.5067

Progress

- 2023-24 focused on statistical analysis of the VMS trace element database at the project's core, including a complete PCA and machine-learning experiments as part of the MSc thesis of R. Penner. The database now contains over 3900 individual analyses from more than 320 Canadian VMS deposits and massive sulfide showings. An extensive compilation of supporting information was added to the database, including host rock characteristics and mineralogy. A full range of statistical analyses was completed, focusing on pyrite chemistry in Archean VMS and emphasizing the Abitibi Greenstone Belt (AGB).
- Version 2.0 of the database is a large digital supplement of the M.Sc. thesis. Results from the analysis were presented during the Metal Earth partner meetings and at the PDAC-SEG Student Minerals Colloquium.
- Petrographic work by T. Monecke and his students (L. Patterson, F. Kasprowicz, supervised by K. Pfaff) at Colorado School of Mines was completed, focusing on samples from the Matagami and Noranda districts. The study emphasized mineral mass balances and the distribution of critical trace elements. I.M. Kjarsgaard completed a parallel study of 700+ polished sections from 20 additional deposits in the Abitibi Greenstone Belt.

Future Work

- Synthesis of the initial study comparing trace element variations to host rocks, deposit sizes and grades in 55 deposits. The data set includes 258 samples of pyrite from 47 deposits in the AGB, together with 30 samples from 8 deposits in the Western Superior (Sturgeon Lake, Uchi, Benny, and Manitouwadge belts) and 45 samples from 6 deposits in the Slave Province (Hackett River, Hood River, and High Lake belts). These data are being compared to

volcanic rock compositions from over 4000 published high-quality analyses of samples from the Superior Province.

- Follow-up on the data set of R. Penner is being performed by I. Kjarsgaard, with MSc student K. Ojaste. F. Kasprowicz and L. Patterson are completing externally-funded MSc thesis projects on the petrography and trace element geochemistry of Matagami and Noranda ores. This work will include key mineralogical controls on trace element distribution in Archean VMS using QEMSCAN, EPMA, and LA-ICP-MS.
- D. Diekrup (GSNL) is providing continuing guidance in the project.

Anticipated Outcomes

- Multivariate statistics and machine learning approaches will be aimed at establishing regional time-stratigraphic and spatial control on the distribution of trace elements in Archean VMS deposits of Canada, with an emphasis on:

  i) lithogeochemical controls on trace element geochemistry and links to the sizes and grades of the deposits and their source rocks;

  ii) key trace element signatures and mineral balances of critical elements in deposits in well-endowed versus poorly endowed assemblages;

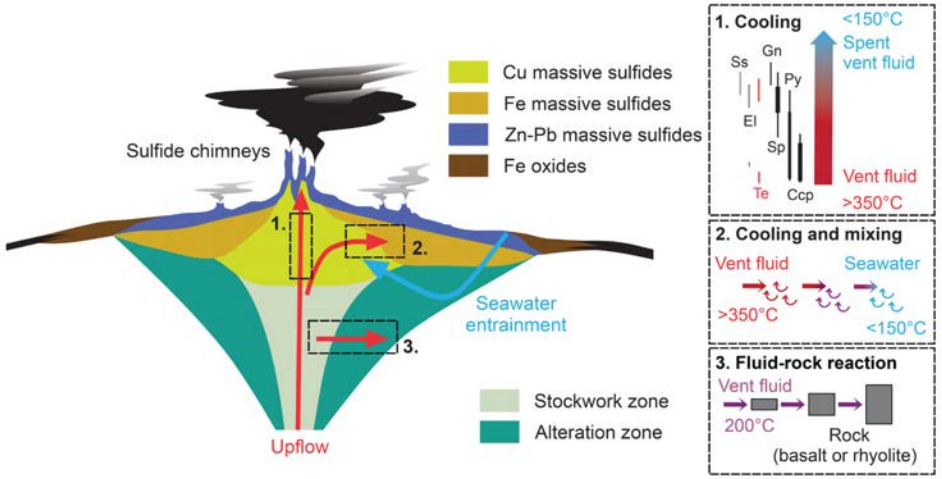
  iii) trace element signatures of the leached volcanic footwall;

  iv) comparisons of Archean deposits to modern VMS-forming systems.

- An important goal is pathfinder elements and element ratios that can be applied in exploration.
- The analysis has shown that the trace element geochemistry of pyrite is a useful fingerprint of the different mineralizing systems, with enrichments and depletions reflecting different source rocks, inferred temperatures of ore formation, and the scales of the hydrothermal systems. District-scale variations in pyrite chemistry mainly reflect host rock and correlate with the bulk tonnage and Cu and Zn grades of the deposits.
- Two peer-reviewed articles by M. Fassbender have established metal distribution in volcanic host rocks, including different assemblages of the AGB.
- A new project by MSc student R. Dentelbeck compares VMS geochemistry to data from coeval carbonaceous shales and chemical sediments throughout the Abitibi.

Implications

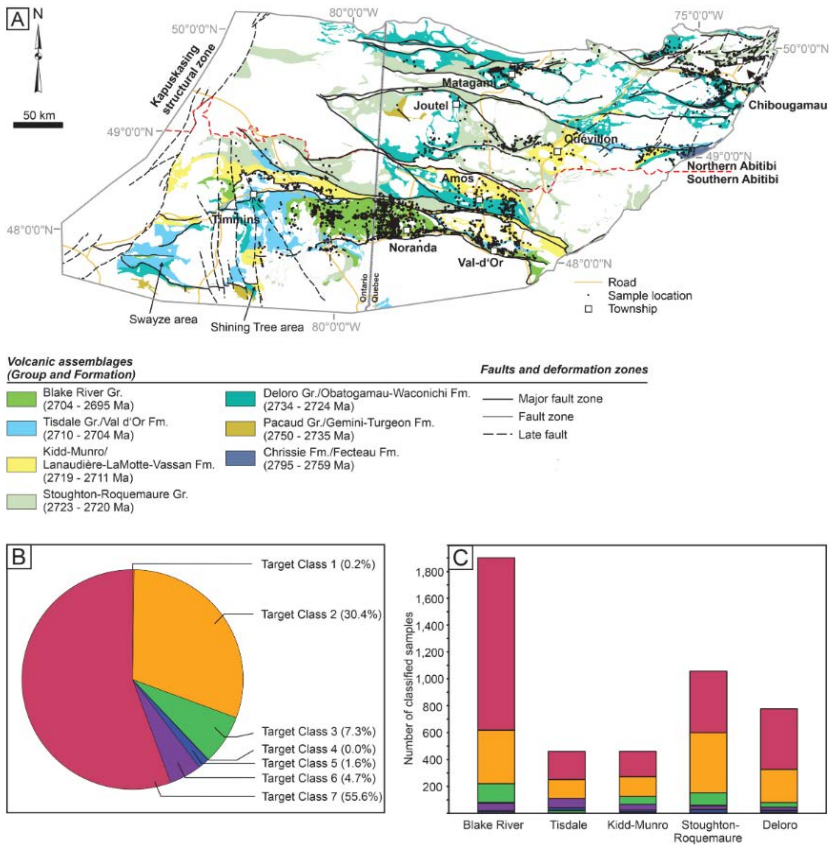
- The Neoarchean greenstone belts of the Canadian Superior Province host world-class Au and base metal (Cu-Zn-Pb) massive sulfide deposits with distinct geological features, including a wide range of different host rocks and crustal settings. The range of settings is reflected in the trace metal signatures of their ores.



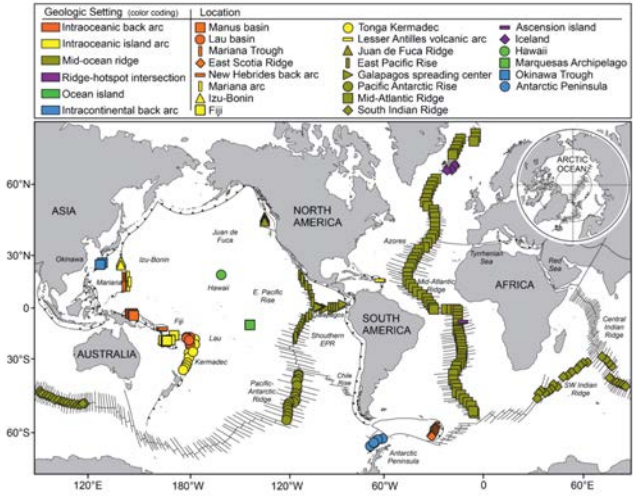
Modern sea-floor hydrothermal system forming a mound-style sulfide accumulation. The mineralized zones consist of massive Cu, Zn-Pb, and Fe sulfides underlain by a stockwork vein system. The diagram shows key processes occurring at the high-temperature vents that are modeled in this study, including cooling and mineral precipitation from the hot vent fluid, cooling and mixing of the hot vent fluid with entrained seawater, as well as fluid-rock reaction. Mineral abbreviations: Ccp = chalcopyrite, El = electrum, Gn = galena, Py = pyrite, Sp = sphalerite, Ss = sulfosalts, Te = tellurides. Source: Hurtig et al, 2024.

The goal of subproject 3b is to test the use of trace metal signatures of VMS mineralization as a guide to well-endowed versus poorly endowed greenstone belt assemblages. Systematic trace element behaviour in VMS have already been identified as reflecting greenstone belt crustal composition (e.g., including potential inheritance), which is thought to play a key role in metal endowment in VMS systems.

These differences highlight the potential application of the trace element signatures of pyrite during exploration for different deposit types in the same region.



A) Geologic assemblage map of the Abitibi greenstone belt (AGB) showing the locations of mafic volcanic rock samples compiled for this study (modified from Thurston et al., 2008; Monecke et al., 2017; Dube and Mercier-Langevin, 2020). B) Pie chart of the random forest classification results for the entire AGB data set, colored according to the different target cdlasses. The majority of the samples are classified as target class C2, C3, and C7. C) Number of samples in each target class identified among the different assemblages of the AGB. The distribution of the different target classes corresponds generally to the north and south rift zones of the Abitibi previously identified by Mole et al. (2022). The Blake River Assemblage (Noranda Volcanic Complex) and Deloro Assemblage have the highest proportion of samples belonging to target class C7, consistent with a combination of arc-like magmas influenced by wet melting and probable crustal contamination. The Kidd Munro Assemblage has a high proportion of samples belonging to target classes C2 and C3, similar to ridge-hotspot intersections. The Tisdale Assemblage has a high proportion of samples belonging to target class C6 and C7, consistent with a combination of arc-like magmas influenced by wet melting and probable crustal contamination. Stoughton-Roquemaure has the highest proportion of samples in target class C2 and C3 similar to ridge-hotspot intersections and mid-ocean ridge (MOR)-like settings. The Deloro Assemblage has the highest proportion of samples belonging to target class C7 consistent with a combination of arc-like magmas influenced by wet melting and probable crustal contamination.

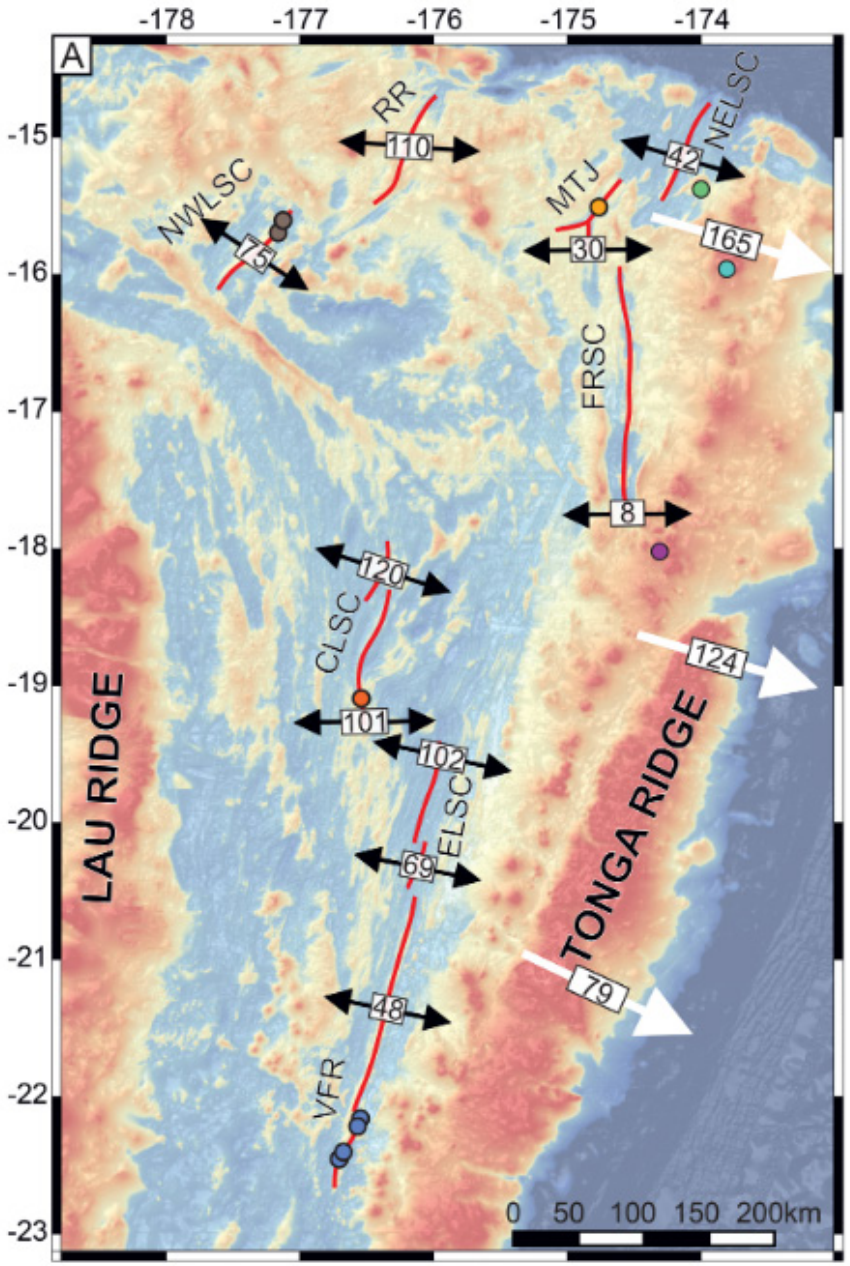


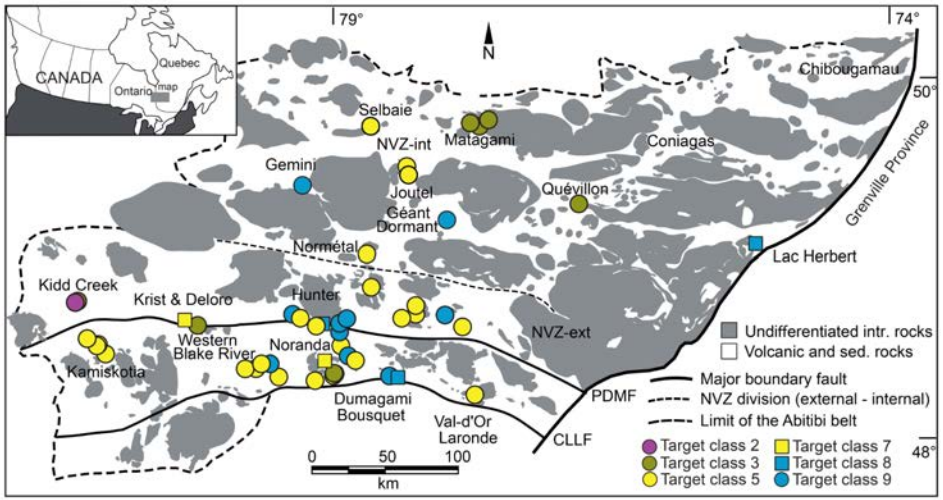
Global map of mafic volcanic rock samples from the oceans compiled for this study. Six different tectonic settings are represented, including intraoceanic back-arc basins (orange: Manus basin, Lau basin, Mariana Trough, East Scotia Ridge, New Hebrides arc-back arc), intraoceanic island arcs (yellow: Mariana arc, Izu-Bonin, Fiji, Tonga Kermadec arc, Lesser Antilles volcanic arc), mid-ocean ridges (olive: Juan de Fuca Ridge, East Pacific Rise (EPR), Galapagos spreading center, Pacific Antarctic Rise, Mid-Atlantic Ridge, South Indian Ridge), ridge-hotspot intersections (purple: Ascension Island, Iceland), ocean islands (green: Hawaii, Marquesas Archipelago) and intracontinental arc-back arc basins (blue: Antarctic Peninsula, Okinawa Trough).

Source:Fassbender, M. L., Hannington, M., Baxter, A. T., Diekrup, D., Stewart, M., & Brandl, P. A. (2024). Geochemical signatures of mafic volcanic rocks in modern oceanic settings and implications for Archean mafic magmatism. Economic Geology, 119(2), 445–470. https://doi.org/10.5382/econgeo.5044

Highlights

- In 2023-24, one paper with the Colorado School of Mines was accepted for publication in Economic Geology (Hurtig et al., 2024).
- Three MSc theses were completed: R. Penner (uOttawa), L. Patterson (CSM), and F. Kasprowicz (CSM).
- R. Penner (2023 PDAC-SEG Student Minerals Colloquium) and F. Kasprowicz (2023 Society of Economic Geologists Conference in London, UK) made two presentations at conferences.





Results of the random forest classification of Abitibi felsic volcanic rocks according to target class C2 (purple), C3 (olive), C5 (yellow circle), C7 (yellow square), C8 (blue square), and C9 (blue circle). Samples from the Noranda Volcanic Complex and Blake River Group belong to several target classes (e.g., C2, C3, C5, and C8), whereas samples from Kidd Creek (C2) and Matagami (C3) fall into only one target class each (see text for discussion). CLLF = Cadillac-Larder Lake fault, NVZ = Northern volcanic zone, PDMF = Porcupine-Destor Manneville fault. Source: Fassbender et al, Economic Geology, 2023.

VIEW OR DOWNLOAD
Fassbender, M. L., Hannington, M., Stewart, M., Brandl, P. A., Baxter, A. T., & Diekrup, D. (2023). Geochemical signatures of felsic volcanic rocks in modern oceanic settings and implications for Archean greenstone belts. Economic Geology, 118(2), 319–345. https://doi.org/10.5382/econgeo.4967

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Fassbender, M. L., Hannington, M., Baxter, A. T., Diekrup, D., Stewart, M., & Brandl, P. A. (2024). Geochemical signatures of mafic volcanic rocks in modern oceanic settings and implications for Archean mafic magmatism. Economic Geology, 119(2), 445–470. https://doi.org/10.5382/econgeo.5044

Left: A) Locations of felsic volcanic rocks sampled in the northern Lau basin, which contains at least eight major zones of active extension: CLSC = Central Lau spreading center, ELSC = Eastern Lau spreading center, FRSC = Fonualei rift and spreading center, MTJ = Mangatolu triple junction, NELSC = Northeast Lau spreading center, NWLSC = Northwest Lau spreading center, RR = Rochambeau rifts, VFR = Valu Fa rift and spreading center. Spreading rates in mm/yr are shown on the ridge axes (red lines), and convergence rates of the Indo-Australian and Pacific plates are shown by the white arrows. The sample locations are overlain on the regional bathymetry from GMRT v3.5 (Ryan et al., 2009). Source: Fassbender, M. L., Hannington, M., Stewart, M., Brandl, P. A., Baxter, A. T., & Diekrup, D. (2023). Geochemical signatures of felsic volcanic rocks in modern oceanic settings and implications for Archean greenstone belts. Economic Geology, 118(2), 319–345. https://doi.org/10.5382/econgeo.4967

Mineral Prospectivity Maps for the Kamiskotia Volcanic Complex

Dr. Stefanie Brueckner, Laurentian University

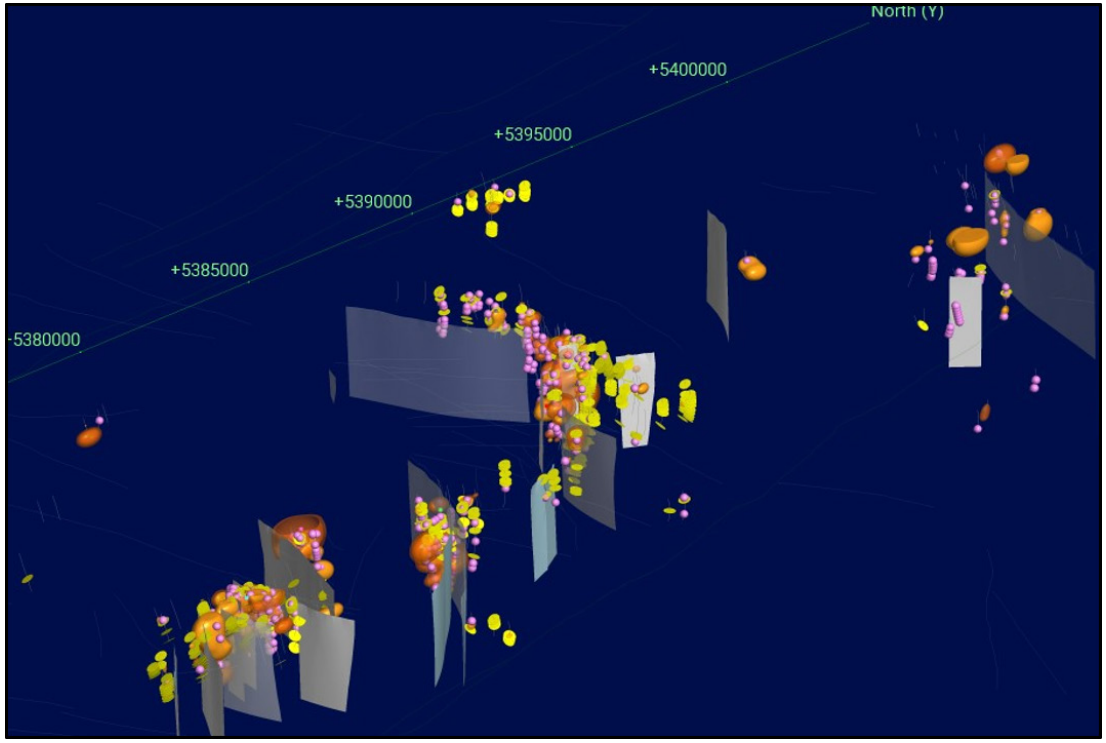
Progress

The Kamiskotia Volcanic Complex (KVC), located near Timmins, Ontario, in the western Abitibi greenstone belt, is a metal-endowed volcanic sequence of Neo-Archean age (2705+/-2Ma) and is the host of past producing volcanogenic massive sulfide VMS deposits (i.e., Kam Kotia, Jamesland, Half Moon, Canadian Jamieson, Genex).

This project aims to:

- identify lithologies favourable to host VMS mineralization in the KVC using geochemical parameters (i.e., mafic and felsic composition, alteration indices)
- create a mineral prospectivity map utilizing machine learning (e.g., random forest) and geostatistical (e.g., principal component analysis) methods in combination with geological, geochronological and geochemical information.

MSc student Samuel Tetteh began this project in January 2023, using 10,357 geochemical data points from the KVC that were collected from past VMS producers and exploration projects. Detailed geochemistry was used to decipher the composition of mafic and felsic volcanic lithologies regarding their potential to host VMS mineralization, including their geochemical affinity (tholeiitic vs intermediate vs calc-alkaline), the TiO2 and P2O5 concentration of basalts (high-Ti vs low-Ti basalts), and the type of rhyolite present (FI, FII, FIII, FIV). These are known parameters to distinguish between lithologies likely to host VMS mineralization or to be barren. Common mineral indices (AI, CCPI, chlorite index, sericite index) were used to identify least- to most-altered lithologies.



A 3D LeapFrog numerical model of Cu and Zn showing potentially anomalous areas in orange. These areas coincide with zones with strong hydrothermal alteration signatures (i.e., CCPI), favourable geochemical signatures (i.e., high silica rhyolites) and synvolcanic faults (i.e., light grey planar surfaces). Source: Tetteh 2023.

VIEW OR DOWNLOAD

Tetteh, S. E. K. et al. (2023, November 6-7). Controls on volcanogenic massive sulphide mineralization in the Kamiskotia area, Ontario, Canada: insights from lithogeochemical analysis and mineral prospectivity modelling [Poster Presentation]. Central Canada Mineral Exploration Convention (CCMEC). Winnipeg, Manitoba, Canada.
https://merc.laurentian.ca/sites/default/files/21974_samueledemkodzotetteh_poster.pdf

After geochemically identifying the different lithologies, Sam produced 2D and 3D maps in Leapfrog to identify fertile rocks at past VMS deposits and locations between these deposits that underwent exploration.

Based on the geochemical results, Sam has been working with Jeff Harris to integrate the geochemical data into geostatistical analyses (e.g., principal component analysis) and to apply machine learning techniques (Random Forest) to identify future exploration targets. Results from principal component analyses underlined the close relation between host rocks most likely to be fertile (e.g., tholeiitic, high Ti-basalts; FIII rhyolite), elevated Cu and Zn assay results, and more intensively altered rocks.

Future Work

The project is in the final phase. Mineral prospectivity maps are generated using more than 40 evidence layers based on intensive geochemical analysis and other geologic criteria, including synvolcanic faults, geochronology and geophysical data.

Anticipated Outcomes

The outcomes for this project are:

- Detailed geochemical characteristics of >10,000 lithogeochemical data points from past producing mines and exploration projects in the KVC
- Creation of 2D and 3D maps using the geochemical characteristics of the available data
- Creation of a mineral prospectivity map for the KVC identifying past VMS deposits and future VMS exploration targets.

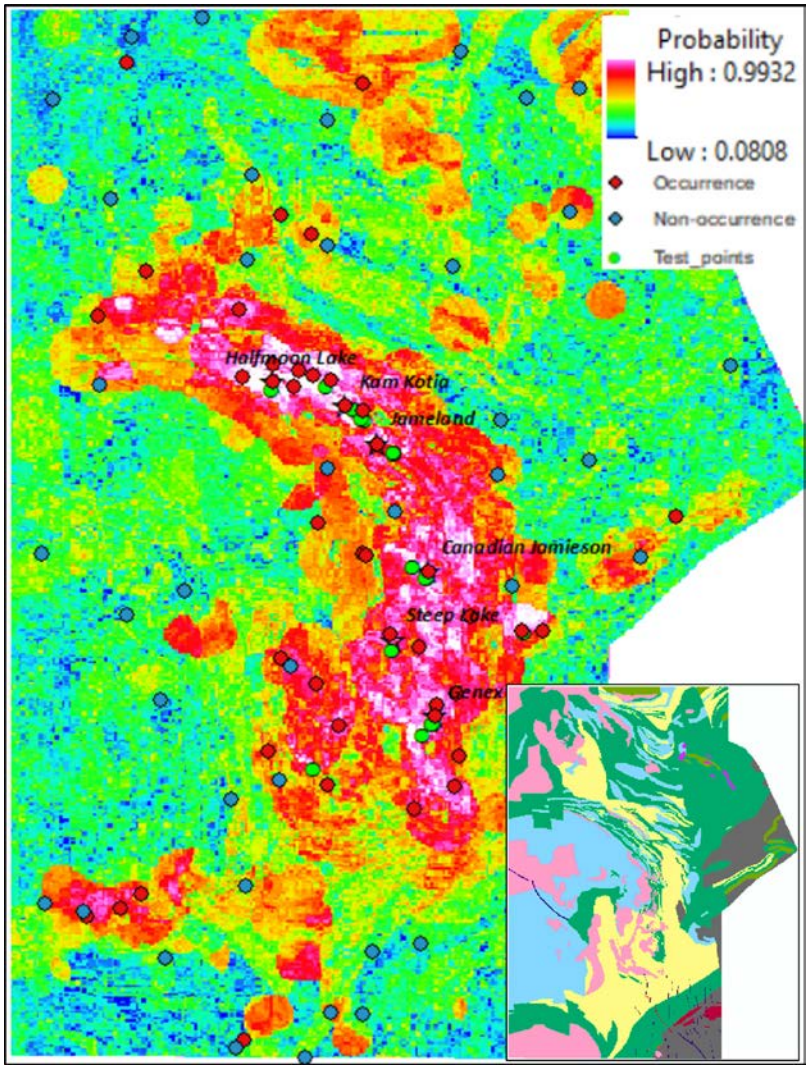
Implications

This study contributes to our understanding of the Abitibi greenstone belt. Creating mineral prospectivity maps using machine learning methods will help identify future mineral exploration targets.

Highlights

Sam received three awards over the course of this project, including:

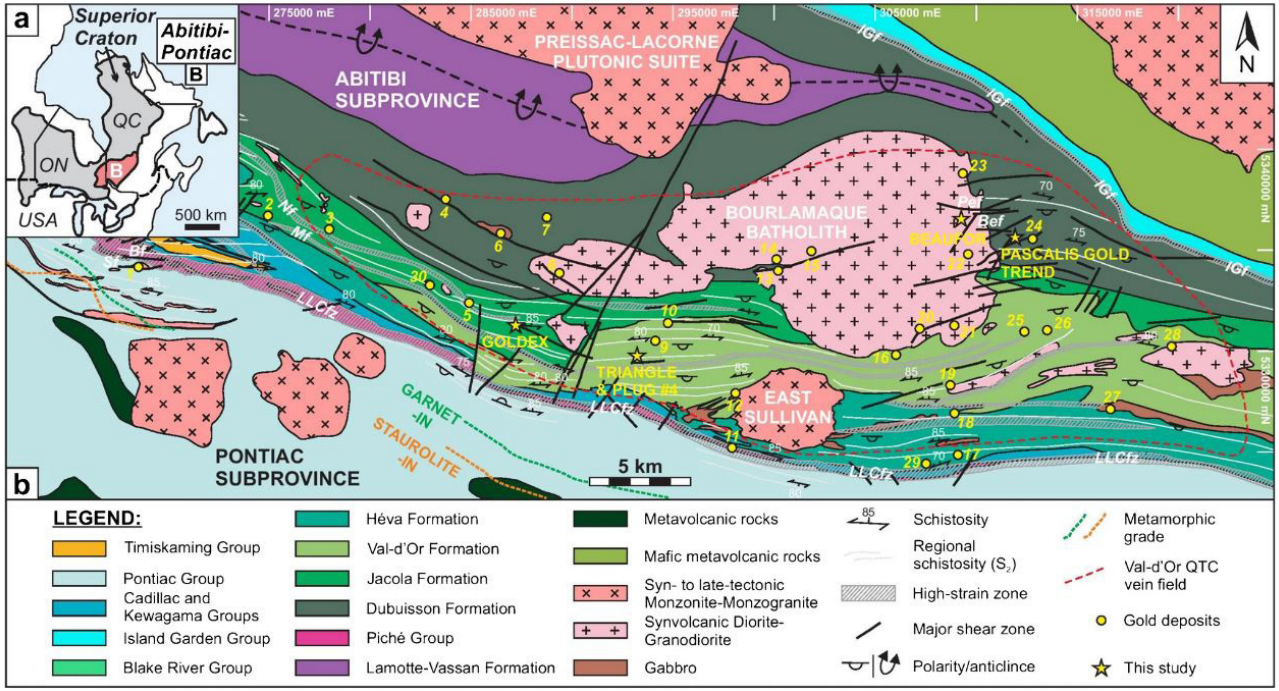
- Central Canada Mineral Exploration Convention (CCMEC) poster competition, November 2023, 3rd place, MSc category
- Society of Economic Geologists Foundation 2023 Graduate Student Fellowship
- C. H. Riddell Faculty of Environment, Earth, and Resources 2023 Graduate Entrance Scholartations at conferences.



RF probability map, with an overall accuracy of 86.8%, demonstrates a high degree of correspondence with previous known mineralization sites and also highlights new areas with potential for VMS deposits. Source: Tetteh 2023.

Source to Sink

Dr. Georges Beaudoin, Université Laval



a) Map outlining the extent of the Superior Craton and location of the Abitibi and Pontiac subprovinces. b) Geological map of the area between Malartic and Val-d'Or showing the outline of the Val-d'Or vein field, as well as the studied and other gold deposits (after Wong et al. 1991; Morasse et al. 1995; Pilote et al. 2000; Bedeaux et al. 2017; Montsion et al. 2018; SIGÉOM 2020). Bf=Barnat fault, IGf=Island Garden fault, MF=Marbenite fault, Nf=Norbenite fault, QTC=quartz-tourmaline-carbonate, Sf=Sladen fault. 1=Canadian Malartic, 2=Camflo, 3=Norlartic, 4=Wesdome, 5=Shawkey, 6=Siscoe, 7=Siscoe Extension, 8=Sullivan, 9=Lamaque, 10=Sigma, 11=Orenada Zone 4, 12=East Sullivan, 13=Bras d'Or, 14=New Formaque, 15=Lac Herbin, 16=Manitou-Barvue, 17=Akasaba, 18=Louvicourt Goldfield, 19=Dunraine, 20=Wrightbar, 21=Beacon 2, 22=Courvan, 23=Pascalis North, 24=Lucien C. Béliveau, 25=Louvem, 26=Louvicourt, 27=Sigma 2, 28=Bevcon, 29=Akasaba West, 30=Kiena.
Source: Herzog, M., LaFlamme, C., Beaudoin, G. et al. Fluid-rock sulfidation reactions control Au-Ag-Te-Bi precipitation in the Val-d'Or orogenic gold vein field (Abitibi subprovince, Canada). Miner Deposita 59, 1039–1064 (2024). https://doi.org/10.1007/s00126-024-01247-6

Progress

M. Herzog successfully defended his PhD in November 2023, and the thesis is published. A paper on sulfide chemical composition and multiple sulfur isotopes (SIMS collaboration UWA) and one on the geochronology of orogenic gold mineralization in the Malartic-Val-d'Or camp were published. Another paper on sulfide inclusions and gold transport/deposition documenting nanoparticles by TEM (collaboration UWA) will be submitted to Economic Geology in 2024.

G. Raymond submitted a paper about fluid flow at Augmitto-Bouzan to Mineralium Deposita (accepted, minor revisions).

A draft on in-situ δ18O analysis of various quartz generations from orogenic gold veins from Val-d'Or camp is in preparation and will be submitted in 2024.

A draft on the variations in O and H isotope compositions in orogenic gold veins from Val-D'Or to Kirkland Lake is in preparation, to be submitted in 2024.

I. Siles Malta modeled phase equilibria on selected key samples from the Pontiac subprovince to quantify P-T-t-X paths and fluid dehydration reactions.

VIEW OR DOWNLOAD
Herzog, M., LaFlamme, C., Beaudoin, G. et al. Fluid-rock sulfidation reactions control Au-Ag-Te-Bi precipitation in the Val-d'Or orogenic gold vein field (Abitibi subprovince, Canada). Miner Deposita 59, 1039–1064 (2024).
https://doi.org/10.1007/s00126-024-01247-6

He submitted an article on the singular metamorphic gradient in the metased-imentary Pontiac Subprovince to the Journal of Metamorphic Geology.

Y. Nemati focuses on assessing the petrophysical characteristics of hydrothermal gold deposits using borehole geophysical data gathered from 7boreholes in Rouyn Noranda. The findings indicate a strong correlation between petrophysical characteristics and geochemistry data. Employing the mass balance method, it was demonstrated that areas gaining K+ exhibited an increase in Gamma Ray values, while regions with Carbonate alteration showed a gain in Ca2+, resulting in a decrease in density. Furthermore, areas likely corresponding to the alteration of magnetite from the komatiite by hydrothermal fluids to form pyrite and arsenopyrite and to precipitate gold were identified. This hydrothermal alteration coincides with variations in magnetic, resistivity, density, velocity, and IP responses measured downhole. Further analysis of electrical logs revealed significant differences in the resistivity of altered rocks compared to less-altered rocks. Optical televiewer logs and core images illustrated that this discrepancy is attributed to the increased presence of quartz veins in altered sections. Moreover, it was observed that less-altered sections exhibited erratic behaviour in IP logs, whereas altered sections displayed relatively constant IP values. Furthermore, an in-depth examination of the relationship between hydrothermal alteration and sonic and SP logs demonstrated that sonic logs exhibited higher values in more altered sections, primarily due to the presence of quartz veins. Conversely, SP values were elevated in less altered sections owing to the presence of sulfides.

Transitioning to the latest phase of the project, a 3D model of the electrical tool in the borehole environment has been designed and prepared with a particular focus on the influence of veins, fractures and the geometry of the normal resistivity tool. The completion of this model has revealed intriguing revelations, elucidating how vein characteristics such as thickness, radius, conductivity, and angle impact normal resistivity measurements. Using this model, we are investigating the effects of multiple veins and complex fracture systems. Continuous comparison with actual measurements enhances comprehension, leading to nuanced insights into the interplay between geological features and geophysical tools.

We encountered significant delays in establishing the correct model in SFePy. After a full year of work on this, the model is now functional and generating the results that allow us to go forward.

Future Work

S. Sömnez will work on the timing of mineralization and the source of auriferous fluids along the Porcupine-Destor Fault Zone. Particular focus will be set on comparing H-O isotope composition along the PDFZ to the variation documented by the Metal Earth team along the CLLFZ.

M. Bertauts will constrain the P-T-X conditions of ore-forming fluids using pyrite-hosted fluid inclusions from well-endowed deposits (Ormaque and Triangle) and compare it to barren quartz veins from the Val-d'Or camp.

S. Webb will work on the timing of auriferous fluid flow and sulfur source along the Larder-Kirkland segment.

M. Herzog will submit his 3rd paper on sulfide inclusions and gold transport/deposition documenting nanoparticles by TEM to Economic Geology.

I. Siles Malta:

- Finalize phase equilibria modelling by including the fluid behaviour in the MnNCKFMASHTO-S system
- Preparation of the second manuscript for publication in an international peer-reviewed journal (in progress).
- Write, submit, and defend the thesis.

Y. Nemati plans to submit the results of her work in three separate papers:

1. Petrophysical Signatures and Mineral Endowment: The Piché Group, Rouyn-Noranda, Quebec. (under internal review)
2. Finite Element Modeling of the Borehole Electrical Resistivity Tool to Understand the Effects of Veins
3. Untangling the Effect of Multiple Veins: Understanding the tool geometry effects in vein dominated deposits.

The results for the second paper are almost ready. Y. Nemati is currently running the model to finish gathering data for the third paper. Once the modelling is completed, data analysis and writing the last two papers can start.

Anticipated Outcomes

- Compendium of stable isotope composition of orogenic veins stable isotope composition in the Superior province, comparing gold-endowed and less-endowed domains
- Improved understanding of the sources of auriferous fluids along the CLLSZ.
- Age of gold mineralization events, sources of sulphur and gold precipitation mechanisms in the Val-d'Or area.

VIEW OR DOWNLOAD

Herzog, Michael. 2023 Multi-scale controls on vein-type orogenic gold precipitation and remobilization in the Malartic-Val-d'Or district of the Abitibi subprovince (Québec, Canada) Doctoral thesis. Université Laval.)
https://hdl.handle.net/20.500.11794/130903

- Improved understanding of the petrophysical characteristics of gold-endowed and less-endowed segments of the CLLSZ.

Implications

Compare the stable isotope signature of fluid flow along transects cutting across well-mineralized and poorly mineralized segments of major crustal faults and volcanic centers in the Superior Province. Identify the sources of fluids and sulfur in Superior Province gold deposits.

Determine hydrothermal features that explain the metal accumulation of endowed areas versus those that are less endowed. Understand fluid generation during the metamorphism of sedimentary rocks (timing and P/T conditions), the sources of volatiles (including sulfur, a critical ligand for gold transport to deposition sites), the processes involving fluid at the deposit and the timing of hydrothermal fluid pulses to better constrain what are the key parameters required to form a deposit.

Y. Nemati's results show that the measurement of physical properties and, therefore, geophysical data can be affected by the geometry of the instruments used. This is an important insight when trying to build models that explain larger-scale datasets. This work confirmed that measurements that appeared erroneous on the different channels of the normal resistivity tools are associated with thin resistive structures. This is important because, without this insight, modellers may include low resistivity layers in their models that are measurement artifacts. Furthermore, the resistivity alteration index developed this year provides a simple and powerful tool that enables the users to determine, simply from the resistivity data, if the rock mass was host to significant hydrothermal alteration which could have led to mineral enrichment.

WATCH NOW!
Georges Beaudoin - *Georges Beaudoin - Source to Sink of orogenic Au fluids: Fluid flow modelling at Augmitto-Bouzan. Presented at the Metal Earth scientific meetings, February 2024, in Toronto, Ontario.*

WATCH NOW!
Isaac S. Malta - *P-T-t-deformation-fluid evolution of the Pontiac metasedimentary subprovince (Superior craton) and its implications for orogenic gold mineralization, presented at the Metal Earth scientific meetings, February 2024 in Toronto, Ontario.*

Highlights

- M. Herzog presented his work on gold precipitation mechanism in Val-d'Or, and at the SGA in Zurich.
- I. Siles Malta and Y. Nemati presented their research at the GAC-MAC in Sudbury (May 2023); and JSTE in Québec (March 2024).

Y. Nemati was awarded:

- « Bourse des pionniers de la géophysique québécoises », KEGS Foundation, in November 2023; and the Joan Margaret Stewart New Canadian Scholarship, Young Mining Professionals Scholarships, in December 2021.
- Y. Nemati project's aim is to understand how the physical properties of rocks have been altered by hydrothermal processes. We discovered that areas with higher gold content, especially those with visible gold, were often associated with high resistivity. These areas contained complex sets of quartz-carbonate veins. The intricate geometry of resistive bodies in orogenic gold deposits has always posed a challenge in determining how they affect resistivity readings and their relationship to gold endowments. Our findings demonstrate how the presence of single and multiple veins influences these factors. Results also show that physical properties are closely associated with alteration mechanisms and not lithologies. This is an important insight for everyone trying to train artificial intelligence algorithms associated with mining.

Mantle Group

Dr. D.G. Pearson, University of Alberta

Progress

- Successfully approached Smithsonian to leverage ~ $80k of indirect support for a 2-week field season in July 2024
- Completion of fieldwork – acquisition of samples from key traverses across the western portion of the Slave craton into the Li pegmatite belt. Samples of local granites and sediments – the course of Li mineralization, in had at University of Alberta
- The initial batch of zircons was analyzed for U-Pb and Hf from the basement of the Lac De Gras area.
- U-Pb and Hf data obtained for Mesoarchean basement in N. Slave (west of Tree River), around Eokuk uplift and on the northern coast – Discovery of an extensive Eoarchean terrane. Paper submitted to Precambrian Research
- U-Pb dating and Nd isotope study of Nachalacho REE deposits, southern Slave, submitted.
- Completed 90% of isotopic measurement campaign for Knee Lake diamond deposit, NW Superior craton (Oxford-Stull domain). Extensive X-ray diffraction analyses. The long abstract was published at the 12th International Kimberlite Conference, and the manuscript draft is being revised.
- Begun thermal modelling of craton roots (to be continued by post-doc Kristi Kublik once she has graduated with her PhD).
- Basement samples of the Hope Bay area were received. Mineral separation work began.

Future Work

- U-Pb, Hf and O isotope analysis of new field samples from Slave to expand the understanding of the new Eoarchean terrane.
- Perform U-Pb and Hf isotope analysis of basement samples of the Hope Bay area.
- Begin sample processing of the West Slave transect.
- Begin sample processing of Slave Li-Ta source area samples
- Publish Knee Lake study and inferences on NW Superior lithosphere
- Extend lithospheric thermal modelling to include latent heat of fusion effects and look at the temporal trends in the thermal evolution of cratonic lithosphere under different formation models and their potential implications for mineralization.

The new Eoarchean terrane discovered in the northern Slave is one of only 15 extant on Earth. This discovery should generate much interest in the early Earth community. Source: Dr. D.G. Pearson.

VIEW OR DOWNLOAD
Legros, H., Czas, J., Luo, Y. et al. Post-Archean Nb-REE-U enrichment in the Superior craton recorded in metasomatised mantle rocks erupted in the 1. 1 Ga Midcontinental Rift event. Miner Deposita 59, 373–396 (2024).
https://doi.org/10.1007/s00126-023-01214-7

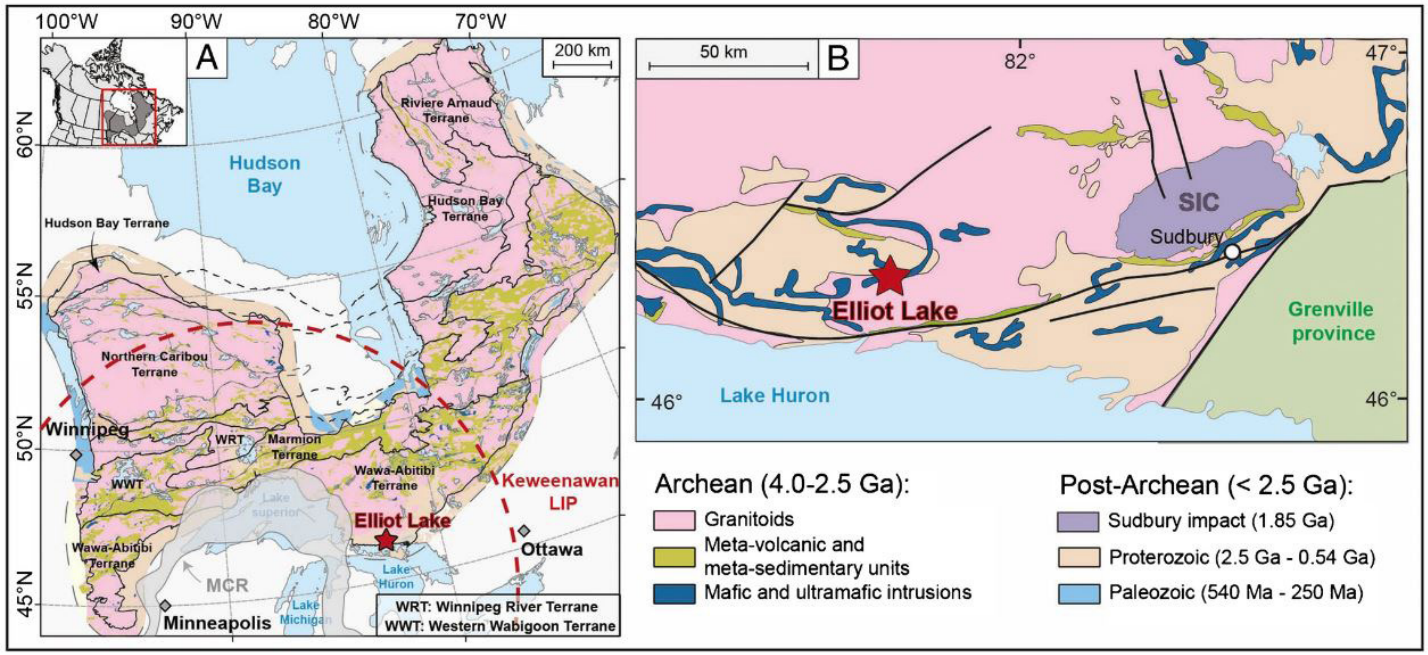
WATCH NOW!
Hélène Legros - *Nb-REE mineralization in the Superior and Slave cratons: source and geochronology*

Anticipated Outcomes

- Characterization of what might be one of Earth's largest Eoarchean terranes and the geological complexity that often masks the presence of these terranes.
- Implications for metallogeny in the sense that these very ancient terranes appear to have very poor endowment. Understanding how widespread they are has clear implications for exploration.
- Publication of a new understanding of the age and evolution of the ancient basement in the Hope Bay area and its relation to isotopic signatures in the mineralized greenstones.
- Much enhanced understanding of the geological evolution of the western Slave craton basement and the sources of its associated Neoarchean Li-Ta mineralized pegmatites.
- Definitive constraints on craton formation models from a combination of diamond inclusion P/T data and enhanced thermal modelling.

Implications

- The Slave geology studies make fundamental contributions to understanding the crustal architecture of a highly endowed cratonic nucleus, better enabling us to understand why mineralization is located where it is. The Slave craton was one of the key study areas of the original ME proposal.



- The thermal evolution modelling, in particular, will provide insights into how the lithospheric mantle evolves in temperature space over the first 500 Myr of craton evolution in various tectonic models. It will yield a new understanding of the time-scale of generation of mineralizing fluids and melts from the deep cratonic lithosphere, deepening our understanding of the role that this reservoir plays in mineral endowment within cratons.

Regional geologic maps of the study area. A) Main geologic formations and structures from the Superior Craton (East Canada). The map is after Montsion et al. (2018). Our case study is located in the Wawa-Abitibi terrane, in the SE part of the Superior craton. Keweenawan LIP spatial range and MCR are after Wu et al. (2017) and Stein et al. (2018), respectively. MCR=Midcontinent Rift, LIP=large igneous province; B) local geological map of the Elliot Lake area, north of Lake Huron and west from Sudbury (Ontario, Canada; after Lightfoot (2017)). Both gold and uranium paleo placers are disseminated within the Proterozoic sediments surrounding Elliot Lake while the Nipissing intrusions are part of the Archean mafic intrusions. Source: Legros et al 2024.

Highlights

- The new Eoarchean terrane discovered in the northern Slave is one of only 15 extant on Earth. This discovery should generate much interest in the early Earth community.
- The geochron study on Nachalacho, in review, has shown the very extended (>200 Myr) evolution of mineralizing processes in this deposit. This has interesting applications to other REE syenite/carbonatite deposits and clearly shows the power of baestnesite dating.

Modern Ocean Crust (Metal Oceans) & VMS Sub-project (Appended)

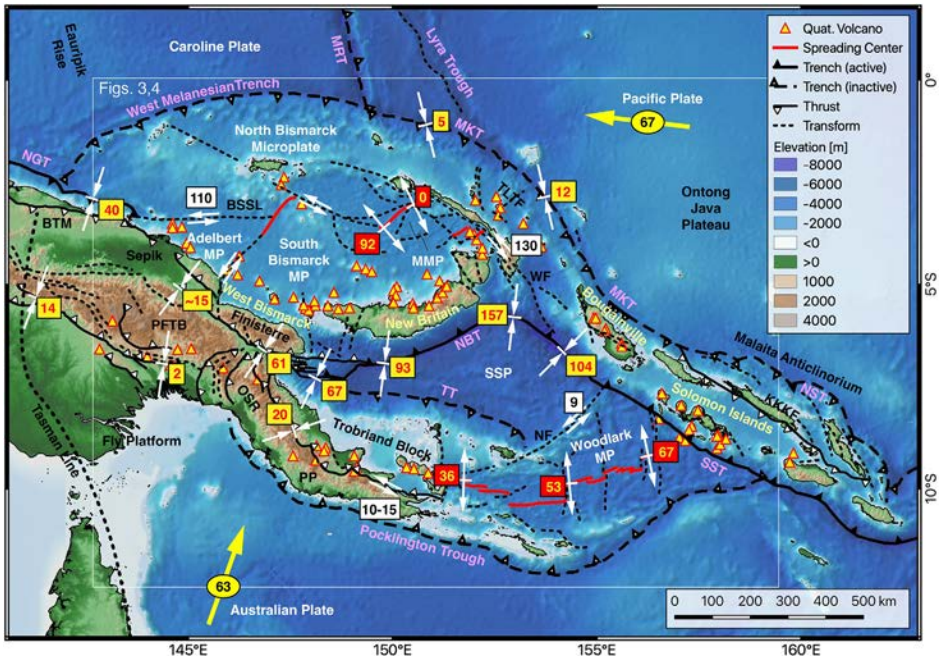
Dr. Mark Hannington, University of Ottawa

Progress

In 2023-24, Metal Oceans continued to work more closely with the Metal Earth team to compare modern microplate formation to greenstone belt assemblages at a scale useful for exploration. This research included quantitative modelling of crustal growth and a direct comparison of modern and ancient terranes.

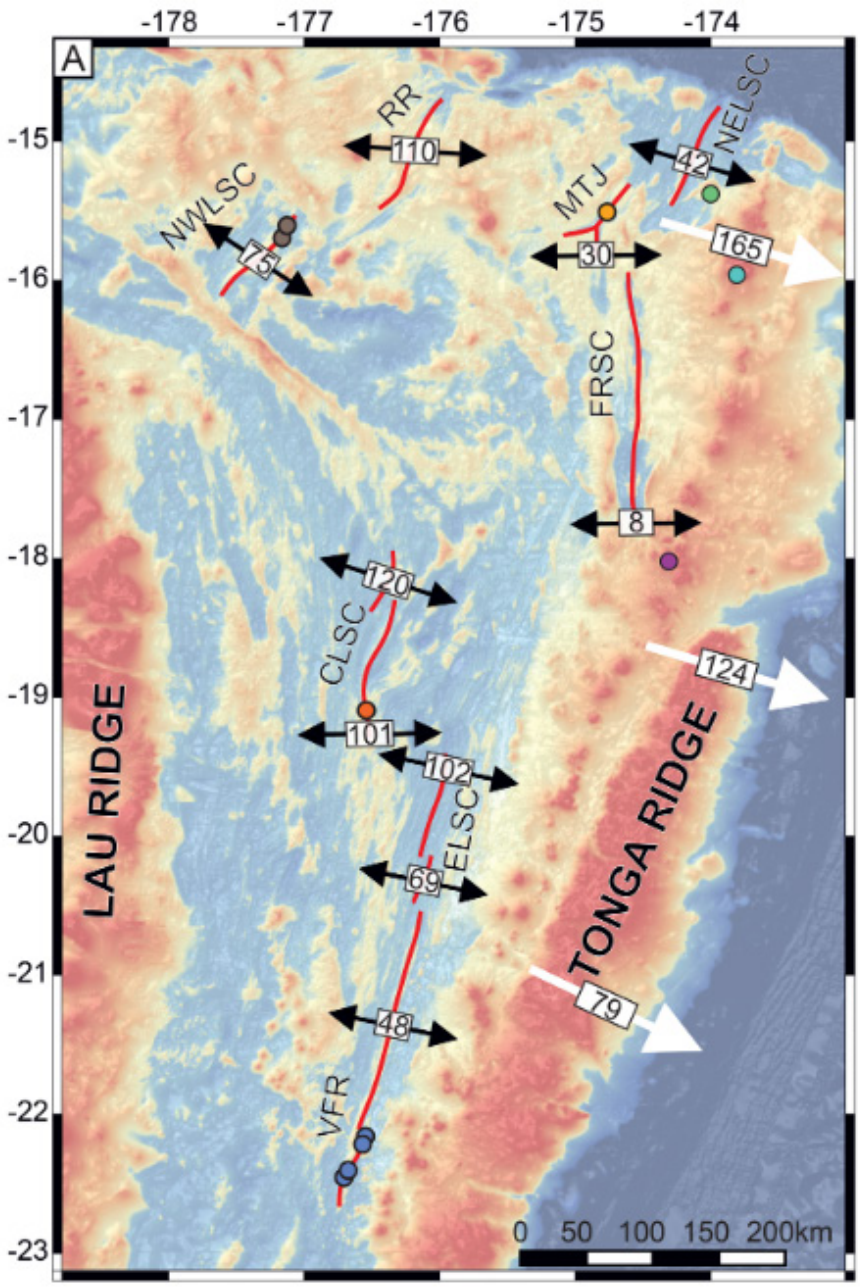
The interpretations of processed geophysical data from the Lau Basin (SO-267) were published in several papers. Multibeam, side scan, and magnetics were processed and incorporated into several new thesis products. Inversions of gravity and seismic data were advanced and are now being incorporated into the studies. Two GEOMAR PhDs (A. Jegen, G. Franz) and two postdoctoral fellows (A. Beniest, A. Avdeeva) completed the interpretation of the seismic and electromagnetic data, revealing significant conductive and non-conductive anomalies that coincide closely with deep structures at the microplate boundaries.

Two MSc (J. Kehew, M. Ryan) and two PhD students (T. Sitnikova, M. Fassbender) at UOttawa completed and defended their theses. In 2023-24, their work shifted from map production to modelling of crustal growth in different microplate systems. The completed thesis projects included: i) arc rifting in the Fonualei spreading center of the NE Lau Basin, ii) anomalous magmatism associated with the Rochambeau and Northwest Lau spreading centers in the Lau Basin, iii) links to intraplate magmatism and mantle input in the Niuafo'ou assemblages, iv) diachronous extension in the NE Lau back-arc basin, and v) rift propagation into the southern NFB margin. Individual research projects have established type sections for the different settings that can be compared with ancient analogs.



Morpho-tectonic map of eastern Papua New Guinea and the Solomon Islands. White labels denote tectonic plates, light yellow to active magmatic arcs, and light purple to troughs and trenches. Numbers denote relative plate motions and are given in mm a–1 for convergence (yellow box), divergence (red box), and transfer (white box). Abbreviations: BSSL – Bismarck Sea Seismic Lineation, BTM – Bewani–Torricelli Mountains, KKKF – Kia-Kaipito-Korigole Fault zone, MKT – Manus-Kilinailau Trench, MMP – Manus Microplate, MP – Microplate, MRT – Mussau Ridge and Trench, NBT – New Britain Trench, NF – Nubara Fault, NGT – New Guinea Trench, NST – North Solomon Trench, OSR – Owen Stanley Ranges, PFTB – Papuan Fold and Thrust Belt, PP – Papuan Peninsula, SSP – Solomon Sea Plate, SST – South Solomon Trench, TLTF – Tabar-Lihir-Tanga-Feni island chain, TT – Trobriand Trough, WF – Weitin Fault. Source: Brandl et al, Lithosphere, 2024

WATCH NOW!
Mark Hannington - *Metal Oceans - Modern-Ancient Crust Project; Metal Earth scientific meetings March 2024, Toronto*



J. Kehew and M. Ryan presented their results on intrabasinal sedimentation and magmatic productivity. Sitnikova and Fassbender presented their results on regional-scale evolution of back-arc basins, including petrogenetic evolution. Two Honour's BSc students (R. Dentelbeck and R. Magee) completed projects on the Niuafo'ou intraplate volcano and on intraplate volcanism in the NFB. Students were assisted in their research by RAs Erin Bethell and Alan Baxter.

Postdoctoral fellow C. Galley completed the first large-scale constrained 3D inversions of gravity in the Lau Basin. The results involved state-of-the-art computational approaches supported by the infrastructure of the Digital Alliance Canada. The inversions highlighted strong links between the microplate mosaic and mantle upwelling that can be compared to the architecture of greenstone belts. These findings have been submitted for publication in the Journal of Geophysical Research and are currently being compared to similar modelling of the Moho topography of the Abitibi greenstone belt. Comprehensive crustal-scale inversions are currently underway for the NFB and easternmost PNG.

The regional kinematics and stress regime of the northern Lau Basin has been integrated into a GPlates model by research associate A. Baxter. The new model is providing a unique solution to the rapid growth of the Niuafo'ou microplate, which is linked to the emergence of the MTJ in the north and the Peggy Ridge transform boundary in the west. A manuscript on the GPlates modelling is nearing completion.

Results of the ongoing lithogeochemical compilation of the Lau Basin have been published in the second of a series of papers in Economic Geology (Fassbender et al., 2023, 2024). A machine-learning approach was developed to classify magmatic suites according to discrete

WATCH NOW!
Alan T. Baxter - *Applied Geodynamics - Crustal architecture, sedimentation and metallogeny in syn-collisional settings; Metal Earth scientific meetings March 2024, Toronto.*

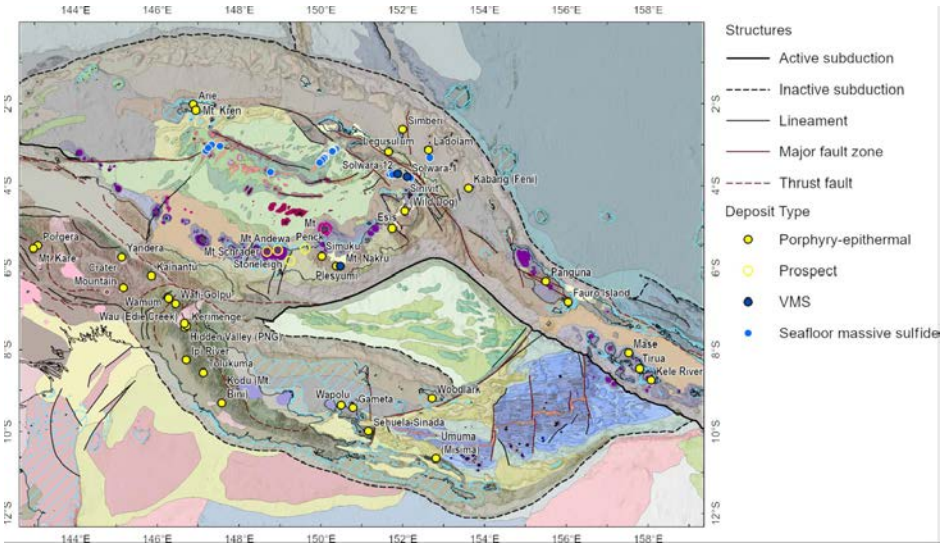
A) Regional bathymetric map of the Lau back-arc basin (Ryan et al., 2009) showing spreading ridges, spreading rates, and rates of retreat of the active arc (in mm/yr; modified from Sleeper and Martinez, 2016). The basin includes at least eight major zones of active extension: ELSC = Eastern Lau spreading center; VFR = Valu Fa Ridge; CLSC = Central Lau spreading center; FRSC = Fonualei rift and spreading center; MTJ = Mangatolu Triple Junction; NELSC = Northeast Lau spreading center; NWLSC = Northwest Lau spreading center; RR = Rochambeau rifts. Source: Fassbender et al, 2024.

volcanic and tectonic settings of the arc-backarc system. These findings are also compared to Archean greenstone assemblages in the Abitibi. New 40Ar/39Ar data highlight the complexity of the crustal growth in the back-arc of the Lau Basin, including non-linear rift propagation and microplate growth.

A new 1:1 million geological map of the marginal basins of eastern PNG (P. Brandl) has been submitted for publication with an accompanying manuscript. The paper, submitted to Lithosphere, focuses on the geodynamic influences of large-scale oblique collisions on regional metallogeny. This is the second in the series of maps that included Stewart et al.'s contribution on the Lau Basin. A third map in this series of the N. Fiji Basin (A. Baxter, R. Mensing, T. Sitnikova) is currently in progress.

The ARCHIMEDES II Transect DynaMet (SO-299) in eastern PNG was completed, and a cruise report has been submitted to the funding agency (Brandl et al.). The cruise's results will be published following the release of the new 1:1 million geological map of this area.

Closer collaboration with MERC researchers was initiated to identify type sections for different assemblages and formations in modern back-arc basins that can be compared to the Abitibi greenstone belt. A dedicated workshop and discussions about a new postdoctoral project on Abitibi comparisons are underway. A 2-day workshop involving Metal Earth and Metal Oceans was held in Ottawa in October 2024.



Main copper–gold deposits of eastern PNG and the Solomon Islands and seafloor massive sulfide deposits superimposed on the reduced version of the geological map on the formation level.

Source: Brandl et al, Lithosphere, 2024.

- Completed assemblage-level attributes tables and structural/stratigraphic sections for the study areas (Metal Oceans team)
- Published 2D and 3D inversions of Lau Basin seismic sections, gravity and MT (A. Jegen, A. Beniest, F. Schmid, published)
- Completed microplate reconstruction of the northern Lau Basin and Fiji Basin in GPlates (A. Baxter)
- Completed lithogeochemical comparison of endowed versus non-endowed oceanic settings (M. Fassbender, published)
- Completed ARCHIMEDES II Transect in the marginal basins of PNG (SO-299, June-July 2023)
- Completed constrained 3D inversion of regional gravity of the Lau Basin (C. Galley et al., submitted)

Milestones and Deliverables:

Use of Human Resources:

RAs (A. Baxter, E. Bethell): conducted data compilation and synthesis for seafloor mapping; geological interpretations at 1:1 million scale; large-scale tectonic reconstructions; interpretation and quantitative modelling of crustal growth, with direct comparison to architecture and mineral endowment in greenstone belts. D. Diekrup moved to the Geological Survey of Newfoundland but continues participating in Metal Oceans and the VMS Sub-project 3b (appended).

PDF (C. Galley): Marine geophysical expertise for analysis and inversion of seismic, magnetic, and gravity data in the Lau Basin. Chris is leading the comparison of crustal density models of the modern ocean transects with the Metal Earth transects in the Abitibi.

PhD (M. Fassbender): completed litho-geochemical database compilation; interpretation of the Lau Basin; comparisons with greenstone belt evolution; and global compilation of submarine mafic and felsic volcanic rocks. PhD thesis defended on May 30, 2023.

WATCH NOW!
Chris Galley - *Identifying Neoarchean rifting using gravity modelling; Metal Earth scientific meetings March 2024, Toronto*

PhD (T. Sitnikova): regional geological compilation of the Fiji Basin, including magmatic and tectonic evolution of high-heat flow intraoceanic back-arc basin and comparisons with greenstone belt evolution. Continuing in 2024-25.

MSc students (J. Kehew, M. Ryan): targeted 1:100,000 mapping of key areas related to back-arc evolution, microplate formation, and the emergence of magmatic-hydrothermal mineralizing systems. They defended in October and December 2023.

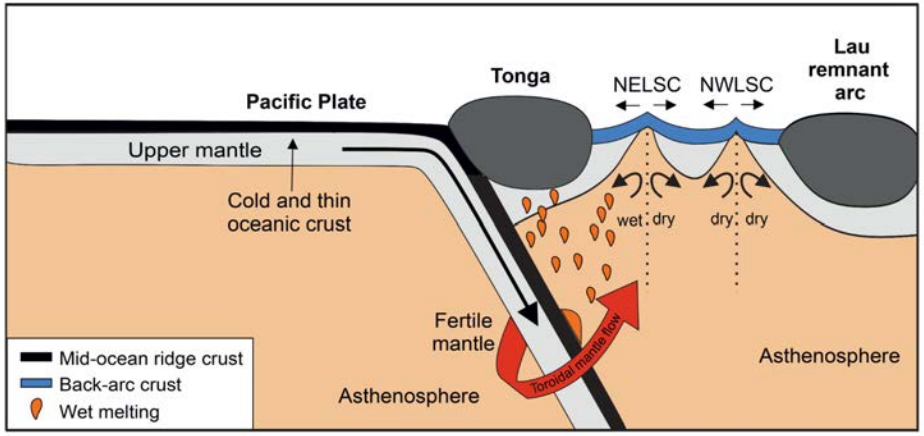
BSc Honours students (R. Dentelbeck, R. Magee): targeted 1:100,000 mapping of the Niuafo'ou assemblage of the NE Lau Basin and the intraplate volcanoes of the NFB with an emphasis on quantifying magmatic productivity and magmatic-hydrothermal activity. Completed in April 2023 and 2024.

The GEOMAR Team continued to support Metal Oceans objectives, working on other regional mapping initiatives, geophysical compilations, modelling, and cruise preparation: S. Petersen, P. Brandl, M. Klischies, A. Krätschell.

Future Work

The focus for 2024-25 will be on completing the Indo-Australian margin maps (Lau Basin, North Fiji Basin, Bismarck Archipelago) and comparisons with possible microplate mosaics in the Abitibi region. Collaboration with MERC researchers will focus on identifying type sections that can be compared to Abitibi assemblages. The work will include:

- Compilation and interpretation of processed geophysical data from ARCHIMEDES II (DynaMet SO-299) focusing on structures related to terrane collision. These data will be prepared for several new publications in 2024-25.
- PhD candidate T. Sitnikova will continue her work on the evolution of back-arc basins, with emphasis on the North Fiji Basin. Targeted PhD thesis completion in 2025.
- Postdoctoral fellow C. Galley will assemble and publish the first large-scale gravity inversions of the Lau Basin, NFB, and easternmost PNG, together with a comparison to crustal models of the Abitibi. The Lau Basin inversion model is completed.
- A. Baxter will complete the regional kinematic model of the northern Lau Basin in GPlates. The new model will incorporate propagating rifts, which are not part of the standard GPlates output. This work will be submitted for publication in 2024.
- The results of 40Ar/39Ar dating of the Lau Basin microplate crust will be submitted for publication by M. Fassbender.



Schematic illustration of general mantle flow at microplate edges and terminating back-arc spreading centers as in the northeast Lau basin. Different mantle flow regimes may be dominated by (1) hydrated mantle, due to dehydration of the subducting slab; (2) asthenospheric dry mantle, due to mantle upwelling; and (3) fertile mantle introduced into the back-arc region via flow around the subducting slab. These three mantle components are all present near the slab tear at the northeast corner of the Tonga Plate. Models suggest the fertile asthenospheric mantle is brought into the back arc by toroidal flow around the slab (e.g., Magni, 2019) and is not related to direct influx from the Samoan hotspot (Haase et al., 2022). Source: Fassbender et al, 2024.

Highlights

Scientific:

- Two papers in Economic Geology on the lithogeochemistry of Lau Basin volcanic rocks. Two MSc theses (J. Kehew, M. Ryan) and one PhD (M. Fassbender) defended. One manuscript on the seismic data was published in G-Cubed (Jegen et al.), and a second manuscript is in preparation (Beniest et al.). Two papers were submitted to Lithosphere (P. Brandl) and the Journal of Geophysical Research (C. Galley).

VIEW OR DOWNLOAD

Brandl, P. A., Hannington, M. D., Krätschell, A., Petersen, S., Baxter, A. T., Stewart, M. S., Galley, C., Emberley, J., & Sander, S. G. (2024). A New Geological Map of the Marginal Basins of Eastern Papua New Guinea: Implications for Crustal Accretion and Mineral Endowment at Arc–Continent Collisions. Lithosphere, 2024(4). https://doi.org/10.2113/2024/lithosphere_2024_145

- A special issue/review volume will be assembled on "Arc-Rifting and Back-arc Basin Development with Implications for Metal Endowment in Modern and Ancient Oceanic Crust" (see contents below). Results of 2 PhDs and 5 MSc thesis projects will be published in this volume.

Milestones and Deliverables:

- Results of ARCHIMEDES II Transect (SO-299 completed for publication in 2024)
- Assemblage-level attributes tables and structural/stratigraphic sections, including Eastern PNG-New Ireland geodynamics and metallogeny (to accompany 1:1 million maps, P. Brandl, new for 2024-25)
- North Fiji Basin 1:1 million geological compilation (A. Baxter, T. Sitnikova, new for 2024-25)
- Constrained 3D gravity and seismic inversions of eastern PNG and NFB (C. Galley, new for 2024-25).
- Characterization of mantle sources participating in back-arc basin evolution (M. Fassbender et al., new for 2024-25)
- Microplate reconstruction and GPlates model of the northern Lau Basin and Fiji Basin (A. Baxter, new for 2024-25)
- First-order assemblage-level comparison with the Abitibi (based on outcomes of the workshop scheduled for 2024)

Further, the team will produce a Special Publication on Metal Oceans, including at least four Thematic papers and eight Case Studies.

Thematic Papers:

- Microplate Solutions to Crustal Growth and Metal Endowment with Implications for Greenstone Belts (Synthesis Paper, Hannington et al.)
- Origin and Evolution of Lithospheric-scale Structures in Oceanic and Arc Crust (Baxter et al.)
- Identifying Neoarchean Seafloor Spreading using Modern Back-arc Basin Analogs: Results of Regional Geophysical Inversions (Galley et al.)
- Linking Geochemical Signatures of Volcanic Rocks to Geodynamics in Modern Oceanic Settings: Examples of Mantle Domains from Microplate Architecture (Fassbender et al.)

Case Studies:

- Geology of the Fonualei Rift and Spreading Center (Hannington et al.)
- Geology of the Mangatolu Triple Junction (Mensing et al.)
- Geology of the Rochambeau Rifts and NWLSC (Ryan et al.)
- Back-arc sedimentation in the Lau Basin (Kehew et al.)
- Geology of the Niuafo'ou Volcanic Complex (Dentelbeck et al.)
- Geology of the Louisville Segment and Monowai Volcano, Tonga-Kermadec (Gray et al.)
- Geology of the North Fiji Basin Triple Junction (Besaw et al.)
- Geological Map of the Marginal Seas of Eastern Papua New Guinea: Insights into Regional Metallogeny of the Melanesian Archipelago (Brandl et al.)

Use of Human Resources:

HQP from Year 7 will continue to work on the project, including one MSc and two PhD students (Fassbender, Sitnikova, Dentelbeck). The work will shift from map production and case studies to interpretation and modelling of crustal growth for comparison with greenstone belts. To ensure timely completion, postdoctoral fellows and research assistants (Baxter, Bethell, Galley) will take over a larger share of the publication process.

Anticipated Outcomes

We have developed the first high-resolution structural-magmatic framework for microplate evolution and metallogenesis in several large-scale transects across the Lau Basin, North Fiji Basin, and marginal basins of Eastern PNG for comparison with greenstone belt architecture and metal endowment.

Outcomes of the project will include establishing type sections for different assemblages that can be compared to greenstone belt assemblages; documentation of the architecture and evolution of different types of microplate boundaries, including triple junctions, ridge-transform boundaries, and arc rifts (from precursors through inception, to failure); identifying different types of unconformities between assemblages; establishing sedimentary sequence stratigraphy of back-arc and intra-arc sub-basins to identify different stages and styles of arc rifting and back-arc opening; quantitative comparisons of crustal growth (magma volumes and area-age relationships as a first-order metric); modelling of microplate mosaics, and especially links to mantle topography, as a guide to identifying similar structures in deformed terranes; detailed lithogeochemical comparisons of magmatic suites in different types of assemblages and microplate settings. New for 2024-25 will be expanded 3D inversions of gravity, regional lineament analysis, comparisons of regional metallogeny with extensional and compressional tectonics in different settings, and criteria for identifying fossil

microplate architecture in greenstone belts.

Results published or presented in 20 publications, reports, and theses: 5 papers for peer-reviewed journal articles (published or submitted), 6 student theses, 1 cruise report, and 8 conference abstracts at national and international scientific meetings (See Publications).

13 continuing active participants from 6 institutions have received training as part of the project. An additional 19 collaborators have been involved from across Canada and abroad. Members of the Metal Oceans team in Ottawa continue to work alongside researchers at MERC to ensure the results are being applied directly to Metal Earth's objectives. ME funds continue to be significantly leveraged through external partnerships, including direct and indirect in-kind contributions. Six members of GEOMAR (Petersen, Brandl, Krätschell, Klischies, Lange, Jegen, and Beniest) continue to work directly with the Ottawa Team.

Implications

New knowledge of the thermal and structural evolution and architecture of modern microplate systems is important for understanding ancient crustal growth and metal endowment. While the modern interactions are mainly driven by subduction, which may or may not have operated in the same way in the Late Archean, the responses to plate stresses in the form of microplate formation, autochthonous growth, mantle flow, and development of critical melt and fluid pathways are expected to be very similar. This project is investigating the role of microplates in controlling melt and fluid pathways – a role that may be common to both modern oceanic crust and ancient greenstone belts.

Relevant Metal Earth themes:

- Craton and greenstone belt assembly study
- Geophysical and geological transects

Relevant Metal Earth Questions

- Is there an architectural and or structural control on crustal-scale ore fluid pathways?
- How is the structural evolution of major fault systems related to metal endowment? Is there a common structural evolution of endowed structures? Does it differ from similar structures in less endowed areas?
- How did Archean tectonics differ from Phanerozoic, subduction-driven tectonic models based on Archean crustal architecture and gold and base metal metallogeny?
- Data integration and interpretation tools for assessing metal endowment predictability.

Highlights

Personnel

- E. Bethell, C. Galley, and A. Baxter were co-convenors of a Special Session of the GAC-MAC Annual Meeting in Sudbury on Marine Geodynamics and Georesources, May 2023.
- J. Kehew (MSc student) presented her research on intrabasinal sedimentation and tectonostratigraphy of the Lau Basin at GAC-MAC and Prospectors and Developers Association of Canada (PDAC) - Society of Economic Geologists (SEG) Student Minerals Colloquium.
- T. Sitnikova (PhD student) presented her research on arc-rifting in a nascent subduction zone of the south Fiji Basin at the Prospectors and Developers Association of Canada (PDAC) - Society of Economic Geologists (SEG) Student Minerals Colloquium.
- R. Dentelbeck (BSc Honour's student) presented her research on the Niuafo'ou volcanic complex at the Prospectors and Developers Association of Canada (PDAC) - SEG Student Minerals Colloquium and received one of the undergraduate poster awards.
- M. Fassbender (PhD student) defended on May 30, 2023. J. Kehew and M. Ryan (MSc students) defended in October and December 2023.

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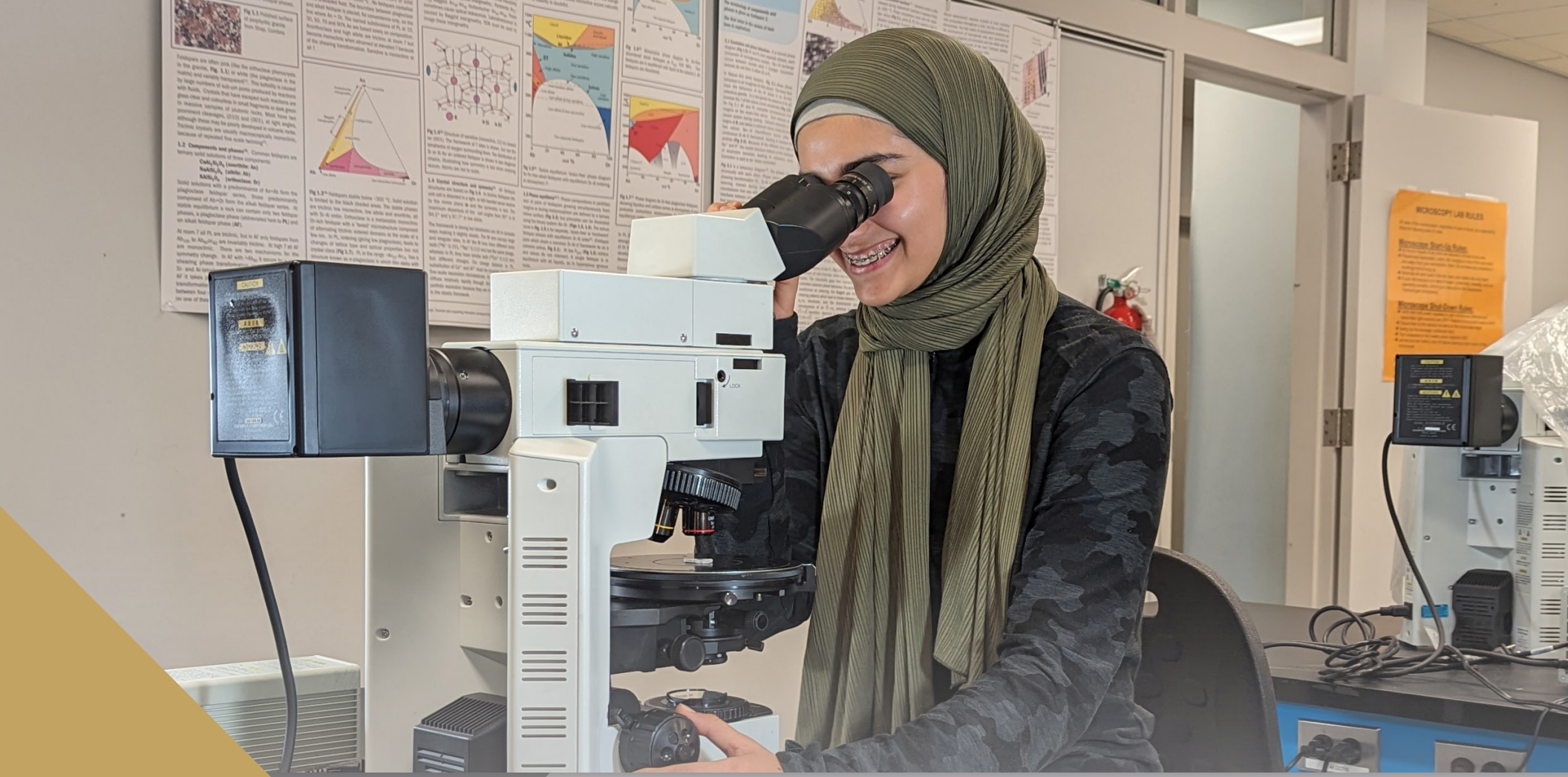

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