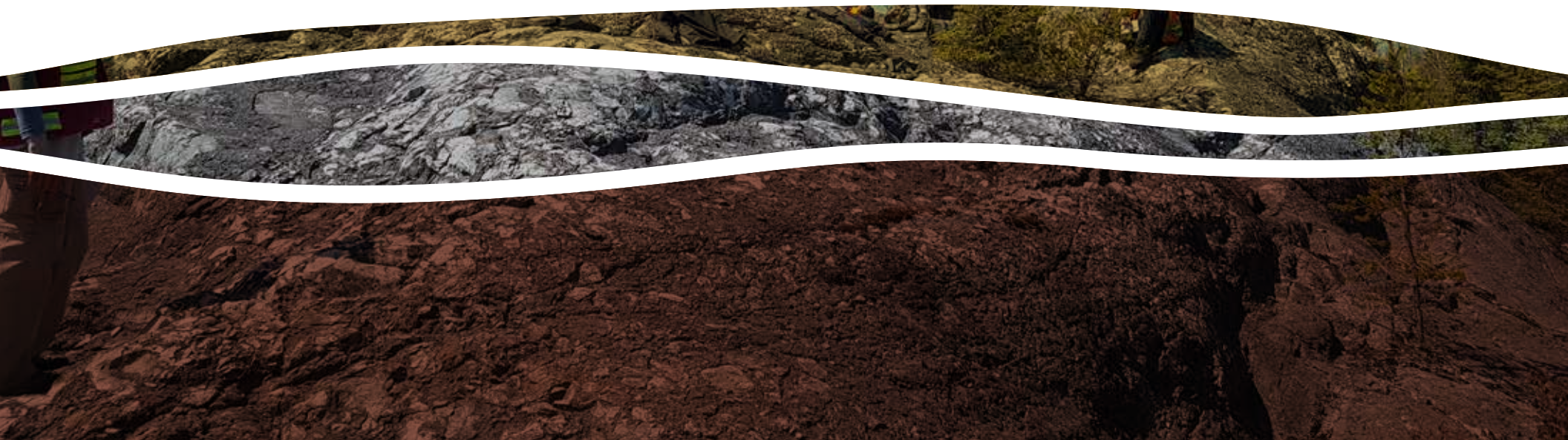
MERC

Mineral Exploration Research Centre
at the HARQUAIL School of Earth Sciences

ANNUAL REPORT 2020-21



IN THIS REPORT

MERC

Metal Earth

About us

Laurentian University's Mineral Exploration Research Centre (MERC) in Sudbury, Ontario, Canada, conducts and promotes global, collaborative, lab- and field-based research focused 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, which is one of the largest public geoscience research projects in the world.

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

WATCH NOW!
Metal Earth - Benefits to Canada

WATCH NOW!
Metal Earth - Building Research Capacity

104M largest university-led geoscience project in the world

Message from TAMMY **EGER**

VP Research, Laurentian University

Reviewing the contents of the Mineral Exploration Research Centre's 2020-21 annual report, the volume and calibre of geoscience research produced by MERC and the Metal Earth project is remarkable.

This is critically important work providing scientific breakthroughs – and the development of highly-qualified professionals that the world needs to keep up with mineral resource demands.

Through this work, MERC, and the $104M Metal Earth geoscience research project are transforming our understanding of Earth's early evolution and formation of metal deposits while developing the next generation of geoscientists.

Support for Metal Earth has enabled the Harquail School of Earth Sciences (HES) and MERC to establish extensive collaborations with other leading global research institutions, industry partners, and government geological surveys.

International collaborative multidisciplinary projects have never been conducted at this scale in Canada, and they position Laurentian as a global leader in geoscience and mineral exploration research.

The activities enclosed in this report demonstrate MERC's success in attracting a diverse group of highly qualified professionals and students who are collectively advancing geoscience knowledge and initiatives and attracting global attention.

As Vice-President, Research, at Laurentian University, it is my pleasure to introduce this annual report outlining the progress and outcomes of MERC and the Metal Earth project.

WATCH NOW!
About Metal Earth (2021)

Message from ROSS **SHERLOCK**

MERC and Metal Earth Director

44.1M MERC-managed research funds, 2015-2020

As MERC and Metal Earth Director, I'm pleased to present this annual report, which outlines the tremendous progress made by researchers, students, faculty and staff. We have compiled a thorough update of our MERC and Metal Earth projects, providing a view of research results and future plans.

I would like to thank our funding, industry, government, and institutional partners for their continued support through this year, which marks year five of the Metal Earth project. Despite challenges posed by COVID-19 and the CCAA process at Laurentian University, this report documents many breakthroughs in geoscience research, high-profile publications, and remarkable accomplishments by researchers, students, faculty, and staff.

As a leading mineral exploration research centre focused on ore deposits, and an arm of the Harquail School of Earth Sciences (HES) we offer an integrated approach to undergraduate and graduate studies through applied research, education, and HQP training that is designed to

i) solve challenges related to mining and mineral exploration,

ii) fill knowledge gaps and promote the advancement of geological and exploration education, and ultimately

iii) supply the sector with a qualified workforce.

The Canada First Research Excellence Fund's support of the Metal Earth project has a positive impact on Laurentian University. Together with our partners, we are collaborating with researchers from various backgrounds and countries around the world, making valuable scientific breakthroughs. The volume and quality of geoscience and mineral exploration research have continued to increase -exponentially, and positive attention from industry continues to build.

While 2020 was an exceptional year because of the pandemic, in review, it was a remarkable year for adaptation, collaboration, and sharing results.

I am pleased to present this report on our activities and look forward to what the next year will bring.

Foundation Members

Tier 1 Members

Tier 2 Members

Metal Earth health and safety program allows for essential exploration activity during pandemic

Taus R. C. Jørgensen, Research Associate
Mineral Exploration Research Centre (MERC), Harquail School of Earth Sciences
Laurentian University

Published on September 16, 2020, PDAC Geoscience Resources

The Atikokan Field Crew, Summer 2020
Left to right: Mohamed Farhat, MSc student Metal Earth; Gabrielle Fouillard, MSc student Metal Earth; Dr. Bruno Lafrance, Structural Geology professor at Harquail School of Earth Sciences, and Metal Earth Associate Director; and Khadija Kadu, field assistant from the University of Waterloo

Since its inception in 2016, Canada's largest mineral exploration research project, Metal Earth, has developed and improved upon an extensive field crew health and safety program for new and experienced researchers. Typically, up to 50 geoscientists are engaged in summer fieldwork for four months, across 13 transects in the Superior Craton. The coronavirus pandemic impacted both the duration of the 2020 field season and the number of researchers involved. Under new provincial and university health and safety guidelines, 18 researchers cautiously continued essential research activities, with only half of the usual field season.

Researchers had to self-isolate for 14 days before departure. This delayed plans but was necessary to protect communities, individuals, and crews from possible viral exposure and illness in the field. New protocols including symptom assessments, regular hand-washing and sanitizing vehicles were added to the daily safety routine involving a toolbox meeting, equipment and vehicle checks, and emergency communication planning.

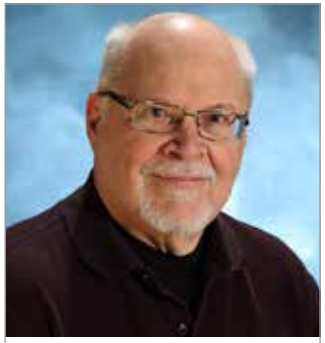
International travel restrictions meant fewer tourists in remote towns and lodges, making it easier to book accommodations. Nevertheless, interactions with people outside the crew "bubbles" were inevitable and occurred periodically to acquire gas and provisions. However, acting safely and complying with protocols, e.g., wearing masks, was consistently enforced. The shorter field season meant no room for error because our projects depend on gathering necessary field data.

The successful implementation of new pandemic protocols was possible because of dedicated crews and our safety culture. This begins with our extensive training program, modelled upon the Ontario Geological Survey safety manual and the Occupational Health and Safety Act Green Book. During a full week of health and safety training, crews are exposed to off-road vehicle driving, first aid, ergonomics, sexual harassment and assault awareness, and modules on fatigue, forest fires, and wildlife encounters.

Some researchers experienced incidents like heat stroke, sunburn, or strained Achilles tendons, but crews dealt with these issues in the field. Minor incidents act as a test to the system, ensuring protocols are working.

Moving through this shortened field season built our crews' confidence in handling evolving situations and demonstrated that they could put training into practice. This is an essential skill, and we are proud of how our new and experienced researchers performed. Two crew members near Rainy River even helped others in need, finding and returning two lost and exhausted beagles to their owner.

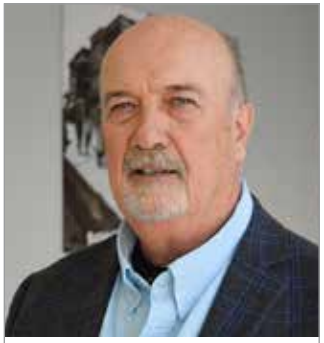
Administration



John Ayer
MERC Associate Director, Adjunct Professor

Lynn Bulloch
Communications Manager

Courtney Folz
Administrative Coordinator



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

Natalie Lafleur-Roy
Finance and Operations Administrative Manager

Bruno Lafrance
Metal Earth Associate Director

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

Research Leads


Ademola Adetunji


Sheree Armistead

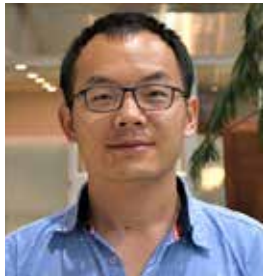

Saeid Cheraghi


Ben Frieman


Rasmus Haugaard


Gaetan Launay


Taus Jørgensen


Chong Ma


Haiming Liu


Jeff Marsh

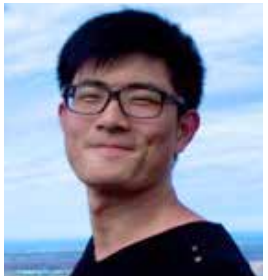

Kate Rubingh


Eric Thiessen


Szuszanna Toth


Gyorgyi Tuba


Rajesh Vayavur


Longbo Yang

IT/GIS Support

Benjamin Daniels, *GIS Specialist*

Kipp Grose, *IT Technologist*

Brandon Smith, *GIS Specialist*

Graduate Students - PhD

Sandra Baurier Aymat

Fabiano Della Justina

Nicolas Estrada

Thomas Gemmell (OGS)

Hossein Jodeiri Akbari Fam

Klaus Kuster

Christopher Mancuso

Dylan McKevitt

Xuyang Meng

Rebecca Montsion

Kristine Nymoen

Dustin Peters

Adrian Rehm

Eric Roots

Marina Schofield

Henning Seibel

Keaton Strongman

Graduate Students - MSc


Sahibzada Ali


David Downie


Mohamed Farhat


Gabrielle Fouillard


Anna Haataja


Stefanie Kisluk


Mattea McRae


Benjamin Mark


Amokelani Mavundza


Julian Melo Gomez


Blake Mowbray


Ruth Orloci-Goodison


Louise Rush


Connor Small

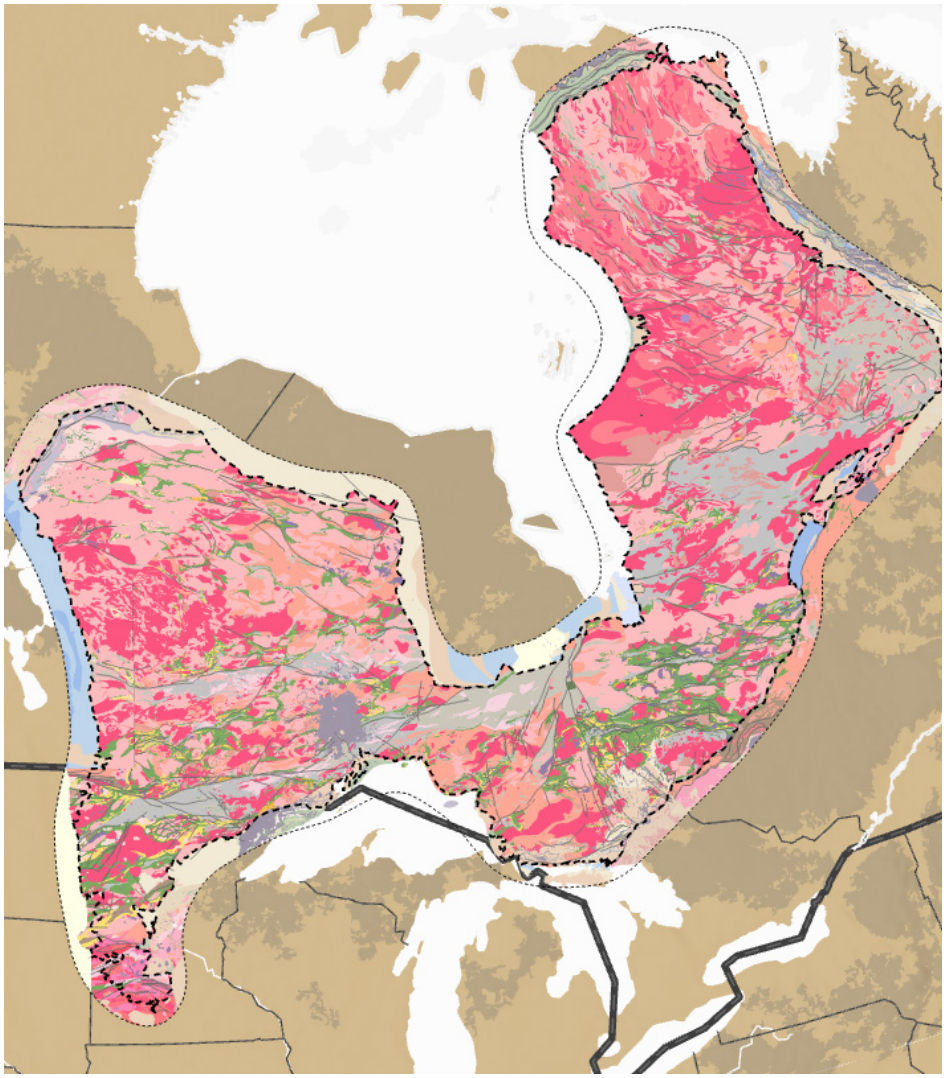

Michael Tamosauskas


Limin Xu

WATCH NOW!
Metal Earth: A Canadian Mineral Exploration Research Project (2019)

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 research and development program led by Laurentian University.

The project will transform our understanding of the genesis of base and precious metal deposits during Earth's evolution. It will make Canada a world leader in mineral deposit 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 will be 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

Metal Earth Science Advisory Board Members

METAL EARTH

Australian Government
Geoscience Australia

GOLD FIELDS

LULEÅ UNIVERSITY OF TECHNOLOGY

Natural Resources Canada | Ressources naturelles Canada
Canada

THE UNIVERSITY OF BRITISH COLUMBIA

UPPSALA UNIVERSITET

UNIVERSITY OF WATERLOO
FACULTY OF SCIENCE

Rodney L. Allen
Consulting Geologist and Adjunct Professor, Economic Geology, Luleå University of Technology, Sweden

Benoît Dubé
Research Scientist, Natural Resources Canada and Science Advisor, MERC

Andrew Foley
Geophysicist, Gold Fields

Eric Grunsky
Adjunct Professor, University of Waterloo

David Huston
Research Scientist, Geoscience Australia

Alireza Malehmi
Professor, Geophysics, University of Uppsala, Sweden

Patrick Mercier-Langevin
Research Geoscientist, Natural Resources Canada

John A. Percival
Research Scientist, Natural Resources Canada

Richard Tosdal
Independent Consultant, Past-Director, MDRU, and CMIC Footprints project

Dominique Weis
Professor and CRC in Geochemistry of the Earth's Mantle, University of British Columbia

Metal Earth Primary Academic Partners

METAL EARTH

UQAC
UNIVERSITÉ DU QUÉBEC
À CHICOUTIMI

uOttawa

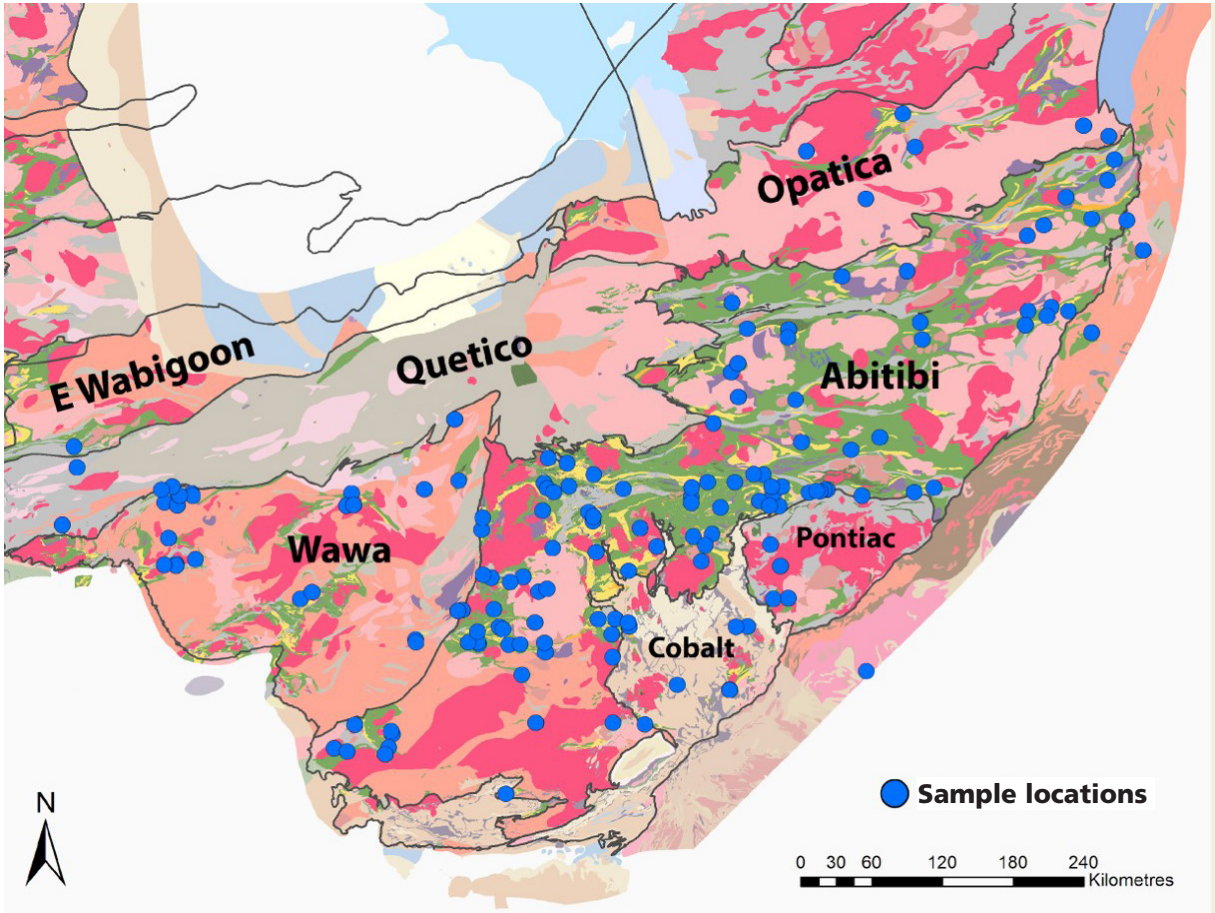
UNIVERSITÉ
LAVAL

UNIVERSITY
OF ALBERTA

UNIVERSITY OF
TORONTO

Isotopic Studies

Lead Researchers: Phillips Thurston and David Mole



A PhD study began in January 2020 to perform detailed spatial isotopic work, along with other items in the study program.

Lithospheric and crustal architecture, the framework of major tectonic blocks, terranes and their boundaries, represents a fundamental first-order control on major geological systems including ore deposits and the location of world-class mineral camps. Previous work, particularly by Begg et al. (2009) and Begg et al. (2010), used seismic tomography to demonstrate how gold and Ni-Cu-PGE camps are controlled by major intercratonic lithospheric discontinuities. In other studies, workers attempting to constrain time-resolved intracratonic lithospheric architecture turned to the mapping of isotopic systems from crustal rocks (mainly granitoids). Champion and Cassidy (2007) used regional Sm-Nd isotopic data to map the crustal architecture of the Yilgarn Craton, and Mole et al. (2013) demonstrated the association between that lithospheric architecture and BIF-hosted iron, orogenic gold, and komatiite-hosted Ni-Cu-PGE systems. Those results demonstrated the underlying control of lithospheric architecture and the potential for isotopic mapping as a greenfields area selection tool.

Further work by Mole et al. (2014), using Lu-Hf isotopes, demonstrated that the technique could account for mineral systems of different ages, showing how Ni-Cu-PGE mineralized komatiite systems of the Yilgarn Craton migrated with the changing lithospheric boundary (craton margin) from 2.9 to 2.7 Ga. Similar work has since been performed in West Africa (Parra-Avila et al., 2017), Tibet (Hou et al., 2015), and Canada (Lu et al., 2013); Bjorkman et al. 2015).

This project aims to take that technique and apply it to the Superior Craton, in a bid to constrain large-scale intracratonic controls on magmatism, crustal evolution, and mineralization in the Earth's largest Archean terrane. This will be done in a much higher resolution, both spatially and temporally than previously contemplated.

METAL EARTH **CRATON SCALE RESEARCH**

Progress

- Completed Lu-Hf study on the southeast quadrant of the Superior craton, mainly the Abitibi subprovince, involving ~ 200 zircons and over 8000 analyses including the combination of 4 new methods of using zircon geochemistry to constraint magma temperature, state of hydration and oxygen fugacity.
- Produced two craton-scale publications, both in journals with high impact factors: Precambrian Research and Geochemistry, Geophysics and Geosystems.

Future Work

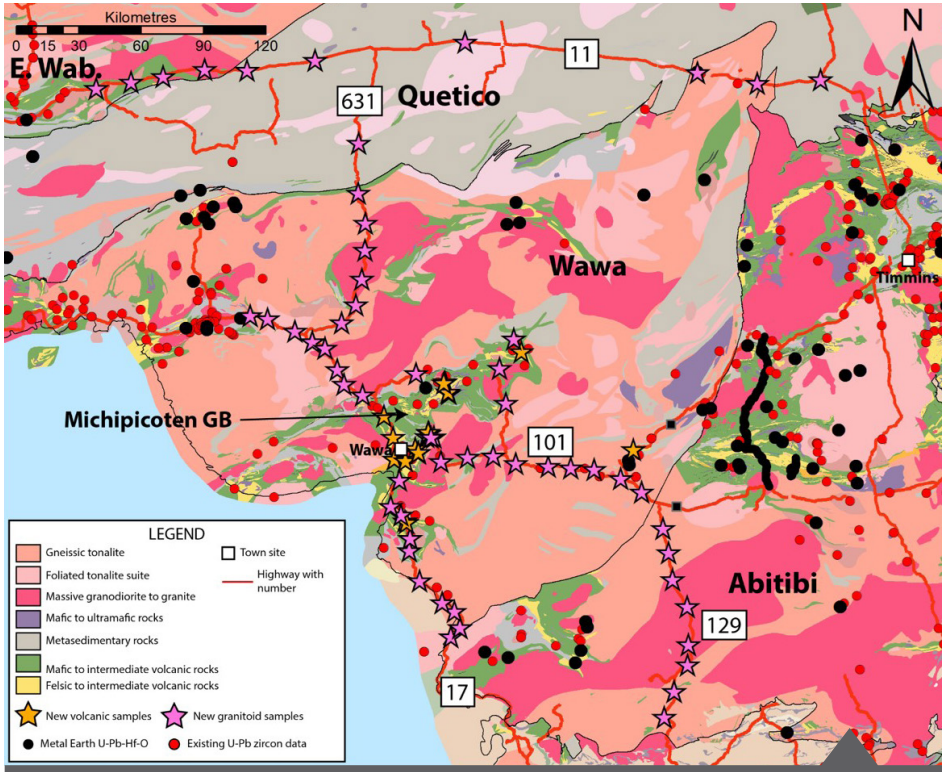
- Application of Lu-Hf results to mineral systems: Mole, Frieman, Thurston, Marsh, Jørgensen, Gibson, Stern Marint, Lu 2022 Crustal Architecture of the SE Superior Craton and controls on mineral systems: Minerals: submitted 2021
- Use Lu-Hf results to demonstrate older substrate beneath several subprovinces (e.g., northern Geraldton transect, Dryden-Winnipeg River)

Anticipated Outcomes

- Understanding of differences in crust and mantle in Abitibi vs terranes to the west which in turn explains differences in metallogeny

Implications

- The rift-based tectonic model in Mole et al., (2021) may cause a move away from simple plate tectonics interpretations for the entire craton.
- Recommendation to sample quartzites in northern Sturgeon transect important for overall tectonic interpretation at craton scale.



Fieldwork in Wawa, 2019, resulted in 85 samples collected across the region, 20 Fv and 65 granitoids.

Highlights

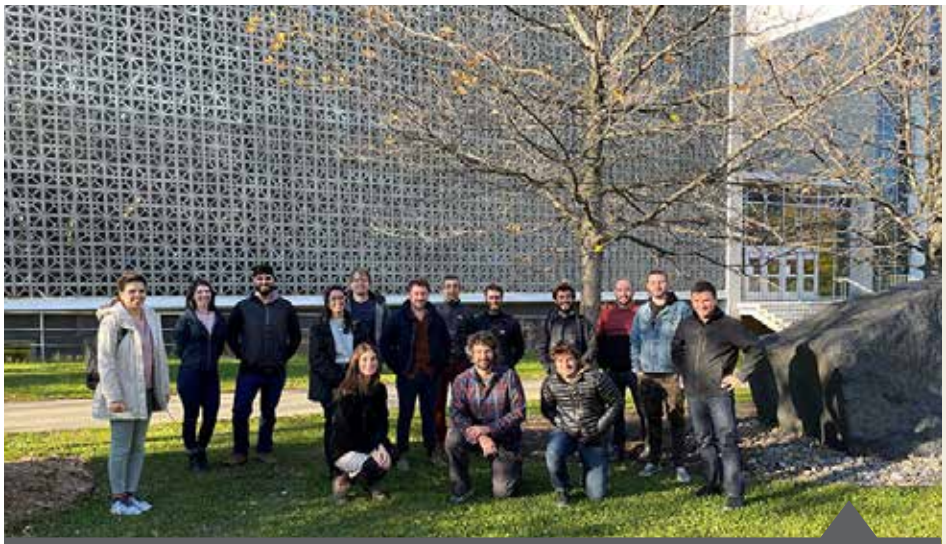
1. PhD student Nymoen has completed course work and nearly completed sampling for PhD
2. Paper by Mole (Mole 2021) has interested exploration industry
3. Can relate Lu-Hf results to mineral systems.
4. The rift-based tectonic model in Mole et al., (2021) may cause a move away from simple plate tectonics interpretations for the entire craton.

WATCH NOW!
Metal Earth at the Craton Scale

WATCH NOW!
Source to Sink

Source to Sink

Lead Researcher: Georges Beaudoin



The Source to Sink team. Back row: Yasaman Nemati, Bruna Coldebella, Isaac Siles Malta, Rita Rodrigues dos Santos, Michael Herzog, Benoît Quesnel, Christophe Scheffer, Guillaume Barré, Diogo Ribeiro, Antoine Godet, Guillaume Raymond, Georges Beaudoin. Front row: Crystal LaFlamme, Carl Guilmette, and Bertrand Rottier. Not pictured: Christian Dupuis

The Source to Sink research group focuses on the characterization through time and space of the auriferous fluid flow system(s). As such, the project endeavours to characterize the transport of gold from its source to its sink. A multidisciplinary team for mineral geochemistry, geochronology, geophysics, and pressure-temperature-time (P-T-t-X) constraints modelling is pursuing this objective by trying to answer aspects of the following categories:

Source:

- What are the source(s) of fluid(s) and volatiles?
- What are the geological processes driving fluid release?
- What are the lithologies the fluids are derived from?
- What are the source(s) of Gold?
- What is the mobility of Au and related elements associated to geological processes?
- What is the timing of fluid generation?
- What is the corresponding geodynamic?

Sink:

- What are the mechanisms driving destabilization of gold-carrying causing gold endowment?
- Are fluid flow conditions and fluid-rock interactions important to form a deposit?
- What are key parameters (T, P, fO2, fS2, pH) to form a deposit?
- What is the timing of gold mineralization?
- Is gold mineralization a result of successive hydrothermal fluid events?

Progress

- B. Quesnel and C. Scheffer worked on one article in collaboration with the Chibougamau transect team and on one book chapter that will be published by the SGA on Springer. They continued to analyse vein samples from the 2020 field campaign and they organized new sampling in the Beardmore-Geraldton area to complete the stable isotope database for the Superior Province. They performed analyses for Marina Schofield (Rouyn-Noranda transect). They developed a collaboration with Gyorgyi Tuba (Larder Lake postdoc fellow). They obtained results from clumped isotope thermometry and processed and interpreted results in collaboration with Josué Jautzy (GSC). They processed and interpreted results focused on the Cadillac-Larder Lake area.
- G. Raymond completed the stable isotope analyses, processed and interpreted results and completed the 3D modelling of fluid flow. He has all the material needed to write his Master thesis.
- I. Siles Malta started the phase equilibria modelling and performed Lu-Hf garnet and U-Pb zircon, monazite, apatite dating.
- M. Herzog completed a second run of in-situ phosphate U-Pb geochronology

of accessory minerals, processed and interpreted results. He also prepared a new analytical block and sent epoxy mounts containing sulfides mineral samples for multiple sulfur isotope analyses of sulfide mineral assemblages associated with orogenic gold mineralization. Moreover, he prepared a complete first draft of the first manuscript for internal review dealing with phosphate U-Pb geochronology of orogenic gold mineralization of the Abitibi subprovince.

- Y. Nemati arrived in Canada during spring 2021 and started the required course work, to process geophysical data collected in 2019 and organized a new field campaign at Yorbeau.
- G. Barré completed the ICPMS installation and started analytical procedure development. He designed his research project related to the characterization of sulfur reservoirs in Abitibi and organized field work. Installed a new extraction line at U Laval to prepare bulk samples for triple S isotope analyses.

Future Work

- B. Quesnel and C. Scheffer have completed the stable isotope database with new analyses of samples from the Beardmore-Geraldton area; they have processed and will interpret results for publication. They continue to collaborate on Gyorgyi Tuba and Marina Schofield's projects. They will write an article focused on the stable isotope composition of orogenic veins and fluids along the Cadillac Larder Lake deformation zone (CLLDZ). They will complete interpretation of clumped isotope results and of complementary data for publication. They will start to perform 3D modelling of fluid flow along the CLLDZ.
- G. Raymond will finish his MSc thesis.
- I. Siles Malta finalizes phase equilibria modelling and geochronology. He will process and interpret the data and will start the writing of his first article.
- M. Herzog will submit a first paper on in-situ phosphate U-Pb geochronology of accessory minerals. He has acquired multiple sulfur isotope analyses (collaboration CET-UWA) and trace elements in sulfides (collaboration UQAC). He is working on the second manuscript on fluid sources. He is preparing samples for TIMS analysis (collaboration CET-UWA) to better understand gold occurrences.
- Y. Nemati has processed and interpreted new data acquired on the field in 2021 to characterize geophysical properties of lithologies from the Yorbeau segment. She will attempt to relate geophysical features variation to other geological parameters (alteration, chemistry etc.).
- G. Barré will complete the LA-ICP-MS installation and will start analytical procedure development for sulfur analysis by LA-ICP-MS. He is completing multiple s isotope analysis from VMS deposits from samples collected in 2020 and 2021 in the Rouyn-Noranda camp and Matagami camp.

Anticipated Outcomes

- Scientific articles related to the different projects of the team and in collaboration with other Metal Earth team members will be in the review process.
- LA-ICP-MS ready for multiple-sulfur analyses

Implications

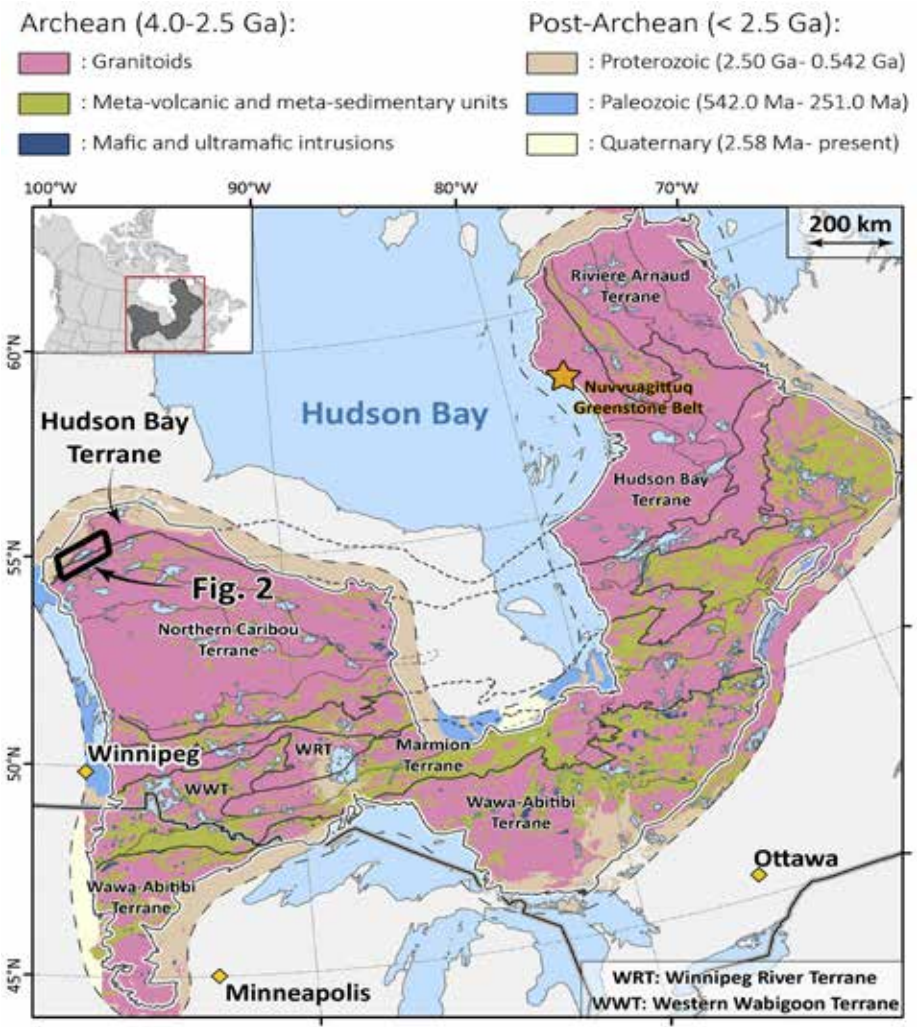
- Compare the stable isotope signature of fluid flow along transects cutting across well mineralized and poorly mineralized segments of major crustal faults and volcanic centres in the Superior Province. Identify the sources of fluids and sulfur in Superior Province gold deposits.
- Determine hydrothermal features that explain the metal accumulation of endowed areas versus those that are less endowed. Understand fluid generation during 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 in order to better constrain what are the key parameters required to form a deposit.

Highlights

1. Guillaume Raymond will defend his MSc thesis.
2. The new LA-ICP-MS facility will enable in situ triple sulfur isotope analysis, a method for rapid determination of S isotope composition to help select samples for more accurate and precise analyses by SIMS.
3. A better understanding of fluid flow along the CLLDZ will provide predictive understanding to industry to identify areas of higher potential for orogenic gold deposit.

Mantle Group Partner Project

Lead Researcher: Graham Pearson



Geological overview of the Superior Province, eastern Canada. Lithology contours are from Montsion et al. (2018), terrane boundary (thick dark grey line) and domain boundary (dotted dark grey lines) are after Percival et al. (2012). The study area is located at the Northwestern edge of the Superior Province, within the sheared black rectangle. Source: Adrien Vezinet, et al, Lithos, ***doi.org/10.1016/j.lithos.2020.105600***

Progress

- Cu isotope analysis completed on Kirkland Lake mantle xenoliths, Keewanawan copper and Kirkland Lake Gold
- Cu isotope project analyses started for Diavik mantle xenoliths and Slave gold
- All analytical work on phase 1 of Tree River project completed.
- Publication by Vezinet on Assean Lake Superior craton evolution, published September 2020.
- Vezinet, D.G. Pearson, L.M. Heaman, C. Sarkar, R.A. Stern (2020). Early crustal evolution of the Superior craton – a U–Pb, Hf and O isotope study of zircon from the Assean Lake complex and a comparison to early crust in other cratons. Lithos, 368-369. ***doi.org/10.1016/j.lithos.2020.105600***
- Masters student Jason Hinde completed all data acquisition for project on precious metal hosts in mantle metasomes.
- Elliott Lake mantle xenolith data collection completed

Future Work

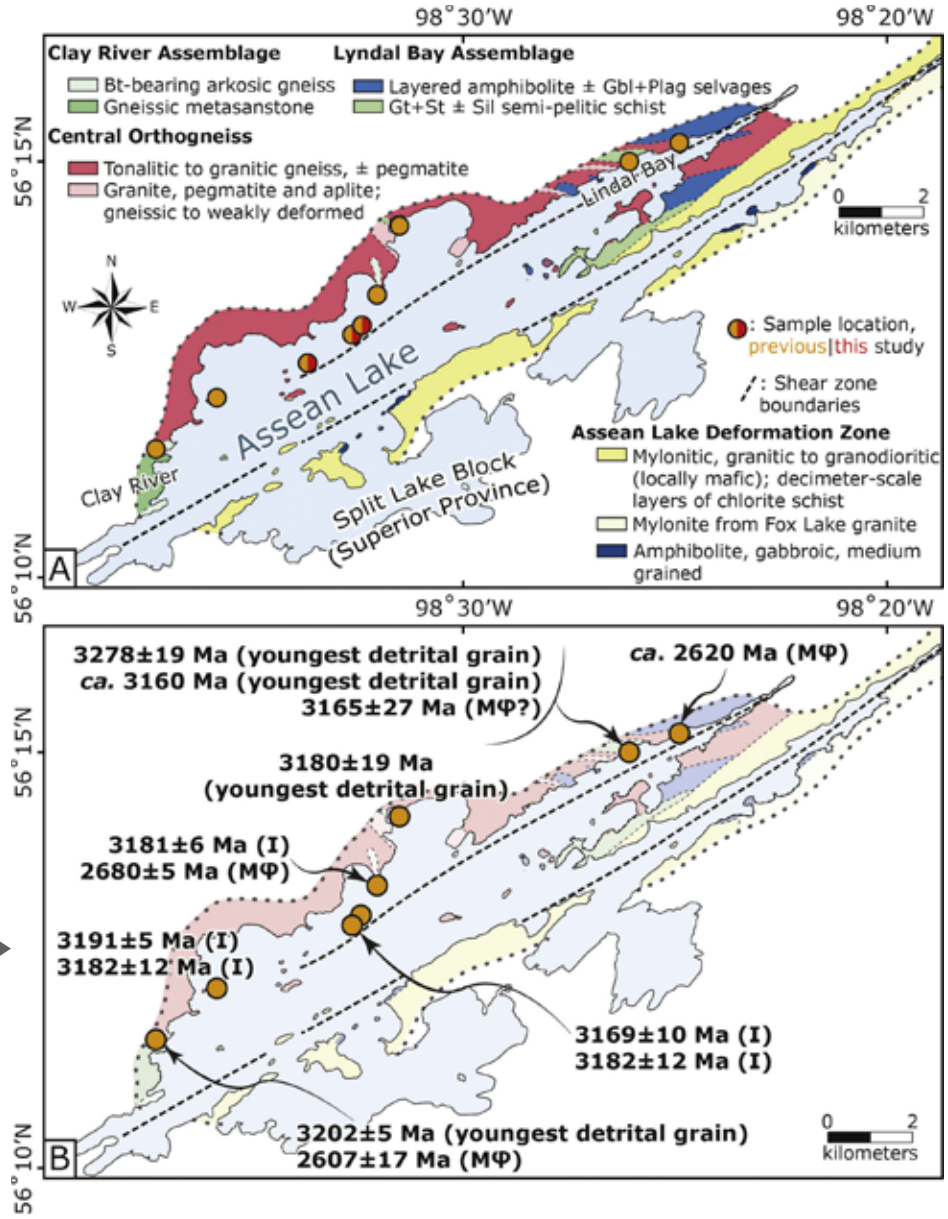
- Begin work on developing REE carbonate Nd isotopes and dating – Focus on Thor Lake, NWT
- Submit Tree River paper for publication. Begin new diamond separation work on Tree River gold/diamonds
- Begin work on Lynx Lake diamonds – Manitoba

Anticipated Outcomes

- We aim to provide new constraints on the source inputs to the world-class Thor Lake REE deposit, NWT by Nd isotope analysis of REE carbonates. We will also try to provide new, improved geochronological constraints for the REE mineralization via direct dating of REE carbonates rather than previous zircon ages. In doing so, we will develop, more broadly, U-Pb carbonate dating in ore systems that should improve geochronology approaches in ore systems in general.
- The Lynx Lake diamonds (collaborative work with Adia Resources) are hosted in unusual mafic volcaniclastics that may not be kimberlites. These volcanics were clearly sourced at depths in the diamond stability field. Dating the host deposit and better understanding the source of the carbon in the diamonds (through C-N isotope analyses) will give us a better insight into the varied lithosphere thickness that appears to be present in Mesoarchean in proto-cratonic nuclei. This varied lithospheric architecture appears to control the location of mafic/ultramafic volcanism and hence the sources and hosts for gold later in craton development.

Implications

- The carbonate dating project will result in an improved ability to understand the timing of formation of many different types of ore deposits, including REE deposits.
- The Lynx Lake and Tree River diamond projects will result in a greater understanding of the evolving lithospheric architecture during craton formation. This varied lithospheric architecture appears to control the location of mafic/ultramafic volcanism and hence the sources and hosts for gold later in craton development.
- Two of these projects focus on the NWT – one of the key target areas outlined in the original Metal Earth proposal.



Geological map of the Assean Lake crustal complex. Contours and labels are after Böhm et al. (2019). B. Same area with the age of the samples previously investigated, modified after Böhm et al. (2019). I: Age interpreted as igneous. Mφ: Age interpreted as metamorphic. Source: Vezinet et al. ***doi.org/10.1016/j.lithos.2020.105600***

Highlight

1. Masters student Jason Hinde won $5k Scholarship Award from SEG

Overview

The Superior Province is the largest exposed Archean craton in the world. It consists of generally east-striking subprovinces (e.g., Abitibi, Wabigoon, Uchi) consisting of metavolcanic and granitoid rocks separated by subprovinces (e.g., Pontiac, English River) which are dominated by metasedimentary and gneissic rocks Numerous world-class gold, volcanogenic massive sulphide and less-common magmatic nickel-copper deposits are spatially associated with east-striking subvertical crustal-scale fault zones along the subprovince boundaries (e.g., Cadillac–Larder Lake fault zone), or along the contact zones (Porcupine–Destor–Manneville fault zone) between metavolcanic and metasedimentary rocks within subprovinces.

Transect mapping is an integral part of the Metal Earth project that aims to explain the differential metal endowment of Archean greenstone belts with otherwise comparable geological characteristics. The purpose of the transect mapping is to complete focused mapping to add value existing geological framework. By integrating newly acquired geological and geophysical (seismic, gravity and magnetotelluric) data with historical data, each transect will produce a crust- and mantle-penetrating cross-section through a Superior Province greenstone belt.

Thirteen transects totaling approximately 1,000 line km comprise the transect work on the Superior Craton. These transects range from Chibougamau in the northeast to Rainy River in the far west. The transects were chosen to cover ancestral fault systems and volcanic centres with variable metal endowment.

Geologic fieldwork on these transects consists of targeted mapping to improve the understanding of the structural and stratigraphic framework. Graduate student projects are developed as the students and researchers identify a topic of interest to them, which supports the overall goal of Metal Earth.

Each transect will be roughly three years in duration. In 2020-2021 (Year 3), 5 transects were active including Ben-Nevis – Larder Lake, Chibougamau, Geraldton-Onaman, Rainy River, and Sturgeon.

WATCH NOW!
Mike Hamilton: U-Pb CA-ID-TIMS Geochronology

WATCH NOW!
Chibougamau Transect

Chibougamau

Lead Researcher: Lucie Mathieu

WATCH NOW!
Magmatic-hydrothermal Au and Cu-Au systems

The Chibougamau area, when compared to the rest of the Abitibi subprovince, has several unique characteristics i) fold-dominated architecture; ii) lack of komatiites; ii) unusual intrusions (layered complex and polyphased pluton); and, iv) in the broadest sense, a large amount of "intrusion-related" mineralisation.

Progress

- Pierre Bedeaux (PDF) completed most of his project (two pending publications remain).
- Completed project: Adrien Boucher (MSc 2020)
- Project completed by the publication of a paper (official completion was delayed to Fall 2021, as a consequence of immigration delays): Baptiste Madon (MSc, year 2 – funding: NSERC 75% + Metal Earth 25%)
- Project that progressed well: Taylor Wasuita (MSc, year 1).
- Project that progressed slowly due to lockdown (both projects are now nearing completion as MSc projects, as of Fall 2021): Patrik Berthoty (PhD, year 2), Alexandre Crépon (PhD, year 2).
- Project that was cancelled due to lock-down: Adrien Boucher (PhD, year 1).
- Project that was initiated in January 2021: Théo Hassen Ali (PhD, year 1).
- Completed projects by Lucie Mathieu: integration of seismic and geological data, pyrite chemistry, and important steps taken in the TTG petrogenesis project

Future Work

- Chibougamau transect project – complete the regional review publications (Pierre Bedeaux), and present geochronological data (Lucie Mathieu and/or Pierre Bedeaux publication). Complete the work on the Chibougamau pluton (Alexandre Crépon PhD, now MSc, and additional analyses performed by Lucie Mathieu on zircon in Fall 2021)

Anticipated Outcomes

- Renewed understanding of ancient magmatism (synvolcanic and syntectonic period).
- Integration to geodynamic framework and renewed comprehension of mineralizing systems at regional to local scales.

Implications

- General insights gained on magmatic systems (including the physico-chemical parameters of magmas) are changing our comprehension of Au-Cu transportation in the ancient crust.
- Integration of seismic, other geophysical ata, geological, geochronological, and geochemical data unable a deeper comprehension of the geodynamic evolution of the Chibougamau area, which can now be compared to other parts of the Superior craton.

Highlights

1. Adrien Boucher completed his MSc and published a paper on the Obatogamau Fm.
2. Baptiste Madon published a paper on the fO2 of syntectonic magmas of the Chibougamau area (MSc is now completed, as of August 2021).
3. The Chibougamau seismic profile was published and a scenario for the geodynamic evolution of the Chibougamau area has emerged from this work.
4. The oxygen fugacity of several intrusions has been measured (and published) and a better comprehension of the metal potential of ancient magmas is being gained.
5. The term TTD suite and its implication of the Abitibi greenstone belt has been discussed in a 2020 paper, and description of this magmatism (which is associated to Cu-Au porphyries in Abitibi) has begun.
6. Results of the project were presented during short-courses organized by MERC at the PDAC and SEG 100 conferences in 2021.

Geraldton-Onaman

Lead Researcher: Zsuzsanna Tóth

Exceptional radial kyanite crystals in an advanced argillically altered rhyolite.

The Geraldton-Onaman transect is a 105 km long traverse that crosses a major terrane boundary between the eastern Wabigoon and the Quetico subprovinces in the western Superior Province. Significant gold mineralization in the area is indicated by several past-producing and future gold mines in the Beardmore-Geraldton belt that stretches along the boundary between the eastern Wabigoon and Quetico subprovinces.

The transect area has a complex and poorly understood geological evolution. The research area is made up of several Mesoarchean and Neoarchean mafic to felsic volcanic assemblages (~2970 Ma to 2720 Ma) overlain by fine to coarse-grained clastic and chemical sedimentary successions (~2710 Ma to 2690 Ma) and large granitoid plutonic bodies (~2920 Ma to 2650 Ma; Stott et al., 2002).

The transect research aims to improve our understanding of the geological evolution of the transect area using geological mapping, whole rock and isotope geochemistry, geochronology,

structural analyses and various geophysical methods that provide an insight into the 3D lithospheric architecture. The outstanding questions include the petrographic and petrologic characterization of the various metavolcanic, metasedimentary and intrusive rocks, the characterization of various metallogenic processes, as well as deformation and metamorphic events.

Lead researcher Zsuzsanna Tóth presented findings and research updates in a PDAC 2021 and SEG 100 Short Courses. Her March 2021 update to Metal Earth partners is available for public viewing on the ***Harquail School of Earth Sciences Metal Earth YouTube playlist***.

Projects

1. The provenance and depositional age of the metasedimentary packages with testing their possible correlation across the eastern Wabigoon, English River and Quetico subprovinces

   Researcher: Zsuzsanna Tóth, Postdoctoral Fellow, Laurentian University

2. Assessment of the structural evolution of the Onanam-Tashota greenstone belt and its comparison with the BGB

   Researcher: Zsuzsanna Tóth, Postdoctoral Fellow, Laurentian University

3. The petrographic an petrologic characterization of the eastern Wabigoon and Quetico subprovinces

4. Metallogeny, volcanic stratigraphy, and geodynamic evolution of Onaman-Tashota greenstone belt with focus on magmatic-hydrothermal mineralization styles

   Researcher: Keaton Strongman, PhD candidate, Laurentian University

5. The characteristics and timing of regional and contact metamorphism in the Onaman-Tashota greenstone belt

   Researcher: Anna Haataja, MSc candidate, Laurentian University

6. The structural evolution and orogenic gold mineralization of the Tashota area, northern Onanam-Tashota greenstone belt

   Researcher: Ben Mark, MSc candidate, Laurentian University

WATCH NOW!
Geological evolution of eastern Wabigoon and Quetico subprovinces, Geraldton-Onaman

Ben Nevis - Larder Lake

Lead Researcher: Kate Rubingh

WATCH NOW!
Structure and stratigraphy of the Larder Lake area

The Ben Nevis – Larder Lake transect is approximately 45 km in length and is located in the Abitibi subprovince of the Superior Province in northeastern Ontario. This transect is focused on three main areas; i) the Ben Nevis volcanic complex, part of the Blake River Group; ii) the Timiskaming assemblage and the associated Cadillac-Larder Lake Deformation Zone (CLLDZ), and the Larder Lake Group (Piché Group); iii) and the volcanic and intrusive rocks around the Lincoln Nipissing shear zone in the southern portion of the transect.

At the northern extent of the transect the Archean rocks of the Blake River Group (2701 ± 3 – 2698.5 ± 2Ma) host the Ben Nevis volcanic complex (2696.6 ± 1.3 Ma) (Péloquin et al., 2008). The Blake River Group in Québec is host to significant VMS deposits of the Noranda camp, however the Ben Nevis volcanic complex, despite its similarities, does not host any significant deposits.

The Ben Nevis – Larder Lake transect also crosses the Timiskaming assemblage (ca. 2680 – 2670 Ma; Ayer et al., 2005) with fluvial alluvial-marine sedimentary rocks along with syenitic to quartz monzonite intrusions and their trachytic volcanic equivalents. Within the Timiskaming assemblage is a panel of mafic-ultramafic volcanic rocks, considered the Larder Lake Group (ca. 2705) (Corfu et al., 1989) equivalent to the Piché Group in Québec. The contact between the Larder Lake Group and the Timiskaming assemblage is typically considered the Cadillac – Larder Lake break, a 250 km, east-west trending, regional crustal scale fault, which extends from Matachewan in Ontario to Val d'Or in Québec and has a fundamental control on the distribution of gold deposits. The area of this transect is associated with significant gold mines along the break including the Kerr-Addison deposit and the smaller deposits such as McGarry, Bear Lake, Cheminis, Fernland and Omega.

The Metal Earth project aims to characterize the original relationship between the Larder Lake Group and the Timiskaming assemblage to determine if there was an original sedimentary (unconformable) relationship or if it is solely a structural relationship. The project also aims to understand the volcanic stratigraphy of the Larder Lake Group and the association of the stratigraphy and structural geology to gold mineralization along the break.

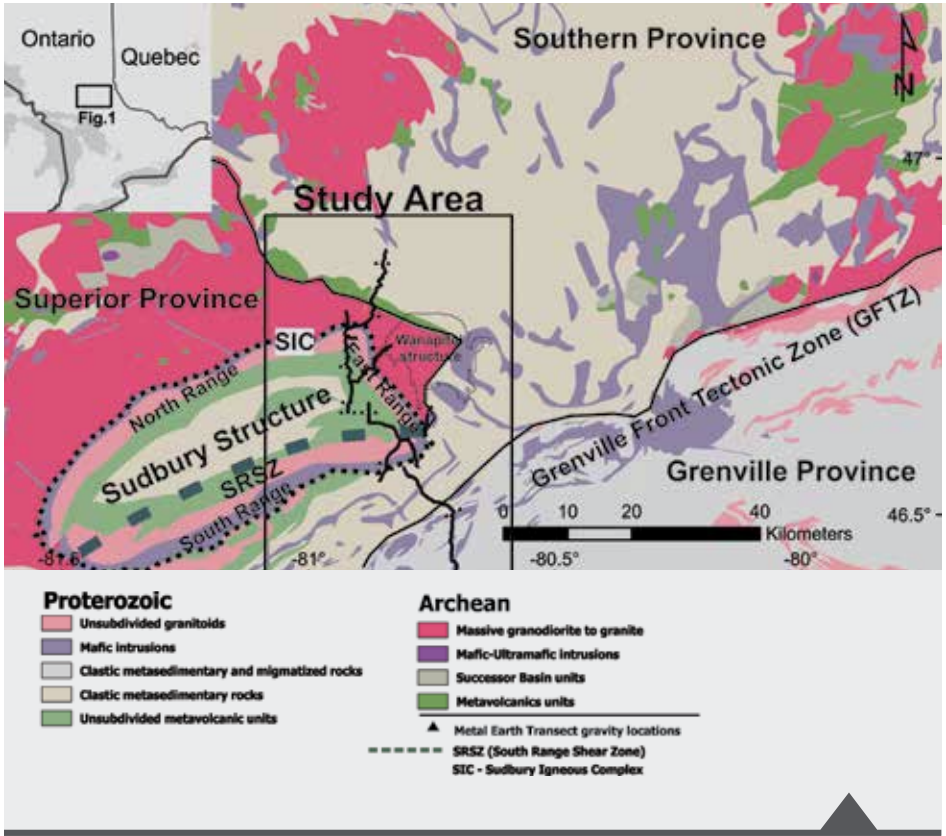
Stefanie Kisluk, M.Sc. candidate, uses drone photography as part of her Metal Earth research project in the Ben Nevis – Larder Lake transect.

Stefanie Kisluk has been working to complete her MSc on the volcanic environment in the Ben Nevis volcanic complex. Kisluk has been able to subdivide the volcanic strata into a number of different chemostratigraphic intervals representing variable volcanic environments. Her research will place the base and precious metal prospects into the regional stratigraphic context.

Sudbury

Lead Researcher: Rasmus Haugaard

WATCH NOW!
3D potential field modelling and inversion; 3D Geometry Gravity Inversion



Sudbury Transect study area. Map produced using data from Montsion et al. (2018).

With support from an NSERC Collaborative Research and Development (CRD) grant, MERC started this project in November 2020 under the direction of Rasmus Haugaard, Research Associate.

Collaborators include MERC research associates Rajesh Vayavur, Ademola Adetunji, and Saeid Cheraghi.

Scope

The project will complete integration of the geophysical data set, and subsequently, an interpretation of the overall crustal scale geology and associated mineralizing structures.

The complete interpretation of the crustal architecture over the eastern part of the impact structure will help constraining mineralized (Ni, PGE and Cu) structures, their orientation and volume.

Anticipated Outcomes

- One paper in a high-impact scientific journal
- One paper in a lower-impact journal
- Strengthen the collaborative relationship with key -mining and exploration companies in Sudbury (Vale and Glencore)

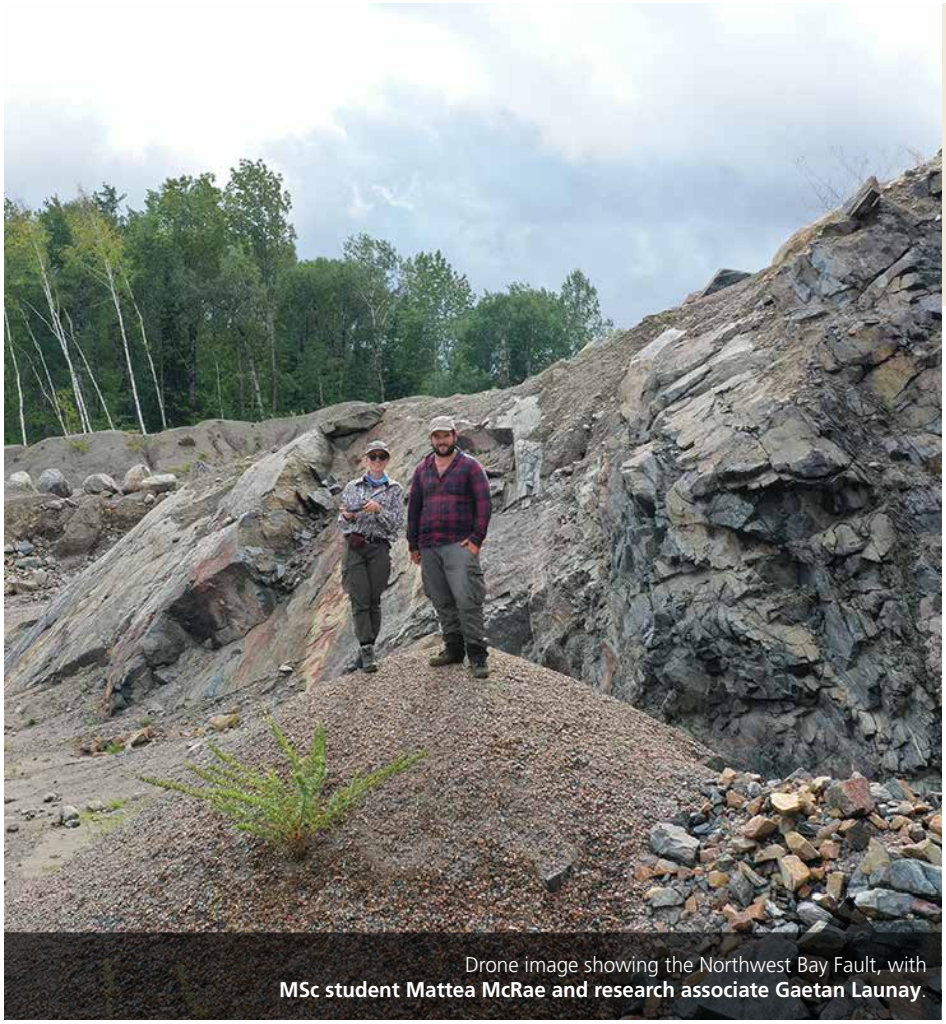
Since the project's inception, a geophysical data set has been processed and finalized, including seismic high and lower resolution profiles, MT, gravity and magnetic data. R. Vayavur presented a poster at the September 2021 Geoconvention, called Geophysical evidence of upper-crustal Archean basement folding and/or faulting below the East Range of the Sudbury impact crater. A manuscript on this topic is in progress.

Some field work occurred in July of 2021. Key visits to Vale and Glencore's Sudbury exploration offices for consultation occurred in October 2021.

WATCH NOW!
Rainy River Transect

Rainy River

Lead Researcher: Gaëtan Launay



Drone image showing the Northwest Bay Fault, with **MSc student Mattea McRae and research associate Gaetan Launay**.

The Rainy River transect is a north-south 40 km long transect in the Western Wabigoon Subprovince crosscutting the Quetico deformation zone and the gold endowed volcanic center of Rainy River. The project is investigating the crustal architecture of the Rainy River greenstone belt and the Quetico deformation zone in order to improve knowledge of the geodynamic evolution of this area and provide new insights for the identification of mechanisms controlling the gold endowment of the regional deformation zones. The project also aims to examine the stratigraphy, the physical volcanology and the petrogenesis of the Rainy River greenstone belt to identify the geological environment favourable for the formation of the Au-rich syn-volcanic deposits occurring in the Wabigoon subprovince.

Progress

- Four weeks of fieldwork was carried out in the Rainy River area during summer 2020. The work focused on detailed mapping and sampling of the Morson gneissic dome that constitutes an exposed section of the mid-lower crust underlying the Rainy River greenstone belt. Exhumation of the Morson gneissic dome was induced by a dextral E-W striking mylonitic corridor occurring along the northern contact of the gneissic dome. This deformation zone is related to a transpressive deformation involving a NW-SE regional shortening compatible with structures observed in the Quetico deformation zone. The ages of the gneissic crust and timing of the crustal reworking will be determined by U-Pb analysis (using LA-ICP-MS) during winter of 2021.
- Detailed mapping in the Pinewood lake and Off-Burditt lakes area (field seasons 2019 and 2020) showed that these different felsic volcanoclastic packages are similar than those hosting the gold mineralization of Rainy River (Pelletier et al., (2015)) and are the eruptive expression of the rhyolitic cryptodome of Off Lake. Samples for whole rock major and trace elements geochemistry were collected across the stratigraphy of the Rainy River greenstone belt to characterize the petrogenesis of the different volcanic assemblages. Results highlight crustal contamination of

mafic magmas by the lower gneissic crust underlying the Rainy River greenstone belt. Samples for U-Pb detrital and igneous zircon were also collected at a different stratigraphic level to constrain the timing of the different volcanic events across the Rainy River greenstone belt. The deposition of the felsic volcanoclastic units of Burditt and Pinewood Lake are coeval (2715-2716 Ma) with the emplacement of the felsic volcanic unit hosting the Rainy River gold deposit (2716 ± 1 Ma) (Hamilton 2008, Pelletier et al. 2015). The rhyolitic cryptodome of Off Lake emplaced at 2721 ± 0.88 Ma providing a minimum age span constraint on the duration of felsic magmatism of ~5 Ma. These results demonstrate that the Au-Ag-rich sulphides mineralization of Off-Burditt Lakes and Rainy River are related to the same volcanic center and belong to the same short-lived volcanic-hydrothermal system. The presence of inherited zircons (2750-2880 Ma) in the rhyolitic cryptodome of Off Lake confirms the assimilation of the older gneissic crust during the formation of the Rainy River greenstone belt.

Drone photo depicting the Cameron Lake deformation zone crosscutting the DogPaw lode gold mineralization.

- Interpretation of seismic, gravity and magnetotelluric data sets and integration with surface geology has been undertaken to produce a crustal scale geological cross-section of the Rainy river greenstone belt. Preliminary interpretations show that the crust beneath the Rainy river greenstone belt is relatively thick (Moho at 40 km) and can be subdivided in 3 domains:

1. An upper resistive crust (up to 9 km) corresponding to the greenstone belt and characterized by reflectors (sills/dikes?) depicting a regional scale syncline compatible with a Dome-and-keel structure.

2. A middle reflective crust occurring between 9 and 15 km is interpreted as interlayered mafic and TTG gneisses. The middle crust is conductive and forms a dome under the Sabaskong batholith. This upwelling of the mid-lower crust is consistent with the presence of the Morson gneissic dome mapped in the western part of the Sabaskong batholith.

3. A lower conductive aseismic ductile homogeneous crust characterized by rare subhorizontal reflectors.

The Quetico deformation zone is characterized by a limited depth extension (12-15 km) and is associated with a weakly conductive corridor. This limited depth extension of the structures may (i) inhibit the circulation of the gold-bearing metamorphic fluids produced in the mid-lower crust (amphibolite facies) and (ii) explain the absence of gold mineralization and hydrothermal alteration along the Quetico deformation zone.

Future Work

- Completing U-Pb dating by LA-ICP-MS on samples from the Morson gneissic dome to constrain ages of the mid-lower gneissic crust and timing of the crustal reworking during the formation of the Rainy River greenstone belt.
- Completing U-Pb dating on Xenotime from different generations of gold-bearing veins of the Cameron Lake gold deposit to constrain the timing of the different gold mineralization events. Results will be integrated with structural-microstructural analysis to assess structural evolution of the Western Wabigoon subprovince.
- Finalizing a robust geological model of formation of the Rainy River greenstone belt integrating the stratigraphy, the volcanic architecture, geochemistry and geochronology.
- Constrain the structural evolution of the Rainy River greenstone belt
- Comparing the crustal architecture of the Rainy River transect with the metal-endowed transects of Metal Earth to identify the processes responsible for metal endowment.
- Finalizing the interpretation of geological and geophysical data at the end of 2021, in order to constrain the metallogenic implications of the transect
- Publication of results in peer-reviewed journals.

Anticipated Outcomes

- Geological, geochemical and geochronological data will be released in the Metal Earth geodatabase.
- Cross-section across the Rainy River greenstone belt and the Quetico deformation zone with integrated geological and geophysical interpretation will be completed.
- Comparing at the crustal-scale between the Rainy River transect and metal-endowed transects of Metal Earth will be completed to identify key mechanisms responsible for the genesis of deposits.
- A poster format of the regional geological map including a compiled geophysical and geological map will be produced and submitted to the Ontario Geological Survey.
- Research on different topics will be published in the various formats of technical reports and peer-reviewed journal papers.

Implications

- Research activities carried out on the Rainy River greenstone belt will provide a better understanding of the geodynamic evolution of this area and identify processes and the geological environment that is favourable for the formation of synvolcanic Au-rich sulphides deposits, which represent the most significant source of gold in the Western Wabigoon subprovince.
- Detailed structural study of the Quetico deformation zone combined with interpretation of seismic, magnetotelluric and gravity dataset will provide:

  (i) new constraints on the crustal stratigraphy and architecture of the Western Wabigoon subprovince.

  (ii) new insights for identification of geological parameters controlling the gold endowment of the crustal deformation zones occurring the Superior craton.

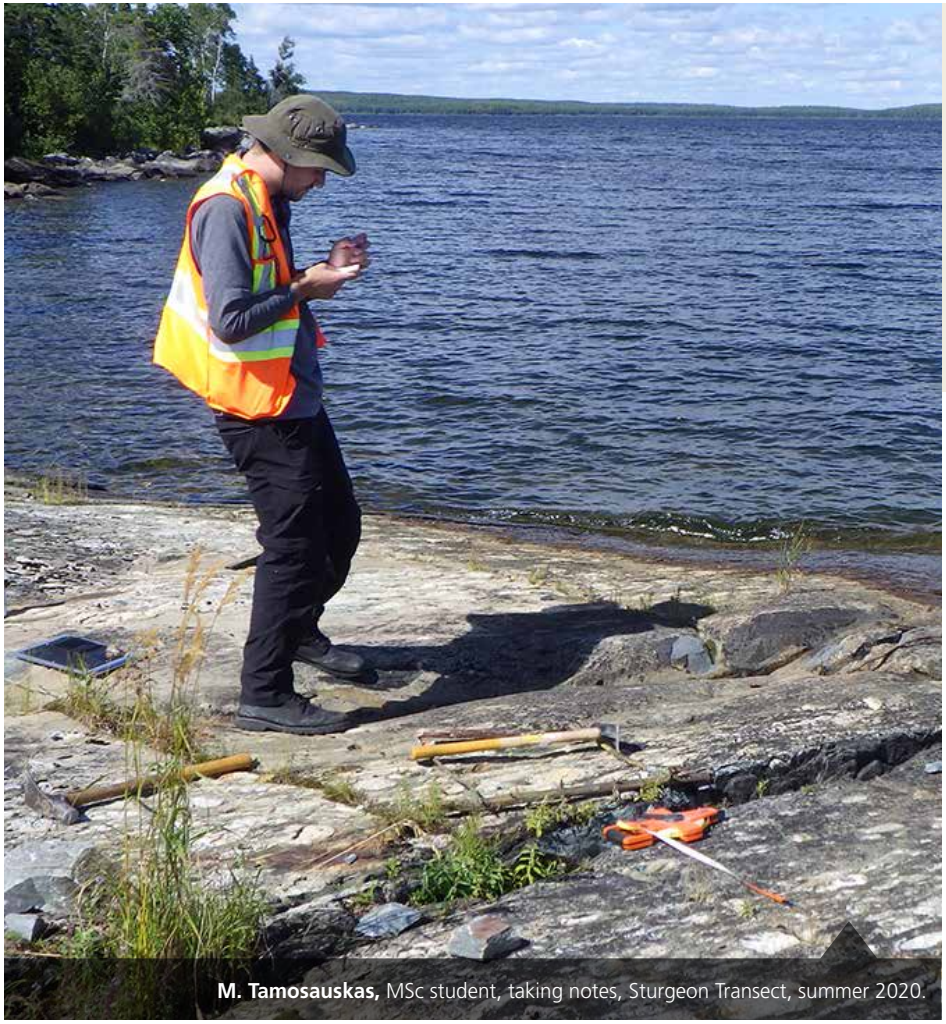
Highlights

1. Results of this project were presented during a short course organized by Metal Earth at the SEG 100 conference (September 2021).
2. Defense of M.Sc. thesis (Mattea McRae) focused on the synvolcanic gold-rich sulphide deposit of Goliath is scheduled for early 2022.

Sturgeon

Lead Researchers: Chong Ma, Robert Lodge (University of Wisconsin-Eau Claire)

WATCH NOW!
Tectonic evolution of the western Wabigoon and Winnipeg River terranes



M. Tamosauskas, MSc student, taking notes, Sturgeon Transect, summer 2020.

The Sturgeon transect of the Metal Earth project investigates the easternmost part of the western Wabigoon terrane and the adjacent Winnipeg River terrane. It is broadly north-south oriented and extends 70 km in the two terranes. The overarching research approach is to integrate detailed geologic mapping with geochemistry, petrology, geochronology, and high-resolution geophysical data. The primary datasets include structural and kinematic analyses of deformational fabrics, whole-rock major and trace elements, zircon U-Pb geochronology and Lu-Hf isotopes, zircon trace elements, and seismic-gravity-magnetotelluric surveys of the crust and uppermost mantle. All acquired data will be integrated into the regional context including the legacy Lithoprobe data from the region. The overall goals are to better understand (1) the formation of the Archean continental and oceanic crust in the region, (2) the geodynamic processes associated with crust growth, recycling, and amalgamation, and (3) metal endowment related to VMS deposits in the Sturgeon Lake greenstone belt of the western Wabigoon terrane.

Progress

- Started the MSc project about the Ament Bay assemblage
- Completed the first geologic mapping season of the MSc project in the summer of 2020
- Field data of the stratigraphy of the Ament Bay assemblage and the surrounding volcanic and plutonic rocks were collected
- Representative stratigraphic columns and detailed geologic maps of the Ament Bay assemblage were made
- Geochemical analysis of whole rocks and U-Pb analysis of zircons were completed for samples collected in 2020
- Published the transect-scale geophysical and geological data and revealed the crustal architecture of the Sturgeon Transect in Precambrian Research: Chong Ma, Mostafa Naghizadeh, Ademola Adetunji, Robert Lodge, David Snyder, Ross Sherlock, 2021. Imaging Neoarchean crustal structures: An integrated geologic-seismic-magnetotelluric study in the western Wabigoon and Winnipeg River terranes, Superior craton. Precambrian Research, v. 364, p. 106339. ***doi.org/10.1016/j.precam-res.2021.106339***

- ▶ Published 3 abstracts.
- ▶ Completed second manuscript of the Sturgeon Transect to be published in peer-reviewed scientific journals.

Future Work

- Conduct the second geologic mapping season for the MSc project in the summer of 2021.
- Complete data collection for the MSc project.
- Carry out the final transect-scale geologic mapping and sample collecting in the summer of 2021.
- Complete U-Pb, Lu-Hf, and trace element analyses of zircons from previous samples.
- Submit the second manuscript to a research journal for publication and write two more manuscripts in the coming year.

Anticipated Outcomes

- Finish all the data collecting for the MSc project and be able to write all the thesis chapters related to introduction, geologic background, geologic mapping results, petrography, and whole-rock geochemistry.
- Publish 3 peer-reviewed papers.
- Publish more than 2 abstracts in professional conferences.
- Present talks and posters on PDAC, GAC-MAC, and SEG meetings.

Implications

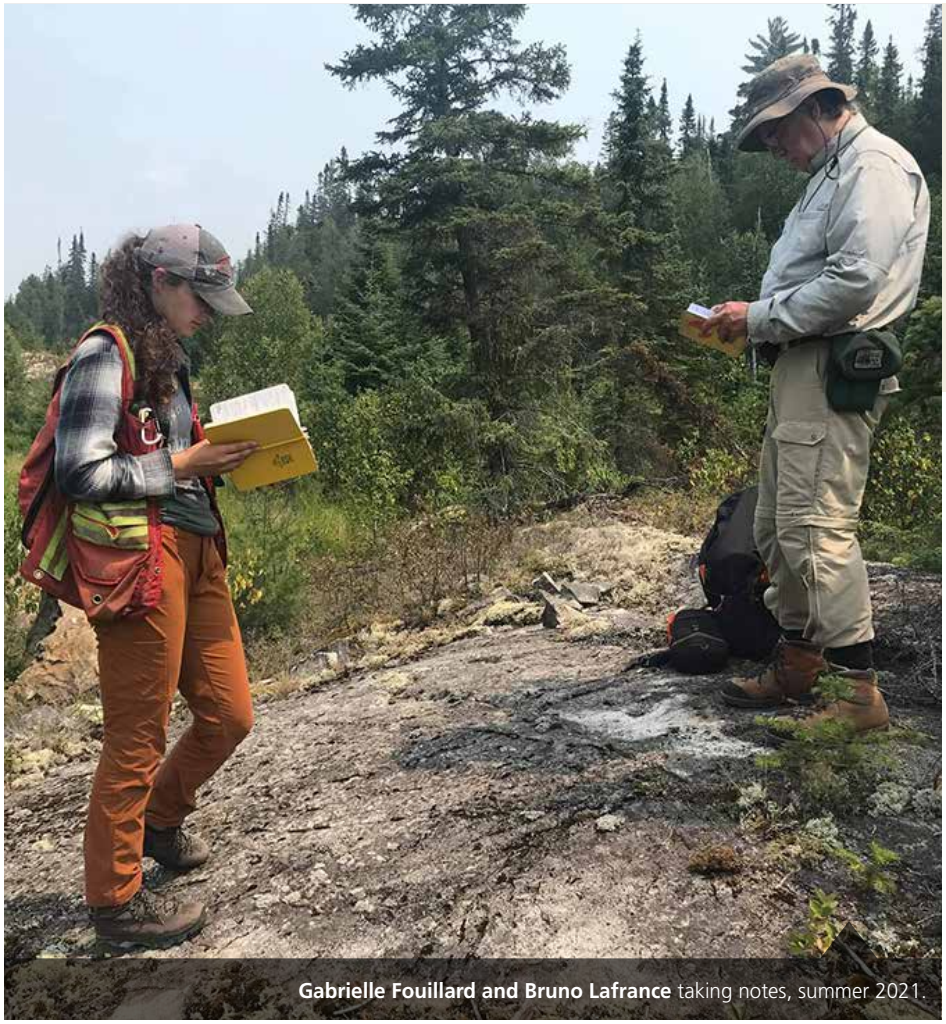
- This year's work was a significant step forward for the Sturgeon Transect of Metal Earth, especially the starting of the MSc project that will be the only graduate thesis from this transect and the publishing of the crustal architecture paper in Precambrian Research.
- The published paper serves as the foundation for our further understanding of the evolution of the Sturgeon Lake greenstone belt and its basement.
- The starting and great progress of the MSc project this year will ensure the completion of a graduate research thesis, not to mention the implications of the study to understanding Timiskaming-type basins and metal explorations.

Highlights

1. The publication of "Imaging Neoarchean crustal structures: An integrated geologic-seismic-magnetotelluric study in the western Wabigoon and Winnipeg River terranes, Superior craton" systematically integrated regional geology with the Metal Earth geophysical data and previously acquired data in the region and provided a first-order interpretation of the crustal architecture underlying the Sturgeon-Savant Lakes greenstone belt. This work provides compelling evidence for horizontal tectonics in the Neoarchean and has implications for the role of accretionary orogenesis in the processes of cratonization.
2. Presented a short course: Tectonic evolution of the western Wabigoon and Winnipeg River terranes in the Sturgeon Lake region: implications for understanding structural controls on the greenstone belt and its VMS deposits, in Crustal scale controls on gold and base metals in the southern Superior Craton, Prospectors & Developers Association of Canada Annual Meeting (Virtual), 7–10 March 2021; and at the SEG 100 Meeting (Virtual) Sept 22 and 23, 2021.

Atikokan

Lead Researcher: Bruno Lafrance



Gabrielle Fouillard and Bruno Lafrance taking notes, summer 2021.

The Atikokan transect crosses the northern margin of the metasedimentary Quetico Subprovince and the southern margin of the granite-greenstone Wabigoon Subprovince, where a Neoarchean platformal sequence overlies older Mesoarchean greenstone belts. Two MSc studies are underway. One study focuses on the stratigraphy and structural geology of a volcanic sequence that either unconformably overlie or was thrusted above the platformal sequence. If the latter, it would be one of the oldest thrust fault in the Wabigoon Subprovince with important implications on the buildup of greenstone belts. The second study is on the formation of the Hammond Reef deposit, one of a few major gold deposits in the Wabigoon Subprovince. The Hammond Reef deposit is one of several gold occurrences occupying northeast-trending shear zones oriented oblique to the orogenic trend of the subprovince. Determining how the Hammond Reef deposit formed is crucial for understanding the metal endowment of the Wabigoon Subprovince.

Progress

- A Research Associate was recruited for this transect but did not start because of the combined effects of the CCAA and pandemic. Thus the work done on the transect are one MSc project on the structural and stratigraphic setting of the Witch Bay Formation of the Steep Rock greenstone belt and a second MSc project on the genesis of the Hammond reef deposit
- MSc thesis on Witch Bay Formation (MSc student Mohamed Farhat): A three-week summer field season was completed and involved detailed mapping of a section and collection of samples for geochronology, petrography and geochemistry across the lower half of the Witch Bay stratigraphy and overlying conglomerate and Quetico turbidites. The samples were analyzed over the winter and interesting new results on the age and genesis of those rocks. A summary of field work was written and published on MERC's website. In total, analytical work included: petrography on 21 thin sections, 6 days on the SEM, 1 day on the LA-ICP-MS, 1TIMS samples, and 6 detrital zircon samples (3 Wagita, 2 Quetico, 1 Timiskaming-like conglomerate).

- ▶ MSc thesis on Hammond Reef deposit (MSc student Gabrielle Fouillard): A three-week summer field season was completed and involved detailed mapping of three outcrops, including the main mineralized zone, logging of 5 drill holes along a section across the deposit, and reconnaissance inspection of the property. Two samples of the host rocks were collected for TIMS geochronology at the University of Toronto, and 37 samples were collected for thin sections and optical and SEM petrography. A sequence and paragenesis of veining and alteration events were determined as well as their relative timing to deformation. Monazite and xenotime were dated to provide constraints on the timing of mineralization, and pyrite was analyzed to determine the sitting of gold. Two presentations were done to the company (Agnico Eagle), which owns the Hammond Reef deposit, and a summary of field work was written and published on MERC's website. In total, analytical work included: petrography on 37 thin sections, 6 days on the SEM, 1 day on the LA-ICP-MS, and 2 TIMS samples.

Future Work

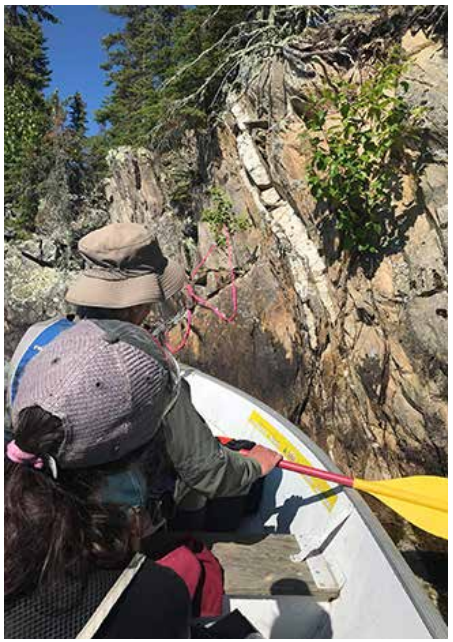
- MSc thesis on Witch Bay Formation (MSc student Mohamed Farhat): A complete summer of field work will be needed to complete the project. Samples will be collected for petrography and geochemistry of the upper part of the Witch Bay Formation stratigraphy, and at least one more sample will be collected for TIMS geochronology to provide absolute constraints on the age of the formation. Thesis will be written as a journal publication.
- MSc thesis on Hammond Reef deposit (MSc student Gabrielle Fouillard): Similar to above, a summer of field work will be needed to complete the project and provide a structural model for the emplacement and formation of the Hammond Reef deposit. A second drill hole section across the main mineralized zone will be done. Samples will be submitted for whole rock geochemistry to determine the mass gain and loss during alteration and further LA-ICP-MS analyses will be done to determine gold metal associations.
- A research associate will be recruited to reconcile the surface geology with the new seismic and MT sections and resolve unanswered questions on the structural geology and stratigraphy of the area.

Anticipated Outcomes

- The two MSc projects will be written as papers for submission in Precambrian Research, Canadian Journal of Earth Sciences, and Economic Geology.

Implications

- Hammond Reef is one of the largest gold deposits in the Wabigoon subprovince. Thus, how the deposit formed and was emplaced is important for understanding the endowment of the Wabigoon subprovince.
- The Witch Bay Formation plays a pivotal role in our understanding of the early buildup of greenstone belts. As the Witch Bay Formation may have been emplaced by early thrust faults above the platformal sequence of the Steep Rock Group, it will contribute to the discussion and debate on the early autochthonous versus allochthonous growth of greenstone belts.



Highlights

Agnico Eagle is completing a feasibility study of the Hammond Reef deposit with the aim, if positive, of bringing the deposit into production. They requested two presentations from Gabrielle Fouillard, and provided positive feedback, commenting on the usefulness of her study for their understanding of the deposit.

WATCH NOW!
Magnetotelluric Project Updates

Gravity and Magnetics

Lead Researcher: Richard Smith

The work on the Metal Earth project has primarily been focused on modelling the data on individual traverses to assist with the geological interpretation on those traverses. This work has been included in presentations and publications that relate to these individual traverses.

The work on the physical properties compilation, relates to many traverses. A paper describing the results and significance of the compilation is being revised for publication, with an example for the Chicobi traverse being generated by Rajesh Vayavur. This example shows that knowing and specifying the physical properties of each lithology and using these as an initial model in an inversion results in the inversion changing the values if they are inconsistent with the geophysical data. This can be used to identify where the physical properties are different from typical values, perhaps as a consequence of alteration.

Progress

- The gravity and magnetic modelling that was completed on the Chibougamau line by the MSc student Amir Maleki was submitted for publication in the Canadian Journal of Earth sciences. A number of revisions were made and the article was accepted for publication at the end of the reporting period. It was observed that some of the felsic batholiths evident in the Chibougamau profile were spatially correlated with features evident on the seismic data. The number of features that correlate is small, as there are not a statistically significant number of features on the Chibougamau traverse. Hence, a meta-analysis of all Metal Earth profiles was undertaken and the correlation was observed on all the profiles, using a number of methods. The paper describing this work was submitted to a journal.
- The work by MSc student William McNeice on the usefulness of outcrop magnetic susceptibility measurements was prepared for publication and submitted to a journal. It is currently in the process of being revised.
- PhD student Fabiano Della Justina completed 2D modelling on four profiles at Matheson, which he wrote up for presentation at a conference held during the reporting period. He also started 3D modelling during the reporting period.
- Rajesh Vayavur is working on 3-D potential-field inversion modelling of Metal Earth transects. Modelling for the following traverses has been completed: Malartic, Chicobi (Malartic sub-transect), Swayze, Matheson, Rouyn-Noranda, Sturgeon, Larder-Lake, Cobalt and work is in progress for remaining transects. The results are provided to various transect RA's to write-up for collaborative publications and should be reported on in more detail elsewhere on the report.
- Independent of the traverse work, Rajesh Vayavur has been undertaking some modelling of the Chicobi traverse to show the value of the physical properties compilation undertaken by Esmaeil Eshaghi.
- New magnetotelluric (MT) data were acquired at Geraldton, Red Lake, and Timmins between September 2020 and February 2021. The data, acquired for Metal Earth by Quantec Geosciences, consists of 36 audio-frequency MT (high-resolution data targeting the upper crust) and 140 broadband MT (regional data targeting mid-crust to upper mantle structures).

  Ademola Adetunji oversaw the acquisition and quality control process.

  Eric Roots created a new 3D resistivity model for the Geraldton transect.

  The newly acquired data was used to create 3D control for the existing MT data along the transect.
- As part of his MSc work, Robert Rapolai completed 2D analysis, modelling, and inversion of Rouyn-Noranda MT data. The result, integrated with other geophysical data, was written up in the thesis completed during the reporting period.

METAL EARTH **GEOPHYSICS**

Field photo from Metal Earth magnetotelluric project work.

- Ademola Adetunji completed 3D resistivity models for the Swayze Mallard Road, Cobalt, Chibougamau, and Rainy River transects. These results are at different stages of interpretation and write-ups.
- PhD student Eric Roots submitted a paper on the 3D MT modelling of the Abitibi subprovince. This work was also presented at a conference held during the reporting period.
- Saeid Cheraghi was processing R2 seismic profiles for different transacts which includes:

a. Cobalt area: LN 382, LN391, LN402, and LN412 (four profiles)

b. Geraldton: LN301

c. Dryden area: north profile and south profile (two profiles)

d. Rainy River: LN361

These are being interpreted and written up by the relevant transect research associates.

- PhD student Hossein Jodeiri Akbari Fam has developed production codes for 2.5D Multi-Focusing (MF) Imaging of crooked seismic lines. His novel MF method was published in the journal *"Geophysics"*. He has also developed and coded 3D MF Imaging method for crooked seismic lines and currently applying the method on the Metal Earth data.
- Christopher Mancuso, an M.Sc. Student (currently PhD student working on joint inversion of Metal Earth geophysical data) has published his novel cross-dip move-out correction of crooked seismic lines in *"Geophysics"*. He applied his proposed and developed algorithm on Larder Lake transect generating high-resolution seismic images.

Future Work

- Fabiano Della Justina will complete his 3D modelling and write up the results in a thesis and prepare three articles for publication. A conference presentation will be made in the next reporting period. Other publications currently under review or revision will be completed.
- Eric Roots will complete his 3D modelling of the western Superior and write up the results in a thesis. A conference presentation will be made in the next reporting period.
- Ademola Adetunji is currently working on modelling and inversion of the Red Lake and Timmins dataset.

- The Chibougamau MT (R1 and R2), Rainy River and Mallard Road manuscripts are in progress and should be published in the next reporting period. Final results/models for Timmins transect will also be available.
- Matheson R2 seismic paper is under review (Tectonophysics) and should be published in the next reporting period. A manuscript on Swayze east R2 seismic (Mallard Road) is in progress.
- Heterogeneity and scaling behavior for R2 seismic profiles will be investigated in a comparison of the Abitibi and Wabigoon greenstone belts.
- Christopher Mancuso is working on joint inversion of Metal Earth's Geophysical data as part of his PhD program. The experience and knowledge that he gained during his MSc program will be a great asset for his success in this difficult and interesting project.

WATCH NOW!
Metal Earth Active and Passive Seismic Results and Imaging Progress

- Hossein Jodeiri Akbari Fam is developing 3D Multi-Focusing production codes to be applied on Metal Earth seismic transects. He has already one published Journal Paper and two papers are in the preparation stage and will be submitted to peer-reviewed journals soon. He is aiming to complete his PhD program in Winter 2022.

Anticipated Outcomes

- The work by Amir Maleki and Fabiano Della Justina has been used to better understand the Chibougamau and Matheson traverses and will be discussed in those parts of the report.
- More generally, the work of McNeice has shown that a single outcrop measurement of magnetic susceptibility is only within an order of magnitude of the value that is necessary to adequately model the data. However, many outcrop measurements, when statistically analyzed, can be used as a guide to an appropriate range that the values might fall within.
- The statistical correlation between felsic batholiths and interpreted seismic features implies that the felsic batholiths and the features are associated with each other, so the batholiths could be emplaced by movement up the seismic features, or the seismic features could be structures resulting from emplacement of the batholiths.
- Analysis of the MT data suggests electrical anisotropy is present in the western Superior mantle. Determination of the source of this apparent anisotropy has implications on the geodynamic history of the western Superior.
- The Chibougamau MT article is expected to provide detailed insights into the small and large-scale structures conductivity structures that can be associated with mineral districts in the region. It will also provide more details about the geodynamic crustal evolution in the area.
- Investigation of the scaling behavior from seismic data could provide some criteria about reflectivity pattern, scattering in crystalline rock environment.
- The seismic processing flows coded and developed by Hossein Jodeiri and Christopher Mancuso are being used for the processing of Metal Earth seismic transects. These methods are specifically developed for Metal Earth seismic data that are acquired on crooked lines and suffer from irregular distribution of shots and receivers.

Implications

- The spatial correlation between the felsic batholiths and the seismic features could have implications for the mechanism that built the Archaean crust in Canada and other counties of the world. A better understanding of the manner that the crust is constructed will have implications for mineral deposit emplacement and exploration.
- The role of lithospheric structure on the mobilization and localization of metalliferous fluids, as revealed by the MT and seismic data, has implications on our understanding of the metallogenic processes active in the Archean, and therefore on mineral exploration in Archean terranes.
- We are generally seeing the exploration industry interested in the use of MT for identifying large scale plumbing systems that are associated with metal transport and deposition. There have been a number of requests for MT data.

METAL EARTH **GEOPHYSICS**

PhD student **Fabiano Della Justina** and research associate **Rajesh Vayavur** preparing field equipment.

Highlights

1. One paper prepared by an MSc student (Maleki) has been accepted for publication and a second (McNeice) is well on the way to publication.
2. The PhD student (Justina) is getting close to completing his research, has presented one talk at a conference, prepared a second, and is excited about the content of his thesis.
3. Hossein Jodeiri Akbari Fam and Christopher Mancuso each published one paper in Geophysics journal. Both students have developed and coded their algorithms for seismic data processing using Shell Scripting and Seismic Unix which makes it practical to use them for processing of real seismic data. The application and implementation of these software on Metal Earth seismic data will produce high resolution seismic images that will be crucial to understanding the subsurface and mineralization process of study areas. The paper published by Akbari Fam has been nominated by the Editor to be highlighted to all the members of the Society of Exploration Geophysicists in their monthly magazine.
4. The MT results will benefit the mineral industry by depicting the nature and extent of the current/known deposits. It will also suggest possible new deposits along with the structural dynamics.
5. The high-resolution seismic sections could provide details about subsurface architecture which could benefit the transects RAs in their research.
6. The final cross-section and 3-D iso-surface models from 3-D potential field inversions are helping transect RA's to refine their interpretation of crustal-scale faults dips and upper crustal architecture.

WATCH NOW!
Geophysical evidence for emplacement of felsic plutons

Gold Fluid Window

Lead Researcher: Carl Guilmette and Doug Tinkham

WATCH NOW!
Gold Fluid Window
Update 2020-2023

The Gold Fluid Window thematic project aims to define the P-T-t-X conditions to form typical orogenic gold fluids from potential sedimentary source rocks, and the geodynamic settings where these favourable conditions are met at the right time to form orogenic gold deposits.

The main objectives are to constrain the volume, chemistry and timing of fluid pulses released by important potential sources of volatiles, ligands and metals for gold deposits of endowed and less endowed segments of the Superior Craton.

This approach will reveal the different factors affecting gold endowment of mineralized systems such as source fertility, initial fluid composition, timing and rate of fluid generation, and the geodynamic setting at the mineralization stage. In addition, this study evaluate the relative importance of these different factors on the formation of economic deposits, and thus to better target future well-endowed mineralized orogenic gold style systems.

Progress

- This period constitutes the first 10 months of the Gold Fluid Window Metal Earth thematic project. Three HQP including a research associate (Antoine Godet) and two PhD students (Adrian Rehm, Diogo Ribeiro) were recruited to carry out the specific studies related to our research themes.
- This period was dedicated to literature compilation, fieldwork, and preliminary analyses.
- The first fieldwork campaign was conducted during the summer 2020 in both the Quetico and the Pontiac metasedimentary belts. Field isograds were mapped in the Thunder Bay area. More than 300 outcrops were described and about 180 samples were collected. The plutonic suites located south of Rouyn-Noranda were targeted for petrogenetic study. About 50 samples were collected.

Gold Fluid Window project, Quetico Subprovince, Granodiorite sill, metawacke, and S-type granite pictured.

- The first analyses were made in laboratories. This includes about 100 thin sections, 100 whole-rock analyses, and 50 µXRF scanning.

Future Work

- Pursue the ongoing compilation of geological record in both the Quetico and the Pontiac subprovinces.
- Prepare and accomplish the second fieldwork campaign that will focus on the Geraldton and Thunder Bay areas.
- Perform in-situ EPMA analyses on rock-forming minerals. Acquire LA-ICP-MS on datable accessory phases2

Anticipated Outcomes

- This project will generate new understanding on the metamorphic and tectono-thermal evolution of the Quetico and Pontiac basins considered as key lithotectonic domains that recorded the final stages of the assembly of the Superior Craton during which most orogenic gold deposits were formed. It will provide new high quality quantitative data in term of pressure-temperature-time-chemistry-deformation (P-T-t-X-D) path that will contribute 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.

Implications

- The project is contributing to Metal Earth by addressing fundamental aspects of gold endowment in the Superior Province and as such the relevant knowledge that can be transferred to other geological terranes.
- This project will generate new understanding on the metamorphic evolution of key lithotectonic domains that record the final stages of the assembly of the Superior Craton during which most orogenic gold deposits were formed.
- Collectively, the results will contribute 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.

Sillimanite (fibrolite) porphyroblasts in a metapelitic rock.

Highlights

1. A student was recruited for the Quetico PhD
2. A student was recruited for the Elemental mobility PhD
3. A researcher was recruited for the Research Associate position.
4. Successful fieldwork was conducted in both the Quetico and the Pontiac metasedimentary belts.

Factors contributing to metal endowment in the western Wabigoon and Abitibi subprovinces: a mineral prospectivity modelling approach for Precambrian greenstone belts

Lead Researcher: Stéphane Perrouty

This thematic project is a comparative study utilizing innovative and novel approaches to qualitative understanding which factors control mineralization in the western Wabigoon and southern Abitibi subprovinces of the Superior Province. Its objective, which is to compare a modestly endowed region (western Wabigoon) to the world-class southern Abitibi district, follows the Metal Earth plan to understand what controls mineralization in Archean greenstone belts. Also, application and development of new tools such as statistical learning (data science), multi-disciplinary integration (e.g., field geology, GIS, geophysics, geochemistry), and machine learning techniques are generating tools that will improve exploration methods for industry.

Progress

- During the third year of this thematic project, two publications were released (co-submitted Tectonophysics and Data in Brief) for a new method of mapping structural complexity and data/map release of greenstone belts near Dryden and Timmins, ON.
- A comprehensive, sub-province scale geochemical database was compiled for the western Wabigoon and southern Abitibi. This database was used to define a new geochemical classification diagram for Precambrian igneous rocks and three rock favourability indices (magmatic Ni-Cu-PGE, VMS, orogenic Au).

The manuscript outlining these new tools and a comparison to other Archean cratons is prepared and undergoing internal edits with co-authors. Additionally, a related manuscript presenting the comprehensive geochemical database is prepared and awaiting internal edits.

- The fourth and final field season of this thematic project was completed and resulted in the collection of >600 outcrop observations that will result in a ~1km resolution (70x90 km map area) alteration map for the Dryden area and training points for machine learning techniques.

Future Work

- The final stage of this thematic project will be to combine features generated from the structural complexity and favourability indices described above and several other layers (e.g., distance to deformation zones, distance to contacts, chemical/magnetic contrast) using a Random Forests approach. The aim of this work will be to investigate/compare which factors control magmatic Ni-Cu-PGE, VMS, and orogenic Au mineralization in the Dryden and Timmins areas.

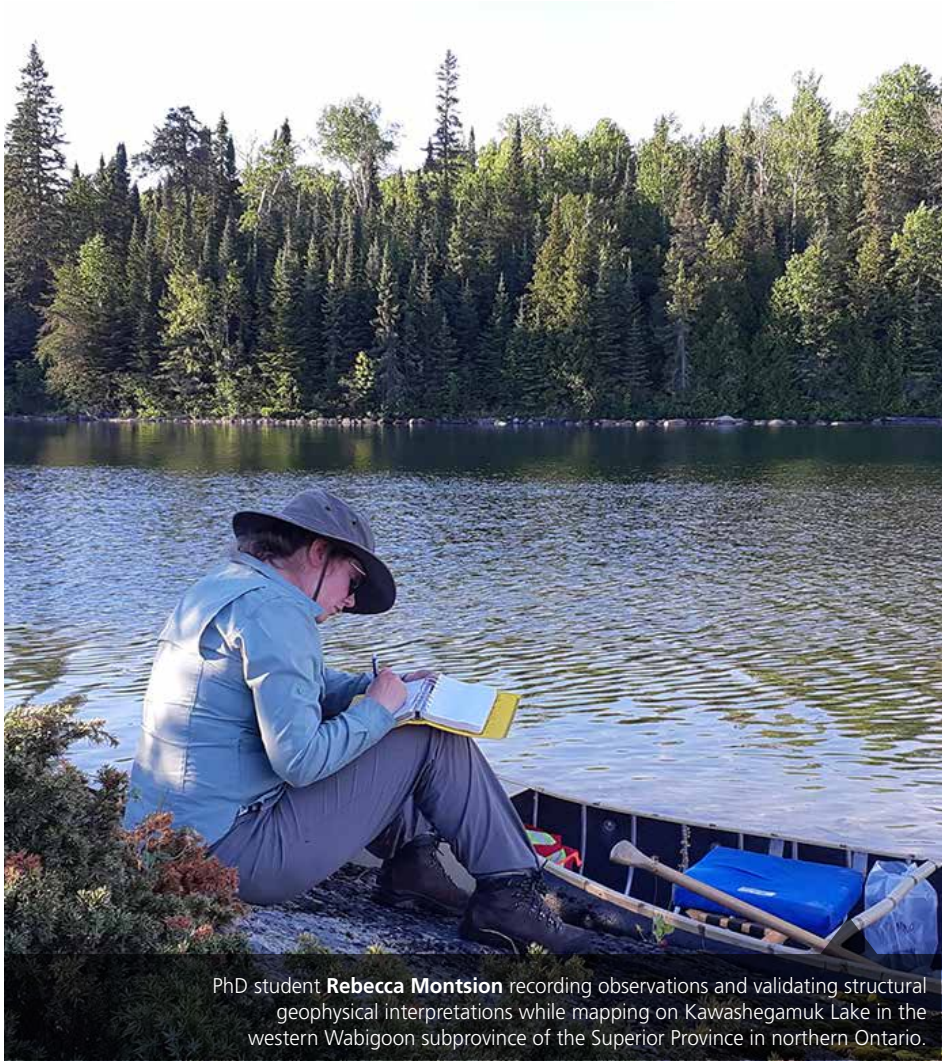
Anticipated Outcomes

- The major outcomes of this research will be the identification of factors that control mineral distribution in greenstone belts and a recommendation of methods that efficiently delineate areas of interest in greenstone belts. Deliverables associated with this work include two 3D geological models, data-driven "prospectivity" maps (one for each study area), a comparison of the western Wabigoon and the Abitibi at the scale of mineral systems, one PhD thesis and one BSc thesis.

Benefits to mineral industry

1. New quantitatively-based methods for early stage mineral exploration (feature engineering methods for mineral prospectivity)
2. New geochemical classification diagram (ultramafic to felsic compositions) for Precambrian igneous rocks regardless of alteration/ weathering and texture (i.e., intrusive, extrusive).
3. Three new rock favourability indices (magmatic Ni-Cu-PGE, VMS, orogenic Au) regardless of alteration / weathering, texture (i.e., intrusive, extrusive) and rock compositions (i.e., ultramafic to felsic).

This thematic project is a comparative study utilizing innovative and novel approaches to qualitative understanding which factors control mineralization in the western Wabigoon and southern Abitibi subprovinces of the Superior Province. Its objective, which is to



PhD student **Rebecca Montsion** recording observations and validating structural geophysical interpretations while mapping on Kawashegamuk Lake in the western Wabigoon subprovince of the Superior Province in northern Ontario.

WATCH NOW!
Factors contributing to metal endowment in western Wabigoon and southern Abitibi

compare a modestly endowed region (western Wabigoon) to the world-class southern Abitibi district, follows the Metal Earth plan to understand what controls mineralization in Archean greenstone belts. Also, application and development of new tools such as statistical learning (data science), multi-disciplinary integration (e.g., field geology, GIS, geophysics, geochemistry), and machine learning techniques are generating tools that will improve exploration methods for industry.

Highlights

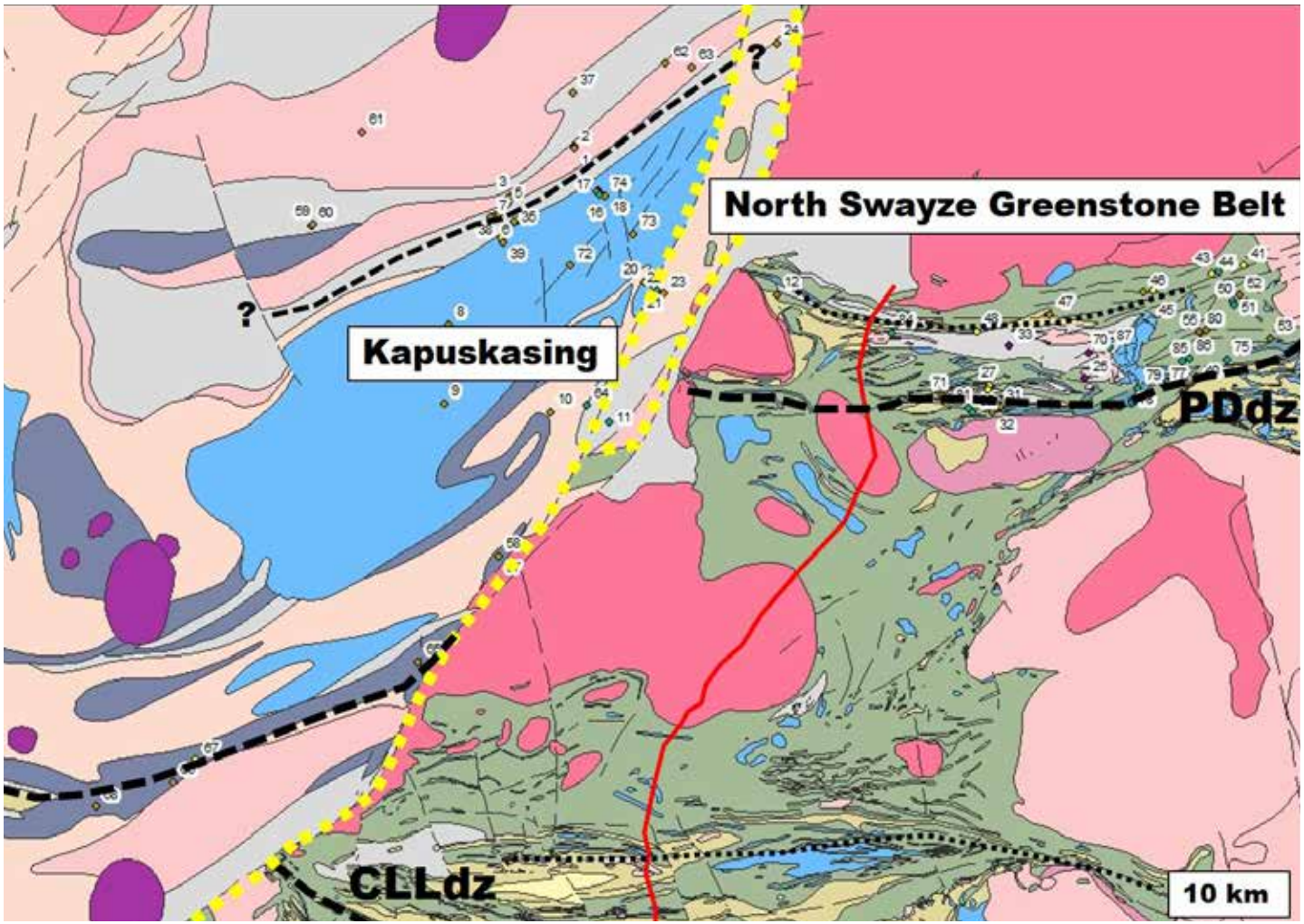
Rebecca Montsion, PhD candidate, Laurentian University and University of Western Australia has earned a number of awards, as listed below:

1. CSEG Foundation Award (2020), Canadian Society of Exploration Geophysics (CSEG)
2. Michael Smith Foreign Study Grant (2020) Natural Sciences and Engineering Research Council of Canada (NSERC)
3. Post-Graduate Scholarship (2020) Natural Sciences and Engineering Research Council of Canada (NSERC)
4. Queen Elizabeth II Graduate Scholarship in Science and Technology (2020) Canadian Federal Government
5. Innovation in Mining (2019) Young Mining Professionals (YMP) and Orefinders
6. Joan Bath Bursary (2019), CSM Global and Prospectors and Developers Association of Canada
7. Goodman School of Mines PhD Fellowship (2018) Goodman School of Mines

WATCH NOW!
Westward Extension of the Porcupine-Destor Deformation Zone

Western Extension

Lead Researcher: Eric Thiessen



Progress

- New post-doc Eric Thiessen started work on the Western Extension Project in July 2020. Field work occurred in July and August 2020, based out of Foleyet, ON, and conducted field investigation of the north Swayze greenstone belt and Kapuskasing structural zone.
- In addition to rock type and structural observations, 30 samples have been analyzed for whole rock geochemistry, 30 samples have been analyzed for U-Pb zircon geochronology, one sample has been analyzed for Re-Os geochronology, and 10 samples have been analyzed for both monazite and titanite U-Pb geochronology.
- Field relationships and analytical results are helping constrain the timing and style of plutonism, deformation and mineralization within the north Swayze greenstone belt in order to better place these attributes in a regional context with the Timmins mining camp as well as to compare tectonics with other areas in the Abitibi that have historic gold production.

- Currently, Thiessen has data that suggests gold deposition occurred in an intrusion-like setting at 2730 Ma, but may also occur in orogenic-like veins at 2.66 Ga. Deformation and metamorphism are also being constrained within the Kapuskasing, where a clockwise pressure-temperature (regional burial metamorphism) cycle is documented between 2665 and 2640 Ma.
- Timing of this major orogenic event presumably coincides with deformation and orogenic gold mineralization in the north Swayze, however, this suggestion is currently being tested with further work. Both the Kapuskasing and the north Swayze have (meta)sedimentary rocks that were deposited as young as 2670 Ma and have sedimentary characteristics that infer they belong to the Timiskaming Assemblage.
- Timiskaming occurrences in the north Swayze help locate the extension of the Porcupine Destor deformation zone (PDdz), which runs east-west, and roughly south of the Timiskaming basin therein. Why Timiskaming-like rocks were buried to lower-crustal depths in the Kapuskasing, and remained in the upper crust in the north Swayze remains an area of inquiry.
- Also, it appears as though the north Kapuskasing has slightly older metamorphic ages ~2.66 to 2.64 Ga whereas the south Kapuskasing contains much younger events between 2.65 and 2.60 Ga. This may suggest a diachroneity in burial and heating of the lower crust as the Abitibi was assembled during north to south accretion. Relating this lower-crustal thermal history to the deposition of orogenic gold within the PDdz and the CLLdz is ongoing.

Future Work

- Continue to build a model for north Swayze plutonism, deformation and gold deposition that can be related with the Timmins mining camp.
- Ascertain why the Kapuskasing has such a different history compared to the north Swayze.
- Constrain the metamorphic evolution of the north and south Kapuskasing to compare with the age and distribution of gold deposits in the Abitibi.

Anticipated Outcomes

- This work will develop a holistic understanding of the relationship between the deep-crust orogenic processes and upper crustal plutonism, deformation and gold localization. Currently, three separate journal manuscripts are in preparation for eventual submission for peer-review.

Implications

- This project and its goals are in-line with Metal Earth's objectives of better understanding the tectonics and fundamental mechanisms that help control mineral endowment. Continued work on this project will place robust constraints and linkages between lower-crust metamorphism and upper-crust deformation that are responsible for orogenic gold deposition in the Abitibi. Future work will allow for a set of criteria to be followed that could be used to continue to trace the PDdz farther west and into the Wawa terrane.

Highlights

1. Post-doc Eric Thiessen has moved on to a faculty position at Memorial University. He will continue to advance the ongoing projects described above. Chong Ma, Metal Earth Research Associate will continue working on this project.
2. This work helps give robust constraints on the tectonic history of the north Swayze and shows it is akin to other gold-endowed areas in the Abitibi, and thus, is a westward extension of the PDdz. It also suggests the PDdz runs south of the basin, which helps exploration companies focus their attention north of this first-order structure. This work has also confirmed 2.68 Ga alkaline lamprophyre dykes, not previously dated, occur within the PDdz south of the north Swayze basin, which further contributes to a favourable comparison to the Timmins mining camp.

WATCH NOW!
Magmatic Cr-Ni-Cu-PGE Thematic Projects

Superior Margin Ni-Cu-PGE – Raglan Thematic Project

Lead Researcher: Michael Lesher

Most mineralized magmatic Ni-Cu-(PGE) systems are poorly exposed and thus poorly characterized, and therefore our understanding of how and where sulfide deposits are located within these plumbing systems is limited. The eastern portion of the Paleoproterozoic Cape Smith Belt (Nunavik, Québec), on the other hand, contains a well-exposed crustal scale komatiitic system of both mineralized and barren extrusive and invasive lava flows, intrusive sills and dykes, and associated volcano-sedimentary sequences.

The main objective of this project is to petrographically, geochemically, and geochronologically characterize the plumbing system in order to determine how various parts are related temporally and geochemically. Specifically, differentiated mafic-ultramafic sills and poorly differentiated dykes in the lower part of the sequence (Expo-Ungava area) overlying Archean Superior Province basement rock, are being compared to differentiated sills and poorly differentiated ultramafic lava flows located stratigraphically higher in the sequence (Raglan area).

Progress

The following work was completed in 2020-2021:

- The Circum-Superior geochemical compilation was completed, and includes ~18,800 unique whole-rock analyses from the Cape Smith Belt (87%) and surrounding domains in Nunavik (13%) with major ± trace elements and accompanying metadata (drillhole collars and depths, sample locations, rock descriptions, and references) from 130 sources. Duplications of records from different sources allowed cross-validation and identification of transcription errors, and preliminary QA-QC of data generated for the same rock units using multiple methods revealed differences in sample preparation and analytical methods employed at various laboratories. A preliminary interpretation of the data was published in McKevitt, D.J., Lesher, C.M., and Houlé, M.G., 2020, Regional lithogeochemical synthesis of mafic-ultramafic volcanic and intrusive rocks in the Cape Smith Belt, Nunavik, northern Quebec; in Targeted Geoscience Initiative 5: Advances in the understanding of Canadian Ni-Cu-PGE and Cr ore systems – Examples from the Midcontinent Rift, the Circum-Superior Belt, the Archean Superior Province, and Cordilleran Alaskan-type intrusions, (ed.) W. Bleeker and M.G. Houlé; Geological Survey of Canada, Open File 8722, p. 99–115. ***doi.org/10.4095/326883***
- The database is in the process of being published as a Geological Society of Canada Open File report, and the interpretations are being written up as Chapter 2 of McKevitt's PhD thesis and a journal paper for publication in a peer-reviewed, internationally-circulated geoscience journal.
- A preliminary interpretation of the geochemical and petrological relationships between the barren and mineralized parts of the syn-Chukotat magmatic plumbing system in the east-central Cape Smith Belt was also completed and preliminary results are summarized in the same publication.
- This work, including PRIMELT3 petrological calculations of parental magmas not included in the GSC report, is being written up as Chapter 3 of McKevitt's PhD thesis and a journal paper for publication in a peer-reviewed, internationally-circulated geoscience journal.
- Work on the major-, minor-, and trace-element geochemistry of olivine in the Katinniq Peridotite Complex, the type locality of the Ni-Cu-PGE mineralization is still in progress, and will be written up as Chapter 4 of McKevitt's PhD thesis and a journal paper for publication in a peer-reviewed, internationally-circulated geoscience journal.

Future Work

- PhD candidate Dylan McKevitt experienced unavoidable delays in 2020-2021, but is still making progress and is expected to complete his degree by May 2022. The final whole-rock trace-element geochemical analyses were delayed by COVID, but are currently in progress. In situ major-minor-

trace-element analyses (EPMA and LA-ICP-MS) of relict igneous olivine are in progress. All that remains is formatting the first two journal papers for submission, completing the geochemical work, and writing up the final journal paper.

Anticipated Outcomes

- Better understanding of the geochemistry and petrogenesis of mafic-ultramafic rocks in the Cape Smith Belt, New Québec.

Implications

- At the craton scale, the results from this study will be integrated with our previous work in the Thompson Nickel Belt and previously published work for other parts of the Circum-Superior Belt to better understand why some parts of the Belt (e.g., Ragan, Thompson) contain world-class Ni-Cu-PGE mineralization, why some parts (e.g., Expo-Méquillon, Labrador Trough) are only moderately mineralized, and why some parts are only poorly mineralized.
- At the regional scale, this study has confirmed that mineralization in the Cape Smith Belt is hosted by channelized lava flows, channelized sills, and channelized dikes that have incorporated sulfide from S-rich sediments, and that the magma that formed all mineralized bodies was derived from similar (likely the same) source region(s) in the mantle, but that the mineralization formed at more-or-less the same time in multiple "parallel" flow-through systems at multiple stratigraphic levels, and did not form in a single "serial" flow-through system. This greatly increases the possibility for finding additional mineralization at similar and different stratigraphic levels.

Highlights

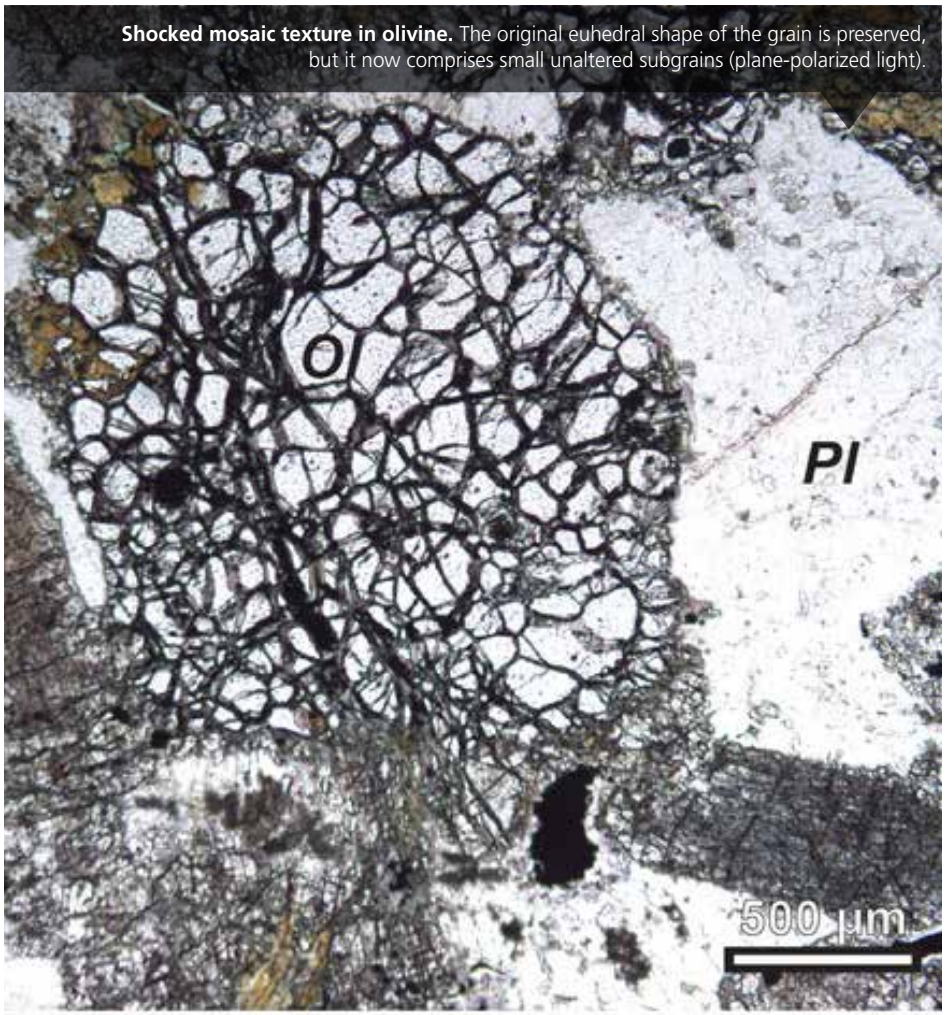
1. The geochemical database, including proprietary analyses from Glencore Ltd. (Raglan area) and Canadian Royalties Ltd. (Expo-Méquillon area) has already been given to the companies. This will expand the size and increase the quality of their databases considerably and – together with our interpretations of the petrogenetic relationships between the mineralized Raglan, Delta, and Expo-Méquillon parts and unmineralized other parts of the system – aid them in mineral exploration in the Cape Smith Belt.
2. Our results show that the magmas that formed the mineralized parts of the system are fundamentally different from those that formed the unmineralized parts of the system (as shown by our previous work) and that the Expo-Méquillon parts of the system did not feed the Raglan parts of the system (as suggested by other workers).

Dylan McKevitt (PhD candidate) and Dr Michel Houlé (GSC, Adjunct Professor) in the field in the Cape Smith Belt (photo by CM Lesher).

Superior Margin Ni-Cu-PGE – Sudbury Thematic Project

Lead Researcher: Michael Lesher

WATCH NOW!
Magmatic Cr-Ni-Cu-PGE Thematic Projects



Shocked mosaic texture in olivine. The original euhedral shape of the grain is preserved, but it now comprises small unaltered subgrains (plane-polarized light).

Progress

The following work was completed in 2020-2021:

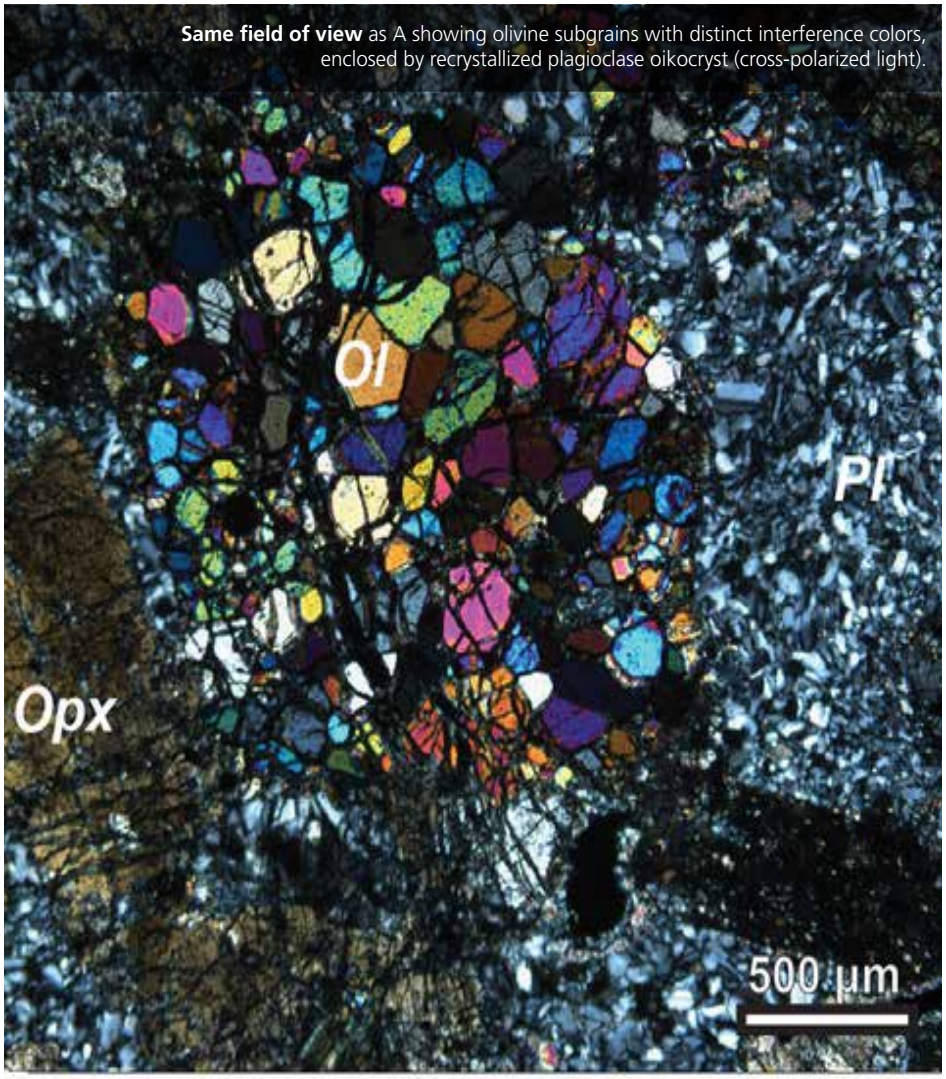
- Chapter 3 of Yujian Wang's PhD thesis was published as Wang Y, Lesher CM, Lightfoot PC, Pattison EF, Golightly JP, 2020, Geochemistry and petrogenesis of mafic and ultramafic inclusions in Sublayer and Offset dikes, Sudbury Igneous Complex, Canada, Journal of Petrology 61(6), ***doi.org/10.1093/petrology/egaa059***.
- Chapter 4 of Wang's PhD thesis "Genesis of Sublayer in the Sudbury Igneous Complex" was submitted for publication in a Special Issue of Economic Geology dedicated in memory of Prof Anthony J Naldrett, who was a world leader in Ni-Cu-PGE deposits, did his PhD on Sudbury, and spent the early part of his career in Sudbury. It has been accepted pending revisions and should be published in late 2021 or early 2022.

Future Work

- Three spin-off projects have been generated from this project, funded by NSERC and Vale Ltd. to study the genesis of Ni-Cu-PGE mineralization in the Sudbury Igneous Complex.

Anticipated Outcomes

- Better understanding of sources of Ol-bearing mafic and ultramafic inclusions in the Sublayer of the SIC, which are characteristic of mineralized portions of the basal contact of the complex and offset dikes. Some are anteliths ("cognate xenoliths," some are local xenoliths, and some are exotic xenoliths.)
- Determination of an intermediate crustal depth of formation for the exotic Ol-bearing mafic and ultramafic inclusions in the Sublayer of the SIC, which is different from recent models proposing deep or shallow levels of impact excavation.
- Better understanding of the relationship between these inclusions and mineralization, which appears to be due to the more refractory nature



Same field of view as A showing olivine subgrains with distinct interference colors, enclosed by recrystallized plagioclase oikocryst (cross-polarized light).

of ultramafic inclusions and their hydrodynamic equivalence to 1-3 cm diameter sulfide melt droplets, their formation during thermomechanical erosion of footwall rocks, and emplacement as congested suspensions during gravity flow.

Implications

- The Sudbury Ni-Cu-PGE camp – like the Raglan (QC) and Thompson (MB) Ni-Cu-PGE camps – occurs along the margin of the Superior Craton. All can be attributed to the emplacement of mantle-derived magmas being focused along the craton margins. In the case of Raglan and Thompson, the mineralization formed in the magmas as they were emplaced into sulfide-rich country rocks and generated Fe-sulfide xenomelts that interacted with the magma to increase the Ni-Cu-PGE contents. In the case of Sudbury, the impact melted older but similar and generally lower-grade Ni-Cu-PGE mineralization in 2.4 and 2.2 Ga mafic intrusions, forming Fe-Ni-Cu-PGE xenomelts.

Highlights

1. Student graduated in Dec 2019, has published 2 papers in high-profile journals: one in Geology (one of the top general geoscience journals) and one in Journal of Petrology (the top petrological journal), and is publishing the final part of her thesis in Economic Geology (one of the top two mineral deposits journals).
2. The demonstration in the Geology paper that the exotic xenoliths show impact shock textures with mineral compositions that indicate middle-crustal depths of equilibration has changed
3. Most other magmatic Ni-Cu-PGE sulfides form by incorporation of sulfide xenomelts from crustal sources and this study has shown that this also applied to Sudbury, even though it formed from an impact melt rather than a mantle-derived magma.
4. Many other magmatic Ni-Cu-PGE sulfides are associated with mafic-ultramafic inclusions, which are typically poorly characterized. This study has shown that the association is attributable to fluid-dynamic controls.

Superior Cr-Ni-Cu-PGE Thematic Project

Lead Researcher: Michael Lesher

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Magmatic Cr-Ni-Cu-PGE Thematic Projects

Progress

- Continued compilation of whole-rock geochemical data for komatiitic rocks and iron formation facies in the Superior Province. The database presently includes ~4,000 komatiites, ~2,300 komatiitic basalts, ~166 siliceous high-Mg basalts, and ~2,300 basalts associated with those rocks; and ~2,000 iron formations (silicate ± oxide ± sulfide facies).
- Continued compilation of geological and geochemical data for the Shebandowan (ON), Lac des Montagnes (QC), and Lac Fed (QC) areas.
- Continued work with the MELTS thermodynamic modelling program to define chromite phase equilibria in komatiitic systems.
- Planning for field work in summer 2021 and summer 2022.

Future Work

- Continued compilation of whole-rock geochemical data for komatiites, komatiitic basalts, basalts, and iron formation facies (silicate ± oxide ± sulfide) in the Superior Province, including ongoing extraction from OGS maps, merging maps, and converting IF bodies to outcrop points in GIS.
- Continued work with the MELTS thermodynamic modelling program to define chromite phase equilibria in komatiitic systems.
- Completion of compilation of geological and geochemical data for the Shebandowan (ON), Lac des Montagnes (QC), and Lac Fed (QC) areas.
- Field work in the McFaulds Lake greenstone belt ("Ring of Fire") in summer 2021 to log and sample drill cores in the Blue Jay (AT-12) area for inclusions of chromite.
- Field work in the Shebandowan area, and logging of Shebandowan drill cores at the Ontario Geological Survey Core Facility in Thunder Bay.
- Field work Lac des Montagnes and Lac Fed areas of northern Québec in summer 2022.

Anticipated Outcomes

- Better understanding of the controls on why some 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; Western Australia), some contain only Cr mineralization (e.g., Inyala and Railway 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 systems that contain both Cr and Ni-Cu-PGE (McFaulds Lake and Shebandowan, Ontario; Utikomst, South Africa; some parts of the Stillwater and Bushveld Complexes).
- Better understanding of the controls on 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 is a recently discovered and very 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 differences like this is a fundamental goal of Metal Earth.

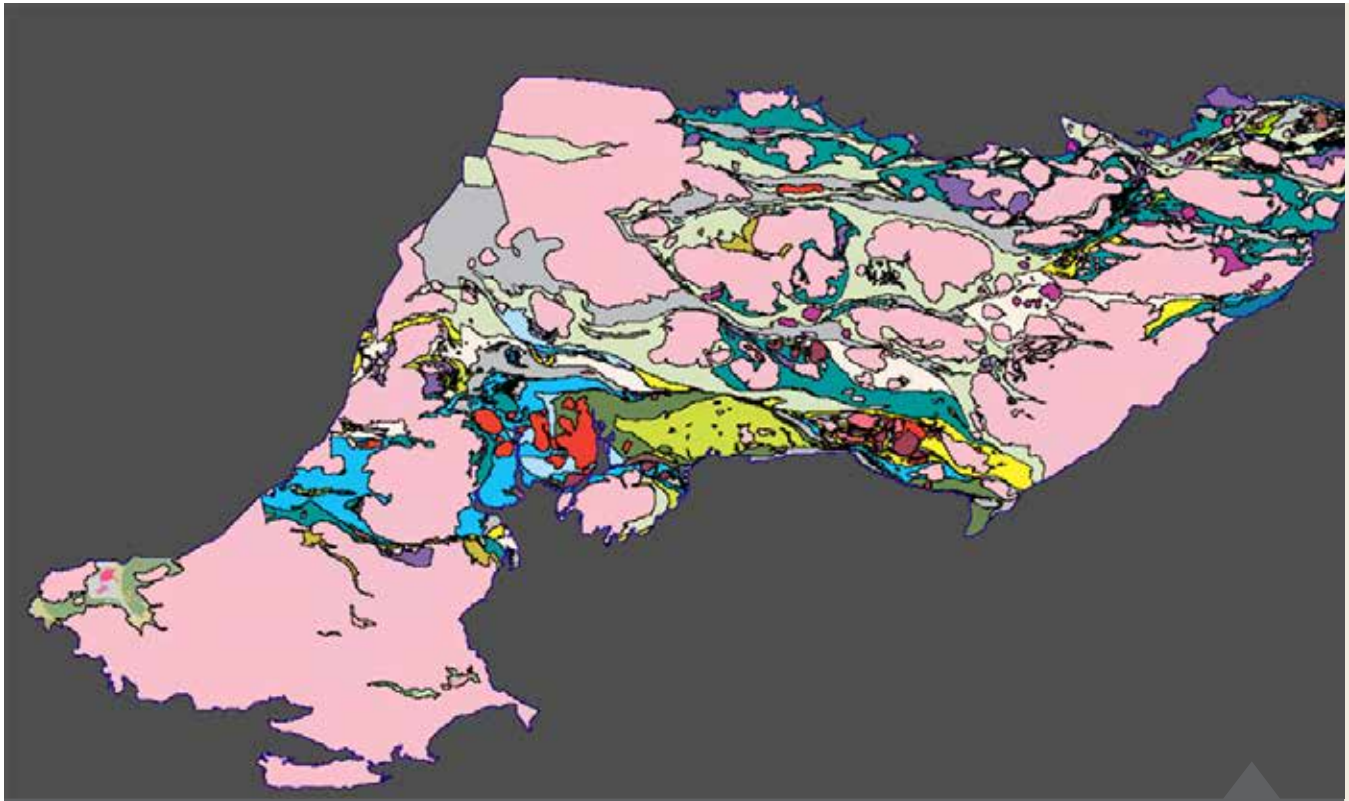
Highlights

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

VMS

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

Lead Researcher: Taus Jørgensen



Abitibi subprovince assemblage map based on Ayer and Chartrand (2011) and SIGÉOM (2016; 2020), and modified from Thurston et al. (2008) Dubé and Mercier-Langevin (2020). The compilation was done in ArcGIS using the GSC Bedrock tool (Brouillette, Girard, and Huot-Vézina, 2019) and will allow for the quantification of features related to VMS endowment within each assemblage (e.g., lithologies, lithofacies, magma affinity, syn-volcanic intrusions, etc.).

The constructional history of Archean greenstone belts is more complicated than commonly thought (e.g., Jackson et al., 1994). There remain uncertainties regarding Archean tectonic processes, complex inheritance, and variable contributions from mantle and crustal melts, all of which impact the overall metal budget and VMS endowment (Mercier-Langevin et al., 2014). The differential base and precious metal endowment of assemblages within a greenstone belt and between greenstone belts suggest there are fundamental differences in assemblage-scale tectonic, magmatic and crust-mantle processes that impact metal endowment during greenstone belt construction (Groves and Bierlein, 2007; Huston et al., 2014; 2016). To address this problem, research will involve a comparison of variably VMS endowed assemblages within the AGB (Ayer et al., 2002; Thurston et al., 2008) and a comparison with the less endowed assemblages comprising the OTGB. Can a comprehensive review of assemblage attributes and pre-deformation reconstructions identify the unique combinations of geological events or conditions that correlate with regional VMS endowment (Wilkinson and Kesler, 2009; Singer and Menzie, 2010). Assemblage-scale attributes, including volumes of volcanic products, types and styles of synvolcanic intrusions, area-age relationships, and compositions, as well as reconstructions, will be studied to isolate the differences between richly-endowed and poorly-endowed assemblages, supported by comparisons with the modern ocean floor (Metal Oceans) to provide new insights into Archean tectonics and metallogeny – a goal of Metal Earth.

Progress

- An assemblage-level compilation of the Abitibi greenstone belt was completed. The compilation relies mainly on the mapping carried out over the years by the Quebec and Ontario geological surveys. It captures the most up to date distribution of the Abitibi volcanic and sedimentary assemblages. It also contains the many intrusions within the Abitibi greenstone belt and their timing with respect to their host assemblage. It contains metadata which will allow future users in industry or research institutions to easily find the original references used.

Future Work

- Continued refinement of the Abitibi greenstone belt compilation. Quantify geological attributes contained in the Abitibi greenstone belt compilation. Perform a pre-deformation palinspastic reconstructions to identify unique combinations of geological events or conditions that correlate with VMS endowment and allow comparison with the modern ocean floor (Metal Oceans).

Anticipated Outcomes

- Improve on the VMS model that is mainly based on deposit- to district-scale research. The 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 there are fundamental differences in assemblage-scale tectonic, magmatic and crust-mantle processes that impact metal endowment during greenstone belt construction.
- This research will improve on 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.

Highlights

An assemblage-level compilation of the Abitibi greenstone belt that includes the Quebec and Ontario sides will be useful to companies doing exploration in the area and might serve as the backbone of many scientific breakthroughs relying on big datasets.

WATCH NOW!
VMS Projects - Intro by H. Gibson; Updates by T. Jørgensen and P. Ross

WATCH NOW!
VMS Projects - Intro by H. Gibson; Updates by T. Jørgensen and P. Ross

VMS
Petrogenetic Evolution of the Abitibi Greenstone belt

Lead researcher: Pierre-Simon Ross

The Ayer et al. (2002) and Thurston et al. (2008) subdivision of the AGB into assemblages is largely based on mapping, lithological packages and geochronology, but not on a complete geochemical assessment. In these publications, geochemistry is limited to broad classifications (komatiite, basalt, etc.) and magmatic affinities (tholeiitic, calc-alkaline). Felsic rocks have been studied in some assemblages (e.g., Lesher et al., 1986; Hart et al., 2004), but not all, and are much less abundant than basalts. It is not clear what types of basalts each assemblage contains, for example with regards to trace element patterns, tectonic setting (Piercey, 2010, 2011), etc. In other words, there has been no systematic attempt to compare the full geochemical signature of VMS-endowed versus VMS-depleted assemblages.

This research will examine variations in magmatic affinity (Ross and Bedard, 1999), composition, and petrogenetic evolution (e.g., Pearce et al., 2008) of assemblages within the AGB relative to VMS endowment. Focusing on immobile elements (those that are not influenced by hydrothermal alteration), we will use existing and new geochemical diagrams, multivariate statistical analyses (e.g., Fresia et al., 2017), and if needed, machine learning techniques (e.g., Caté et al., 2018), to classify the rocks into geochemical groups (e.g., different types of basalts) and document which of these geochemical groups are most closely linked with VMS deposits.

Progress

- This subject is the PhD project of Octavio Vite at INRS. Octavio fortunately arrived in Canada in January 2020, just before the COVID-19 pandemic started. However, the pandemic delayed field work by one year, and caused other delays.
- 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 don't completely understand why. The long-term goal of subproject 1b is therefore to compare variably VMS endowed volcanic assemblages within the Abitibi Greenstone Belt (AGB), focussing 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, area-age relationships, etc.), we hope that we can identify the unique combinations of geological events or conditions that correlate with regional VMS endowment.

During the period April 1, 2020 to March 31, 2021, the following work has been done:

- Geochemical compilation of volcanic rocks in the AGB using government, academic and industry sources. More than 12000 high-quality, complete analyses have been compiled. This compilation work is ongoing.
- The geochemistry of volcanic rocks in the Blake River assemblage, the youngest of the 7 subalkaline volcanic assemblages in the AGB, was interpreted on a preliminary basis. Mafic to intermediate volcanic rocks were classified into 8 geochemical groups using a number of diagrams involving immobile element ratios. The groups were separated based on magma differentiation and the intensity of crustal contamination, and were checked for spatial coherence on the geological map. This work is ongoing.
- Scientific and logistical planning was done for the summer 2021 field season.

Future Work

From April 2021 to early September 2021, the following work was done:

- Ten weeks of field work were carried out in the AGB, focussed on sampling the oldest volcanic assemblages (pre-2750 Ma and Pacaud), which are underrepresented in the database. This lead us to the regions of Chapais (near Chibougamau) and La Sarre (north of Noranda). Approximately 250 samples were obtained and prepared for geochemical analysis.

- Taus Jørgensen, who is in charge of Assemblage-level compilation project, visited us in Chapais for about a week. This allowed great discussions in the field and will facilitate continued strong collaboration between subprojects.
- The geochemical compilation of the AGB was largely completed. We are still waiting for about 3000 analyses from the Ontario Geological Survey (at the moment we have only their geographic positions), a few hundred from the Quebec geological survey (to be published this fall in SIGEOM), and our own new data

Work beginning in September 2021 to end of project is planned as follows, with each step yielding a publication in an international journal:

- The mini-project on geochemistry of mafic to intermediate volcanic rocks in the Blake River assemblage will be completed. We will also try to look at felsic volcanic rocks.
- A paper will be written on the very poorly known geology and geochemistry of the oldest volcanic assemblages in the AGB in Quebec, based largely on new data.
- VMS endowed volcanic assemblages will be geochemically compared to those with less or no endowment.

Anticipated Outcomes

- This subproject, will produce a better understanding of the constructional history of the Abitibi greenstone belt. In particular, we will shed light on the poorly know early phase (about 2790-2730 Ma) of this constructional history. We will clarify which volcanic assemblage is well-endowed with VMS deposits, and why, from a petrogenetic point of view. We hope 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 our understanding of the processes responsible for differential VMS endowment. It will also facilitate comparisons with the western Pacific Ocean (Lau basin).

Pierre-Simon Ross, Enza Magnier, and Octavio Vite in the field. Photo by Taus Jørgensen.

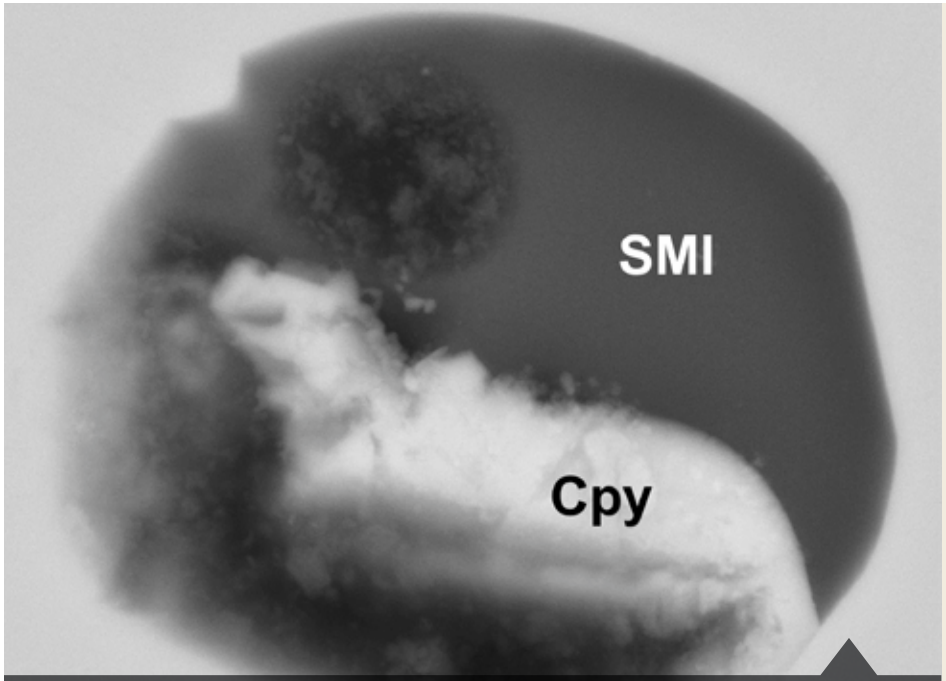
Highlights

Our BSc-level field assistant, Enza Magnier from UQAM (Montreal), has decided to do a BSc thesis related to Octavio's project, under the supervision of Ross Stevenson and Pierre-Simon Ross as co-supervisor. Thirty samples for thin sections from the Pacaud volcanic assemblage, north of La Sarre are being prepared. Enza will describe those in detail and this will be integrated in Octavio's second paper (see above).

WATCH NOW!
Melt inclusions/Archean volcanogenic massive sulfide deposits

VMS
Volatile and melt chemistry of melt inclusions in accessory minerals in Archean VMS

Lead Researcher: Jacob Hanley



Backscattered electron image of a silicate melt inclusion containing chalcopyrite. Source: Priyal Daya.

Despite decades of research on felsic volcanic and intrusive rocks associated with VMS mineralization, numerous questions related to endowment remain. Previous work using whole rock methods (e.g., FI-FIV classifications; Lesher et al., 1986; Hart et al., 2004) have been good, but not sufficient to answer the question of crustal fertility and/or magmatic processes in controlling the endowment of VMS belts and individual deposits (e.g., Mercier-Langevin et al., 2007). Resistant minerals in felsic rocks provide key information regarding magmatism, crustal architecture, crust-mantle interaction, metal budgets, and the physicochemical conditions of magma formation (e.g., fO2, pH, T, P; Bell et al., 2002; Bell, 2016; Watson and Harrison, 2005; Trail et al., 2012; Konecke et al., 2017)

In this project, melt inclusion assemblages identified in zircon, monazite and apatite will be analyzed using SEM, EMPA, LA-ICP-MS/LA-ICP-MS-Hf-Nd, SIMS and IR/Raman spectroscopy. Mineral chemical data for zircon, monazite and apatite will be used to evaluate differences in the physico-chemical conditions of magma formation and evolution (e.g., fO2, T from Ti-in-zircon, Zr saturation, Ce/Ce* and Eu/Eu* in zircon; F-Cl-budgets of magmas using apatite as proxy; and S budgets using monazite) to test for variations in magma sources, crust-mantle interaction, mixing, and basement domaining. Melt inclusion compositions will provide direct measurements of magmatic metal tenor, as well as provide constraints on volatile budget, degassing and fractionation history, and source region. Melt inclusion data in robust minerals (e.g. zircon) are not obscured by bulk rock alteration, metamorphism or metal loss (either primary hydrothermal or late secondary weathering) and, consequently, constitute the only means possible to evaluate the primary metal and volatile content of melts at different stages of magma evolution. Constraints on the pre-eruptive metal tenor, changes in metal tenor at different stages of melt ascent, emplacement or eruption, and comparisons of the relative metal fertility of different eruptive products or source magmas will be sought.

Progress

- Completed detailed petrographic and melt inclusion mapping characterization of 28 zircon suites from 14 key lithologies in the LaRonde and Kidd Creek deposits and surrounding Timmins district (Pacaud, Kidd-Munro, Deloro, Porcupine, Blake River felsic volcanics) encompassing the entire petrogenetic age bracket before, during and after mineralization
- Completed cathodoluminescence imaging and reconciliation of melting inclusion timing of entrapment with zircon petrogenesis on 7 of these key lithologies
- Completed detailed SEM-EDS analysis of all homogenized melt inclusions and accessory minerals in 7 of these key lithologies
- Scheduling and sample preparation partly completed in anticipation of first LA-ICP-MS analytical sessions in January, 2022 (Geneva) and February, 2022 (Memorial)
- Writing of introduction, methods and partial results for 2 manuscripts (Daya et al.)
- Finalized writing and submission of 1 manuscript (Neyedley et al.)

Future Work

- Analytical session scheduled from January 12-25th (2022) at the University of Geneva that will include full trace element analysis (including ore metals, trace elements and major elements) and associated zircon host analysis for 28 lithologies
- Analytical session scheduled from Feb 10th to 20th (2022) at Memorial University that will include U-Pb and Hf isotope analysis of host zircon to melt inclusions analyzed in at the University of Geneva
- Completion of 2 manuscripts for submission (Daya et al. 2022 #1, #2); one of these manuscripts will be a methodology paper comprising a detailed description of the coupled zircon-melt inclusion microanalytical and petrographic approach, and the other a paper on the melt inclusion systematics of the Kidd Creek camp
- Volatile chemistry of melt inclusions, from coeval assemblages to those analyzed for trace elements, will be determined at some stage during the 2022 academic year.

Anticipated Outcomes

- A complete trace element/U-Pb geochronology/Hf isotope data set for 28 melt inclusion bearing lithologies identifying:

  1. Changes in melt chemistry from pre-, syn-, and post-mineralization volcanic assemblages in the Kidd Cree and Doyon-Bousquet-LaRonde camps

  2. Changes in associated volatile content across these assemblages, to be correlated to melt chemical changes

  3. Details from melt inclusion analysis on the petrochemical classification and origin of volcanic assemblages to reconcile with bulk rock geochemistry

  4. Primary metal concentrations and associated mass balance constraints associated with active (degassing) and passive (leaching) models

- Publications: (3 planned for 2022; 1 submitted, and 2 in preparation) highlighting the data sets and key interpretation/implications of the items listed above

Implications

- Metal Earth intends to transform our understanding of the genesis of base and precious metal deposits during Earth's evolution. The program aims to make Canada a world leader in metal endowment research and world class innovator through open source delivery of new knowledge and the implementation of new technology.
- The research in progress described above within the VMS Thematic Project has implications relevant to both the intent and aim described above. The data and interpretation from melt inclusions in Archean VMS will be transformative with respect to contributing to revising current models for VMS systems.
- The methodology being developed, and application to world class VMS systems in the Abitibi will lead to the first melt inclusion data for Archean-age volcanic rocks globally and will provide the novel constraints on the metal and volatile content on VMS-related magmas of variable metal endowment that cannot be provided by other geochemical techniques from bulk rocks.

Highlights

Preliminary compositional data obtained from melt inclusions leads to 2 major breakthroughs:

1. Magmas associated with fertile VMS camps were Cu-sulfide-saturated during their history; this observation has major implications for the metal storage budget and endowment of these magmas during emplacement/eruption and may be used as a proxy for melt fertility in exploration settings
2. Magmas associated with fertile VMS camps were commonly strongly alkalic at early stages during their evolution in the crust; subsequent contamination during ascent/eruption changed the character of the magmas to "erase" or diminish this alkalic signature; this observation has significant implications for source region discrimination and metal endowment in fertile vs. barren VMS camps

   Ph.D. student Daya won best Ph.D. poster at the PDAC Student Minerals Colloquium (March, 2021)

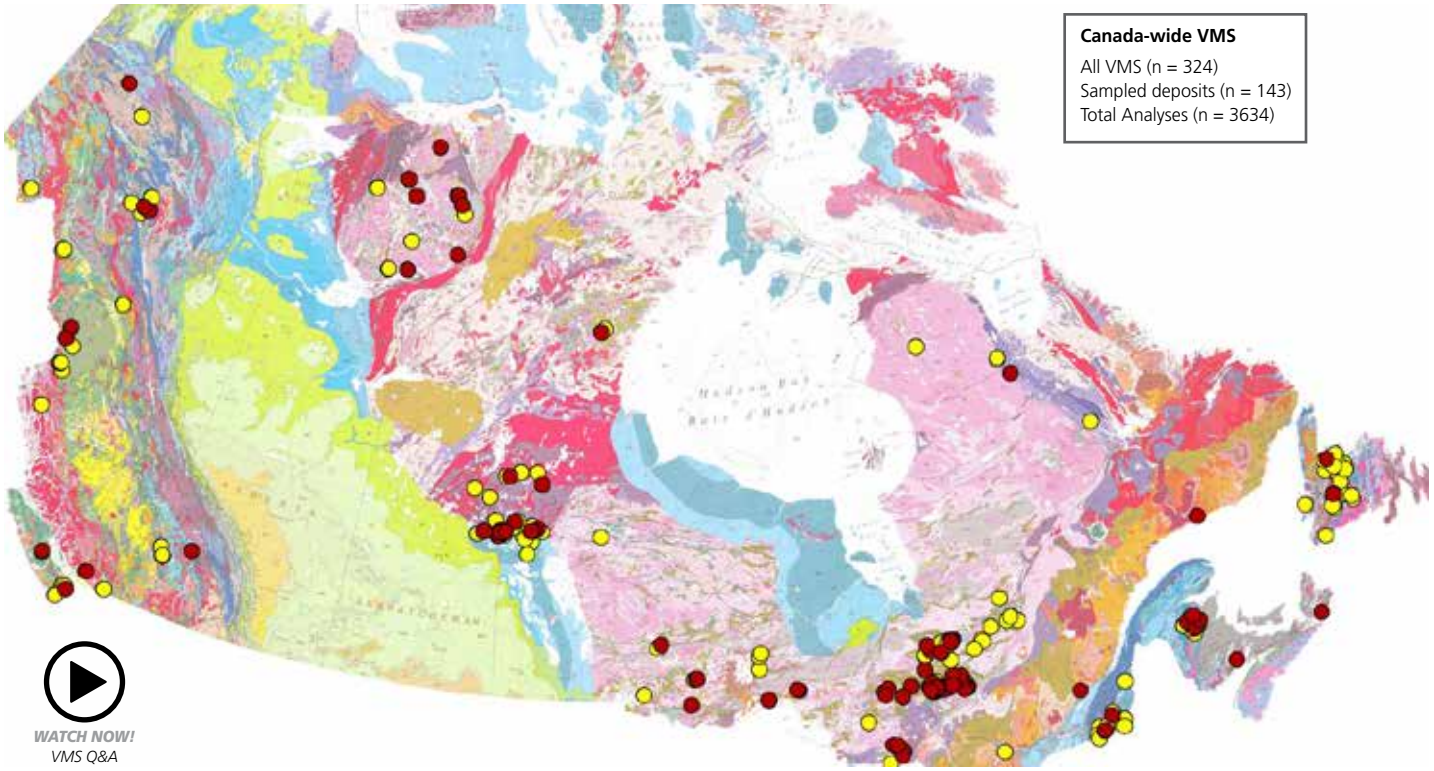
   Ph.D. student Daya presented an oral/poster contribution at the international ECROFI conference (virtual; Nancy, France; May 2021)

   3 manuscripts were advanced for publication in peer-reviewed journals; 1 has been submitted (Neyedley et al., Precambrian Geology)

VMS
Crust-Mantle Processes Responsible for VMS Endowment during the evolution of Archean Greenstone Belts: Trace metal constraints on the setting and source of metals.

Lead Researchers: Mark Hannington and Patrick Mercier-Langevin

In this project, data for the major ore-forming elements in VMS deposits are available (e.g. Cu, Zn, Pb, Au, Ag), but data for trace elements is sparse (e.g. Sn, Ge, Ga, Cd, In, Te, Tl, Co, Ni etc). These may provide a key fingerprint for conditions of ore formation, and source of metals that may be correlated with productivity, requiring comprehensive trace element analysis of representative ore samples. The AGB contains >80 VMS deposits (not all were mined) and from these, 50 deposits will be selected that are representative of the different assemblages, and variations in base and precious metal tenor (e.g. Cu-rich, Au-rich), volcanic affinity and volcanic setting. On average 10 samples will be collected from each deposit for complete geochemical characterization (500 samples in total) and a representative subset of 100 samples will be analyzed for S isotopes.



WATCH NOW!
VMS Q&A

Progress

- Efforts in Year 5 focused on the expansion, quality control, and transformation into a machine-readable VMS trace element database at the core of the 3b subproject.
- Key milestones planned for the data-base-related work have been achieved and resulted in an expansion to now contain over 3900 individual analyses from more than 320 Canadian VMS deposits and massive sulfide showings. All entries have been organized and undergone rigorous quality control screening. Additional information for deposits has been compiled and integrated in the overall database. Initial statistical analyses have been carried out and time-stratigraphic trends not previously recognized are beginning to emerge.
- The original database has been published in an open file in collaboration with partners at the Geological Survey of Canada. Initial results from statistical analysis have been compiled and presented during the Metal Earth Partner Meeting in March 2021.

- The parallel petrographic work by T. Monecke at Colorado School of Mines has commenced and initial sets of thin sections have been produced from archive samples at CSM.

Future Work

- With the data compilation and organization completed, the focus in the subproject will now shift to an interrogation of the database using advanced multivariate statistics and machine learning. R. Penner will commence a MSc thesis project in close collaboration with colleagues in the Metal Oceans group and with D. Diekrup on the statistical and machine learning approach. A systematic sampling and analytical effort is planned to expand the database with a special focus on smaller deposits and showings so far underrepresented in the database. However, this part of the project is dependent on ongoing and future Covid-19 restrictions.
- L. Patterson will commence an externally-funded MSc thesis project at Colorado School of Mines, working on the petrography of a selection of samples represented in the database. Results from the petrographic-petrogenetic study will later be combined with the database work by R. Penner and D. Diekrup as a measure of mineralogical control on trace element distribution in VMS.

Anticipated Outcomes

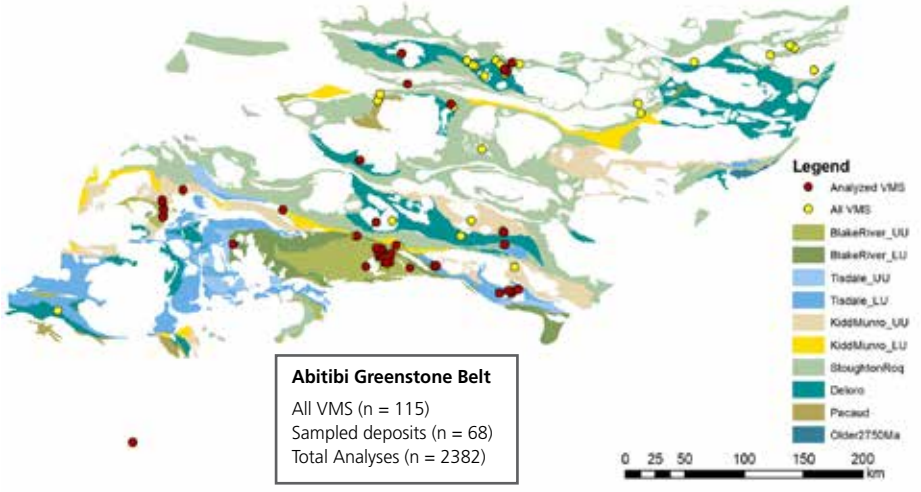
- The anticipated key outcome of the 3b subproject is a representative and interrogable trace element database, analyzed by multivariate statistics and machine learning approaches to yield a time-stratigraphic and spatial distribution of key trace elements.

From that database, information will be extracted to identify:

- Architectural and lithogeochemical control on crustal-scale ore fluid pathways and their relationship to the size and grade of VMS deposits.
- Trace element composition of ore material and its relationship to deposit size and well- vs. poorly endowed assemblages and greenstone belts.
- Similarities of trace element fingerprints in VMS deposits compared to the leached volcanic footwall.
- Preferential formation of VMS deposits in pre-enriched host rocks and related geochemical patterns.
- Similarities between modern VMS-forming environments and Archean equivalents.
- Fundamental processes allowing the formation of giant deposits in the Abitibi greenstone belt and their presence or absence in modern seafloor settings.

Implications

- The goal of the 3b subproject is to undertake a coordinated, in-depth, multi-disciplinary, and multi-parameter assemblage scale comparison of VMS endowment. This approach aligns with the overall goals of Metal Earth by addressing a knowledge gap in our understanding of the processes responsible for differential VMS endowment during the evolution of greenstone belts. The trace element systematics already identified to potentially reflect greenstone belt dynamics by enrichment in more evolved crust (e.g., As) will be expanded systematically to provide a new understanding of Archean tectonic processes, an underlying theme of Metal Earth.



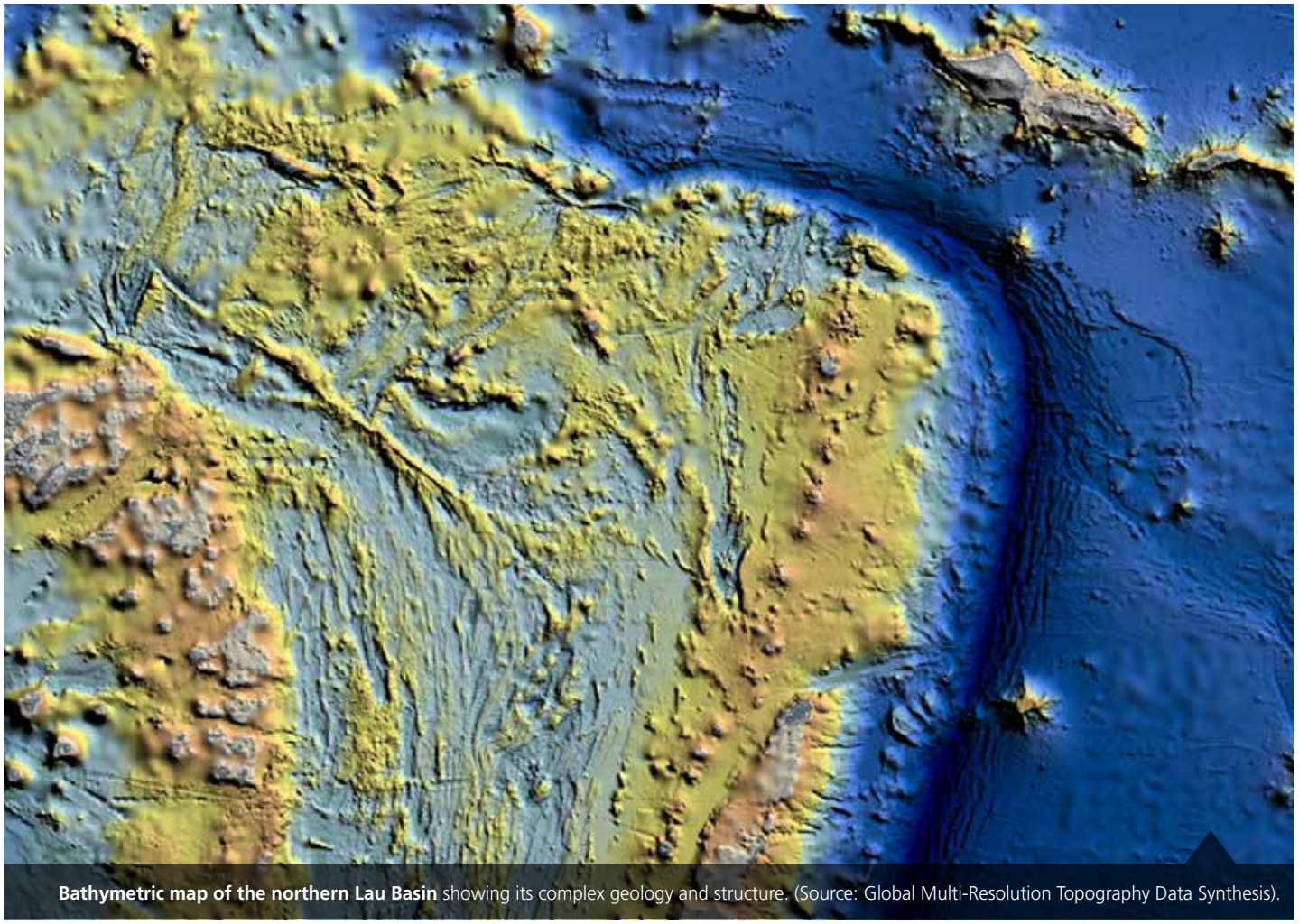
Highlights

1. Delivery of a significantly expanded, quality-checked, and fully transformed database of trace elements in VMS for fingerprinting and exploration targeting.
2. Recruiting of R. Penner to undertake database analysis and test applications (e.g., in the current NGEA Next Generation Explorers Award competition).

Modern Ocean Crust Project (Metal Oceans)

Lead Researcher: Mark Hannington

WATCH NOW!
Metal Oceans: Modern-Ancient Crust Project



Bathymetric map of the northern Lau Basin showing its complex geology and structure. (Source: Global Multi-Resolution Topography Data Synthesis).

Progress

- a) Processing of geophysical data from ARCHIMEDES I (SO-267) has been mostly completed and research papers have been prepared or published (see publications). Multibeam, sidescan and magnetic (ship-based and AUV) data have been processed and incorporated in publications. Processing of seismic data is partly completed (3 of 6 lines), with refraction data interpreted for two long sections. These data have been presented in two wide-angle tomographic inversions (2D velocity-depth models). Joint inversions with OBMT data are in progress. One GEOMAR PhD (A. Jegen) and two post-doctoral fellows (A. Beniest and A. Avdeeva) were recruited to assist with the processing of the geophysical data and interpretation of the crustal sections. A new postdoctoral fellow (C. Galley) has been recruited to conduct the joint inversions.

  b) The Lau Basin transect has been supplemented with a new microplate model and plate vector analysis by A. Baxter and K. Breker, which

constrains the regional kinematics and stress regimes related to microplate interactions and arc rifting. Magma volume and area-age relationships for different assemblages provide a first order metric of microplate growth.

c) The lithogeochemical compilation of the Lau Basin system has been completed (795 unique sample locations) and supplemented with new samples from ARCHIMEDES I analyzed by high-resolution ICP-MS in Germany. Analyses of Sr, Nd, Hf and Pb (double spike) isotope ratios by TIMS and multi-collector ICP-MS have been completed (A. Sandhu and K. Hoernle). The first batch of samples for 40Ar/39Ar dating is at OSU for analysis (M. Fassbender). These samples will constrain the location and timing of mantle input during arc rifting and the influence of microplate formation on back-arc crustal composition. The first paper on the lithogeochemical study by M. Fassbender has been submitted for publication. The link to metal endowment was established in the sub-project GoldTrace with C. Timm.

d) A second lithogeochemical study is underway, focusing on 810 high-quality analyses in the area of ARCHIMEDES II (Manus-New Ireland Basin and Woodlark subprovinces) led by P. Brandl. This compilation will be supplemented with new samples collected during ARCHIMEDES II, including major and trace element geochemistry by ICP-MS in Germany, Sr-Nd-Hf and Pb (double spike) isotope studies by TIMS and multi-collector ICP-MS, and 40Ar/39Ar dating.

e) The Ottawa and GEOMAR teams continued to work on 1:1 million geological compilations of the Indo-Australian margin, with plans to complete the new maps of the N. Fiji Basin and New Hebrides in 2021-22, led by A. Baxter, R. Mensing, and T. Sitnikova. Additional mapping will focus on the Coriolis Troughs and Jean Charcot Troughs in the New Hebrides and Vanuatu led by M. Anderson and P. Brandl. The New Ireland Basin mapping led by P. Brandl was completed and is being prepared for publication. We also began shifting work from map production to interpretation and modelling of crustal growth in different assemblage types and at different types of microplate boundaries.

Milestones for 2020-21:

- Lau Basin 1:1 million Geological Map published
- PNG 1:1 million Geological Map completed and preparing for submission
- Completed lithogeochemical study of the marginal basins of eastern PNG
- Re-scheduling of PNG Transect ARCHIMEDES II after Covid-19 delay
- Two final reports for shiptime funding of SO-267 submitted to BMBF
- Completed (2 MSc summer students, 1 BSc thesis)
- Completed Marie Sklodowska-Currie ERC International Fellowship (C. Timm)
- Recruited 1 new PhD, 2 new MSc, 1 new PDF for geophysical inversions

Deliverables for 2020-21:

- Coriolis-New Hebrides Transect (published in Economic Geology by M. Anderson)
- PNG-New Ireland tectono-magmatic framework (published in Ore Geology Reviews)
- Crustal structure of Niuafo'ou microplate (published in Journal of Geophysical Research)
- Lau Basin 1:1 million Geological Map (published in Geosphere)
- Lau Basin CMT analysis and microplate model (published in G-Cubed)
- NE Lau Basin seismicity of Fonualei rift (published in Journal of Geophysical Research)
- Volcanism at the arc front of the Fonualei segment (published in Journal of Volcanology)

Use of Human Resources:

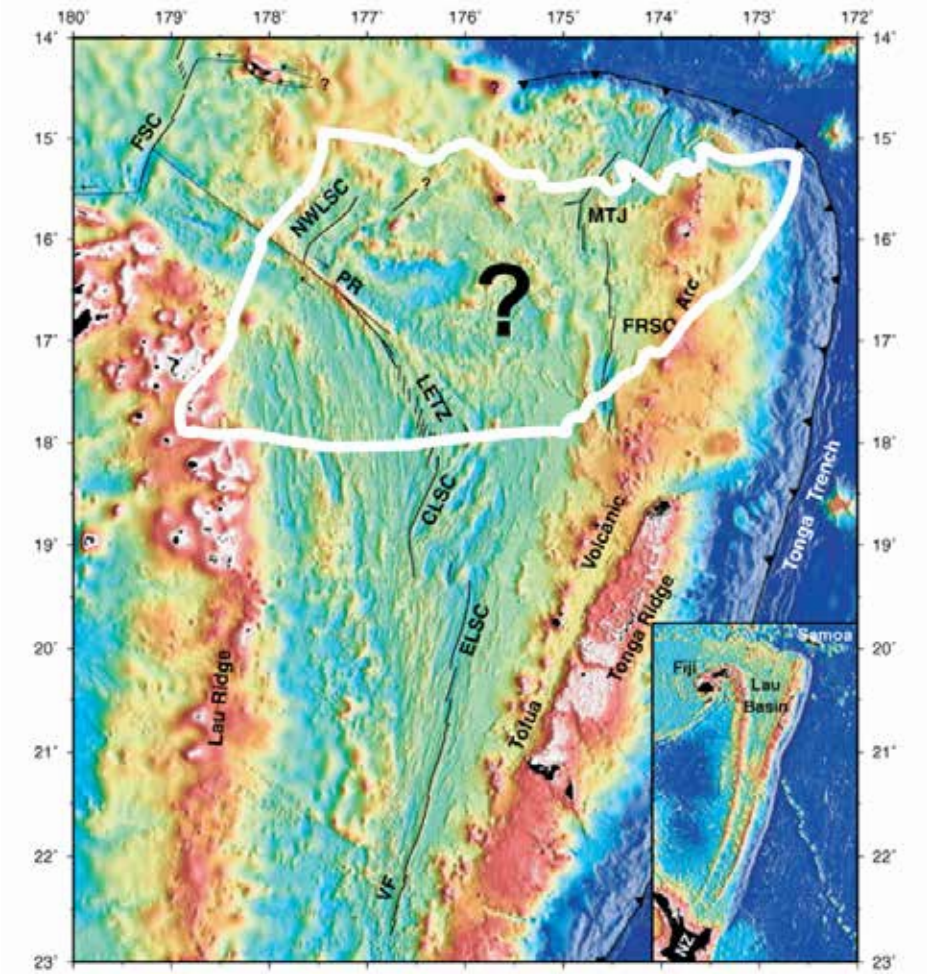
- RA/PDF (A. Baxter, D. Diekrup): data compilation and synthesis for seafloor mapping; geological interpretations at 1:1 million scale; large-scale tectonic reconstructions; interpretation and quantitative modelling of crustal growth, with direct comparison to crustal architecture and mineral endowment in greenstone belts. M. Stewart moved to a faculty position but continues to be supported from the Metal Oceans budget. D. Diekrup is also responsible for the VMS Sub-project 3b (appended).
- GIS technicians (K. Breker): GIS and geomatics expertise for 1:1 million lithostratigraphic mapping; map production; quantitative analyses of maps.

- PhD (M. Fassbender): lithogeochemical database compilation; lithogeochemical interpretation of the Lau Basin; comparisons with greenstone belt evolution; global compilation of submarine silicic volcanic rocks.
- PhDs (R. Mensing, T. Sitnikova): regional geological compilation of the North Fiji Basin and New Hebrides, including magmatic and tectonic evolution of high-heat flow intraoceanic back-arc basin and comparisons with greenstone belt evolution.
- MSc students and summer interns (M. Besaw, A. Gray, 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. Mary Besaw finished her work on the formation and evolution of triple junctions. Alexandra Gray completed her examination of the formation and evolution of large-scale submarine calderas. Jessie Kehew and Michael Ryan started their work on intrabasinal sedimentation and magmatic productivity.
- The GEOMAR Team continued to support Metal Oceans objectives, working on the geological and kinematic reconstruction of the North Fiji Basin and New Hebrides Arc and other regional mapping initiatives, geophysical compilations, modelling, and cruise preparation (Petersen, Brandl, Klischies, Graber, Krätschell).

Future Work

Specific research targets for 2021-22 are:

- The nature of the crust just prior to rifting – imaging of the Fonualei Rift in the NE Lau Basin;
- The styles of faulting and the role of pre-existing basement structures – modelling of 2D and 3D structure of arc rifts in the NE Lau Basin and triple junctions in North Lau and in the North Fiji Basin;
- The nature of the magma plumbing systems during microplate formation – mapping and sampling of anomalous volcanic centers at emerging microplate boundaries of the NE and NW Lau Basin;
- The consequences for mantle flow – tracing mantle contributions as a control on the magmatic and hydrothermal budgets at different types of microplate boundaries;
- Melt sources and pathways in the microplate context – analysis of old and deep structures to obtain a comprehensive geochemical and isotopic profile of the crust at microplate edges;



Bathymetric map of the Lau Basin showing major spreading centers and structures. White line represents the outline of the Abitibi greenstone belt at the same scale as the bathymetric map. Many complex structures and geologic domains occur within an area the size of the Abitibi greenstone belt.

- The link to hydrothermal systems – identifying the origins of near-seafloor architecture and deeper controls on hydrothermal fluid ascent and storage potential.

The new focus for 2021-22 will be on modern-ancient comparisons, working closely with the Metal Earth Team to establish the link between microplate formation, greenstone belt assemblages, and magmatic-hydrothermal systems at a scale that is useful for exploration.

In the second half of the project we will focus on quantitative modelling of crustal growth, with direct comparison to the architecture and mineral endowment in greenstone belts. The emphasis will be on microplate boundaries with the aim of recognizing possible ancient analogs in the Abitibi region.

We will collaborate with MERC researchers on identifying type sections for different assemblages, which can then be compared to modern assemblages; identifying different types of unconformities between assemblages; compiling sedimentary sequence stratigraphy; making quantitative comparisons of the structure and evolution of large-scale silicic versus mafic submarine calderas; and comparing modern microplate architectures to relict structures in deformed terranes.

Milestones for 2021-22:

- Complete 2D and 3D inversions of Lau basin seismic sections, gravity and MT
- Microplate modelling of the NE Lau Basin (GPlates and Move3D)
- Assemblage-level attributes tables for the Lau, PNG and North Fiji map sheets
- Representative stratigraphic sections for assemblages in the Lau and North Fiji basins
- Completed lithogeochemical study of the Lau back-arc (Fassbender PhD), including Ar-Ar dating
- Preparation and logistics for ARCHIMEDES II research cruise in eastern PNG

Deliverables for 2021-22:

- Lithogeochemical study of felsic rocks in modern intra-oceanic settings (submitted for publication)
- North Fiji Basin 1:1 million geological compilation (published map and paper)
- Eastern PNG-New Ireland Basin 1:1 million geological compilation (published map and paper)
- Case study of the origin and evolution of the Mangatolu Triple Junction (submitted for publication)
- Abitibi-Lau Basin Assemblage-level comparison of crustal growth (published paper)
- Two completed MSc projects (Besaw, Gray)

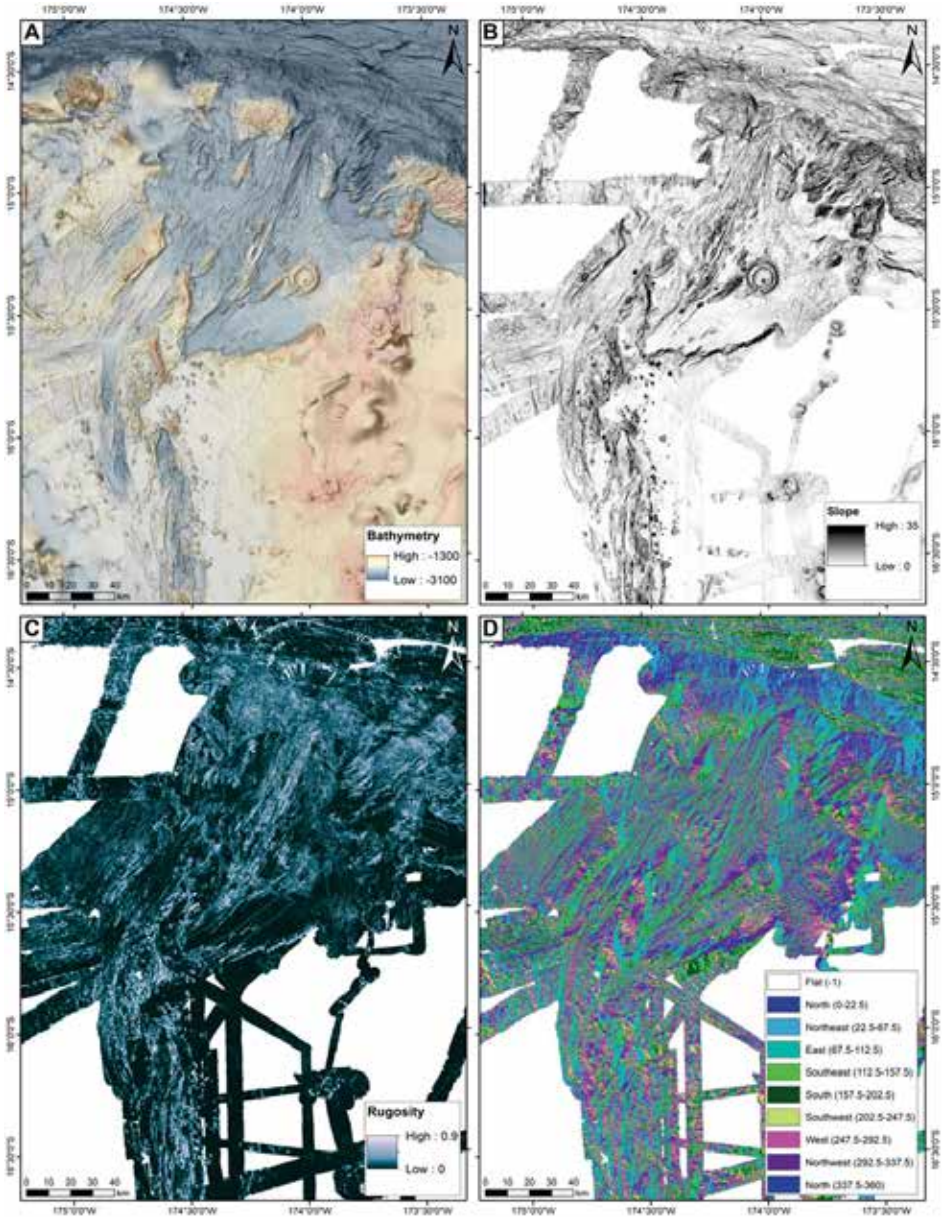
Most HQP from Year 5 will continue to work on the project. Five MSc and PhD students (Mensing, Kehew, Ryan, Fassbender, and Sitnikova) will shift their work from map production to interpretation and modelling of crustal growth in different assemblage types and at different types of microplate boundaries, with direct comparisons to crustal architecture of greenstone belts. The focus for these comparisons will be in the mapped regions of the North Fiji Basin and Northern Lau Basin, where several different types of triple junctions are present (e.g., MTJ formed by arc-rifting versus NFBTJ formed by mature back-arc opening), as well as triple junction precursors (e.g., emerging triple junctions of the NWLSC, Rochambeau, and Niuafo'ou assemblages), and evidence of anomalously hot mantle that may be analogous to Archean greenstone belts.

The lithogeochemical and structural datasets developed for Metal Oceans (Baxter and Fassbender) are now large enough to employ Machine Learning techniques and integration with other large marine data sets in their analysis. We have discussed this approach with Mira Geoscience and its partners, including Metal Earth partner GoldSpot.

Preparation for ARCHIMEDES II (DynaMet) will continue throughout Year 6, including pre-cruise logistics, submission of contracts for work, diplomatic clearances, securing equipment and preparing shipments to the port of Singapore (pending).

Anticipated Outcomes

- Using coordinated multiparameter geophysics, geochronology and geochemistry, we have developed the first high-resolution structural-petrologic-magmatic framework for microplate evolution and metallogenesis in several large-scale transects across the termination of the Tonga arc in the NE Lau Basin, in the high-heat flow North Fiji Basin, and in actively rifting forearc crust of the New Ireland Basin in PNG. These results will underpin direct comparisons with crustal architecture and metal endowment of greenstone belts planned for the balance of the Metal Oceans project.
- The results have included: establishing type sections for different assemblages, which can now be compared to greenstone belt assemblages; documenting 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; making quantitative comparisons of the structure and evolution of large-scale silicic versus mafic submarine calderas; modelling of microplate mosaics (especially shortening) as a guide to identifying relict architecture in deformed terranes; detailed lithogeochemical comparisons of magmatic suites in different microplate settings as a means of identifying domains of mantle contribution related to microplate mosaics.

- Results for 2020-21 have been presented in 32 publications: 7 peer-reviewed journal articles, 1 government publication, 7 student reports and theses, 17 conference abstracts (posters and oral presentations) at national and international scientific meetings. The Final Report of the geophysical survey of the Lau Basin (Project SO-267) was submitted to BMBF for publication. This was one of the key outcomes of the Metal Oceans project.
- In 2020-21, there were 17 active participants in the project from 4 institutions. An additional 19 collaborators and co-authors on publications were involved from 7 institutions in Canada and abroad. Members of the Ottawa Team worked alongside researchers at MERC and Laurentian in several on-line workshops to ensure the results of Metal Oceans are being applied directly to the Metal Earth objectives. Major external infrastructure was accessed for this project through GEOMAR and its partners, including BGR. ME funds are significantly leveraged through

Ship multibeam bathymetry and derived datasets from the NE Lau Basin:
(A) ship multibeam bathymetry from Rubin and Shipboard Scientific Party (2010), Martinez and Shipboard Scientific Party (2013), Sleeper and Martinez, (2016), Merle et al. (2018), and Haase and Shipboard Scientific Party (2018), overlain on the GEBCO 2019 regional bathymetric grid (GEBCO Compilation Group, 2019), processed using Terrain Texture Shading (after Brown, 2014); (B) slope of the ship multibeam bathymetry compilation; (C) rugosity (or vector ruggedness measure) of the ship multibeam bathymetry compilation; and (D) aspect of the ship multibeam bathymetry compilation. Source: Anderson et al,Geologic and Structural Evolution of the NE Lau Basin, Tonga: Morphotectonic Analysis and Classification of Structures Using Shallow Seismicity. ***doi.org/10.3389/feart.2021.665185***

external partnerships, including direct and indirect in-kind contributions and ship time. Six members of GEOMAR (Petersen, Brandl, Krätschell, Klischies, Graber, Mensing) are now working directly with the Ottawa Team. Each year they come together for up to one month to work on cruise results, data processing and mapping initiatives. Most graduate-level HQP from Year 5 will continue to work on the project until the completion of their degrees.

Implications

• New knowledge of the thermal and structural evolution 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 and the implications for mantle upflow 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 at relatively shallow to mid-crustal levels – a role that may be common to both modern oceanic crust and ancient greenstone belts.

Relevant Metal Earth themes:

Theme 1
Craton and Greenstone Belt Assembly Study

Theme 2
Geophysical and Geological transects

Relevant Metal Earth questions:

Question 1
Is there an architectural and or structural control on crustal-scale ore fluid pathways?

Question 2
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?

Question 3
How did Archean tectonics differ from Phanerozoic, subduction-driven tectonic models based on Archean crustal architecture and gold and base metal metallogeny?

Question 4
Data integration and interpretation tools for assessing metal endowment predictability.

Highlights

Scientific:

The first 1:1 million geological maps of Lau basin and Marginal Basins of Eastern PNG were completed. Using coordinated multiparameter geophysics, geochronology and geochemistry, we developed the first high-resolution structural-petrologic-magmatic framework for microplate evolution and metallogenesis in several large-scale transects: across the termination of the Tonga arc in the NE Lau Basin, in the high-heat flow North Fiji Basin, and in actively rifting forearc crust of the New Ireland Basin in PNG. This work established the first complete and same-scale structural, magmatic, and geophysical framework of modern microplate domains for comparison with ancient greenstone belts.

Personnel:

R. Penner (BSc student of M. Stewart) was the prize winner for his poster on the Geological mapping of the SE Futuna Volcanic Zone, Lau Basin, presented at the Mount Royal Faculty of Science and Technology research fair.

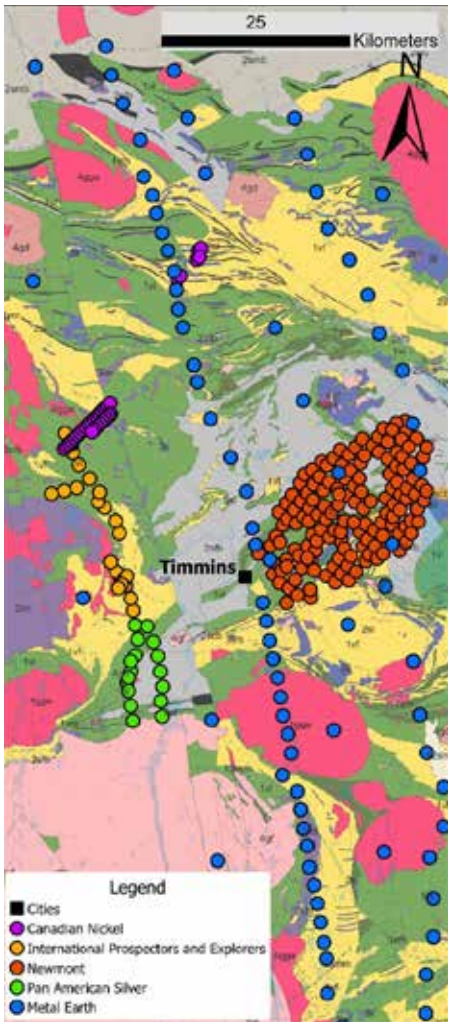
J. Kehew (MSc student of M. Hannington) received the Husky Research Award ($10,000) for her proposal to study intrabasinal sedimentation in the Lau back-arc by integration of geological mapping and sub-bottom profiling data sets. Jessie also received free training on the commercial software, Kingdom Suite, used for seismic data processing.

T. Sitnikova (PhD student of M. Hannington) was selected to participate in the ECORD Summer School on downhole geophysics for the Ocean Drilling Program.

M. Besaw (MSc student of M. Hannington) completed her final report for her 2019 Mitacs Globalinks Award.

Timmins

Lead researcher: John Ayer



Timmins Transect MT, AMT, and broadband stations

Progress

- This MT project was begun in Sept 2020 with Metal Earth contracting Quantec Geosciences to provide magnetotelluric data for 59 MT stations in two N-S lines across the Timmins region. The MT data was acquired by February 2022 at a cost of $170,000.
- A partnership was established to acquire higher resolution AMT data within this region with 5 mining companies in the region. The AMT data was acquired by March 2021 with an industry investment of $424,000. The companies will also be providing an additional in-kind contribution of $1.5 million of geophysical and geological data from the project area.

Future Work

- This Metal Earth project will require an additional 2 years and is currently working on the analysis and integration of this new MT and AMT data with the additional in-kind and publically available geophysical and geological data. The project current involves work by 3 of Metal Earth's geophysical RAs (Adetunji, Vayavur and Cheraghi) and 1 geological RA (Launay).

Anticipated Outcomes

- A much-improved understanding of the Subsurface geology associated with Gold and Base metal deposits in the Timmins region, one of Canada's best-endowed mining camps and crustal.

Implications

- The ability to compare and contrast the Timmins camp's crustal architecture and metallogeny with that of the other Metal Earth transects across endowed areas of the Superior Craton.
- It demonstrates the effectiveness of MT as a tool for targeting endowed greenstone belts, or portion thereof, in poorly understood and less explored remote areas for green fields exploration programs in that the MT instruments are much more portable and considerable less costly than seismic surveys.

Highlights

The initial success of this project highlights the strength of integration of crustal scale MT surveys with high resolution, upper crustal scale AMT surveys funded by the partner companies. The in-kind geophysical and detailed geological knowledge contributed from the partner companies adds considerably to the project, and is particularly beneficial when combined with the regional scale geophysical contributions and expertise of Metal Earth's researchers. This type of project greatly expands the scale and effectiveness of our research and represents a powerful model for the benefits of integration of university- and company-sponsored research.

Ormaque

The Ormaque Deposit is a new gold discovery within the renowned Val D'Or district in the Archean Abitibi greenstone belt, Quebec. The deposit is hosted by a porphyritic diorite intrusion in contact with volcaniclastic supracrustal rocks of the ca. 2703 Ma Val d'Or Formation. It consists of steeply north-dipping shear zones, which are broadly parallel to the diorite-volcaniclastic contact, and shallowly south-dipping extensional veins, which form multiple gold mineralized intervals of stacked quartz-carbonate-tourmaline veins surrounded by variably mineralized wall-rock. The extensional veins are oriented near perpendicular to the fault zones, and thus differ in geometry from that of the nearby world-class Sigma Mine, where the influential fault-valve model for the formation of orogenic gold deposits was originally proposed. The main objectives of the research project are to characterize the geology of the Ormaque Deposit and explore new models for the formation of the veins and faults at the deposit. The findings from this study will not only shed new information on the formation of gold deposits in the Val D'Or district, it will also provide new insights on the fault-valve model and formation of orogenic gold deposits worldwide.

Magino

Magino is one of several gold deposits within a re-emerging gold district in the Michipicoten greenstone belt of the Wawa subprovince in the Archean Superior craton, northern Ontario. The Magino gold deposit is hosted by the tonalitic Webb Lake Stock and cross-cutting gabbroic and quartz-feldspar porphyry dikes. The formation of the deposit is attributed to magmatic fluids related to the pre- or early syn-deformation emplacement of the porphyry dikes. Alternatively, the Island gold deposit, which is hosted within the Goudreau Lake deformation zone along strike of the Magino gold deposit, is interpreted as an orogenic gold deposit that formed during sinistral, north-side-up shearing along the deformation zone, similar to world–class orogenic gold deposits hosted by major transcrustal shear zones in the nearby Abitibi subprovince. The main objective of the research project is to determine the structural controls on mineralization at the Magino gold deposit and provide a chronological framework for dike emplacement, structural events, and the deposition of gold mineralization and associated quartz veins. The research will involve detailed structural mapping of stripped outcrops and drill core, U-Pb and Re-Os geochronology, and optical and scanning electron microscope characterization of microstructures and textures associated with gold mineralization. It will address whether the deposit is orogenic or intrusion-related and will help mineral exploration by determining the geological features that control gold mineralization in the district.

Ulu

MERC, in partnership with Blue Star Gold Corp., will employ a MSc student to undertake a field-based mapping project to outline the structural and stratigraphic framework of the Ulu gold deposit.

This project is within the Slave Province in Nunavut, part of the High Lake greenstone belt. The goal of this project is to provide a structural/stratigraphic context for the Ulu deposit, focused on structural observations, geologic mapping and lithogeochemical sampling. These will be combined with standard petrography (transmitted and reflected light) and SEM observations. The project is fully funded and will be supervised by Drs Bruno Lafrance, Ross Sherlock and Blue Star Gold's technical Team. Fieldwork will be during the summers of 2022 and 2023 in the far north of Nunavut, based in a field camp.

International Explorers Inc. (IEP)

MERC, in partnership with International Explorers and Prospectors Inc., is seeking a MSc student to undertake a research project to outline controls on volcanogenic massive sulfide (VMS) deposits in the Kamiskotia Volcanic Complex. The goal of this project is to provide insight into the geochemical, alteration and stratigraphic controls on VMS mineralization. The project will utilize existing geochemical and geochronological data for the five deposits, augmented by new lithogeochemical and petrographic sampling. The project will integrate mapping, core logging and lithogeochemical data with petrographic and SEM studies of alteration and mineralization. The project is fully funded and will be supervised by Drs. Ross Sherlock and John Ayer (MERC), and members of IEP's technical team.

Canadian Nickel Corp. (CNC)

MERC, In partnership with Canadian Nickel Corporation, will employ an MSc student to undertake a research project to outline controls on nickel mineralization at CNC's Crawford intrusive complex. The goal of the MSc project is to provide insight into the nature and controls on Ni, Co, and PGE mineralization by focusing on the petrography, geochemistry, and mineralogy of the Crawford intrusive complex. The project is fully funded, will be supervised by Dr. Pedro Jugo and CNC's technical team, and will combine core logging, portable XRF analysis, petrography, lithogeochemistry and mineral chemistry.

Red Lake

An embedded research position with Evolution Mining to refine the structural and stratigraphic framework for the Balmer sequence stratigraphy.

The objective of the research position is to refine the Balmer sequence stratigraphy. This will be used to further define the structural framework for the Red Lake camp, identify potential repetitions of stratigraphy, and establish the geological setting of gold mineralization.

Structural controls on gold mineralization along the the LP Fault, Dixie property, Red Lake.

The LP Fault, immediately south of the Red Lake camp in northwest Ontario, hosts the footwall LP Fault Zone and the hanging wall the Dixie Limb Zone and the Hinge Zone. The main objectives of the project are to determine the structural controls on gold mineralization at the three mineralized zones, their relative structural chronology, and absolute timing. The research will involved surface mapping, the collection of drill core structural measurements, the investigation of microstructures under the SEM and optical microscope, and the dating of monazite and xenotime using the LA-ICP-MS instrument at Laurentian University. The project is funded through a partnership with Great Bear Resources Ltd.

The P-T-t-fluid history of metamorphism across gold-bearing structures, Dixie property, Red Lake

Amphibolite and greenschist facies metamorphic assemblages are developed in host rocks that contain shear zones and structures hosting Au mineralization at the Dixie Property, Red Lake, 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 favorable rock types, and determine if there are metamorphic discontinuities across major structures. The research includes investigation and sampling of available drill core, whole rock geochemistry, mineral geochemistry (SEM, EPMA, and LA-ICP-MS), phase equilibrium modelling, and metamorphic geochronology (LA-ICP-MS and garnet geochronology). The project is funded through a partnership with Great Bear Resources Ltd.

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