METAL EARTH

ANNUAL REPORT **2018-2019**

METAL EARTH:
A GLOBAL INITIATIVE - YEAR 3

This annual report represents the work completed in Year 3 of Metal Earth (May 2018 to April 2019), a seven-year, $104 million applied R&D program. This global initiative began in 2016 as a strategic consortium of 25 Canadian and international (United States, Australia, and Germany) researchers from academia, government and industry, and led by the Mineral Exploration Research Centre (MERC), part of the Harquail School of Earth Sciences (HSES) at Laurentian University in Sudbury, Ontario.

The Metal Earth program was made possible with $49.2 million in funding from the Canada First Research Excellence Fund (CFREF), the largest geoscience grant in Canadian history, $5 million in funding from the Northern Ontario Heritage Fund Corp. (NOHFC), a $1 million donation from the (David) Harquail family's Midas Touch Foundation, and cash and in-kind contributions from 22 private sector and government survey partners.

More than 60 projects and subprojects were conducted this year by Metal Earth researchers and collaborators. Research activities included 5 of the 6 thematic research projects that were approved in Year 2 and began in Year 3. In addition to publishing 24 government survey reports and maps, progress and related findings have been shared through 157 workshop and conference presentations, journal articles, theses, and summary of fieldwork reports.

A total of 8 Metal Earth projects were successfully concluded. Their results, along with the results of ongoing projects, can be found in the **Downloadable Reports and Papers** section of Appendix E in this document. Findings along all transects and through data compilation have also been shared in numerous publications listed in **Appendix D** of this annual report.

Another 7+ projects in 5 transects are slated to begin in Year 4 and are briefly described in the Future Work section of this document. All other projects and subprojects profiled in this annual report will be completed between Years 4 - 7.

Projects undertaken from May 2018 - April 2019 were led by Canadian and international research associates, postdoctoral fellows, and Ph.D. and M.Sc. students supervised by Metal Earth faculty and science leaders for a total of 41 person years of training and mentorship in Year 3 alone.

Metal Earth is proudly supported by

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES

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THE HARQUAIL FAMILY

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VISION AND OBJECTIVES

STRATEGIC OBJECTIVE

Laurentian University's expertise in mining and environmental stewardship will drive knowledge creation, economic prosperity, and ecological sustainability locally, nationally, and internationally.

INSTITUTIONAL VISION

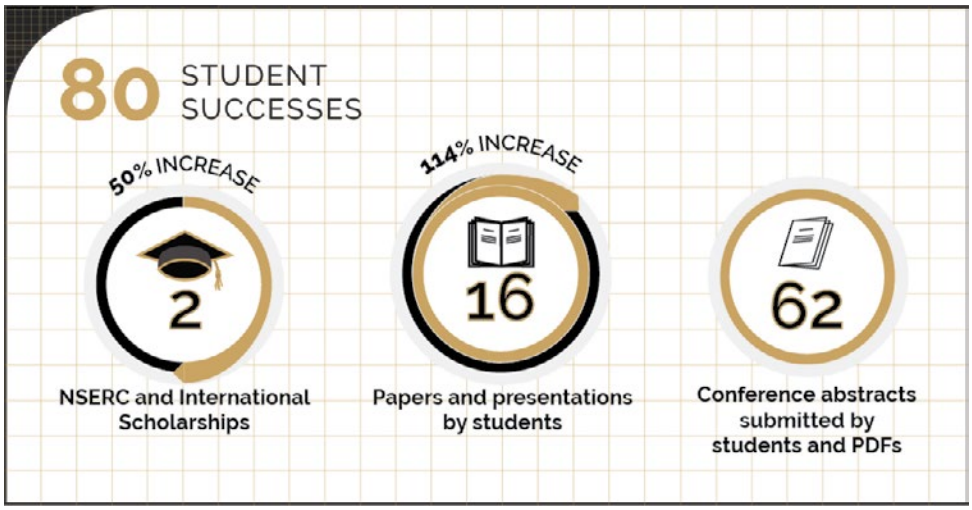
Our institutional vision for Harquail School of Earth Sciences is to be the university of choice for resource-based regions around the world seeking innovation and breakthrough knowledge in geology, mineral exploration, and natural resource engineering. Metal Earth is a large research project led by the Mineral Exploration Research Center, part of the Harquail School of Earth Sciences.

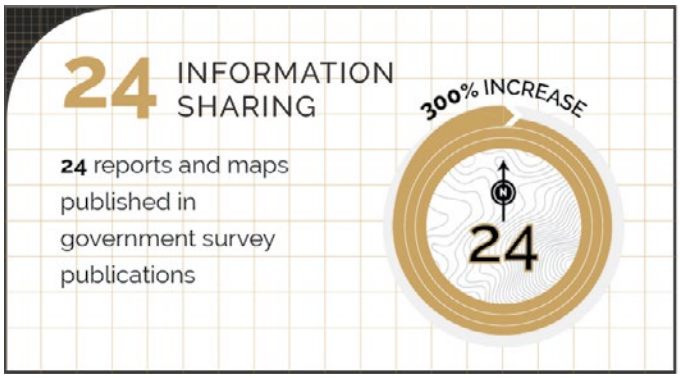
METAL EARTH CORE GOALS AND OBJECTIVES

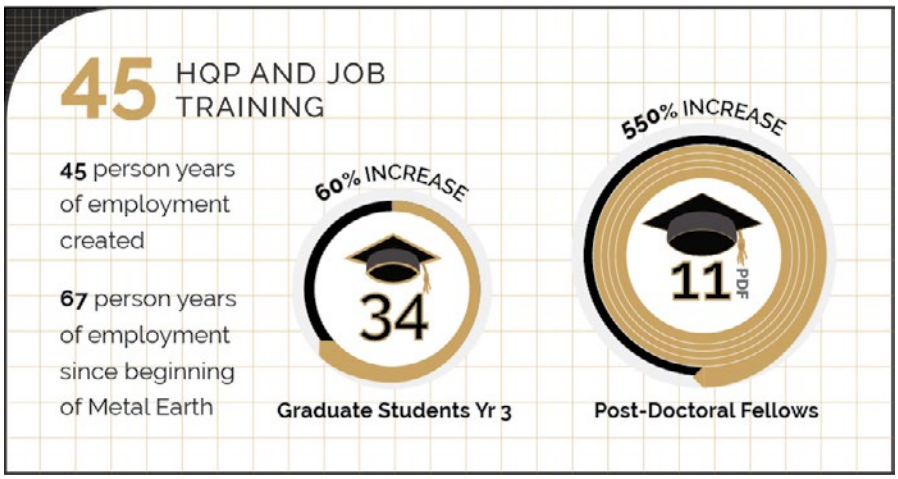
1. Fundamental Science
   - transform our understanding of Earth's early evolution and processes that govern differential metal endowment
   - improve the science for targeting and finding new orebodies
2. Applied Innovation and Commercialization
   - cement Canada's position as a global leader in mineral 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

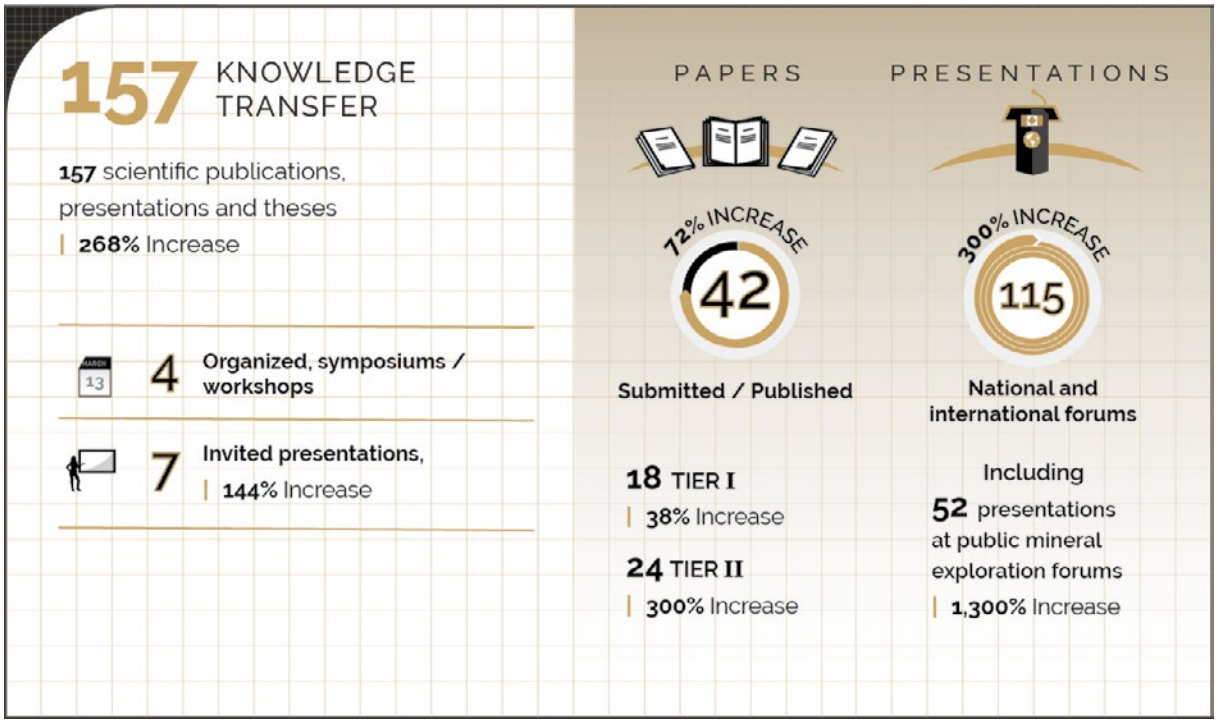
ACHIEVEMENTS IN BRIEF - YEAR 3

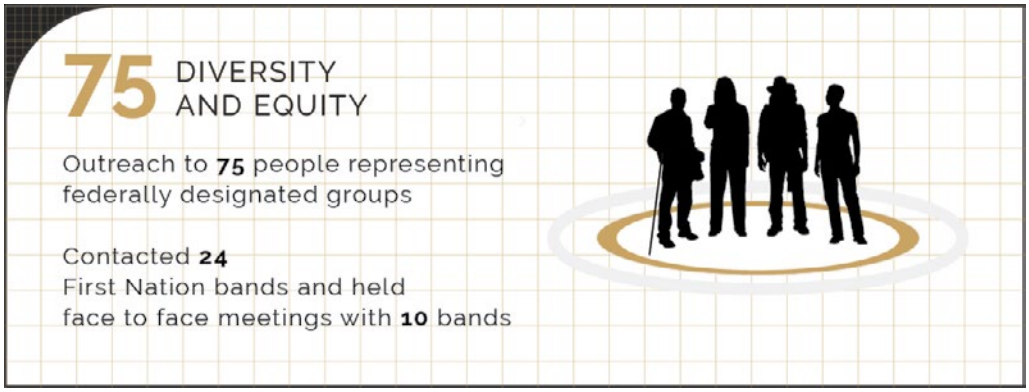
STATS AND INCREASES FROM YR 1 - YR 3








157 KNOWLEDGE TRANSFER
157 scientific publications, presentations and theses
| 268% Increase
4 Organized, symposiums / workshops
7 Invited presentations,
| 144% Increase
PAPERS
PRESENTATIONS
72% INCREASE
42
300% INCREASE
115
Submitted / Published
National and international forums
18 TIER I
| 38% Increase
24 TIER II
| 300% Increase
Including
52 presentations at public mineral exploration forums
| 1,300% Increase


75 DIVERSITY AND EQUITY
Outreach to 75 people representing federally designated groups
Contacted 24 First Nation bands and held face to face meetings with 10 bands

WELCOME MESSAGES

MESSAGE FROM President & Vice-Chancellor, Laurentian University

Robert Haché, Ph.D.

Laurentian University is proud to be the lead institution for Metal Earth, the largest geoscience program in the world. This $104 million, seven-year applied research and development program has already begun generating globally relevant research. As the only university in Canada where geology and mineral exploration are integral components of its strategic plan, Laurentian is pleased with the results to date, and welcomes the continued responsibility for Metal Earth.

In Year 3 of Metal Earth, Laurentian's Mineral Exploration Research Centre (MERC), the respected research arm of the University's Harquail School of Earth Sciences (HSES), conducted / oversaw more than 60 research projects. This has led to international collaborations with experts in academia, the public sector, and industry from the United States, Australia, New Zealand, Germany, the Netherlands, Switzerland, and Sweden.

Laurentian continued to work toward making significant impact in Northern Ontario through thoughtful consultation with Indigenous communities; provincially and nationally with other Canadian institutions, research centres and government surveys; and internationally through the collaborative efforts of researchers spanning three continents.

While Metal Earth draws global expertise and attention, Laurentian University is increasingly seen as a world leader in mineral exploration and targeting research. This recognition has had a ripple effect in building both MERC and HSES by broadening their networks and strengthening their partnerships and collaborations worldwide.

Metal Earth has also increased the number of students coming into the program and participating in direct research activities. This growth, in terms of attracting students from Canada and abroad, allows the University to have a greater impact on the education and training of highly qualified personnel. Laurentian University is pleased to provide unprecedented opportunities with more than 400 person years of training and mentorship for student researchers, research associates and postdoctoral fellows throughout the seven-year term of Metal Earth.

Laurentian anticipates that Metal Earth will continue to directly impact industry on a global scale through the open source delivery of new knowledge, the implementation of new or adapted technology, and the exceptional training of a new generation of students fully prepared to enter the workforce of tomorrow.

As President & Vice-Chancellor, Laurentian University, it is my privilege to introduce this annual report outlining the work completed on the Metal Earth project in Year 3.

Robert Haché, Ph.D.
President & Vice-Chancellor, Laurentian University

MESSAGE FROM Director, MERC and Metal Earth


Dr. Ross L. Sherlock

As Director of MERC and Metal Earth, I was pleased to continue my leadership role in Year 3 of this global applied research initiative. The core Metal Earth team is an exceptional group of dedicated individuals who support the program's research objectives including the direct development and training of earth science students.

The training of highly qualified personnel (HQP) is of prime importance to MERC and Metal Earth. I am proud to announce that in virtually every metric taken in Year 3, Metal Earth exceeded benchmark targets for HQP training and professional development. These powerful indicators represent MERC and Metal Earth's determination to properly prepare the future generation for an industry that will increasingly need a more qualified workforce.

Metal Earth received an overwhelming level of collaborative support this year. A total of 169 collaborators (69 from Canadian and international academia, 35 from the public sector, and 65 from industry) contributed to Metal Earth research activities in Year 3 through their direct participation / guidance. I would like to thank these collaborators for their contributions as members of the extended Metal Earth team. Their expertise directly impacted HQP training while also working to expand global understanding of earth sciences related to the mineral exploration sector.

Discovery of new ore deposits is vital to the mining industry. Metal Earth's research recognizes that value and will continue to develop a deeper understanding of the geological, geophysical, and geochemical markers indicating the presence of ore deposits. One of the main objectives of Metal Earth is to develop an understanding of the processes that result in differential metal endowment With this understanding, the mining and exploration industry will be more effective at area selection, which will reduce exploration risk and the cost of discovery.

Since our Year 1 report, industry has benefited from Metal Earth's 300% increase in the number of reports and maps published in government survey publications, and a 1,300% increase in the number of presentations made at public mineral exploration forums.

Along with the extended Metal Earth team, I anticipate further impacts to industry through accelerated development of tools and services with commercial potential, and to the economy through improvements in mineral exploration targeting.

Dr. Ross L. Sherlock
Director, MERC and Metal Earth

PROGRESS STATUS UPDATE: YEAR 3

CRATON SCALE PROJECTS

ISOTOPIC MAPPING OF THE SUPERIOR CRATON

Dr. David Mole

Dr. David Mole, PDF, Dr. Phillips C. Thurston, Adjunct Professor, Metal Earth, Mineral Exploration Research Centre (MERC), Harquail School of Earth Sciences.

SCOPE OF PROJECT

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) [1] and Begg et al. (2010) [2], 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) [3] used regional Sm-Nd isotopic data to map the crustal architecture of the Yilgarn Craton, and Mole et al. (2013) [4] 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) [5], 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) [8], Tibet (Hou et al., 2015) [9], 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.

Project collaborators include Dr. John A. Ayer, Associate MERC Director; Dr. Jeffrey H. Marsh, PDF, Metal Earth, MERC, Harquail School of Earth Sciences; and Dr. Richard A. Stern, Managing Director, Canadian Centre for Isotopic Microanalysis, University of Alberta and Metal Earth collaborator.

PROGRESS YEAR 3

The timetable for data collection is on track, as the first quadrant (1/6) of the Superior Craton is now finished. The O-isotope data were completed at the University of Western Australia (UWA) in Perth and University of Alberta in November 2018. The U-Pb-Hf-TE (trace element) data were then collected via laser ablation at Laurentian University. Metal Earth now has over 3,300 analyses from 165 samples across the southeast (SE) Superior Craton. Currently, these data are being processed into a form from which the first isotopic maps will be produced.

In August 2018, a joint helicopter survey of the Bienville Domain, central Québec, was undertaken with the Ministry of Energy and Natural Resources (MERN), Québec to fill a major sampling gap across a 90,000 km2 area (**Figure 1**).

Figure 1: Dr. David Mole, PDF, and Dr. Phillips C. Thurston, Adjunct Professor, Metal Earth, MERC, Harquail School of Earth Sciences, at the start of the Bienville Domain helicopter survey, in conjunction with MERN, Québec, August 2018.

FUTURE WORK

Summer 2019 presentations of work will be made at major international conferences including Goldschmidt (the largest geochemistry conference in the world), and SGA 2019 (one of the world's premier economic geology conference).

The work plan for Year 4 is to i) complete the first isotopic maps of the SE Superior region; and ii) begin sample selection for the next quadrant, the SW Superior region (2/6). Samples will be selected and prepared in May-June 2019, ready for O-isotope work in July-August and laser ablation analysis in September 2019. In July 2019, fieldwork will be performed in the Wawa area of the SE Superior. This region is under-sampled in the Metal Earth dataset and represents an important area, due to the occurrence of relatively old volcanic rocks, which could provide important information on Mesoarchean crust in the region.

MODERN OCEAN CRUST (METAL OCEANS)

Project lead Dr. Mark D. Hannington, University of Ottawa, and GEOMAR – Helmholtz Centre for Ocean Research Kiel; Dr. Margaret Stewart, RA; Dr. Alan T. Baxter, RA; Marc Lorin Fassbender, Ph.D. Candidate Geochemistry; and Kaitlyn Breker, Geographic Information Systems (GIS) Technician, University of Ottawa; Dr. Melissa Anderson, Assistant Professor, University of Toronto; and Justin Emberley, GIS Technician, Government of Yukon.

SCOPE OF PROJECT

Metal Oceans is a subproject of Metal Earth with a global team of collaborative researchers (**Figure 2**) focusing on the comparison of modern ocean crust and its evolution with the structure and composition of greenstone belts. The primary objective is to investigate the relationship between microplate formation and the emergence of magmatic-

Dr. Mark D. Hannington

hydrothermal systems in modern convergent-margin settings. The main objective is to better understand crustal growth and metal endowment, to reveal the geodynamic and magmatic complexity at a fine scale (10s to 100 km) in three sub-regions of the Indo-Australian margin (Lau Basin, North Fiji-New Hebrides, and Eastern PNG).

These sub-regions host spectacular concentrations of metals and hydrothermal activity. The complex microplate evolution in these areas is being documented in a series of crustal imaging experiments using numerous techniques (**Figure 3**). These are mapping projects directly analogous to the ME transects and exploring processes that may be similar to those that dominated late Archean tectonics.

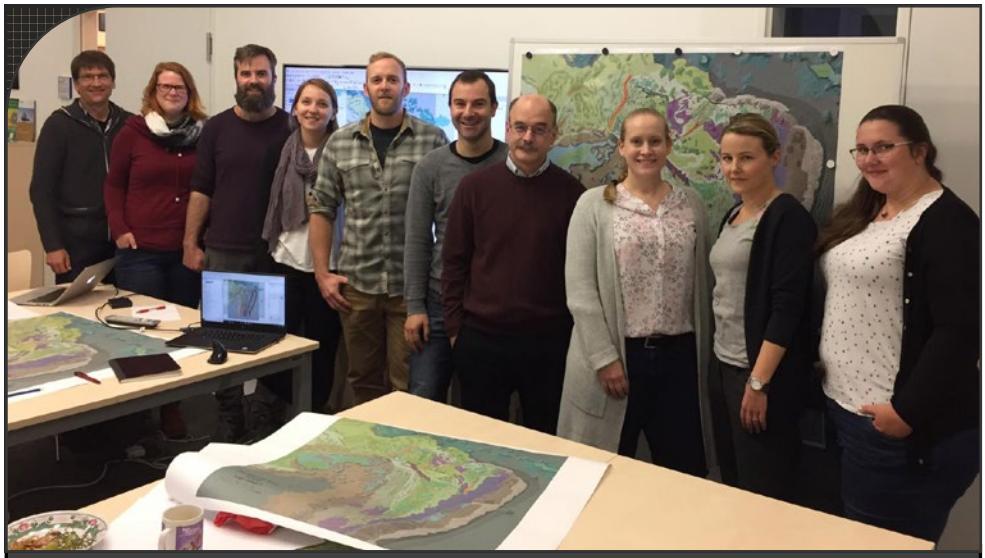


Figure 2: **Metal Ocean team. L-R: Dr. Sven Petersen, Helmholtz Centre for Ocean Research – GEOMAR; Meike Klischies, Ph.D. student, University of Kiel – GEOMAR; Dr. Alan T. Baxter, RA, Dr. Margaret Stewart, PDF, Justin Emberley, GIS Technician, University of Ottawa; Dr. Philipp A. Brandl, PDF, Helmholtz Centre for Ocean Research – GEOMAR; Prof. Mark Hannington (Lead Researcher), University of Ottawa; Asst. Prof. Melissa Anderson, University of Toronto; Dr. Anna Krätschell, GIS Technician, GEOMAR; and Rebecca Lintzel-Mensing, M.Sc. student, Martin Luther University - GEOMAR.**

Project advisors Dr. Harold L. Gibson, Metal Earth, MERC, Harquail School of Earth Sciences; Dr. John W. Jamieson, Memorial University of Newfoundland; Dr. Thomas Monecke, Colorado School of Mines; Dr. Patrick Mercier-Langevin, Geological Survey of Canada; and Dr. Sven Petersen, GEOMAR - Helmholtz Centre for Ocean Research Kiel.

International academic collaborators Dr. Richard Arculus, Australian National University; Dr. Hans-Hermann Gennerich, University of Bremen; and Dr. Brent McInnes, Curtin University.

International research collaborators Prof. Dr. Karsten Haase, and Privatdozent (PD) Dr. Christoph Beier, GeoZentrum Nordbayern, FAU Erlangen-Nürnberg; Prof. Dr. Colin Devey, Prof. Dr. Kaj Hoernle, Prof. Dr. Heidrun Kopp, Dr. Nico Augustin, Dr. Marion Jegen-Kulcsar, and Dr. Florian Schmid, GEOMAR - Helmholtz Centre for Ocean Research Kiel; PD Dr. Udo Barckhausen, Dr. Ingo Heyde, Dr. Michael Schnabel, and Dr. Ulrich Schwarz-Schampera, German Geological Survey, Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Federal Institute for Geosciences and Natural Resources; and Dr. Christian Timm, Geological Society of New Zealand.

Canadian and international industry collaborators are Dr. John McGaughey, Mira Geoscience; John Parianos, Nautilus Minerals Inc; and Paulo Ferreira, BearingPoint, Netherlands; and Dr. Tim McConachy, Neptune Minerals Inc, New Zealand.

PROGRESS YEAR 3

Research activities during Year 3 included:

1. Two proposals for large-scale marine transects using R/V SONNE were approved (ARCHIMEDES I, SO-267 and ARCHIMEDES II, DynaMet).
2. Lau Basin Marine Transect, took place from December 11, 2018 to January 27, 2019. A total of 40 personnel participated, including 3 Metal Earth researchers (M. Hannington, M. Stewart, and P. Mercier-Langevin).
3. M. Anderson participated on the TongaRIFT Transect in the NE Lau Basin (SO-263) in June 2018. This project has uncovered important new aspects of arc-trench magmatism associated with forearc rifting.
4. Preliminary workplans for ARCHIMEDES II Transect (DynaMet: Arc Rifting, Metallogeny and Microplate Evolution of the New Ireland Basin and Bismarck Archipelago, Papua New Guinea) were submitted for ship scheduling and release of funds, expected in 2020. A scientific prospectus for the transect was completed and is being prepared for publication.
5. The team at uOttawa and GEOMAR developed workflows to convert acoustic bathymetric data, gravity models, and other offshore geophysical data into geological assemblages and formation maps. The first 1:1 million lithostratigraphic assemblage map of the NE Lau Basin was presented in March 2019 and will be released in the coming months as part of a 4-map series of the Indo-Australian margin. Additional maps are being released annually. When completed, the atlas will be the first assemblage-level geological compilation of its kind in the oceans that will allow direct comparisons with greenstone assemblages.
6. Regional geophysical data were compiled and large portions of the New Hebrides and PNG maps were completed. The New Hebrides map sheet was included in the Ph.D. thesis of M. Anderson (defended in March 2018) and published in a series focusing on the Coriolis Troughs (southern New Hebrides) and Jean Charcot Troughs (northern New Hebrides). Another geological compilation was published for the Mariana backarc.
7. Mapping of the Indo-Australian margin is underpinned by new plate boundary refinements completed during Year 3. These data were assembled for a new Microplate Atlas of the Western Pacific (1:5 million) which identifies ~20 different boundary types and their attributes at a resolution approximately 5 times greater than previous compilations by the Circum-Pacific Council for Energy and Mineral Resources and the Commission for the Geological Map of the World.
8. A lithogeochemical compilation for the Lau Basin was completed that will form the basis of a Ph.D. project (M.L. Fassbender) on the magmatic evolution of arc-backarc systems in comparison to their ancient analogs. The compilation includes 1521 unique samples that have been filtered to produce a single high-quality data set for analysis and comparison to ancient volcanic systems.
9. M. Hannington is hosting a one-year Marie Sklodowska-Currie ERC International Research Fellow, Dr. Christian Timm, Geological Survey of New Zealand (GNS), who is contributing to Metal Oceans through the first whole-arc study of chalcophile element variations in volcanic rocks of the Tonga-Kermadec region. Project GoldTrace will be among the first studies to link magma chemistry and metal contents to crustal imaging and velocity structure.
10. Metal Oceans continued to engage several companies on data sharing and project development for predictive mapping technologies. Nautilus Minerals Inc. and Neptune Minerals Inc. provided multibeam bathymetric surveys, backscatter imaging, and other geophysical data sets that have been instrumental in mapping projects along two transects in the Lau Basin and New Hebrides.
11. Drs Hannington, Stewart, and Mercier-Langevin contributed to the Metal Earth Thematic VMS Proposal, which was submitted to the Metal Earth advisory board at the end of March 2019.

FUTURE WORK

Research activities in Year 4 will include:

1. Final post-stack migrations for processing of geophysical data from ARCHIMEDES I, expected by the middle of Year 4. These data will provide information on the uppermost crustal structure (sediments and basement faults), which will be incorporated into wide-angle tomographic inversions, 2D velocity-depth models, and joint inversions with OBMT data.
2. Preparation for ARCHIMEDES II (DynaMet) will continue throughout Year 4, including the planning of ship's operations and organization of research activities.
3. The lithogeochemical compilations started in 2018 will be advanced. The first will supplement the existing Lau Basin compilation with new samples from ARCHIMEDES I. These samples will be analyzed by XRF and high resolution ICP-MS in Ottawa and Germany. Analysis of Sr, Nd, Hf and Pb (double spike) isotope ratios by TIMS and multi-collector ICP-MS, as well as $^{40}Ar/^{39}Ar$ dating, will be performed at GEOMAR.
4. A second lithogeochemical study will focus on 810 high-quality analyses in the area of the ARCHIMEDES II Transect (Manus-New Ireland Basin and Woodlark subprovinces). This data set will be enhanced by new sampling during ARCHIMEDES II including major element geochemistry by XRF; trace elements by ICP-MS, Sr-Nd-Hf and Pb (double spike) isotope studies by TIMS; and multi-collector ICP-MS, as well as $^{40}Ar/^{39}Ar$ dating.
5. The Ottawa and GEOMAR teams will continue work on the 1:1 million geological compilations of the Indo-Australian margin including new maps of the N. Fiji Basin and New Hebrides and expanded maps in the New Hebrides and Vanuatu. These maps will be peer-reviewed in 2019-2020 and published as Metal Oceans products.
6. Interpretation and quantitative modelling of crustal growth, with direct comparison to crustal architecture and mineral endowment in greenstone belts, will include plate vector analysis to constrain the regional kinematics and stress regimes related to microplate interactions and arc rifting. Magma volume and area-age relationships for different assemblages will be established as a first order metric of microplate growth.

ANTICIPATED OUTCOMES

The major outputs of Metal Oceans by the end of Year 4 will include i) publication of the new Microplate Atlas of the Western Pacific region, with a focus on the Indo-Australian margin; ii) a geophysical and lithogeochemical compilation of the study areas; and iii) quantitative analysis of the geological maps and crustal sections for comparison with ancient greenstone belts. Results of the first marine transect in the Lau Basin will be published, including high resolution seismic, electromagnetic, magnetic, and heat flow data, together with volcanic geochemistry and geochronology at a scale that will be directly comparable to the Metal Earth transects.

Figure 3: **Image of one of 18 ocean bottom magnetotellurics (OBMT) stations that were deployed and left on the seafloor, during a period of 41 days, to collect research data.**

An important outcome of the crustal imaging experiments will be to establish new criteria for recognizing melt- and fluid-ascent pathways

at regional scales, how they are organized, and their spatial and temporal link to large magmatic-hydrothermal systems. The identification of fundamental aspects of fertility and mineral endowment in greenstone belts is anticipated, including specific types of microplate boundaries and possible links to mantle heterogeneities that connect with translithospheric faults and evolve into major corridors for melt and fluid transport through the crust. Details of the research goals relevant to Metal Earth will be presented in peer-reviewed publications, abstracts, and conference presentations. The project will contribute to the HQP training of 7 new Canadian researchers and 6 international (including one in Canada) researchers, in the application of regional geodynamics to mineral exploration.

MODERN OCEAN CRUST PROJECT (METAL OCEANS) TOPIC 1

Dr. Margaret Stewart

Project lead Dr. Margaret Stewart, RA, University of Ottawa. Supervised by Dr. Mark D. Hannington, University of Ottawa, and GEOMAR – Helmholtz Centre for Ocean Research Kiel.

PROGRESS YEAR 3

Dr. Stewart played a lead role in starting the mapping projects, establishing working groups, and initiating product delivery in Ottawa. In Year 3, Dr. Stewart i) established the first lithostratigraphic framework and approach to mapping the submarine arc-backarc systems, ii) collaborated with Dr. Emberley to produce the 1:1 million map of the Lau Basin, iii) and summarized this mapping approach and the results in a manuscript to be submitted in Year 4.

In Year 4, Dr. Stewart will i) focus on quantitative modelling of crustal growth, with direct comparison to crustal architecture and mineral endowment in greenstone belts; ii) collaborate with Dr. Baxter to explore the use of plate vector analysis to constrain the regional kinematics of arc rifting and backarc opening; and iii) investigate backarc basin volcanism using volume calculations performed by K. Breker for the Lau Basin.

MODERN OCEAN CRUST PROJECT (METAL OCEANS) TOPIC 2

Justin Emberley

Project lead Justin Emberley, GIS Technician, Government of Yukon. Supervised by Dr. Mark D. Hannington and Dr. Margaret Stewart.

PROGRESS YEAR 3

J. Emberley played a leading role in developing workflow and approach to mapping using integrated geophysical datasets and the assessment of uncertainty for each map unit. In Year 3, J. Emberley i) completed the compilation and production of the 1:1 million geological map of the Lau Basin, ii) began geological interpretation and mapping of the North Fiji Basin and eastern PNG; and iii) established the procedures for cartography, layout and map production for the 1:1 million map series.

In Year 4, J. Emberley will i) complete 1:1 million maps of the North Fiji Basin and PNG, and ii) perform uncertainty analyses for these map sheets and prepare the final layouts for publication.

MODERN OCEAN CRUST PROJECT (METAL OCEANS) TOPIC 3

Dr. Melissa Anderson

Project lead Dr. Melissa Anderson, Assistant Professor, University of Toronto completed her Ph.D. thesis on the *Relationships between tectonics, volcanism, and hydrothermal venting in the New Hebrides and Mariana back-arc basins* in Year 3. Supervised by Dr. Mark D. Hannington.

PROGRESS YEAR 3

This work established the link between magmatism, regional-scale geodynamics, microplate interactions, and hydrothermal activity during arc rifting in 3 key areas (Corilois Troughs, Jean Charcot Troughs, and the central Mariana). Additionally, M. Anderson i) prepared these products for publication during 2018, ii) is publishing the results of her thesis in 2019, and iii) continues as a partner in Metal Oceans as principal supervisor for an M.Sc. project.

In Year 4, Dr. Anderson will lead the application for ship time to complete the mapping project in northern Vanuatu and the Jean Charcot Troughs. She is actively recruiting new M.Sc. and Ph.D. students for the project, which will be funded independently at the University of Toronto with logistical and field support from Metal Oceans and GEOMAR. M. Anderson is currently preparing a white paper with Meike Klischies and the Metal Oceans team on the workflows for seabed geological mapping.

MODERN OCEAN CRUST PROJECT (METAL OCEANS) TOPIC 4

Dr. Alan T. Baxter

Project lead Dr. Alan T. Baxter, RA, University of Ottawa. Supervised by Dr. Mark D. Hannington.

PROGRESS YEAR 3

In Year 3, Dr. Baxter completed the comprehensive data compilation for the North Fiji Basin 1:1 million geological map. Extensive archival bathymetric data was obtained from government and research repositories in France and Australia, which significantly expanded data coverage for the project in the area. All available datasets (shipboard multibeam bathymetry, gravity, magnetics) have been compiled and imported in ArcMap and preliminary mapping at the assemblage-level is complete. A. Baxter developed a novel method for classifying fault types in the Lau Basin by integrating Global Centroid Moment Tensor (CMT) data with mapped seafloor lineaments to produce a present-day stress map of the Lau Basin.

In Year 4, Dr. Baxter will complete the CMT study in the Lau Basin and publish his results in a peer-reviewed journal. He will continue to work with J. Emberley on the 1:1 million map of the North Fiji Basin, linking to the onshore geology of Fiji and to the detailed studies at the western margin of the basin in the New Hebrides. The focus of this mapping is to investigate the timing and evolution of major crustal-scale structures in the basin and at its margins in relation to known mineral deposits.

MODERN OCEAN CRUST PROJECT (METAL OCEANS) TOPIC 5

Project lead Kaitlyn Breker, GIS Technician, University of Ottawa. Supervised by Dr. Mark D. Hannington, Dr. Margaret Stewart, and Dr. Alan T. Baxter, University of Ottawa; and Justin Emberley, GIS Technician, Government of Yukon.


Kaitlyn Breker

PROGRESS YEAR 3

K. Breker was hired as a geomatics specialist to conduct map analysis and plate modelling. Progress in Year 3 included developing a process for the automated calculation of orientations for seafloor lineaments and the cumulative 3D volumes of volcanic formations, using ArcGIS as a platform for new codes and focusing on the Lau Basin where 1:1 million scale to 1:100,000 scale mapping was already completed. This task required extensive conversion of the map data into a format that could be successfully analysed using ArcGIS software.

In Year 4, K. Breker will complete the calculation of formation volumes in the Lau Basin study area. A new project will test methods for calculating 3D extensions of volcanic dikes, which comprise the bulk of the magmatic addition to the arc during initial stages of arc rifting. K. Breker will test the use of the structural modelling software toolkit Move3D for kinematic (geomechanical) modelling, stress analysis and fault response modelling in the map areas of the project. The goal is to better understand the evolution of crustal permeability within the mapped microplate frameworks.

MODERN OCEAN CRUST PROJECT (METAL OCEANS) TOPIC 6


Marc Lorin Fassbender

Marc Lorin Fassbender, Ph.D. Candidate Geochemistry, University of Ottawa. Supervised by Dr. Mark D. Hannington and Dr. Margaret Stewart.

PROGRESS YEAR 3

M. Fassbender is working on host rocks, of seafloor massive sulfide mineralization, in arc and back-arc systems. In Year 3, he compiled, verified, and filtered published and unpublished whole rock geochemical analyses from the Lau Basin to create the first comprehensive geochemical database. The latter focused mainly of mafic rocks. A second global geochemical database is in progress for submarine silicic volcanic rocks, encompassing not only arcs and back-arc basins but also unusual occurrences on oceanic ridges and ocean islands. Preliminary analysis of general geochemical trends within the Lau Basin was completed.

In Year 4, M. Fassbender will complete a detailed analysis of the compiled marine data, establishing a modern petrogenetic framework for arc rifting and microplate interactions. A detailed study of the trace element and isotopic compositions of the Lau Basin volcanic rocks will be conducted using archived and newly collected samples from SO-267 (in partnership with P. Brandl, GEOMAR). The data sets will be compared with a new lithogeochemical compilation of the Abitibi (in partnership with P. Mercier-Langevin, Geological Survey of Canada).

MODERN OCEAN CRUST (METAL OCEANS) ADDITIONAL PROJECT

Joel Ryan, University of Ottawa, is completing his thesis on *Automated lineament analysis in the Lau Basin.* Supervised by Dr. Mark D. Hannington; Dr. Alan T. Baxter, and Dr. Margaret Stewart, University of Ottawa.

MODERN OCEAN CRUST (METAL OCEANS) SPIN OUT PROJECTS

The Modern Ocean Crust (Metal Oceans) project has spawned additional subprojects relevant to the scope of the Metal Earth program including in Year 3:

- Dr. Philipp A. Brandl, Research Scientist, GEOMAR-Helmholtz Centre for Ocean Research, is co-lead on the ARCHIMEDES II (Dynamet) transect in the New Ireland Basin of Papua New Guinea. Supervised by Dr. Mark D. Hannington.
- Chantal Norris-Julseth, M.Sc. Geology, University of Toronto is completing her thesis on Structural evolution of the NE Lau Back-arc Basin at the northernmost termination of the Tonga arc as part of the TongaRIFT SO-263 project. Supervised by Dr. Melissa Anderson, Assistant Professor, Economic Geology, University of Ottawa.
- Sebastian Graber, Ph.D. Candidate Mineralogy and Geochemistry, GEOMAR - Helmholtz Centre for Ocean Research Kiel is working on development of remote-predictive mapping techniques and regional mineral potential mapping for slow-spreading mid-ocean ridges. Supervised by Dr. Mark D. Hannington and Dr. Sven Petersen, Research Scientist, GEOMAR - Helmholtz Centre for Ocean Research Kiel.
- Meike Klischies, Ph.D. Candidate Mineralogy and Geochemistry, GEOMAR - Helmholtz Centre for Ocean Research Kiel is working on development of remote-predictive mapping techniques for seabed mapping. Supervised by Dr. Melissa Anderson and Dr. Sven Petersen.
- Dr. Anna Krätschell, GIS Technician, GEOMAR - Helmholtz Centre for Ocean Research Kiel completed the compilation and production of the Marine Microplate Atlas, and began a global compilation of mineral deposits from Geological Survey of Canada and U.S. Geological Survey databases to begin assessing the spatial and temporal relationship between regional mineral endowment and microplate distribution. Supervised by Dr. Mark D. Hannington and Dr. Sven Petersen.
- Rebecca Lintzel-Mensing, M.Sc. Candidate Geoscience, Martin Luther University and GEOMAR - Helmholtz Centre for Ocean Research Kiel is conducting detailed 1:100,000 structural mapping of the Mangatolu Triple Junction in the northern Lau Basin, a project on the origins of triple junctions. Supervised by Dr. Mark D. Hannington.

FLUID SOURCE AND PATHWAYS


Dr. Georges Beaudoin


Dr. Benoît Quesnel


Dr. Christophe Scheffer

Project lead, Dr. Georges Beaudoin; Dr. Benoît Quesnel, RA, and Dr. Christophe Scheffer, RA, Université Laval. Project title *Source to sink: Toward an integrated understanding of the auriferous fluid flow system(s).*

SCOPE OF PROJECT

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

stable isotopes, geophysics, and pressure-temperature-time (P-T-t-X) constraints modelling is pursuing this objective by trying to answer aspects of the following categories:

A. Source:

i) What are the geological processes driving the release of fluid(s) and volatiles?, and in collaboration with Dr. Iain Pitcairn, Stockholm University;

ii) What is the mobility of Au and related elements associated to geological processes?

B. Sink:

i) What are the mechanisms inducing parameters (T, P, fO2, fS2, pH) variation and driving destabilization of gold-carrying causing gold endowment?; and

ii) Are fluid flow conditions and fluid-rock interactions important to form a deposit?

C. Timing:

i) Is the timing of fluid generation related to different geological processes consistent with the timing of gold mineralization?; and

ii) Is gold mineralization a result of successive hydrothermal fluid events?

Academic collaborators Dr. Ben M. Frieman, Dr. Taus R.C. Jørgensen, Dr. Mostafa Naghizadeh, Dr. Kate E.L. Rubingh, Dr. Richard Smith, Dr. Douglas K. Tinkham, Dr. Zsuzsanna Tóth, and Dr. Xiaohui Zhou, Metal Earth, MERC, Harquail School of Earth Sciences; Dr. Pierre Bedeaux, Université du Québec à Chicoutimi (UQAC); Dr. Matthijs A. Smit, University of British Columbia; Dr. Christopher MacFarlane, University of New Brunswick; Dr. Iain Pitcairn, Stockholm University; Dr. Michael A. Hamilton, University of Toronto; Dr. Steffen Hagemann, and Dr. Nicolas Thébaud, Centre for Exploration Targeting; and Dr. Josué Jautzy, and Dr. Martine M. Savard, Natural Resources Canada.

Industry collaborators Jill Annette Marcotte, and Richard Morel, Goldex Mine, Agnico Eagle Mines Ltd.; Issam Bakari, Francis Tremblay-Bergeron, Mikell Bilodeau, Yanick Champagne, and Marie-des-Neiges Gagnon, Canadian Malartic Mine Corp.; Maxime Le Bacq, and Jacques Simoneau, Eldorado Gold Corp.; Benjamin Gagnon, Émilie Gagnon, Luc Théberge, and Jessy Thelland, Eldorado Gold Lamaque; Claude Pilote, Falco Resources Ltd.; Nicole Houle, IAMGOLD Corp.; Breanne Beh, and Marco Gagnon, Probe Metals Inc.; Baptiste Chapon, Sylvain Lépine, and Dr. Gérald Riverin, Yorbeau Resources Inc.

PROGRESS YEAR 3

The first field campaign associated with Source to Sink research was carried out during the summer of 2018 along the Malartic, Rouyn-Noranda, Larder Lake, Geraldton, and Dryden-Stormy Lake transects. The first objective was to define possible collaborations with transect teams on specific student projects for which fluid characterization could be valuable. The second objective was to sample veins (mainly quartz, carbonates and tourmaline) along transects, in orogenic gold and VMS contexts, and in endowed and less endowed areas, in order to build a stable isotopic compilation for the regional isotopic survey.

Progress on this research project includes:

- Sampling of approximately 150 veins, and analysis of 230 samples;
- Completion of the compilation and georeferencing of stable isotopic data from the literature, to update data for the regional isotopic survey;

- Start of analyses of oxygen isotopic composition of samples;
- Repairs to ensure the oxygen extraction line in operational state;
- Collaboration with Dr. Josué Jautzy, and Dr. Martine M. Savard, geological survey of canada, natural resources canada, to test the applicability of 47 (clumped isotope thermometry) analyses on carbonates associated to orogenic gold fluid circulation system(s); and
- Recruitment of three Ph.D. students and one M.Sc. student to carry out specific studies related to source to sink research themes.

FUTURE WORK

The second field campaign, which will begin in the summer of 2019, will i) complete the regional isotopic survey with datasets along Stormy Lake-Dryden and Geraldton transects, ii) sample veins along the Chibougamau transect, iii) collaborate on projects led by those transect teams, and iv) start the 4 projects being undertaken by Ph.D. and M.Sc. students. **See Transect Scale Projects in Future Work section**.

ANTICIPATED OUTCOMES

Regional isotopic survey:

- Regional scale map of the stable isotope (O, C and D) compositions of veins, fluids, and temperature, and
- New dataset will allow researchers to investigate possible regional variations of fluid circulation conditions between endowed and less endowed area at various scales.

Clumped isotope thermometry:

- Test of the applicability of clumped isotope thermometry on carbonates associated to mesothermal deposits to obtain more widespread and reliable temperature constraints of carbonate formations linked to orogenic gold deposits.

Student studies related to research themes:

- See anticipated outcomes of the 4 subprojects being undertaken by Ph.D. and M.Sc. students from Université Laval in Future Work section under **Transect Scale Subprojects**.

MANTLE GROUP


Dr. Graham Pearson


Dr. Steven B. Shirey


Dr. Richard W. Carlson


Dr. Richard J. Walker

Project leads Dr. Graham Pearson, University of Alberta; Dr. Steven B. Shirey and Dr. Richard W. Carlson, Carnegie Institution for Science; and Dr. Richard J. Walker, University of Maryland.

SCOPE OF PROJECT

The Mantle Group research, for this subproject of Metal Earth, focuses on age and evolution of the early crust and the mantle lithosphere beneath the Superior craton and documentation of metal enrichment in the lithospheric mantle.

Dr. Janina Czas, University of Alberta, was lead PDF on mantle xenoliths, Os isotopes and PGEs. Dr. Chiranjeeb Sarkar, University of Alberta, provided technical support through development of laser ablation split stream (LASS) methods and reference materials. Dr. Adrien Vezinet, University of Alberta, was lead PDF on crustal evolution studies and the role of mantle in crust production.

Project collaborators Dr. Ryan Mathur, Juniata College; Dr. Jesse R. Reimink, Carnegie Institution for Science; Dr. Dan J. Schulze, University of Toronto; Dr. Larry M. Heaman, University of Alberta. Hendrik Falck, Northwest Territories Geological Survey; and Dr. Christopher Lawley and Dr. Bruce Kjarsgaard, Geological Survey of Canada.

PROGRESS YEAR 3

The Mantle Group is pleased to report the following progress to date:

1. Os isotope and PGE work has been completed on the Kirkland Lake suite of Superior mantle xenoliths. Analysis has begun on precious metals and other elements in this suite by LA-ICPMS to look for similar depth dependent metal enrichments as have been observed in the N Slave mantle xenoliths.
2. Work commenced on Os isotope and PGE measurements of Wawa mantle xenoliths. An additional mantle xenolith suite from Elliott Lake, Ontario has been identified through sampling and will be acquired in the coming year.
3. Work has been completed on publishing zircon U-Pb, Hf and O isotope results from the oldest of the Saglek Bay gneisses as a benchmark for the oldest Superior rocks. This has provided a critical understanding of the generation of some of the earliest crust in Canada for comparison to the oldest domains of the Superior craton.
4. U-Pb, Hf and O isotope measurements have been completed on Assean Lake Terrane crustal rocks. Zircon U-Pb/Hf/O spatially resolved analyses of Assean Lake lithologies (i.e., one of the oldest crustal segments of the Superior Province) clearly demonstrates the generation of magmatic rocks at ca. 3.2 Ga deriving from a chondritic mantle reservoir (no depleted Hf signature) with no input of supracrustal material. Altogether, this points toward net addition of crustal material from the mantle at ca. 3.2 Ga and reflects one of the first stages of continental building in the Superior craton (i.e., it reflects the formation of the nucleus of the Superior Province). Strikingly, this NW Superior Province Terrane does not show any substantial metal endowment, like the Eoarchean Saglek block in the North Atlantic craton, Labrador (**Figure 4**). However, this earlier continental mass provides a platform onto which younger crustal blocks are docked. This process could be key in the generation of the endowed areas of the Superior Province.
5. Lastly, the Metal Oceans team completed the characterisation of a new suite of reference materials for the laser-ablation split-stream analysis of U-Pb and Sm/Nd isotopes in monazite, titanite and apatite, as well as characterisation of a new Archean zircon secondary standard.

FUTURE WORK

Work plans for Year 4 include:

1. Completing LA-ICPMS measurements on the Kirkland Lake mantle xenolith suite to compare with N. Slave craton data;
2. A Cu isotope study of Kirkland Lake xenoliths to explore the use of Cu isotopes in the mantle for tracing metal mobility and endowment;
3. Publication of the Kirkland Lake OS-PGE dataset in a high profile journal;
4. Thesis examining metal concentration variations in the mantle lithosphere of the N. Slave craton with inclusion of the Kirkland Lake LA-ICPMS data for comparison.
5. The LASS U-Pb and Sm-Nd methods paper and documentation of reference materials is expected to be submitted with technical support from C. Sarkar.

Figure 4: **Outcrop located on Nulliak Island, Newfoundland and Labrador (Saglek Block) that consists of Eoarchean (3.6 Ga) amphibolite which underwent a partial melting event.**

IMPLICATIONS FOR METAL EARTH

From the mantle xenolith LA-ICPMS study, it is clear that the mantle lithosphere is stratified in its metal endowment with concentrations of high field strength elements between 140 and 120 km related to MARID-type metasomatism, whereas base metal enrichment is more prevalent in the lower lithosphere. This provides great insight into which portions of the lithospheric mantle might provide critical sources of different metals for transfer into Earth's crust for economic enrichment.

HIGHLIGHTS

Unique depth-related trends in metal zonation in the mantle lithosphere have been found beneath the northern Slave craton. These observations are being compared with new data coming from the Kirkland Lake mantle xenolith suite.

A study of the Early Archean rocks from Saglek Bay, Labrador is being widely cited and is a definitive study of the earliest fragments of continental crust. These crustal domains contain minimal metal endowment and can be contrasted with the rich metal endowment of the Neoarchean crust and Proterozoic terranes of Archean cratons such as the Superior.

MANTLE GROUP PDF TOPIC 1

Dr. Adrien Vezinet

Dr. Adrien Vezinet, PDF, University of Alberta, is completing his thesis on *Crust formation in the Archean: Superior craton and other examples and their link to metal endowment.* Supervised by Dr. Graham Pearson, University of Alberta, and Dr. Steven B. Shirey, Carnegie Institution for Science.

PROGRESS YEAR 3

During Year 3, research milestones related to this project included:

- Completion of U-Pb, Hf and O isotope measurements on Assean Lake rocks;
- Publication of zircon U-Pb, Hf and O isotope work from the oldest of the Saglek Bay gneisses in the prestigious *Earth and Planetary Science Letters* journal, with findings presented as a benchmark for the oldest Superior rocks; and
- Preparation of an additional geology paper from this study that documents some of the earliest evidence for water-rock interaction on Earth.

Development of baddeleyite dating for Neoarchean mafic magmas is planned for Year 4.

MANTLE GROUP PDF TOPIC 2

Dr. Janina Czas

Dr. Janina Czas, PDF, University of Alberta, has completed her thesis on *Os isotope and PGE studies of mantle xenoliths from the Superior Craton.* Supervised by Dr. Graham Pearson, University of Alberta, and Dr. Steven B. Shirey, Carnegie Institution for Science.

PROGRESS YEAR 3

During Year 3, research milestones related to this project included:

- Completion of data collection for Os isotopes and pges for Kirkland Lake;
- Wawa data collection started; and
- Obtained ~ 30% of LA-ICPMS precious metals data on KL xenoliths, with P&T determined.

In Year 4, research will complete xenolith analyses (Wawa) and precious metal data acquisition (Kirkland Lake). Xenoliths (Elliott Lake) will be obtained for analysis.

MANTLE GROUP ADDITIONAL PROJECT

Christian Veglio, University of Alberta, is completing his thesis on *Behaviour of ore-forming elements in the subcontinental lithospheric mantle below the Slave craton.* Supervised by Dr. Graham Pearson, University of Alberta, and Dr. Christopher Lawley, Geological Survey of Canada.

TRANSECT SCALE PROJECTS

SCOPE OF PROJECT 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 indistinguishable geological characteristics. The purpose of the transect mapping is to complete focused mapping to add value to 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 2018 (Year 3), 7 transects were active including Chibougamau, Ben-Nevis – Larder Lake, Cobalt, Geraldton-Onaman, Sturgeon, Dryden-Stormy Lake, and Rainy River.

CHIBOUGAMAU TRANSECT

Dr. Lucie Mathieu

Dr. Pierre Bedeaux

Research team leads on *Chibougamau transect / magmas and mineralisation* project are Dr. Lucie Mathieu and Dr. Pierre Bedeaux, Université du Québec à Chicoutimi (UQAC), Center for Mineral Resources Research (CERM) and Metal Earth collaborators.

SCOPE OF PROJECT

The Chibougamau area (**Figure 5**), 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.

Academic collaborators Dr. Sarah-Jane Barnes, UQAC; Dr. Réal Daigneault, UQAC; Dr. Damien Gaboury, UQAC; Dr. Graham Pearson, University of Ottawa; Dr. Edward W. Sawyer, UQAC; Dr. Steven B. Shirey, Carnegie Institute for Science; Dr. Stéphane de Souza, University of Québec in Montreal (UQAM) and Dr. Zsuzsanna Tóth, Laurentian University. Public

sector collaborators Patrick Houle, Ministry of Energy and Natural Resources (MERN), Québec; François Leclerc, MERN; Dr. Patrick Mercier-Langevin, Geological Survey of Canada and Pierre Pilote, MERN. Industry collaborators on Chibougamau Transect project are Frank Guillemette, Multi-Ressources Boréal Ltd.; Andrey Kulynych-Rinta, AmAuCu Mining Corp; and Benoit Lafrance, Tarku Resources Ltd.

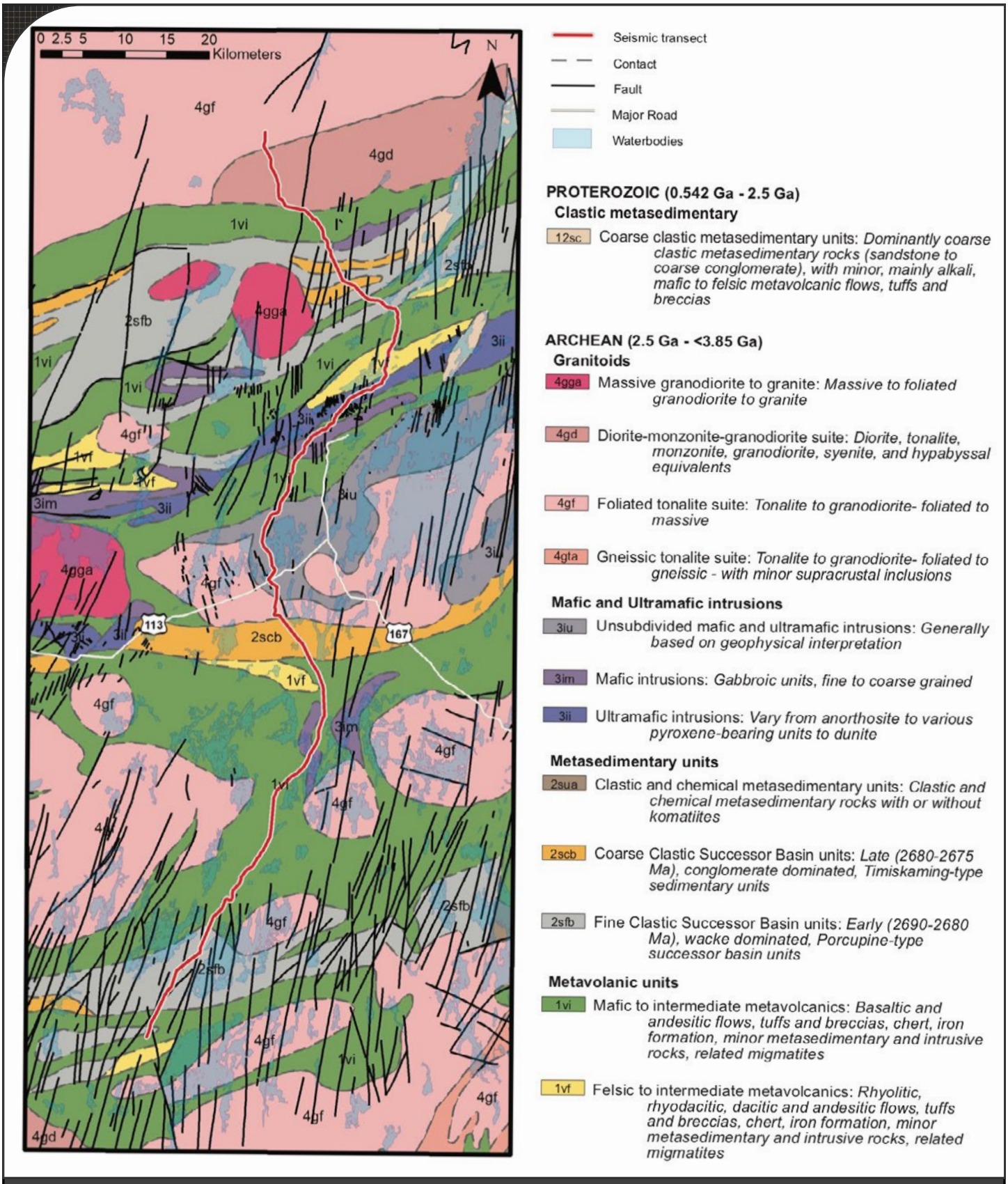


Figure 5: Map of Chibougamau Transect.

PROGRESS YEAR 3

This year had numerous successes, particularly in the areas of training of highly qualified personnel (HQP), knowledge dissemination, and collaborations.

- Three months of field work was completed in summer 2018, and preparations were made for the next field campaign in summer 2019;
- LA-ICPMS analyses were performed at UQAC, microprobe analyses were performed at McGill and Laval Universities, under the supervision of Dr. Lucie Mathieu;
- One M.Sc. project was completed, and three others will be finished in December 2019;
- Three Ph.D. candidates have been recruited – two for transect scale projects and one for a thematic research project;
- Diffusion of results with several scientific articles (6 papers published by L. Mathieu et al. in refereed journals, 9 abstracts presented at conferences / congresses including Xplor, Québec Mines et Énergie, and Prospectors & Developers Association of Canada (PDAC) by L. Mathieu et al. and 8 informal presentations to post-secondary institutions and the Canadian Geotechnical Society;
- Successful application to a thematic project, in collaboration with The Mantle Group; and
- General accomplishments of the team including compilation, data collection, and data generation (petrology and geochemistry) all contributing to advancements in the comprehension of the Chibougamau area.

FUTURE WORK

Continued research activities will include larger-scale processes to comprehend magmatism in the Abitibi and Wabigoon subprovinces.

- Fieldwork carried out along the Chibougamau transect in June, July, and August 2019 to document the geometry of the main contacts, fault kinematics, fold characteristics, and to gather petrological data. A large collection of samples will be gathered.
- Additional lithogeochemical analyses performed to complete the Ph.D. and M.Sc. projects.
- Geochemical modelling to constrain source and crustal processes, to be carried out during Years 3-4. Data integration into map and cross-sections.
- Oxygen isotopes work and Sm-Nd isotopic investigations that may help constrain the timing of older crust involvement in the production of some of the magmas. This will be complementary to the Lu-Hf study undertaken by D. Mole.
- More detailed work to be conducted on minerals resistant to metamorphism, in order to better constrain petrogenetic models. A parallel project will document the volatile content of magmas by targeting minerals including apatite, which may help constrain volatile content and oxygen fugacity, as well as magnetite, and other oxides.
- Sulfide chemistry will be investigated in order to discriminate and map the extent of the various mineralizing systems (VMS, porphyry, remobilized or not) of the area. Thermo-barometers will be used, since some of the pluton may have a complex P-T history.

ANTICIPATED OUTCOMES

For the duration of the project, the team (**Figure 6**) will focus on i) revealing factors that controlled the formation of deposits in the Chibougamau area by comparing it with other greenstone belts; ii) comprehension of the role that magmas play in mineralising processes and in the transport of volatiles and metals in the crust; and iii) interpretation of the Chibougamau transect and 3D modelling.

Figure 6: **Chibougamau transect team in the field. Back row L-R: Marie Kieffer, Julien Huguet, Adrien Boucher, Youssouf Ahmadou Youssoufou, Laura-Pier Perron-Desmeules, Mike Bellemare, Maryse Desrochers. Front row L-R: Dr. Pierre Bedeaux, Antoine Brochu, and Dr. Lucie Mathieu, UQAC.**

CHIBOUGAMAU TRANSECT PDF TOPICS 1 AND 2

Dr. Pierre Bedeaux

Lead researcher Dr. Pierre Bedeaux, PDF, Université du Québec à Chicoutimi (UQAC) on two Metal Earth à Chibougamau subprojects 1) *Evolution and development of Archean sedimentary basin in the Chibougamau area: time constraints and sedimentary environment, and 2) Structural evolution of Barlow Fault: A comparison with large gold-bearing structures in Abitibi Subprovince.* Supervised by Dr. Réal Daigneault and Dr. Lucie Mathieu, Université du Québec à Chicoutimi (UQAC).

PROGRESS YEAR 3

Year 3 of Metal Earth had the initiation of two projects aiming to provide new knowledge to poorlyunderstood parts of the transect, including sedimentary rocks and structures located in the southern and northern extremities of the transect.

At the scale of the Chibougamau area, the main objective of *Evolution and development of Archean sedimentary basin in the Chibougamau area: time constraints and sedimentary environment* is to provide new knowledge of lesser-understood parts of the transect, including sedimentary rocks and structures located in the southern and northern extremities of the transect. This research aims to characterize and produce a synthesis of ages of deposition and spatial distribution of the four sedimentary rock assemblages in the area. Better constraints on timing and environment of deposition will provide clues to the post-volcanic evolution of the Chibougamau transect. During 2018 fieldworks, the Chebistuan Formation sedimentary basin was investigated and sampled for U/Pb analysis on detrital zircons. Preliminary results highlight strong similarities in

age and facies with the Opemiska Group. These results will be included in a large study available in early 2020.

The aim of *Structural evolution of Barlow Fault: A comparison with large gold-bearing structures in Abitibi Subprovince* is to understand the structural evolution of a seismic reflector corresponding to a fault observed on the surface, to determine the possible relationship with mineralization. The Barlow Fault appears as a long-lived structure recording several deformation events, and displays many characteristics of gold-bearing major faults. Fieldworks in 2018 provided significant insights on the variation of the geometry of the faults, while microprobe analysis of amphiboles indicates that most of the fault-related deformation occurred prior to regional metamorphism. A research paper is in preparation and will be completed in early 2020.

Results of both projects were published in a Summary of Fieldwork paper which can be downloaded **HERE**. P. Bedeaux's research will be completed in the spring of 2020.

CHIBOUGAMAU TRANSECT M.SC. TOPIC 1


Adrien Boucher

Adrien Boucher, M.Sc. Candidate Geology, Université du Québec à Chicoutimi (UQAC) is finishing his thesis on *Metal Earth à Chibougamau: chimie, stratigraphie, âge, et structure de la Formation de l'Obatogamau.* Supervised by Dr. Lucie Mathieu and Dr. Réal Daigneault, Université du Québec à Chicoutimi (UQAC).

PROGRESS YEAR 3

Year 3 of Metal Earth had the initiation of this M.Sc. project, which . focused on the structural framework and age of Timiskaming-type basins. During the summer of 2018, three months of field work was conducted. As a result, fieldwork data have been processed, maps have been corrected and drawn, and all the necessary petrographical and chemical analyses have been performed including thin sections, whole rock analyses, and mineral chemistry microprobe,SEM and some analitical work.

This project documented volcanic gaps and found that the Obatogamau Formation was erupted more rapidly than had been thought. This discovery has implications for the VMS potential of this formation. Results were published in a Summary of Fieldwork paper which can be downloaded **HERE**. A similar paper and other articles are being prepared, and A. Boucher's thesis will be completed in the spring of 2020.

CHIBOUGAMAU TRANSECT M.SC. TOPIC 2


Marie Kieffer

Marie Kieffer, M.Sc. Candidate Geology, Université du Québec à Chicoutimi (UQAC) is completing her thesis on *Metal Earth à Chibougamau: géométrie, chimie et mode de mise en place du Complexe à l'Eau-Jaune.* Supervised by Dr. Lucie Mathieu and Dr. Damien Gaboury, Université du Québec à Chicoutimi (UQAC).

PROGRESS YEAR 3

Year 3 of Metal Earth was of the initiation of this project. The data resulting from 3 months of field work during the summer of 2018, have been processed, maps have been corrected and drawn, and all the necessary petrography and chemical analyses have been performed including thin sections, whole rock analyses, and mineral chemistry microprobe, SEM and LA-ICPMS analyses.

Research documented volcanic gaps and found that tonalite-trondhjemite-granodiorite (TTG) intrusions are much more chemically heterogeneous than was previously known. This new knowledge has implications for intrusion-related mineralisation including Au and base metals.

Results were published in a Summary of Fieldwork paper which can be downloaded **HERE**.

M. Keiffer is currently preparing her M.Sc. thesis and articles associated with this project's progress.

CHIBOUGAMAU TRANSECT M.SC. TOPIC 3

Julien Huguet

Julien Huguet, M.Sc. Candidate Geology, Université du Québec à Chicoutimi (UQAC) and *Metal Earth collaborator is completing his thesis on Metal Earth à Chibougamau: caractérisation minéralogique et chimique du pluton de Chevrillon, et de sa relation avec son encaissant sédimentaire.* Supervised by Dr. Lucie Mathieu and Dr. Paul L. Bédard.

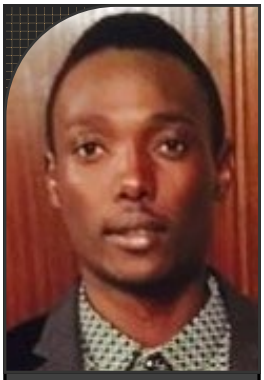
PROGRESS YEAR 3

Year 3 of Metal Earth was Year 1 of this project. Research activities from 3 months of fieldwork in the summer of 2018 include:

- Fieldwork data processed;
- Maps corrected and drawn; and
- All necessary petrography and chemical analyses performed including thin sections, whole rock analyses, and mineral chemistry microprobe, SEM and LA-ICPMS analyses.

Volcanic gaps were documented and a petrogenetic and structural model for a late felsic intrusion, including depth of emplacement, was provided. Knowledge dissemination included a poster (**Figure 7**) and other presentation materials. Results were published in a Summary of Fieldwork paper which can be downloaded **HERE**. Articles will be completed in the fall of 2019, and J. Huguet's M.Sc. thesis will be completed in the spring of 2020.

Figure 7: **Julien Huguet, receiving prize for his Metal Earth poster from M. Robert Giguère, General Manager, Géologie Québec du MERN, November 2018.**



Youssouf A. Youssoufou

CHIBOUGAMAU TRANSECT M.SC. TOPIC 4

Lead researcher Youssouf A. Youssoufou, M.Sc. Candidate Geology, Université du Québec à Chicoutimi (UQAC) is completing his thesis on *Metal Earth à Chibougamau: origine du Sodagranophyre du Complexe du Lac Doré et minéralisations associées.* Supervised by Dr. Lucie Mathieu and Dr. Damien Gaboury, Université du Québec à Chicoutimi (UQAC).

PROGRESS YEAR 3

Year 3 of Metal Earth was the initiation of this project. In the summer of 2018, three months of fieldwork were further supported by processing fieldwork data, correcting and drawing maps, and performing all necessary petrography and chemical analyses including thin sections, whole rock analyses, and mineral chemistry microprobe, SEM and LA-ICPMS analyses. This provided a comprehensive study of the sodagranophyre of the Lac Doré Complex.

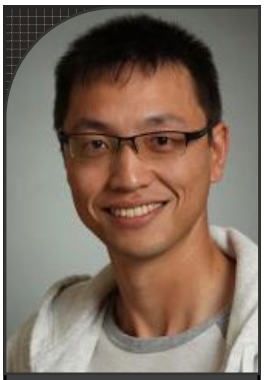
Results were published in a Summary of Fieldwork paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. Y. A. Youssoufou has completed his M.Sc. thesis.

CHIBOUGAMAU TRANSECT ADDITIONAL PROJECTS

Antoine Brochu, Université du Québec à Chicoutimi (UQAC) is completing his thesis on *Contexte de la déformation et du métamorphisme de la faille de Barlow, Chibougamau, Québec.* Supervised by Pierre Bedeaux, PDF, Université du Québec à Chicoutimi (UQAC).

Baptiste Madon, M.Sc. Candidate Geology, Université du Québec à Chicoutimi (UQAC) is completing his thesis on *Determine redox conditions in Neoarchean magmas using apatite and zircon* with 25% financing from Metal Earth and 75% financing from NSERC. Supervised by Dr. Lucie Mathieu, Université du Québec à Chicoutimi (UQAC).

MALARTIC TRANSECT



Dr. Xiaohui Zhou

Transect lead Dr. Xiaohui Zhou, RA, Metal Earth, MERC, Harquail School of Earth Sciences; supervised by Dr. Bruno Lafrance, and Dr. Michael C. Lesher.

SCOPE OF PROJECT

The Metal Earth Malartic transect (**Figure 8**) mapping and research project was initiated in 2017. It was designed to be multidisciplinary and involved various scale targeted bedrock mapping, in conjunction with detailed structural analysis, lithogeochemistry, U-Pb geochronology and mineral deposit investigations. In addition to these fundamental geological techniques, extensive gravity, aeromagnetic, magnetotelluric and seismic data were newly acquired along the transect, for processing by geophysical colleagues.

The intent of this multidisciplinary project is to refine the crust architecture and to elucidate the critical geological processes that led to metal endowment, in comparison to less metal endowed Archean terranes. Fieldwork was done in 2017 and 2018, with a short follow-up season planned for 2019.

The study area extends from Berry Township in the north to Mourier Lake in the south, and is bounded by Highway QC-395 to the west and Highway QC-397 to the east. This area (roughly 50×100 km2) comprises Neoarchean volcanic

terranes and sedimentary basins that are intruded by batholiths of various composition. Multiple crustal scale structures (e.g., Larder Lake-Cadillac deformation zone) and regional faults (e.g., Manneville faults) are spatially associated with numerous gold mines and less-known nickel occurrences.

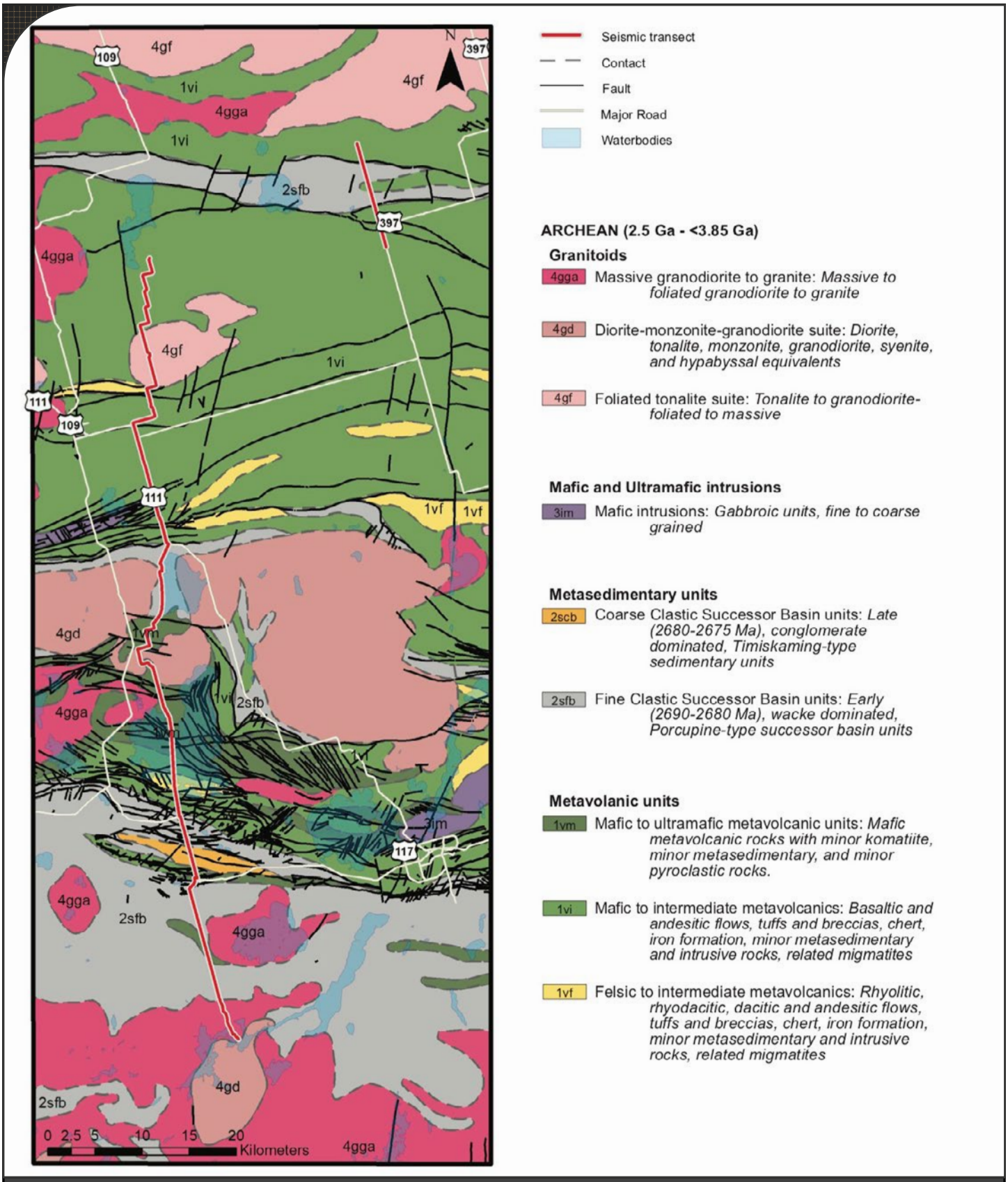


Figure 8: Map of Malartic Transect.

Major scientific topics include 1) contact relationships between the Cadillac basin and Piché structural complex, which defines the Malartic segment of the Larder Lake-Cadillac break; 2) structural evolution of crustal scale deformation zones and its implications for differential metal endowment; 3) structural evolution of the Cadillac basin and its implications for gold mineralization; 4) ore genesis and structural modification of nickel mineralization within the Southern Manneville deformation zone; 5) the emplacement of the S-type La Motte batholith and its constraints on timing of regional deformation; and 6) provenance and evolution of sedimentary basins in southern Abitibi and Pontiac subprovinces.

Project collaborators Dr. Jeffrey H. Marsh, and Dr. Stéphane Perrouty, Metal Earth, MERC, Harquail School of Earth Sciences; Dr. Réal Daigneault, University of Québec at Chicoutimi; Dr. Michael A. Hamilton, University of Toronto; and Pierre Pilote, Ministry of Energy and Natural Resources (MERN), Québec.

Industry collaborators Francois Bouchard, Canadian Malartic Mine Corp.; Normand Champigny, CEO and Director, Québec Precious Metals Corp.; Shana Dickenson, Senior Geologist, IAMGOLD Corp.; Denis Jolin, Geologist, Globex Mining Enterprises Inc.; Olivier Lemieux, Geologist and Founder, GFE Forestry & Exploration Services Inc.; Francis MacDonald, Vice President of Exploration, Kenorland Minerals Ltd.; Mario Masson, VP Exploration, Midland Exploration Inc.; and Denis Vaillancourt, Exploration Manager Canada, Agnico-Eagle Mines Ltd.

PROGRESS YEAR 3

In Year 2 of the project, fieldwork (**Figure 9**) was carried out by X. Zhou, D. Shirriff and B. Samson from late May to August of 2018 with two weeks of field guidance from Dr. Bruno Lafrance (**Figure 10**). New detailed mapping near the Larder Lake-Cadillac deformation zone and Northern Chicobi fault reveals that contacts between sedimentary basins and volcanic terranes were originally unconformities and intruded by granitoid plutons, then overprinted by regional folding. These plutons crystallized between 2680-2675 Ma based on the new geochronology results from Dr. Michael A. Hamilton. In July 2018, Dr. Stéphane Perrouty organized a field tour and meeting at the Canadian Malartic gold mine, which is on the transect, and X. Zhou, B. Samson and Dr. Bruno Lafrance presented an update of the Metal Earth project to mine geologists. Drill holes from the Cubric nickel showing and Marbridge mine area were logged by D. Shirriff under the supervision of Dr. C. Michael Lesher.

In-kind support from the public and private sectors and local residents kept work moving forward. Highlights of the fieldwork were presented to university, government and industry colleagues during the Metal Earth field excursion in September of 2018. Post field season lab work included petrographic and SEM examination of microstructures and rock units, detrital zircon sample preparation and analysis with Dr. Jeffrey H. Marsh, as well as major and trace element geochemistry on mineralized/altered samples. New gravity, aeromagnetic, magnetotelluric and seismic data were correlated with the surface geology along the transect. Updated research results were summarized in the Metal Earth Summary of Fieldwork volume and presented at various conferences and workshops, including CTG, PDAC, GAC-MAC and Kirkland Lake workshop.

Results from the second year's fieldwork were published in a Summary of Fieldwork paper, which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. X. Zhou's research will be completed in the spring of 2020.

FUTURE WORK

A two-week field season is planned for 2019, with the main goal to re-examine key outcrops along the Piché-Cadillac contact as this area defines the Larder Lake-Cadillac deformation zone. Fabrics and kinematics around the La Motte pluton and surrounding supracrustal rocks within the two Manneville fault zones will be checked to determine emplacement and exhumation of late S-type granitoid batholiths with respect to regional deformation.

The following year of the project will be largely devoted to integrating field and analytical data and writing journal papers. One manuscript aims to interpret the crust architecture of southern Abitibi and Pontiac subprovinces based on historical work and newly-acquired geophysical and geological data along the transect. This will provide a district to subprovince scale geologic control on formation of mineral deposits, which is one of the main goals of the Metal Earth projects.

Another manuscript will focus on structural development among three crustal scale deformation zones (i.e., Larder Lake-Cadillac, Porcupine-Destor-Manneville and Chicobi deformation zones) and its implication on metal endowment. Additional fieldwork in conjunction with geochemical and petrographic work will be conducted on the Piché-Cadillac contact, La Motte pluton and Manneville faults. A third paper will attempt to unravel provenance and tectonics of sedimentary basins based on geochemistry and detrital zircon samples collected from different stratigraphic levels. More detrital zircon sample preparation and geochemical analysis need to be completed.

ANTICIPATED OUTCOMES

As a result of this research, it is anticipated that:

- All field and analytical data will be organized and stored in the Metal Earth geodatabase;
- Cross section across Abitibi and Pontiac subprovinces with integrated geological and geophysical interpretation will be completed;
- Research on different topics will be published in the various formats of technical reports, M.Sc. theses and peer-reviewed journal papers;
- Highlights of this work will be presented in various domestic conferences and workshops; and
- Collaborations with university, government and industry partners may stimulate novel ideas for future projects.

Figure 9: **Image of Danielle Shirriff, Brendon Samson, and Naomi Welt looking at microstructures while mapping an outcrop in detail. Grid lines were set up to allow researchers to measure and plot contacts, structures, veining and other details with accuracy, to show specific geological relationships not otherwise shown on a larger scale map.**

MALARTIC TRANSECT M.SC. TOPIC 1

Brendon Samson, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Structural architecture and gold mineralization in the Cadillac basin north of the Larder Lake-Cadillac deformation zone, Abitibi greenstone belt, Québec.* Supervised by Dr. Bruno Lafrance and Dr. Xiaohui Zhou.

Brendon Samson

PROGRESS YEAR 3

The purpose of this study is to examine the deformation history of a metasedimentary basin consisting of turbidites with local iron formation and polymictic conglomerates of the Cadillac Group (<2687 Ma) and the polymictic conglomerates and sandstones of the Timiskaming Group (2677-2672 Ma). This basin is situated along the NW-trending Malartic segment of the overall E-trending Larder Lake – Cadillac deformation zone. Observations made throughout this study provide implications for the history of the movement along this major break during deformation. In addition, the timing and structural controls on gold mineralization within the basin have been defined.

At least three deformation events (D1, D2 and D3) affect the Cadillac and Timiskaming groups. Gold mineralization is hosted by extensional quartz veins and their associated alteration halos emplaced during the second deformation event. Gold mineralization within the basin is likely coeval with the late orogenic overprinting mineralizing event observed at the nearby Canadian Malartic gold deposit.

Results have been published in a Summary of Fieldwork which can be downloaded **HERE**. B. Samson will submit his M.Sc. thesis defense and peer-reviewed manuscript by September 2019.

MALARTIC TRANSECT M.SC. TOPIC 2

Danielle Shirriff

Danielle Shirriff, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *Mobilization of Ni-Cu-(PGE) mineralization at the Cubric showing along the Southern Manneville fault zone, southern Abitibi Subprovince, Québec.* Supervised by Dr. Michael C. Lesher and Dr. Xiaohui Zhou.

PROGRESS YEAR 3

In Year 2 of this project, the following research activities were completed:

- Field mapping at the Marbridge ore zone and Cubric showing,
- Petrographic descriptions and interpretations,
- SEM study on key thin sections to determine sulfide mineralogy, and
- First draft of a manuscript.

In addition, geochemical data was collected from the Cubric showing, thin sections were prepared for petrographic and SEM studies, and IPGE data (Ru, Rh and Ir) was obtained to help characterize deposit type.

In Year 4, sulfur isotope data will be obtained from mineralized samples

Figure 10: 2018 Malartic transect field crew from L-R: Luc Roy, Samuel Duckworth Battye, Naomi Welt, Brendon Samson, Danielle Shirriff, and Dr. Xiaohui Zhou.

to better constrain the formation of the deposits. Results were published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. D. Shirriff's thesis will be completed in the spring of 2020.

ROUYN-NORANDA TRANSECT

Dr. Taus R. C. Jørgensen

Project team lead Dr. Taus R. C. Jørgensen, RA, Metal Earth, MERC, Harquail School of Earth Sciences. Supervised by Drs Harold Gibson and Bruno Lafrance.

SCOPE OF PROJECT

The primary goals of this project are to provide:

1. Transect research which will resolve lithospheric-crustal architecture and fluid (magma/heat) pathways, providing a geological framework to resolve the differential endowment of terranes and structures (mantle-crust slices); and

2. Train HQP for a future in the mining and mineral exploration industry or academia by addressing outstanding geological problems in the transect research area in the form of M.Sc., Ph.D., and postdoctoral projects.

Academic collaborators Dr. Harold L. Gibson, Dr. Bruno Lafrance, Dr. Phillips C. Thurston, Dr. Mostafa Naghizadeh, Dr. Leonardo Feltrin, Associate Professor, Dr. Jeffrey H. Marsh, Dr. Saeid Cheraghi, Dr. Ben M. Frieman, Eric Roots, and S. Hussain Ali, Metal Earth, MERC, Harquail School of Earth Sciences. Dr. Benoît Quesnel, RA, Laval University; Dr. Michael A. Hamilton, University of Toronto; and Dr. Gema R. Olivo, Queen's University.

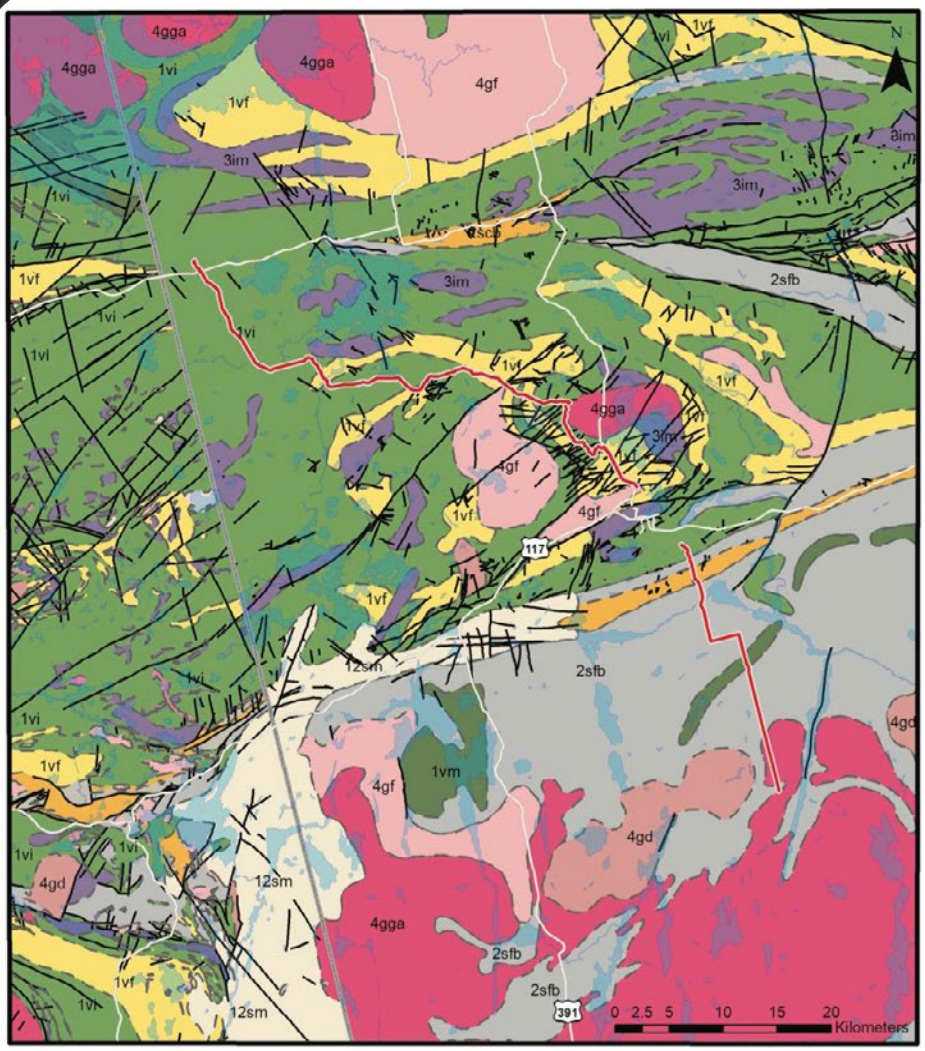
Public sector collaborators Dr. David B. Snyder, Geological Survey of Canada; Jean Goutier, Géologie Québec, Ministry of Energy and Natural Resources (MERN), Québec; and Dr. K. Howard Poulsen, independent consultant. Industry collaborators Claude Pilote, Falco Resources Ltd.; Dr. Gérald Riverin, and Baptiste Chapon, Project Geologist, Yorbeau Resources Inc.; Jack Stoch, Pierre Riopel, and Barbara Guimont, Globex Mining Enterprises Inc.; and Dr. Esmaeil Eshaghi, Thomson Aviation, Australia.

PROGRESS YEAR 3

Research activities focused on these 2 goals were completed as follows:

Transect research:

- Second field season, from May 20th to September 11th, 2018, collecting geological data along the Rouyn-Noranda transect (**Figure 11**);
- Transect geology map (plan view) based on compilation of previous work and mapping;
- Transect geology cross-section based on compilation of previous work and mapping; and
- Interpretation of seismic section and integration with surface geology and aeromagnetic data.



Seismic transect
Contact
Fault
Major Road
Provincial Border
Waterbodies

PROTEROZOIC (0.542 Ga - 2.5 Ga)

Mafic and Ultramafic intrusions

13mm Mafic intrusions: *Gabbroic units, fine to coarse grained*

Clastic metasedimentary

12sm Migmatized supracrustal rocks: *Migmatized metasedimentary rocks with minor migmatized metavolcanic content*

ARCHEAN (2.5 Ga - <3.85 Ga)

Granitoids

4gu Unsubdivided granitoid units: *Includes all units listed below in areas without detailed maps*

4gn Diorite-Nepheline syenite suite: *Pyroxenite, diorite, monzonite, syenite, nepheline syenite*

4gga Massive granodiorite to granite: *Massive to foliated granodiorite to granite*

4gd Diorite-monzonite-granodiorite suite: *Diorite, tonalite, monzonite, granodiorite, syenite, and hypabyssal equivalents*

4gf Foliated tonalite suite: *Tonalite to granodiorite- foliated to massive*

Mafic and Ultramafic intrusions

3im Mafic intrusions: *Gabbroic units, fine to coarse grained*

3il Ultramafic intrusions: *Vary from anorthosite to various pyroxene-bearing units to dunite*

Metavolanic units

1vm Mafic and ultramafic metavolcanics: *Mafic metavolcanic rocks with minor komatiite, minor metasedimentary, and minor pyroclastic rocks*

1vi Mafic to intermediate metavolcanics: *Basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

1vf Felsic to intermediate metavolcanics: *Rhyolitic, rhyodacitic, dacitic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

Metasedimentary units

2sua Clastic and chemical metasedimentary units: *Clastic and chemical metasedimentary rocks with or without komatiites*

2smb Migmatized Successor Basin units: *Migmatized Successor Basin metasedimentary units with undefined or mixed grain size classification*

2scb Coarse Clastic Successor Basin units: *Late (2680-2675 Ma), conglomerate dominated, Timiskaming-type sedimentary units*

2sfb Fine Clastic Successor Basin units: *Early (2690-2680 Ma), wacke dominated, Porcupine-type successor basin units*

2si Iron formation: *Dominantly oxide facies minor sulfide, carbonate and silicate facies*

Figure 11: Map of Rouyn-Noranda Transect.

Transect projects (excluding student projects):

- Follow-up work in the Kinojevis Group, to confirm positive magnetic anomalies correspond to gabbroic dikes and sills intruding the volcanic package;
- Targeted sampling of rocks and veins in the Cadillac-Larder Lake Deformation Zone (CLLDZ) for geochemical and stable isotopic studies;
- Preparation and U-Pb analyses of detrital zircon separates from Pontiac Group metasedimentary rocks; and
- Interpretation of field, geochemical, and U-Pb zircon data obtained from the Kinojevis Group volcanic package.

Results were published in a Summary of Fieldwork that can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. T. Jørgensen's thesis will be completed in the spring of 2020.

FUTURE WORK

In the 4th year of Metal Earth, research will include interpretation of detrital zircon U-Pb and trace element data from the Pontiac Group metasedimentary rocks.

A 3-week field season is planned for 2019 to 1) collect geological data along the Rouyn-Noranda transect between the Horne Smelter and the CLLDZ; 2) conduct fieldwork in collaboration with Dr. Benoît Quesnel and a new M.Sc. student (likely also involving other researchers from Laval University) focusing on differential metal endowment along the CLLDZ in the Rouyn-Noranda area; and 3) conduct fieldwork in the Pontiac Subprovince targeting contact exposures between the Pontiac Group and Timiskaming Group metasedimentary rocks, contact exposures between Pontiac Group metasedimentary rocks and metavolcanic rocks, and structural evidence for the timing of a proposed extensional episode.

Additionally, interpretation and integration of magnetotelluric data with the other datasets, and the preparation of manuscripts for peer-review journals will be completed.

ANTICIPATED OUTCOMES

These research activities are anticipated to result in the following:

- Peer-reviewed journal papers (listed by priority) 1) Crust-mantle architecture of the Abitibi and Pontiac subprovinces in the Rouyn-Noranda area; 2) Geodynamic evolution of the Pontiac Subprovince; and 3) Differential metal endowment along the Rouyn-Noranda segment of the CLLDZ: controls on Au-mineralization.
- Database release of geological and geophysical data; and
- Graduation of two B.Sc. And two M.Sc. Candidates.

ROUYN-NORANDA TRANSECT PH.D. TOPIC 1

Marina D. Schofield, Ph.D. Candidate Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *Metallogeny of the Powell Block, Rouyn-Noranda, Québec*. Supervised by Dr. Harold L. Gibson and Dr. Bruno Lafrance, Metal Earth, MERC, Harquail School of Earth Sciences; and Dr. K. Howard Poulsen, international consultant and Metal Earth collaborator.

Marina D. Schofield

PROGRESS YEAR 3

Research activities in Year 3 included a second field season (**Figure 12**) in Rouyn-Noranda, from May 20th to August 30th, 2018 which resulted in:

- Construction of several cross-sections of the Powell Block,
- Production of alteration and structural maps,
- Collection of samples for geochemistry and geochronology,
- Ph.D. thesis proposal and comprehensive exam, and
- Completion of research for 1st thesis manuscript/chapter.

Results were published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. M. Schofield's thesis will be completed in the spring of 2020.

A third field season in Rouyn-Noranda is scheduled from May 1st to August 30th, 2019. This will result in completion of writing and editing of 1st thesis manuscript/chapter; and the research, writing, and editing of the 2nd thesis manuscript/chapter.

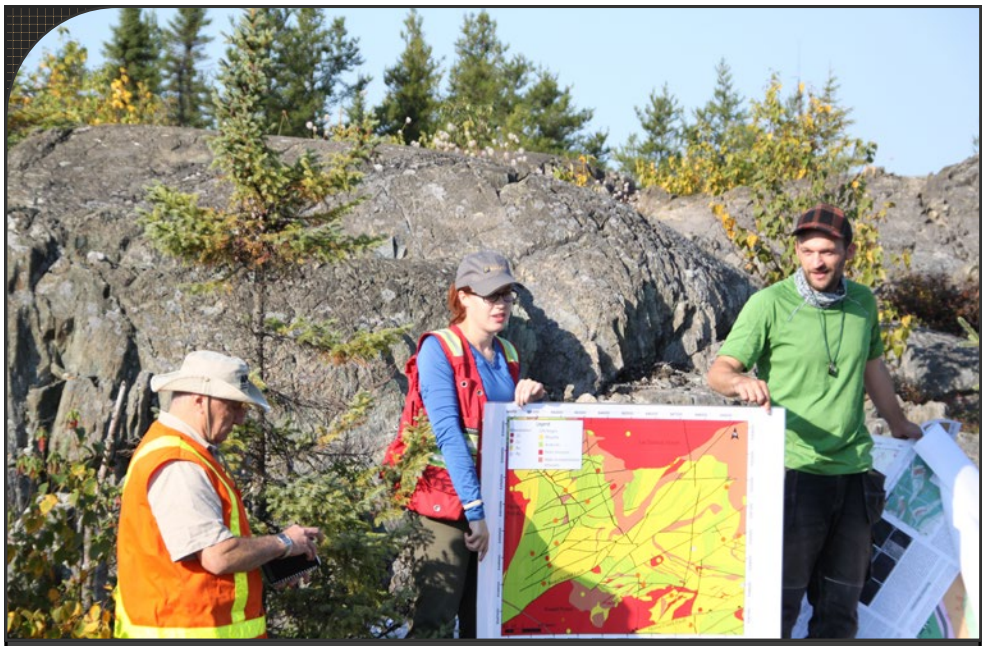


Figure 12: L-R: A Metal Earth field trip participant standing with Marina D. Schofield, and Dr. Taus R.C. Jørgensen as M. Schofield introduces her thesis to show regional distribution of metal occurrences in Rouyn-Noranda. Image taken on Brownlee rhyolite within Powell Block at the outcrop of the Powell-Rouyn orogenic gold vein.

Peer-reviewed journal papers to include 1) Structural-stratigraphic analysis of the Powell Fault Zone: implications for the metallogeny of the Powell Block; 2) The Joliet Breccia: Formation mechanism and relationship to quartz-sulfide vein mineralization and associated alteration; and 3) Metallogeny of the Powell Block. Additionally, M. Schofield will complete a detailed geological map with alteration and structural layers of the Powell Block.

Adrian Rehm

ROUYN-NORANDA TRANSECT M.SC. TOPIC 1

Adrian Rehm, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Emplacement history of mafic and ultramafic metavolcanic rocks in the Pontiac Subprovince, Lac Bellecombe area, Rouyn-Noranda, Québec.* Supervised by Dr. Phillips C. Thurston, Dr. Taus R. C. Jørgensen, and Dr. Harold L. Gibson.

PROGRESS YEAR 3

Research activities in Year 3 included a second field season in Rouyn-Noranda, from May 20th to August 30th, 2018 which resulted in:

- Completion of geological mapping, sampling, and geochemical analysis; and
- Collection of geological data for Rouyn-Noranda transect research.

Results to be published in a Summary of Fieldwork.

In Year 4 of Metal Earth, petrographic analysis will be completed, and a thesis will be written. Additionally, a peer-reviewed journal paper *Emplacement history of mafic and ultramafic metavolcanic rocks in the Pontiac Subprovince, Lac Bellecombe area, Rouyn-Noranda, Québec* will be completed.

ROUYN-NORANDA TRANSECT M.SC. TOPIC 2

Jonathan Sutton

Jonathan Sutton, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Whole rock oxygen isotope mapping integrated with petrographic and lithogeochemical characterization of alteration systems associated with subvolcanic intrusions and VMS mineralization in the Duprat-Montbray formation, lower Blake River Group, Rouyn-Noranda, Québec.* Supervised by Dr. Harold L. Gibson and Dr. Taus R. C. Jørgensen.

PROGRESS YEAR 3

Research activities in Year 3 included a second field season in Rouyn-Noranda, from May 20th to August 30th, 2018 which resulted in:

- Completion of geological mapping, core logging, sampling, geochemical analysis, geochronological analysis, and petrography; and
- Initiation of thesis writing.

Results were published in a Summary of Fieldwork which can be downloaded **HERE**. In Year 4 of Metal Earth, stable oxygen isotope analysis will be completed, a thesis will be written, and a peer-reviewed journal paper submitted.

ROUYN-NORANDA TRANSECT ADDITIONAL PROJECTS

Andrew M. Bradley, Metal Earth, MERC, Harquail School of Earth Sciences complete his H.B.Sc. thesis on *Characterization of an enriched Mg-Cr-Ni unit hosted in Timiskaming Group metasedimentary rocks: implications for subsidiary structures of the Cadillac-Larder Lake deformation zone, Rouyn-Noranda, Québec.* Supervised by Dr. Taus R. C. Jørgensen and Dr. Phillips C. Thurston.

Aidan T. Paleczny, Queen's University, completed his H.B.Sc. thesis on *Stratabound zinc-mineralization in the northwestern Pontiac Subprovince: Implications for contemporaneous volcanism and sedimentation.* Supervised by Dr. Gema R. Olivo, Queen's University; Dr. Taus R. C. Jørgensen and Adrian Rehm, Metal Earth, MERC, Harquail School of Earth Sciences.

BEN-NEVIS – LARDER LAKE TRANSECT

Lead researcher Dr. Kate E.L. Rubingh, RA; Dr. Ross L. Sherlock, Dr. Harold L. Gibson, and Dr. Bruno Lafrance, Metal Earth, Mineral Exploration Research Centre (MERC), Harquail School of Earth Sciences.

Dr. Kate E.L. Rubingh

SCOPE OF PROJECT

The Ben Nevis – Larder Lake transect is approximately 45 km in length and 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) [10]. 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. Metal endowment is one of the fundamental questions addressed under Metal Earth. To approach this, Metal Earth is building upon the existing research to fully characterize the stratigraphy and volcanology of the Ben Nevis area and compare with the Noranda camp to determine processes related to metal endowment.

The Ben Nevis – Larder Lake transect (**Figure 13**) also crosses the Timiskaming assemblage (ca. 2680 – 2670 Ma) [11] 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) [12] 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.

In the southern part of the transect, the Lincoln Nipissing shear zone (LNSZ) is poorly documented, partly due to its lack of exposure. The objective of the Metal Earth project is to characterize the fault zone with the associated intrusion related gold prospects.

Project collaborators include Dr. Michael A. Hamilton, University of Toronto; Dr. Patrick Mercier-Langevin, Geological Survey of Canada; Dr. Shirley Peloquin, Ministry of Northern Development and Mines, Sudbury District Geologist, Resident Geologist Program. Charles Beaudry, Orefinders Resources Inc.; Baptiste Chapon, Yorbeau Resources Inc.; Thomas Hart, Transition Metals Corp.; David LaRocque, Canadian Exploration Services Ltd.; Louis Martin, Agnico Eagle Mines Ltd.; A. Robert McGregor, Skead Holdings Ltd.; and Tim Stubley, Gold Candle Ltd.

PROGRESS YEAR 3

The Larder Lake transect commenced in 2017 with two M.Sc. candidates, Nadia St-Jean and Sean Brace. Fieldwork focused on key research areas, where a preliminary investigation was undertaken in two main areas 1) structural analysis and alteration along the LNSZ; and 2) detailed mapping north of the Lincoln Nipissing shear zone, to investigate the nature of the sedimentary and volcanic rocks which are complexly folded. Fieldwork in 2018 was led by K. Rubingh as the

new project team lead for the transect. Results were published in a Summary of Fieldwork (Rubingh, et al., 2018) which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019.

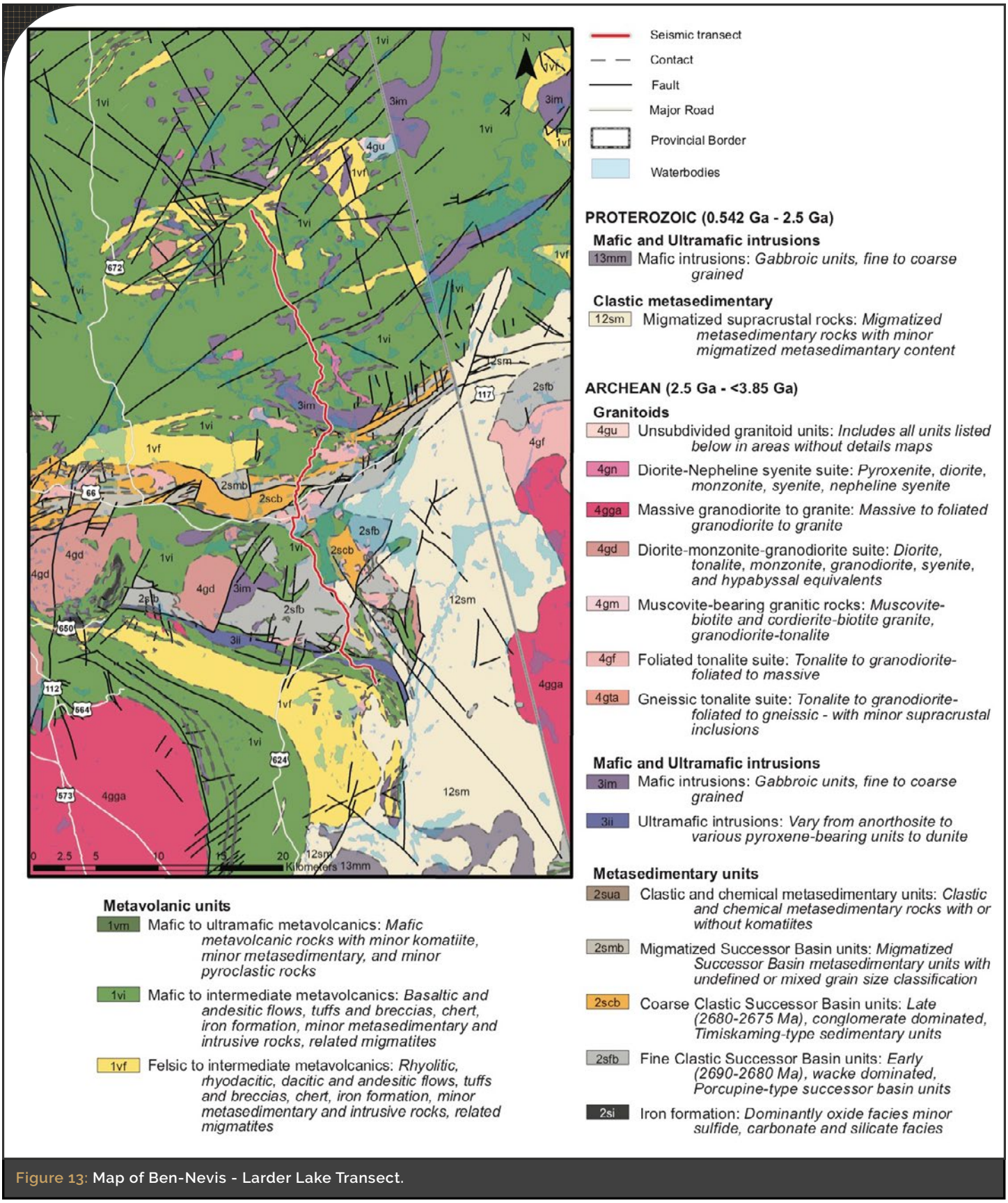


Figure 13: Map of Ben-Nevis - Larder Lake Transect.

FUTURE WORK

Further research during the 2019 field season will investigate two new areas and follow up on the 2018 field season work. These research areas will include 1) focused mapping along the LNSZ, targeted along a series of transects across this structure, to map the intensity of deformation and alteration and examine the relationship with gold mineralization which is associated with a series of gold prospects associated with composite intrusive stocks (these composite stocks have been petrogenetically classified by M.Sc. student Sean Brace); 2) structural analysis to further characterize the complex nature of the sedimentary and volcanic rocks north of the LNSZ; 3) Targeted mapping along the CLLDZ, which will complement the work conducted by M.Sc. candidate Nadia St-Jean and add to a comparative study with the LNSZ; 4) characterization of the Timiskaming volcanic rocks, which will potentially complement the study; and 5) regional mapping in the Lower Blake River Group to investigate a conductivity anomaly delineated from the Metal Earth magnetotelluric study.

ANTICIPATED OUTCOMES

Several research contributions will be available to the public including the entire transect map and cross section, which integrates stratigraphic and structural data as well as seismic, magnetotelluric, gravity and aeromagnetic data. All these Metal Earth data will be integrated into a common platform and made available to the public. Research articles originating from major scientific topics will be published in peer-reviewed journals. One thematic Ph.D., project and 3 M.Sc. theses will be completed associated with the Ben-Nevis Larder Lake transect.

BEN-NEVIS – LARDER LAKE TRANSECT M.SC. TOPIC 1

Nadia St-Jean

Project lead Nadia St-Jean, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *The nature of the Cadillac – Larder Lake Fault zone, implications for gold mineralization in the Kerr-Addison Cheminis area.* Supervised by Dr. Ross L. Sherlock and Dr. Bruno Lafrance.

PROGRESS YEAR 3

This research is focused on the Kerr-Addison Cheminis mine area, on the relationship between the younger Timiskaming sedimentary rocks (ca. ca. 2680 – 2670 Ma) and the older Larder Lake Group volcanic rocks (ca. 2705 Ma) (**Figure 14**). Results were published in a Summary of Fieldwork paper (St-Jean et al., 2018) which can be downloaded **HERE**. A first draft of the Master's thesis was submitted to thesis supervisors, (March 2019). Integration of the Master's research with further transect research to be completed by K. Rubingh during the 2019 field season.

Figure 14: **Gold mineralization in a quartz vein hosted in fuchsite carbonate altered ultramafic rocks from the Kerr Addison Mine.**

BEN-NEVIS – LARDER LAKE TRANSECT M.SC. TOPIC 2


Sean Brace

Project lead Sean Brace, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Metasomatic modification of structurally focused Archean intrusions, Larder Lake, Ontario.* Supervised by Dr. Daniel J. Kontak and Dr. Pedro J. Jugo.

PROGRESS YEAR 3

Petrographical characterization was completed for three of the composite intrusions that are associated with gold prospects, located in the southern portion of the transect, in proximity to the Lincoln Nipissing Shear zone.

Regional geological mapping and sampling in the area in proximity to the intrusions at MacGregor, Wisconsin-Skead (La Fonde showing) and the Webster trench localities, was followed by petrographical analysis including transmitted optical microscopy and SEM-EDS analysis. Detailed petrography identified the textural relationships and alteration of the intrusions, which was performed to examine the effect of alteration on the composition of the stocks, and combined with whole rock geochemistry and geochronology to help determine the original composition and setting for the intrusions.

Recent geochronology by M. Hamilton, (2018) on the Wisconsin-Skead stock dated this intrusion at 2672.5 Ma +/- 0.9 Ma, which is consistent with a syn-Timiskaming age for these intrusions. An additional sample has been submitted for U-Pb TIMS geochronological analysis of the MacGregor stock which will complement this felsic age from the Wisconsin-Skead stock and better constrain the timing of mafic magmatism. Classification of these intrusions will assist in providing a framework for further studies to investigate the timing of alteration with respect to alteration and deformation of these intrusions.

Results were published in a Summary of Fieldwork paper (Brace et al., 2018) which can be downloaded **HERE**. S. Brace's thesis will be completed in the fall of 2019.

BEN-NEVIS – LARDER LAKE TRANSECT ADDITIONAL PROJECT

Leslie Hunt, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *Structural and geochemical analysis of a weakly mineralized segment from the Cadillac - Larder Lake deformation zone: implications for gold mineralization.* Supervised by Dr. Kate E. L. Rubingh and Dr. Ross L. Sherlock.

COBALT TRANSECT


Dr. Shawna Elizabeth White

Transect lead Dr. Shawna Elizabeth White, RA, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *Structural and stratigraphic controls on mineralized veins in Cobalt, Ontario/Cobalt Transect.* Supervised by Dr. Ross L. Sherlock and Dr. Daniel J. Kontak. This project has been supported financially and logistically by First Cobalt Corp.t

SCOPE OF PROJECT

The work carried out along the Cobalt transect (**Figure 15**) represents a portion of the larger Metal Earth project carried out by MERC. Metal Earth is a multiyear, multidisciplinary collaboration focused on determining the factors that control mineralization within Archean greenstone belts. As part of this larger initiative, this project's work aims to determine the structural and stratigraphic framework of the Archean rocks and how this related to the distribution and controls on Ag-Co

arsenide veins using a combination of mapping, geophysical, and geochronological data.

Project collaborators Dr. Michael A. Hamilton, University of Toronto, and Dr. Frank Santaguida, First Cobalt Corp.

PROTEROZOIC (0.542 Ga - 2.5 Ga)

Mafic and Ultramafic intrusions

13mm Mafic intrusions: *Gabbroic units, fine to coarse grained*

Clastic metasedimentary

12sc Coarse clastic metasedimentary units: *Dominantly coarse clastic metasedimentary rocks (sandstone to coarse conglomerate), with minor, mainly alkali, mafic to felsic metavolcanic flows, tuffs and breccias*

12sf Fine grained clastic metasedimentary rocks: *Wacke, arkose, argillite, slate, marble, chert, minor metavolcanic layers*

12sm Migmatized supracrustal rocks: *Migmatized metasedimentary rocks with minor migmatized metavolcanic content*

ARCHEAN (2.5 Ga - <3.85 Ga)

Granitoids

4gga Massive granodiorite to granite: *Massive to foliated granodiorite to granite*

4gf Foliated tonalite suite: *Tonalite to granodiorite- foliated to massive*

4gta Gneissic tonalite suite: *Tonalite to granodiorite- foliated to gneissic - with minor supracrustal inclusions*

Mafic and Ultramafic intrusions

3iu Unsubdivided mafic and ultramafic intrusions: *Generally based on geophysical intrepretation*

3im Mafic intrusions: *Gabbroic units, fine to coarse grained*

3ii Ultramafic intrusions: *Vary from anorthosite to various pyroxene-bearing units to dunite*

Metasedimentary units

2sua Clastic and chemical metasedimentary units: *Clastic and chemical metasedimentary rocks with or without komatiites*

2scb Coarse Clastic Successor Basin units: *Late (2680-2675 Ma), conglomerate dominated, Timiskaming-type sedimentary units*

2sfb Fine Clastic Successor Basin units: *Early (2690-2680 Ma), wacke dominated, Porcupine-type successor basin units*

Metavolanic units

1vi Mafic to intermediate metavolcanics: *Basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

1vf Felsic to intermediate metavolcanics: *Rhyolitic, rhyodacitic, dacitic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

Figure 15: **Map of Cobalt Transect.**

PROGRESS YEAR 3

Geologic mapping was carried out in two main areas just west of Lake Timiskaming (Cobalt and South Lorraine regions) during the 2018 field season (**Figure 16**). Areas were chosen based on lithologies exposed, economic potential, and proximity to geophysical surveys (2D seismic reflection, gravity and magnetotellurics) carried out by Metal Earth in 2017. Particular attention was paid to the deformation history of the region. Aeromagnetic data was also interpreted alongside new geological observations and these results were compiled in ArcGIS software and used to better constrain existing regional maps. Other historical data, including vein orientation and location, were added to the database to aid in interpretations.

Figure 16: **Dr. Shawna Elizabeth White getting her feet wet during early summer field work at Cobalt transect.**

Samples for geochronology, whole rock geochemistry, petrography and structural analysis were collected during the 2018 field season (**Figure 17**). A total of 40 samples (from Archean volcanic basement) were sent to ALS for whole rock geochemistry and results are currently being interpreted. Approximately 80 thin sections were made by Vancouver Petrographics Limited, for petrographic and structural analyses. A total of 5 felsic volcanic and 1 granitic sample from Archean basement were sent to Dr. Michael A. Hamilton at the University of Toronto for TIMS analyses. This work is ongoing, and results are being interpreted as they are obtained. Nine detrital zircon mounts were made (3 Proterozoic Huronian, 3 Archean Timiskaming, 3 Archean interflow sedimentary units) and all mounts have been imaged using, SEM JEOL6400, and U/Pb isotopic ratios were determined using LA-ICPMS with a Neptune Plus High Resolution Multicollector. Results are being used for interpretations regarding both provenance and maximum depositional age of all geologic successions outcropping in the region.

FUTURE WORK

Along with the ongoing work outlined above, a second field season will be carried out from June to August, 2019. Focus is mapping within Archean inliers along the transect that were not mapped in 2018. This added work will complete basement mapping in the region, to define the local Archean volcanic stratigraphy. Detailed structural analyses, in regions where penetrative fabrics are present and well exposed, will be carried out to determin structural history. The structural and stratigraphic framework of the Archean rocks will be compared with Ag-Co arsenide vein orientations to determine if, and how, these features may have controlled vein emplacement. These results will be compiled in a 3D modeling software, along with 2D seismic, magnetotelluric and gravity data to generate a structural model for the local geology in Cobalt.

ANTICIPATED OUTCOMES

Multiple publications and reports will be produced resulting from ongoing work in the Cobalt region. Each peer-reviewed journal paper will address key questions including i) What are the structural and stratigraphic controls on Ag-Co arsenide veins? Are they controlled by Archean basement structures? What role do the major Northwest striking faults

in the region play with respect to fluid migration/vein emplacement?; ii) What is the nature of the Archean basement in Cobalt? Preliminary geochronological and geochemical data suggest possible correlations with volcanic basement in the Pontiac Terrane. Can we define a new (younger) volcanostratigraphic unit within the Abitibi?; iii) What is the provenance of the Huronian Supergroup in Cobalt, Ontario? Is there a provenance shift across the Coleman-Lorrain boundary? If so, what might this tell us about basin evolution?; and iv) What is the provenance of interflow sedimentary units within the Archean volcanic basement succession? Are they locally derived? Are there ages consistent with derivation from local basement sources (determined in the work using TIMS) or more distal sources not present in the embayment? These data might provide information about geology hidden beneath thick sedimentary packages of the Huronian and adjacent Pontiac.

Figure 17: Julian Johnston taking a break from fieldwork on a granitic boulder in the Gowganda Formation of the Cobalt Transect.

MATHESON TRANSECT

Dr. Rasmus Haugaard

Transect lead Dr. Rasmus Haugaard, RA, Metal Earth, MERC, Harquail School of Earth Sciences; and Dr. Michael A. Hamilton, Jack Satterly Laboratory, University of Toronto.

SCOPE OF PROJECT

The purpose of the Matheson transect (**Figure 18**) mapping and research is to gather more information on the timing of formation and mineralization of the extensive metasedimentary and intrusive rocks in the area. More specifically, the work seeks to strengthen the geological knowledge of the stratigraphy in the area, to better interpret the seismic and magnetotelluric surveys being conducted along the transect in the Matheson area. The work along the Metal Earth transect will be image key crustal structures such as the Porcupine–Destor deformation zone and extending the geological architecture of the belt further east. This will contribute to establishing new targets for exploration for gold and base metals.

Project collaborators Ed Van Hees, Ministry of Energy, Northern Development and Mines. Lionel Bonhomme, International Explorers & Prospectors Inc.; Gary O'Connor, Moneta Porcupine Mines Inc.; David Schonfeldt, Kirkland Lake Gold Ltd.; and Steven Scott, and Robin Wolf, Exploration Geologist, McEwen Mining Inc.

PROGRESS YEAR 3

Four weeks of fieldwork was carried out in the Matheson area during the summer of 2018. The work focused on supplementing limited outcrop mapping and sampling with logging and sampling of diamond drill core from the various exploration companies working in the area. The timing of deposition and the provenance of the various metasedimentary

rocks has been undertaken. The age of emplacement of intrusive bodies, including the Bradley Lake syenite and the Carr porphyry, will be determined by U-Pb analysis (using ID-TIMS) on magmatic zircons in the spring-early summer of 2019.

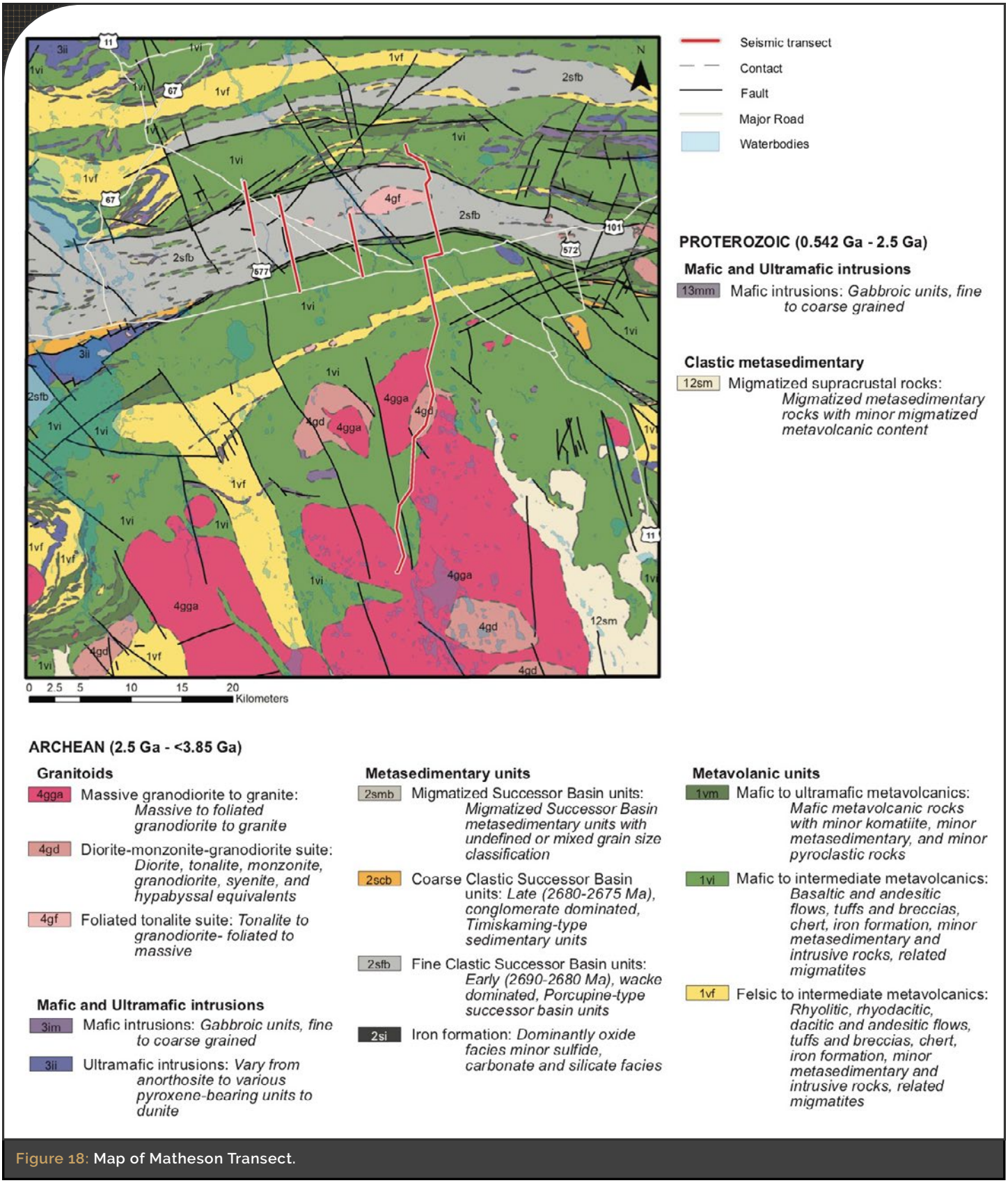


Figure 18: Map of Matheson Transect.

Establishing the timing of intrusions will help establish a minimum age of deposition for the Porcupine metasedimentary basin, and a maximum age of deposition for orogenic gold mineralization. Finally, processed geophysical results along the transect include the seismic R1 and R2 together with gravity. First attempt to integrate the seismic data with the geology along the transect into a working model has been carried out.

Results have been published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. R. Haugaard's research will be completed in the spring of 2020.

FUTURE WORK

The next steps will be:

- Fine-tuning the transect working model by adding new geology and geochronology data from 2018-2019 and by integrating the magnetotelluric data;
- Finalizing the interpretation of geological and geophysical data, at the end of 2019, with the aim of constraining the metallurgical implications of the transect;
- Making detailed comparisons with the discover abitibi seismic lines further west, thereby increasing the knowledge of the architecture in an east-west going direction; and
- Comparing the geochemistry and intrusion ages of key syenites and porphyries from the matheson work with the timing and composition of local sedimentary rocks south-east of the PDDZ.

ANTICIPATED OUTCOMES

Two manuscripts are anticipated for completion, with working titles as follows:

1. The assemblage-scale architecture of the Matheson transect: Tectonic and metallogenic implications, and
2. The timing of late syenite and syn-orogenic clastic sedimentation in the Matheson area.

SWAYZE TRANSECT

Dr. Rasmus Haugaard

Transect lead Dr. Rasmus Haugaard, RA, Metal Earth, MERC, Harquail School of Earth Sciences; and Dr. Michael A. Hamilton, Jack Satterly Laboratory, University of Toronto.

SCOPE OF PROJECT

The key question to solve for the main Swayze project is whether the rocks in the Swayze greenstone belt represent a collage of unrelated metavolcanic fragments or are part of a continuous stratigraphy that can be correlated throughout not only the Swayze area but also the rest of the Abitibi. The Swayze mapping and research project is designed to test this hypothesis, by carrying out more detailed mapping of important lithological contacts in the area and by collecting samples for geochronological analysis, to increase the number of U-Pb ages throughout the area.

Project collaborators Dr. Peter J. MacDonald, Ontario Geological Survey; Alan Smith, and Stephen Roach, IAMGOLD Corp.; Rob Mackie, and Pat Pope, GFG Resources Inc.; and Charlie Mortimer, Independent Prospector.

During the 2018 field season, important work was carried out in the north Swayze area (Figure 19). The extensive sedimentary basin was mapped out and key lithological facies were determined such as conglomerate, sandstone, and mudstone associations. This field work complemented the work done in the south Swayze area during the previous summer. Large uncertainties exist in the depositional ages and the nature of the two metasedimentary successor

Seismic transect
Contact
Fault
Major Road
Waterbodies

PROTEROZOIC (0.542 Ga - 2.5 Ga)

Granitoids

14gd Diorite-monzonite-granodiorite suite: *Diorite, tonalite, monzonite, granodiorite, syenite and hypabyssal equivalents*

ARCHEAN (2.5 Ga - <3.85 Ga)

Granitoids

4gga Massive granodiorite to granite: *Massive to foliated granodiorite to granite*

4gd Diorite-monzonite-granodiorite suite: *Diorite, tonalite, monzonite, granodiorite, syenite, and hypabyssal equivalents*

4gf Foliated tonalite suite: *Tonalite to granodiorite-foliated to massive*

4gta Gneissic tonalite suite: *Tonalite to granodiorite-foliated to gneissic - with minor supracrustal inclusions*

Mafic and Ultramafic intrusions

3im Mafic intrusions: *Gabbroic units, fine to coarse grained*

3ii Ultramafic intrusions: *Vary from anorthosite to various pyroxene-bearing units to dunite*

Metavolanic units

1vm Mafic to ultramafic metavolcanics: *Mafic metavolcanic rocks with minor komatiite, minor metasedimentary, and minor pyroclastic rocks*

1vi Mafic to intermediate metavolcanics: *Basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

1vf Felsic to intermediate metavolcanics: *Rhyolitic, rhyodacitic, dacitic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

Metasedimentary units

2smb Migmatized Successor Basin units: *Migmatized Successor Basin metasedimentary units with undefined or mixed grain size classification*

2scb Coarse Clastic Successor Basin units: *Late (2680-2675 Ma), conglomerate dominated, Timiskaming-type sedimentary units*

2sfb Fine Clastic Successor Basin units: *Early (2690-2680 Ma), wacke dominated, Porcupine-type successor basin units*

2si Iron formation: *Dominantly oxide facies minor sulfide, carbonate and silicate facies*

Figure 19: Map of Swayze Transect.

basins in the Swayze area, the Timiskaming-type conglomerate basin in the south, and the presumably Porcupine-type greywacke-dominated basin in the north. Key sediment, volcanic and plutonic rocks were collected for further petrographical, geochemical and zircon U-Pb work (**Figure 20**). In an attempt to define the specific border between Blake River and Kidd Munro volcanics to the north, a key felsic volcanic unit was sent for U-Pb dating.

The geophysical survey along the transect in 2018 consisted of gravity and magnetotelluric (MT) measurements that complemented the seismic survey obtained in 2017. Fully processed seismic (R1 and R2) profiles, together with the MT profile, are now finished and a working model integrating these geophysical profiles with the geological cross section has been carried out. Results have been published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. R. Haugaard's research will be completed in the spring of 2020.

Figure 20: **L-R: Daniel Meagher and Dr. Rasmus Haugaard view deposits on a banded iron formation outcrop in northern Swayze that are key for finding potential syngenetic mineralisations and for the study of ocean chemistry and atmosphere on early Earth.**

FUTURE WORK

The next steps will be:

- Fine-tuning of the transect working model by adding new geology and geochronology data from 2018-2019, and integrating the gravity data;
- Comparing the metallogeny established for the swayze belt to that of the metal endowed eastern abitibi greenstone belt, to determine assemblage-scale differences and the processes responsible for metal endowment;
- Finalizing a robust model so that the stratigraphy and volcanic architecture of swayze can be improved;
- Evaluating the potential of mineral endowment in swayze; and
- Publication of two manuscripts.

SWAYZE TRANSECT PH.D. TOPIC 1

Thomas Gemmell

Thomas Gemmell, Ph.D. Candidate, Mineral Deposits and Precambrian Geology, Metal Earth, MERC, and Harquail School of Earth Sciences is completing his thesis on *Metavolcanic evolution and differential base metal endowment of the Swayze area, Abitibi greenstone belt, Ontario.* Supervised by Dr. Harold L. Gibson and Dr. Bruno Lafrance.

PROGRESS YEAR 3

Research activities in Year 3 included:

- Integration of 2D R1/R2 seismic data with R1 MT data and surficial mapping resulting in highlighted major structural zones;

- Integration of all Ontario Geological Survey geochemistry into a regional database; and
- Thesis proposal submission.

Next steps will include full integration of all geophysical data; obtaining additional R2 seismic and MT data from Mallard Road and integrating with surficial geology; obtaining gravity information from the transect and integrating with previous compilations; ongoing geochemical characterization of metavolcanic rocks; obtaining more geochronological data to further constrain the regional model of evolution; and working on transect geology paper.

Results of Year 3 progress have been published in a Summary of Fieldwork. A similar paper will be completed in the fall of 2019. T. Gemmell's research will be completed in the spring of 2020.

SWAYZE TRANSECT M.SC. TOPIC 1

Blake Mowbray, M.Sc. Candidate Geology, Metal Earth, MERC, and Harquail School of Earth Sciences is completing his thesis on *Supracrustal stratigraphy of the Jefferson Prospect.* Supervised by Dr. Harold L. Gibson.

Blake Mowbray

PROGRESS YEAR 3

Research activities in Year 3 included:

- ~45 days of field work carried out on the Jefferson Prospect and surrounding area;
- Fall and winter seminar presentation on results from Jefferson prospect mapping with supporting geochemistry, geochronology, isotope work, and alteration found in Archean VMS systems;
- Interpretation and write-up of M.Sc. Results including preparation of a paper on the Jefferson Prospect supracrustal stratigraphy and mineralisation for a peer-reviewed journal;
- Electron micro-probe analysis of garnets obtained, which will help establish relative timing of mineralization; and
- Completion of final maps complete of Jefferson prospect (1:2000).

Results have been published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. B. Mowbray's research will be completed in the spring of 2020.

GERALDTON-ONAMAN TRANSECT

Dr. Zsuzsanna Tóth

Transect lead Dr. Zsuzsanna Tóth, RA, Metal Earth, MERC, Harquail School of Earth Sciences. Supervised by Dr. Harold Gibson and Dr. Bruno Lafrance

SCOPE OF PROJECT

The Geraldton-Onaman transect (**Figure 21**) 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 with ca. 10 Moz Au metal endowment (Mason and White, 1986; G Mining Services, 2016).

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).

Project collaborators Dr. Bruno Lafrance, Dr. Harold L. Gibson, and Dr. Douglas K. Tinkham, Metal Earth, MERC, Harquail School of Earth Sciences; and Dr. Michael A. Hamilton, University of Toronto.

Industry collaborators Paul Dunbar, Argonaut Gold Inc.; John Gartner, Laurion Mineral Exploration Inc.; Cliff Hickman, independent prospector; Mike Koziol, Alto Ventures Ltd.; Myron Nelson, independent prospector; John M. Siriunas, N.W.T. Copper Mines Ltd.; and Andrew Tims, Greenstone Gold Mines Inc.

PROGRESS YEAR 3

The research along Geraldton-Onaman transect began in May 2018 (**Figure 22**) and completed its first field season, led by Dr. Zsuzsanna Tóth, along with Keaton Strongman (**Figure 23**). During the first field season, focus was on the southern half of the transect that covers the Quetico metasedimentary succession, the Beardmore-Geraldton greenstone belt (BGB) as well as the volcanic Elmhirst-Rickaby and Willett assemblages and the sedimentary conglomerate of the Onaman-Tashota greenstone belt (OTGB).

During the 2018 field season, field data was collected in order to characterize the 1) structural evolution of the Quetico subprovince and the OTGB in comparison with the Beardmore-Geraldton belt (BGB), 2) the northern and southern boundaries of the BGB, and 3) the change or increase of metamorphic grade along the transect within the Quetico subprovince. Geochemical samples were collected to characterize the volcanic rocks of the BGB that will be compared to similar volcanic assemblages from the OTGB.

During the past year, all collected samples were processed for one or more analyses including whole rock major and trace element geochemistry, petrography, and U-Pb detrital or igneous zircon geochronology using LA-ICPMS and ID-TIMS respectively.

Results were published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. Z. Tóth's research will be completed in the spring of 2021.

FUTURE WORK

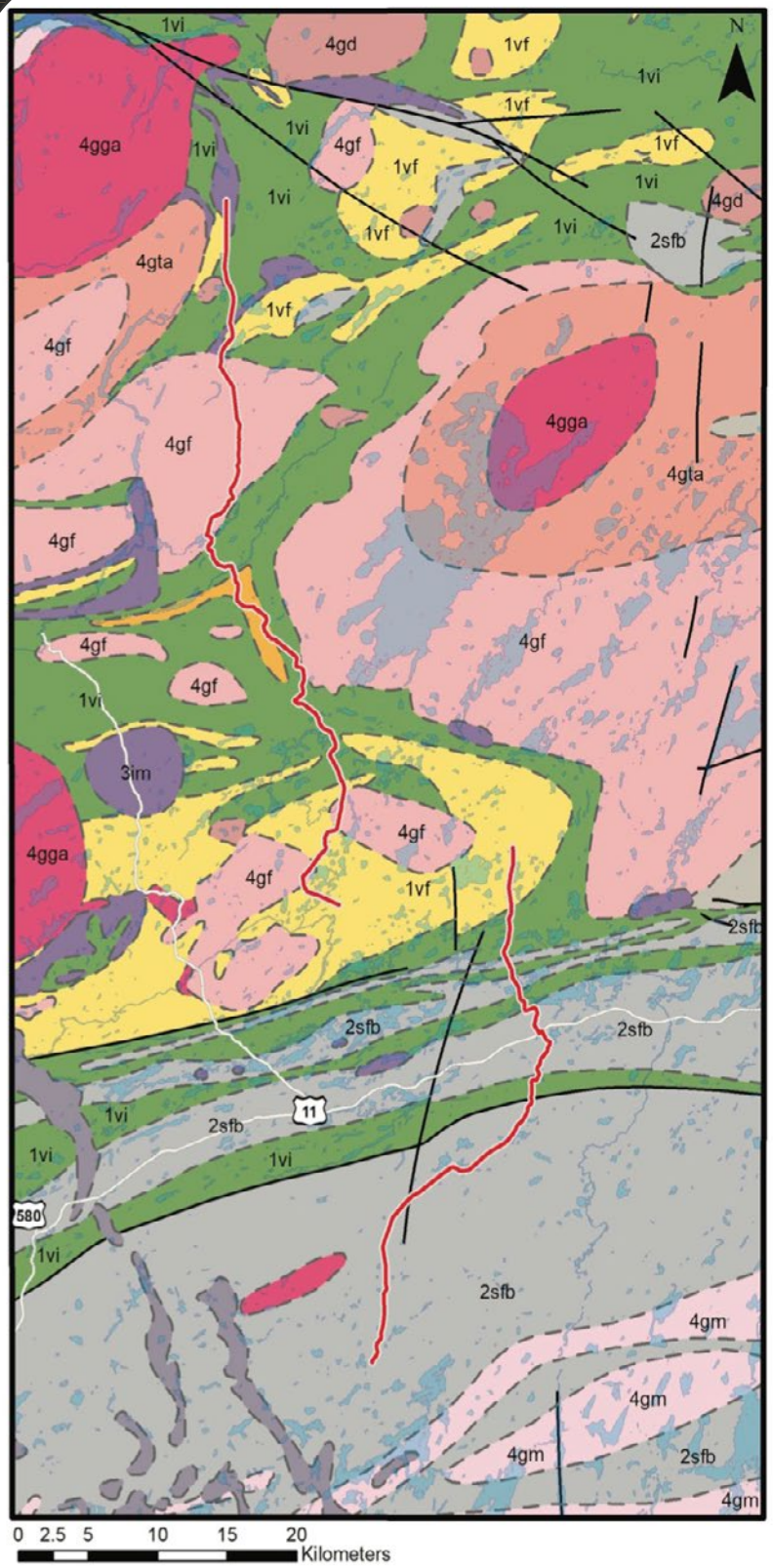
The 3 broad research objectives are to:

1. Characterize the provenance and deposition age of the metasedimentary successions of the eastern Wabigoon and English River subprovince and compare them to those of the metasedimentary rock in the BGB and Quetico subprovince;

2. Describe the structural, petrographic and petrological characteristics and crustal evolution in the eastern Wabigoon and Quetico subprovinces by studying the felsic plutons by whole rock geochemistry, U-Pb geochronology, and trace element, O and Hf-isotope analyses of zircons using LA-ICPMS (done in cooperation with Dr. David Mole, lead researcher on Isotopic Mapping of the Superior Craton project); and

3. Assess the structural evolution of the OTGB.

Additionally, Z. Tóth will collaborate on 2 new M.Sc. projects that will commence in May 2019. These projects will focus on the metamorphic and structural evolution of the OTGB.



Seismic transect
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Fault
Major Road
Waterbodies

PROTEROZOIC (0.542 Ga - 2.5 Ga)

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4gd Diorite-monzonite-granodiorite suite: *Diorite, tonalite, monzonite, granodiorite, syenite, and hypabyssal equivalents*

4gm Muscovite-bearing granitic rocks: *Muscovite-biotite and cordierite-biotite granite, granodiorite-tonalite*

4gf Foliated tonalite suite: *Tonalite to granodiorite-foliated to massive*

4gta Gneissic tonalite suite: *Tonalite to granodiorite-foliated to gneissic - with minor supracrustal inclusions*

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1vf Felsic to intermediate metavolcanics: *Rhyolitic, rhyodacitic, dacitic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

Figure 21: Map of Geraldton-Onaman Transect.

ANTICIPATED OUTCOMES

Z. Tóth will write another Summary of Fieldwork at the end of the 2019 field season. Results of the presented research topics will be presented at national and international conferences and published in peer-reviewed scientific journals. Additionally, a summary of the transect research will be compiled into several journal articles.

Figure 22: L-R: Keaton Strongman, Prof. Bruno Lafrance, Greg Stott, Prof. Harold Gibson, and Anna Haataja on a visit to Marshall Lake area in the northern part of the Onaman-Tashota greenstone belt.

GERALDTON-ONAMAN TRANSECT PH.D. TOPIC 1

Keaton Strongman

Keaton Strongman, Ph.D. Candidate, Mineral Deposits and Precambrian Geology, Metal Earth, MERC, and Harquail School of Earth Sciences is completing his thesis on *Metallogeny, volcanic stratigraphy, and geodynamic evolution of Onaman-Tashota greenstone belt with focus on magmatic-hydrothermal mineralization styles.* Supervised by Dr. Harold L. Gibson and Dr. Bruno Lafrance.

PROGRESS YEAR 3

Keaton has completed the first field season focusing on the Elmhirst-Rickaby, Metcalfe-Venus, Willett and Onaman assemblages. The volcanic stratigraphy of the Elmhirst-Rickaby assemblage was reconstructed and various syn-volcanic mineralization and alteration types from the aforementioned assemblages were described.

Sample processing and analyses for petrography, SEM, whole rock geochemistry, and U-Pb geochronology using ID-TIMS were completed. Preliminary data interpretation is in progress.

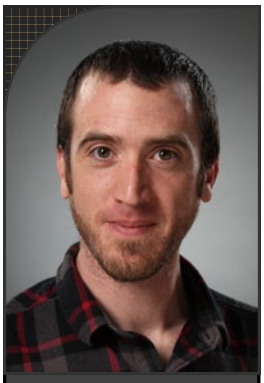
During the 2019 field season, K. Strongman will continue to map, sample and analyse the different volcanic assemblages and mineralization styles of the OTGB in order to reconstruct the Neoarchean volcanic evolution and syn-volcanic hydrothermal processes. Focus will primarily be on the Metcalfe-Venus, Elmhirst-Rickaby and Marshall volcanic assemblages.

Preliminary results from the 2018 field season were published in the Summary of Fieldwork and can be downloaded **HERE**. This Summary of Fieldwork was issued by the Ontario Geological Survey and presented at the Student Mineral Colloquium at PDAC 2019. Additionally, this research will be presented at GAC-MAC in Québec in May 2019.

Summary of Fieldwork papers will be completed at the end of every additional field season and presented at various national and international conferences. Keaton is expected to complete his Ph.D. thesis by April 2022. That will result in the publication of 3 articles in peer-reviewed scientific journals.

Figure 23: L-R: Image of Anna Haataja, Dr. Zsuzsanna Tóth, and Keaton Strongman (taken by drone) at unconformity outcrop along Leopard Lake Road in the Geraldton-Onaman transect. Drones provided a time-efficient method of photographing large outcrops to assist researchers in developing detailed maps of the area.

DRYDEN-STORMY LAKE TRANSECT



Dr. Ben M. Frieman

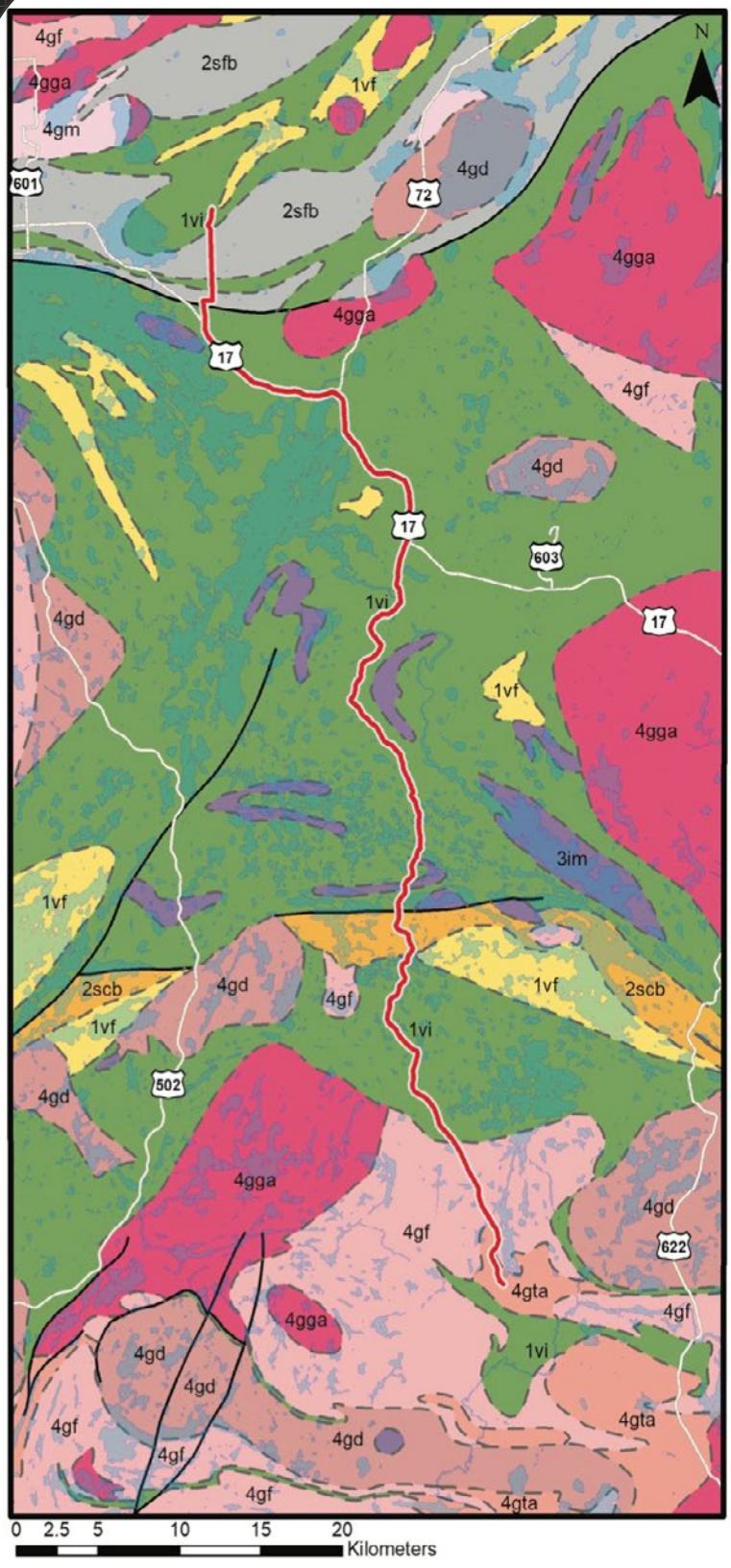
Project team lead by Dr. Ben M. Frieman, RA, Metal Earth, MERC, Harquail School of Earth Sciences and supervised by Dr. Stephane Perrouty.

SCOPE OF PROJECT

The central western Wabigoon subprovince hosts numerous base and precious metal occurrences and prospects but contrasts quite dramatically with the Abitibi subprovince in terms of overall metal endowment. The supracrustal stratigraphy, intrusive history, structural evolution, and metamorphic development are poorly understood compared to the Abitibi. This project aims to investigate and integrate these topics to propose a revised model of Precambrian and metallogenic evolution for the western Wabigoon.

This study is focused on the central portion of the western Wabigoon subprovince, along the Stormy-Dryden transect (**Figure 24**), composed of Neoarchean (ca. 2.75-2.65 Ga) juvenile volcanic, gneissic-plutonic, and clastic sedimentary rocks that are structurally bounded with recycled Paleo- to Mesoarchean crust of the Winnipeg River and Marmion terranes, to the north and south respectively. Despite similarities in rock types, age, and the lithotectonic setting of their formation, greenstone belts in the Superior Province are variably endowed with base and precious metal resources. The heterogeneity of metal endowment among these belts suggests there were processes contributing to mineralization that acted on a regional scale. Fundamental research questions to be investigated in this project include 1) What were these processes?, 2) How did these belts vary at the district- and craton-scales?,

To address these research questions, field work and laboratory analysis seeks to develop a comprehensive synthesis of the western Wabigoon subprovince, in order to develop a new geodynamic model for its formation and to compare to mineralized belts in the Superior Province.



Seismic transect
Contact
Fault
Major Road
Waterbodies

ARCHEAN (2.5 Ga - <3.85 Ga)

Granitoids

4gga Massive granodiorite to granite: *Massive to foliated granodiorite to granite*

4gd Diorite-monzonite-granodiorite suite: *Diorite, tonalite, monzonite, granodiorite, syenite, and hypabyssal equivalents*

4gm Muscovite-bearing granitic rocks: *Muscovite-biotite and cordierite-biotite granite, granodiorite-tonalite*

4gf Foliated tonalite suite: *Tonalite to granodiorite-foliated to massive*

4gta Gneissic tonalite suite: *Tonalite to granodiorite-foliated to gneissic - with minor supracrustal inclusions*

Mafic and Ultramafic intrusions

3im Mafic intrusions: *Gabbroic units, fine to coarse grained*

Metasedimentary units

2scb Coarse Clastic Successor Basin units: *Late (2680-2675 Ma), conglomerate dominated, Timiskaming-type sedimentary units*

2sfb Fine Clastic Successor Basin units: *Early (2690-2680 Ma), wacke dominated, Porcupine-type successor basin units*

2si Iron formation: *Dominantly oxide facies minor sulfide, carbonate and silicate facies*

Metavolanic units

1vi Mafic to intermediate metavolcanics: *Basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

1vf Felsic to intermediate metavolcanics: *Rhyolitic, rhyodacitic, dacitic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

Figure 24: Map of Dryden-Stormy Lake Transect.

PROGRESS YEAR 3

Investigations in the Dryden-Stormy Lake transect area began in Year 3 of the Metal Earth research initiative. As a result, initial fieldwork in the study area occurred during the summer of 2018 (**Figure 25**), identifying 3 primary knowledge gaps in the study area 1) How does the overall stratigraphic progression in the western Wabigoon subprovince compare to other regions of the Superior Province (e.g., the Abitibi subprovince)?, 2) What is the relationship of Neoarchean greenstone belt successions to proximal Mesoarchean crustal fragments (i.e., the Marmion terrane)?, and 3) What can the detrital zircon patterns recorded in successor basin deposits tell us about the geodynamic setting of regional amalgamation?

Figure 25: **Dryden-Stormy Lake transect crew enjoying exceptional exposure of volcaniclastic rocks within the Stormy Lake basin during a field visit with Kenora district geologists of the Ontario Geological Survey (OGS). L-R: Katharina Holt, Austin Goncalves, David David Downie, Craig Ravnaas (OGS), Shadow (dog), Dr. Stéphane Perrouty, and Kristen Weibe.**

To address these research goals, initial mapping focused on 3 portions of the study area. To address the first knowledge gap, mapping of the stratigraphic facing and the location of high-strain corridors was conducted along Snake Bay Road, coincident with where the geophysical surveys (seismic and magnetotellurics) were conducted by Metal Earth. To address the second knowledge gap, mapping and sample collection was conducted along the southern margin of the western Wabigoon subprovince where greenstone successions of the belt are in contact with gneissic-plutonic rocks of the Marmion terrane. To address the third knowledge gap, mapping and sample collection was conducted in the central portion of the study area where metasedimentary and metavolcanic rocks of the Stormy basin are well exposed.

Project collaborators Dr. Stéphane Perrouty, Dr. C. Michael Lesher, and Dr. Jeffrey H. Marsh, Metal Earth, MERC, Harquail School of Earth Sciences; Dr. Audrey Bouvier, Universität Bayreuth, Germany; Dr. Michael A. Hamilton, University of Toronto; and Craig Ravnaas, Resident Geologist, Ontario Geological Survey.

FUTURE WORK

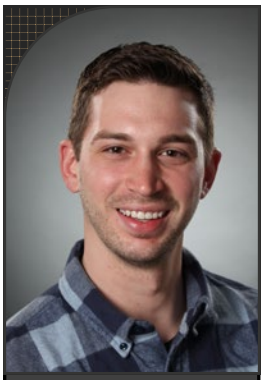
Samples collected during the summer of 2018 were processed through a variety of analytical techniques including whole rock lithogeochemical analysis, detrital and igneous zircon investigations by laser ablation – inductively coupled plasma – mass spectrometry (LA-ICPMS) analysis, and high resolution U-Pb isotopic age dating of the primary age of volcanic assemblage rocks by isotope dilution – thermal ionization mass spectrometry (ID-TIMS). The whole rock lithogeochemical analyses have been conducted and interrogation of these results is ongoing. Sample preparation (rock crushing, mineral separation, picking, and mounting) for isotopic analysis of zircon grains by LA-ICPMS analysis has been completed and analysis of these samples is scheduled in May/June 2019.

ANTICIPATED OUTCOMES

The research conducted by B. M. Frieman in the Dryden-Stormy Lake transect is expected to have several major outcomes including but not limited to the following:

1. New stratigraphic framework for the western Wabigoon subprovince study area based on new and compiled mapping, geochronological, and geochemical results;
2. Interpreted cross section for the study region that incorporates surficial observations, seismic results, and magnetotelluric models, providing a broad, crustal perspective on the defining characteristics of the study region;
3. New constraints on the nature (structural? conformable?, etc.) Of the contact between older, Mesoarchean crustal fragments (the Marmion terrane) and younger, Neoarchean greenstone belts (the western Wabigoon subprovince); and
4. Constraints on regional amalgamations from the detrital zircon age patterns of successor basin deposits.

DRYDEN-STORMY LAKE TRANSECT M.SC. TOPIC 1



David Downie

David Downie, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Characteristics of and structural setting for intrusion-related gold occurrences in the western Wabigoon subprovince.* Supervised by Dr. Ben M. Frieman, Dr. Stéphane Perrouty, and Dr. Douglas K. Tinkham.

PROGRESS YEAR 3

Preliminary fieldwork was conducted during the summer of 2018 (**Figure 26**). This work included identification of the primary areas of focus and initial sample collection for geochemical and geochronological investigations. Preliminary mapping was conducted at 1:2000 to 1:100 scale in several areas of interest. Samples suites were processed for whole rock lithogeochemical and thin section analysis. Preliminary microscopy, optical and SEM, has been completed and further synthesis is ongoing.

Results from this study will be used to construct an interpretive model for the temporal and structural setting of an intrusion-related gold occurrence in the Dryden area. This model will be compared to the better studied and economically significant deposits of the Abitibi in order to identify potential controlling factors that contribute to variable metal endowment of similar systems, in the Archean greenstone belts of the Superior Province, and worldwide.

Results were published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. D. Downie's thesis will be completed in the spring of 2020.

DRYDEN-STORMY LAKE TRANSECT M.SC. TOPIC 2

Kendra Zammit, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *Deformation history and metallogenic potential of regional-scale deformation zones in the western Wabigoon subprovince.* Supervised by Dr. Stéphane Perrouty, Dr. Ben M. Frieman, and Dr. Bruno Lafrance.

Kendra Zammit

PROGRESS YEAR 3

Project goals include investigating the structural history and potential for orogenic gold for three individual deformation zones: the Wabigoon, Manitou-Dinorwic, and Mosher Bay-Washeibemaga deformation zones. Initial fieldwork associated with this project was conducted during the summer of 2018.

Further mapping will be conducted during the summer of 2019 with a primary focus on the Manitou-Dinorwic and Mosher Bay-Washeibemaga deformation zones and crosscutting relationships between them. This will result in the production of several new structural maps for the study region. In order to constrain the absolute timing of deformation along each of the major regional structural zones, isotopic dating of fabric forming minerals such as titanite or rutile will be conducted by LA-ICPMS at Laurentian University.

Results were published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. K. Zammit's thesis will be completed in the spring of 2020.

Figure 26: **Several members of the Dryden-Stormy Lake transect field crew (in foreground) attempting to keep up with 85-year-old prospector, Alex Glatz (in background) while investigating exposures along a logging road.**

DRYDEN-STORMY LAKE TRANSECT ADDITIONAL PROJECT

Katharina Holt, Queen's University, is completing her thesis on *Kinematic analysis of the Manitou-Dinorwic deformation zone and its implications for mineral exploration in the western Wabigoon subprovince.* Supervised by Dr. Laurent Godin, Queen's University and Dr. Stéphane Perrouty.

GEOPHYSICS PROJECTS

SEISMIC R1 AND R2 PROCESSING AND INTERPRETATION

Dr. Mostafa Naghizadeh

The seismic subproject of Metal Earth is led by Dr. Saeid Cheraghi, RA; and Dr. Mostafa Naghizadeh, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

Processing and interpretation of Metal Earth seismic wave reflection (R1 and R2) data (Figure 27) by integrating other geophysical and geological data from the Metal Earth project, as well as previously acquired geophysical data from regional scale projects conducted in the Superior province including Lithoprobe (1990) and Discover Abitibi (2005).

Academic collaborators include Dr. David B. Snyder, Geological Survey of Canada; and Dr. Gerhard Pratt, Western University.

PROGRESS YEAR 3

The initial processing of all 29 Metal Earth R1 and R2 seismic transects was completed and the final seismic sections were plotted and distributed to the research associates working on the specific transect. More than 60 Lithoprobe seismic sections were downloaded from the Natural Resources Canada (NRCan) website. Their UTM coordinates were refined and seismic reflections were enhanced using Dip Coherency Filters and Hilbert Envelope for interpretation purposes. The 3D magnetotelluric resistivity models for Western Superior and Abitibi was downloaded from NRCan and the electrical resistivity sections along Metal Earth and Lithoprobe seismic sections were extracted.

Analyzing seismic reflectivity combined with electrical resistivity reduces the uncertainty of interpretations. Researchers continued developing high resolution seismic imaging algorithms such as multi-focusing imaging and cross-dip correction of crooked seismic surveys.

Figure 27: Metal Earth seismic group planting passive seismic receivers in Larder Lake, Ontario. L-R: Christopher Mancuso, Dr. Saeid Cheraghi, and Hossein Jodeiri Akbari Fam.

FUTURE WORK

In the coming year, this project will apply high resolution seismic data processing algorithms on select Metal Earth seismic lines. A framework will be established for an integrated interpretation of Metal Earth seismic data using other geophysical methods such as magnetotellurics, gravity, and magnetic. It is anticipated that the learning from Metal Earth and Lithoprobe transects will be consistent. Therefore, researchers will be able to draw a comprehensive conclusion on the crustal structure of the Superior province.

The project aims to generate a 3D model of crust for the

Superior province using all available seismic data (Metal Earth, Lithoprobe, Discover Abitibi). Additionally, this 3D model will utilize other geophysical models such as electrical resistivity, density, susceptibility, and P-wave and S (seismic) wave velocities from global seismology studies. High resolution seismic data processing methods will be applied to Metal Earth data to enhance the near-surface image in order to make a better connection between surface geology and subsurface images.

SEISMIC R2 PROCESSING

Dr. Saeid Cheraghi

Lead researcher Dr. Saeid Cheraghi, RA; and Dr. Mostafa Naghizadeh, Metal Earth, MERC, Harquail School of Earth Sciences.

PROGRESS YEAR 3

During the first year of the project, two R2 seismic profiles along Swayze transect and one profile along Larder Lake transect were processed with a flow that includes pre-stack dip moveout (DMO) corrections and post-stack migration. Due to the crooked geometry of the acquired seismic data, seismic data have also been processed as a 3D swath survey.

In future, R2 profiles will be processed with 2D and 3D pre-stack time migration (PSTM) algorithms and compare results with post-stack migrated images. Improving the velocity model in shallower depths (less than 3 km) will be considered to better tie seismic images with surface geology.

SEISMIC PH.D. TOPIC 1

Hossein Jodeiri Akbari Fam

Hossein Jodeiri Akbari Fam, Ph.D. Candidate Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Least-squares multi-focusing seismic imaging of complex geological structures.* Supervised by Dr. Mostafa Naghizadeh.

PROGRESS YEAR 3

In the first year of this Metal Earth geophysics project, passive seismic data was acquired in Larder Lake, ON. This formed the framework of the thesis. A literature review was conducted, followed by coding for a basic application of Multi-Focusing (MF) imaging on seismic data.

A joint inversion algorithm was developed to draw on information from gravity and magnetic data and geological studies for the seismic interpretation and inversion. For practical implementation of 3D cross-gradients joint inversion framework for gravity and magnetic data and conventional separate inversions, additional algorithms were coded in the MATLAB (software) environment and applied on synthetic data.

Development of an MF algorithm aims to generate high resolution seismic images that will have a significant impact on the ability to interpret near-surface and deep geological structures. The first version of MF stacking code has been

developed in MATLAB. The potential of using a metaheuristic global optimization very fast simulated annealing (VFSA) method to optimize the estimation of MF parameters will be investigated.

The results of applying MF on synthetic data show that this proposed method improves the quality of time imaging and alignment of reflection events compared to the conventional common mid-point (CMP) processing. The next step is to adapt and run the MF code using a large-core graphics processing unit (GPU) card. Further tests of the proposed algorithm on more complex synthetic and real data examples are underway.

SEISMIC M.SC. TOPIC 1

Christopher Mancuso

Christopher Mancuso, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *An analysis of seismic information from crooked line acquisitions.* Supervised by Dr. Mostafa Naghizadeh.

PROGRESS YEAR 3

Year 3 of Metal Earth was the initial year of this seismic subproject. Scope of data mining methods includes geological, geophysical (**Figure 27**), statistical and computer science research. A literature review was conducted to build from previous discoveries and fuse research to create novel work. Geophysical data analysis included the discrete inverse theory to transform digitized datasets to a model using physics. Repetitive, scalar modeling was performed for the generation of synthetic data to experiment with different processing methods before trying the various options on real data.

For numerical computing, an environment was created to do parallel computing via a graphics processing unit using the Nvidia *CUDA* language. This was applied to approximate non-linear non-convex problems in a similar fashion to inverse problems, but, with a greater tolerance for variation / noise in datasets. CPU based parallel programming was implemented in Python to perform trigonometric based time corrections to seismic data over cross dipping geology. Additionally, serial programming scripts were implemented for optimization problems using the *Julia* programming language which executes code quickly and with good readability. This led to creation of the first, and so far only, gravity inversion along a Metal Earth transect (Chibougamou). Programming languages were plotted to write equations, display data in 3D, and communicate findings and display geographical information such as maps and cross sections.

SEISMIC M.SC. TOPIC 2

Elton Mpongo

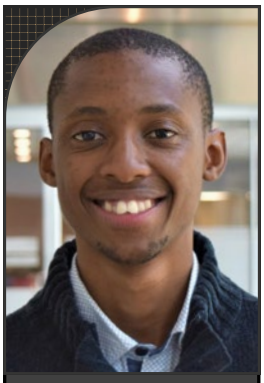
Elton Mpongo, M.Sc. Candidate Metal Earth, MERC, Harquail School of Earth Sciences is completing his M.Sc. on *Seismic interpretation of the Metal Earth's Larder Lake transect.* Supervised by Dr. Mostafa Naghizadeh.

PROGRESS YEAR 3

The objective of this project is to outline the tectonic setting area covered by the transect and provide detailed information on how the geology in the area is projected on the seismic data. A literature review was undertaken to understand the tectonic setting of the area, which is crucial to seismic interpretation. Geophysical inversion methods were studied for future application on preliminary interpretation. This includes application of cross-dip correction in a crooked seismic survey.

Future research activities will seek to determine i) the most effective ways for seismic data acquired on a crooked survey to be projected on 2D transects, and ii) what kind of artifacts might leak into the final seismic stack.

SEISMIC M.SC. TOPIC 3


T. Robert Rapolai

T. Robert Rapolai, M.Sc. Candidate Metal Earth, MERC, Harquail School of Earth Sciences is completing his M.Sc. on *Seismic interpretation of the Metal Earth's Rouyn-Noranda transect, Québec.* Supervised by Dr. Mostafa Naghizadeh.

PROGRESS YEAR 3

Year 3 of Metal Earth was Year 1 of this project, which began with a background study on the geology (tectonics, general geology) and geophysical work (mainly the Lithoprobe transect line 21) on the area. Open-source cross-platform geographic information system software was used for geological maps and open-source seismic interpretation system software was used to view and interpret the sections being studied.

Future research activities will focus on applying seismic attributes to seismic data in order to enhance features of the data for a better understanding of this transect.

GRAVITY AND MAGNETICS


Dr. Richard Smith


Dr. Esmaeil Eshaghi

Project leads Dr. Richard Smith, and Dr. Esmaeil Eshaghi, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

The purpose of the geophysical work involving non-seismic / magnetotellurics methods is to collect and compile geophysical and petrophysical data along, and around, the Metal Earth traverses. Questions being addressed are:

1. Can a petrophysical section of the Metal Earth traverses, that is consistent with the known geology (surface mapping and any drill holes) and the geophysical data including the seismic data, be built?
2. If this section can be built, does it provide indicators about the crustal structures and how they extend to the Earth's mantle?
3. Do these structures reveal a potential source of metals to endow mineral deposits in critical areas of the traverses?

The geophysical data includes magnetic data, available from the Ontario Geological Survey (OGS), Ministry of Natural Resources, Ministry of Energy and Natural Resources (MERN), Québec, the Geological Survey of Canada (GSC) and specific industry partners. The gravity data will be collected by the project and incorporated with regional data available from the GSC.

The magnetic susceptibility data will be collected at each outcrop by the transect mapping teams. In order to provide robust statistics, 10 measurements will be taken on each major lithology evident on each outcrop, provided the lithology

present is large enough to allow 10 distinct measurements. The 10 measurements provide insight into how variable the susceptibility is spatially within the lithology. For example, a gneiss is expected to have considerable variation.

The physical properties data includes magnetic susceptibility and density data from surface exposures. These data will be collected by the Metal Earth geophysical and geological mapping teams and compiled data will come from other sources including the OGS, the GSC, the Minnesota Geological Survey (MGS), and the Footprints (NSERC-CMIC project) databases.

Collaborators Dr. David B. Snyder, Geological Survey of Canada; Dr. Lucie Mathieu and Dr. Pierre Bedeaux, UQAC; and Dr. Pierrick Altwegg, Solexperts AG, Switzerland.

PROGRESS YEAR 3

During Year 3, gravity data collection covered the Sudbury, Cobalt, Larder Lake, Swayze, Matheson, Stormy-Dryden and Geraldton-Onaman transects. Survey methodology was published in a Summary of Fieldwork which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019.

A compilation of the density and magnetic susceptibility data was completed and has been submitted for consideration by the journal *Geophysics*. A conference presentation in this topic has also be submitted to the Australian Exploration Geoscience Conference, Sept 2019.

FUTURE WORK

In the summer of 2019, Year 4 data collection will cover the 3 remaining transects: Rainy River, Atikokan, and Sturgeon. The density data will be acquired by collecting samples and measuring the density using Archimedes method (by measuring in air and then submerged in water). The samples collected by the geophysics crew in the field will be whole rock samples, but those collected by the geological mapping crews and sent to the assay lab for whole rock lithogeochemistry analyses will be pulp samples.

The gravity data are being collected along the same traverses as the seismic data. The data are being collected at 300 m station spacing, which will allow structures larger and deeper than 100 m to be modelled. If the gravity data is observed to change very rapidly, there might be a smaller structure between stations, and the acquisition plan is to collect in-fill data at 150 m station spacing, to define the geometry (location, dip and depth) of the structures more accurately. When the profiles curve, it is helpful to have some data off traverse so that a straight profile can be interpolated. If there is no GSC data available off the traverses, then data will be collected in the corners of the obtuse angles, time permitting.

Gravity data collected along a traverse is difficult to fit with 2.5D models to greater accuracy than 0.5 milligals, so researchers are aiming for accuracy on the gravity data of approximately 0.1 milligals. This requires knowing the station elevation to approximately one-third of a meter, using a differential Trimble GPS system.

The anticipated outcomes are sections showing the density, magnetic susceptibility and conductivity variations as a function of depth, with any structures that are inferred from the data. The sections will be consistent with the physical properties measurements, the geophysical data and the known geology. In some cases, where there is sufficient geophysical data away from the traverses, these sections can be extended to 3D models.

GEOPHYSICS M.SC. TOPIC 1


Amir Maleki

Amir Maleki, M.Sc. Candidate Geophysics, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Gravity data acquisition and potential-field data modelling along Metal Earth's Chibougamau transect using geophysical and geological constraints.* Supervised by Dr. Richard Smith, Metal Earth, MERC, Harquail School of Earth Sciences.

PROGRESS YEAR 3

Thesis research included 1) gravity data acquisition along seven Metal Earth transects, 2) incorporating acquired gravity data from the Chibougamau transect with regional gravity data, 3) combining gravity data with available magnetic data from the Québec Government / Geological Survey of Canada (GSC), and 4) creating geologically constrained 2.5D integrated models along the Chibougamau transect.

It is anticipated that the models generated will be useful in resolving the geometry of features which do not appear in seismic sections, and in helping geoscientists gain valuable information about geological features and formation in depth.

GEOPHYSICS M.SC. TOPIC 2


William McNeice

William McNeice, M.Sc. Candidate Geophysics, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Comparing magnetic susceptibilities derived from aeromagnetic data and outcrop scale measurements in the western Abitibi greenstone belt.* Supervised by Dr. Richard Smith.

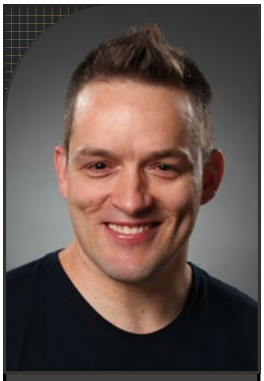
PROGRESS YEAR 3

Thesis research included 1) Acquiring gravity data along seven Metal Earth transects, 2) Investigating the relationship between outcrop magnetic susceptibility measurements and aeromagnetic data, 3) creating synthetic models to help support findings for simpler cases, and 4) creating instruction videos for Metal Earth training week to teach future field teams how to collect magnetic susceptibility data.

It is anticipated that the Ontario Geological Survey and Metal Earth will collect thousands of measurements of magnetic susceptibility each year using KT-10 devices. It is important to understand what the data can be used for, and its limitations. The outcome of this project's research is a better understanding of how useful this data is when applied to forward modelling, and through extension, constraining inversions of aeromagnetic data.

GEOPHYSICS M.SC. TOPIC 3

Fabiano Della Justina, M.Sc. Candidate Geophysics, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Potential-field data modelling along Metal Earth's Matheson transect using geophysical and geological constraints.* Supervised by Dr. Richard Smith.



Fabiano Della Justina

PROGRESS YEAR 3

Project research included 1) gravity data acquisition (**Figure 28**) along seven Metal Earth transects, 2) data reduction and uncertainty analysis of the gravity data from the Matheson transect, 3) incorporating the acquired gravity data along the Matheson transect within regional gravity data, 4) combining gravity data with available magnetic data from the Ontario Geological Survey (OGS) / the Geological Survey of Canada (GSC).

Next steps in this research include 1) gravity data acquisition along three remaining Metal Earth transects, and 2) creation of geological constrained 2.5D integrated models along the Matheson transect.

Figure 28: **Fabiano Della Justina acquiring gravity data using a Scintrex CG-6 gravity meter and Trimble R2 GPS receiver.**

MAGNETOTELLURICS

Project leads Dr. Richard Smith, and Dr. Graham James Hill, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

The purpose of the geophysical work involving non-seismic / magnetotelluric methods is to collect and compile geophysical and petrophysical data along, and around, the Metal Earth traverses. Questions being addressed are:

1. Can a petrophysical section of the Metal Earth traverses, that is consistent with the known geology (surface mapping and any drill holes) and the geophysical data including the seismic data, be built?
2. If this section can be built, does it provide indicators about the crustal structures and how they extend to the Earth's mantle?
3. Do these structures reveal a potential source of metals to endow mineral deposits in critical areas of the traverses?

Collaborators Dr. David B. Snyder and Dr. James A. Craven, Geological Survey of Canada; Dr. Philip E. Wannamaker, University of Utah; and Dr. Mostafa Naghizadeh, and Dr. Saeid Cheraghi, Metal Earth, MERC, Harquail School of Earth Sciences.

PROGRESS YEAR 3

The magnetotelluric (MT) survey measured the conductivity of the rock mass. Data was collected in the summer and fall of 2018. There were some difficulties at start up, due to weather and low signal levels, but all traverses were completed with data quality judged to be good. The data was found to be more complicated than data being comprised of simple 2D structures, therefore, it was decided that 3D inversion would be used. This was confirmed when a 2D inversion undertaken for the Larder Lake profile was judged to make less geological sense than a 3D inversion. As of April 2019, the Swayze, Dryden- Atikokan, and Larder Lake profiles have been inverted using 3D methods.

Survey methodology was published in a Summary of Fieldwork which can be downloaded **HERE**.

FUTURE WORK

The magnetotellurics data for the remaining traverse will be processed in 2019. The challenges to be addressed include how to deal with integrating or merging the high resolution audio-magnetotelluric data and the broadband data. The anticipated outcomes are sections showing the conductivity variations as a function of depth and distance. The sections will be interpreted in a manner consistent with the other geophysical data (gravity, magnetics and seismic) and the known geology.

GEOPHYSICAL PH.D. TOPIC 1

Eric Roots

Eric Roots, Ph.D. Candidate Geophysics, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Magnetotelluric data processing and inversion along Metal Earth's transects.* Supervised by Dr. Richard Smith and Dr. Graham James Hill.

PROGRESS YEAR 3

Thesis research included 1) QA/QC of magnetotelluric (MT) data collected throughout the summer of 2018; 2) analysis and inversion of MT data along several Metal Earth transects; 3) collaboration with supervisors and transect geologists to interpret the preliminary MT models; 4) knowledge dissemination through oral presentations at several conferences and non-conference proceedings; 5) initial development of workflow needed to generate models consistent with MT data collected at regional, transect, and local scale; and 6) development and maintenance of codes necessary for the analysis and visualization of MT data and models.

Next steps in this research include 1) complete the inversions for Swayze, Dryden-Atikokan, and Malartic transects, by beginning of fall 2019 semester; 2) knowledge dissemination through a paper written on the inversion and interpretation of the Dryden-Atikokan transect, by end of winter 2020 semester; and 3) begin process of inverting western Superior MT data to generate mutually consistent regional, transect, and local scale MT models, with inversions completed during summer 2020.

It is anticipated that the models generated will be useful to resolve the geometry of some vertical features which do not appear in seismic sections. These could be indicative of fluid flow pathways which could be pathways for metals from the mantle or deep crust. The models provide useful constraints on the composition of the crust and upper mantle.

THEMATIC RESEARCH PROJECTS

Following a call for proposals in January 2018, Metal Earth initiated a review process of proposals. A subset of the MERC advisory board, independent of Metal Earth, assessed each of the submissions for scientific merit of proposal, excellence of researchers, and fit with the goals of Metal Earth. As a result, 6 new thematic projects were funded. The 5 projects that began research activities in Year 2 are presented below. Information regarding the 6th (upcoming) project is described in the **Future Work** section of this annual report.

FACTORS CONTRIBUTING TO METAL ENDOWMENT

Dr. Stéphane Perrouty

Lead researcher, Dr. Stéphane Perrouty, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

This project will investigate factors controlling gold mineralization in greenstone belts and develop improved methods for greenfield mineral exploration.

Academic collaborators Dr. Ross L. Sherlock, Metal Earth, MERC, Harquail School of Earth Sciences; Dr. Mark Lindsay, and Dr Mark Jessell, University of Western Australia; Eric de Kemp, Geological Survey of Canada; Dr. William Morris, McMaster University; and Dr. Hernan Ugalde, Brock University.

PROGRESS YEAR 3

During the first year of this thematic project, open source geological and geospatial data for the western Wabigoon subprovince (WWS) were compiled, a new geological map near Dryden was interpreted, and machine learning inputs were extracted from structural and lithological data. Additionally, one season of fieldwork was completed in the WWS near Metal Earth's Dryden geophysical transect to better understand geological context and improve field skills of the Ph.D. student.

FUTURE WORK

Future work will include compiling open source data for the Kirkland Lake area, continuing fieldwork near Dryden, ON, continuing feature extraction from geospatial and geological datasets for prospectivity modelling, constructing 3D geological models of the Dryden and Kirkland Lake areas, integrating extracted features and observed datasets using knowledge based and data driven mineral prospectivity modelling methods, and implementing uncertainty calculation in prospectivity analysis.

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 increase efficiency in delineating areas of interest in underexplored regions. Deliverables associated with this work include four 3D geological models, fuzzy logic prospectivity maps for each study area, data driven prospectivity maps (one for each study area), a comparison of the western Wabigoon and the Abitibi at the scale of mineral systems, and one Ph.D. thesis.

FACTORS CONTRIBUTING TO METAL ENDOWMENT PH.D. TOPIC 1

Rebecca Montsion

Rebecca Montsion, Ph.D. Candidate Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis on *Factors contributing to metal endowment in the western Wabigoon and Abitibi subprovinces: a mineral prospectivity modelling approach for Precambrian greenstone belts*. Supervised by Dr. Stéphane Perrouty and Dr. Ross L. Sherlock.

PROGRESS YEAR 3

Work completed during the first year of this Ph.D. project includes compilation of open source geological and geospatial data for the western Wabigoon subprovince (WWS), interpreting a new geological map near Dryden, extracting machine learning inputs from structural and lithological data, and conducting a literature review of ore deposit models and geological context for the western Wabigoon and southern Abitibi subprovinces. Additionally, one season of fieldwork (**Figure 29**) was completed in the WWS near Metal Earth's Dryden geophysical transect to better understand geological context and improve field skills.

Results from last year's fieldwork were published in a Summary of Fieldwork paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019. R. Montsion's thesis will be completed in the spring of 2022.

FUTURE WORK

Upcoming research activities will include:

- Compilation of open source data for the Kirkland Lake area;
- 3 more seasons of fieldwork conducted near Dryden and Kirkland Lake, ON;
- Continued feature extraction from geospatial and geological datasets for prospectivity modelling;
- High resolution 3D geological models of the Dryden and Kirkland Lake areas; and
- Knowledge based and data driven prospectivity techniques applied to both study areas.

Figure 29: **L-R: Rebecca Montsion, David Downie, and Dr. Stéphane Perrouty using a drone to capture detailed aerial images to aid in regional mapping of the Lost Lake area, as part of R. Montsion's research project.**

FACTORS CONTRIBUTING TO METAL ENDOWMENT ADDITIONAL PROJECT

Brandon Smith, Metal Earth, MERC, Harquail School of Earth Sciences completing his H.B.Sc. thesis on *3D architecture of the western Wabigoon subprovince: implications for orogenic gold prospectivity.* Supervised by Dr. Stéphane Perrouty and Rebecca Montsion.

LOCALIZATION OF NI-CU-(PGE) MINERALIZATION


Dylan J. McKevitt

Dylan J. McKevitt, Ph.D. Candidate, Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Localization of Ni-Cu-(PGE) mineralization in an early Proterozoic trans-crustal dike-sill-lava channel system, Cape Smith Belt, Nunavik.* Supervised by Dr. C. Michael Lesher, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

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).

Collaborators Dr. Michel Houlé and Dr. Wouter Bleeker, Geological Survey of Canada; Jean-François Baillargeon, François Gagnon and Adam White, Glencore Canada Corp.; and Michel Cormier, Yueshi Lei and Maxim Boisvert, Canadian Royalties Inc.

PROGRESS YEAR 3

During the first year of this project, the July to August 2018 field season included:

- Collection of 181 surface samples from the 337 localities visited (**Figure 30**);
- Sample preparation of the 181 surface samples resulting in 135 polish thin sections, and whole rock chemistry analysis (major and ± elements) of 166;
- Petrographic descriptions, sample scans, and geochemical interpretation of samples collected during the July to August 2017 field season;
- Compilation and geochemical data reviewed (QA/QC) and interpreted; and
- Regional whole rock geochemical data analysis (major ± trace elements for >9600 samples) and regional mineral chemistry (~700 records).

Results from fieldwork were published in a Summary of Fieldwork paper which can be downloaded **HERE**. A total of 5 abstracts were prepared by D.J. McKevitt, C.M. Lesher and M. Houlé for conference presentations and 3 papers were submitted to refereed journals (see Publications).

FUTURE WORK

Year 2 of this thematic research project will include:

Figure 30: Dylan J. McKevitt traversing a field of felsenmeer (frost-heaved boulders) comprising olivine pyroxenite (in background) of a poorly-differentiated ultramafic dike.

- Digital scanning of hand samples and polished thin sections, petrographic descriptions, QA/QC and interpretation of geochemistry, EMPA-SEM and LA-ICPMS mineral analyses, and continuing compilation of regional geochemical data;
- Mapping and sampling on Raglan Mine property including Northern and Southern Permits, and Expo-Ungava areas on Canadian Royalties Inc. Property. Further detailed mapping in the Expo-Ungava area (Vaillant Lake, Méquillon Lake, Expo Lake,) to constrain the geometry of these ultramafic/mafic bodies in relation to their hosting country rocks;
- In fall 2019 and winter-spring 2020, the focus will be on sample preparation, continued petrography and geochemical analyses and interpretation of results obtained to date, and preparation of journal manuscripts #1 and #2; and
- In summer-fall 2020 and winter-spring 2021, planned research activities include fluid dynamic modelling of sulfide deposition and preparation of journal manuscript #3.

A primary outcome of this project will be improved understanding of the architecture and geochemical-temporal-spatial evolution of this mineralized magmatic plumbing system, as well as where, how and why Ni-Cu-(PGE) mineralization is located in the system. Of interest to industry and exploration will be improved targeting of sulfide mineralization within less studied parts of the system, and prospectivity of regions located to the west (ie., West Raglan) and east of the main study area. These findings will be applicable to greenstone belts within the Superior Province, and Archean greenstone belts and Proterozoic volcanic belts worldwide.

MINERALOGICAL INDICATORS OF OXIDATION / REDUCTION

Connor Small

Connor Small, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *The Rundle Intrusive Complex: Investigating Oxidation Processes Related to Gold Mineralization in an Archean Alkaline Intrusive Setting / Thematic Project.* Supervised by Dr. Andrew M. McDonald, Dr. Daniel J. Kontak and Dr. Pedro J. Jugo.

SCOPE OF PROJECT

This thematic project is focused on the gold mineralization relationship between oxide minerals (magnetite, hematite, goethite) and sulfur isotope (34S) changes in pyrite at a deposit scale. Understanding the mineralogical indicators is critical for interpreting the fO2 control on gold mineralization in an Archean alkaline intrusive setting.

PROGRESS YEAR 3

Detailed mapping, at a 1:1500 scale, was performed at the Rundle intrusive complex (~0.5 x 1 km) located in the southern Abitibi greenstone belt (**Figure 31**). Prior mapping in this area was done at a regional scale in the 1990s by the Geological Survey of Canada.

A total of 120 samples, comprised of mineralized and non-mineralized SiO_2 undersaturated rocks along with mafic to ultramafic rocks, were collected in the 2018 field season for host rock identification, whole rock geochemistry, and S isotopic analyses, in order to assess the spatial and temporal relationships of Au mineralization with oxidation.

Petrographic analysis indicates that the gold is associated within the pyrite grains which are hosted in alkaline to calc-alkaline felsic rocks. Results from SIMS analyses show that $\delta^{34}S$ values range from -15‰ to +18‰, with the most negative values (-5‰ to -15‰) correlating with high-grade gold zones (1 to 100 ppm). This is consistent with previous data obtained at the St. Ives gold mine in Western Australia which also demonstrated a correlation between depleted $\delta^{34}S$ and Au mineralization. Additional preliminary SEM-EDS analyses show gold inclusions (3 to 5 µm) hosted within hematite rims that have replaced pyrite, suggesting a strong positive relationship between development of Au mineralization and oxidation.

However, there are no other S-bearing minerals observed except for very rare barite inclusions, which have a $\delta^{34}S$ value of -3.1‰. This indicates that the only observable sink for heavy sulfur ($\delta^{34}S$) at the Rundle deposit is pyrite.

This could have major implications regarding how we interpret oxidation processes particularly since there is very little sulfate observed at most Archean gold deposits, and the current models invoke sulfate as the sink for heavy sulfur ($\delta^{34}S$). In addition to the sulfur correlation, samples dominated by Fe^{3+} and with Fe-oxide replacing pyrite show good agreement with the gold-rich zones, reinforcing the link between oxidation and mineralization.

Results were published in a Summary of Fieldwork paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. C. Small's thesis will be completed in the spring of 2020.

FUTURE WORK

All sampling required for this project was conducted in the previous 2018 field season. Future activities will focus on petrography work, along with quantitative analyses such as SEM, XRD, and CL.

The analytical techniques previously described will help identify important mineral phases (e.g., sulfides, oxides, and silicates) which will further understanding of the conditions at which the Au mineralization occurred, and help find the exact link between oxidation and depleted $\delta^{34}S$ values at the Rundle intrusive complex. These observations carry important implications,

Figure 31: **L-R: Connor Small and Joey Rainville grid mapping a stripped outcrop at the Rundle Intrusive Complex.**

for ore forming processes and for targeting and exploring new gold deposits in oxidized settings, using 34S values alongside Fe3+ concentration.

NATURE OF ARCHEAN PORPHYRITIC ROCKS


Xuyang Meng

Xuyang Meng, Ph.D. Candidate Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *The nature of Archean porphyritic rocks associated with copper mineralization in the Superior Province, Canadian Shield.* Supervised by Dr. Jeremy P. Richards and Dr. Daniel J. Kontak.

SCOPE OF PROJECT

Amongst a few porphyry-style deposits reported in the Precambrian, the earliest gold-rich deposits are associated with ~2.74–2.68 Ga high-Al or low-Al TTG in the Abitibi greenstone belt, Superior Province, Canada. The Côté Au-Cu deposit is hosted by the Chester intrusion that consists of tonalite, diorite and quartz diorite, and minor magmatic-hydrothermal breccia in the Swayze greenstone belt, Northern Ontario, Canada. A few subeconomic porphyry-style breccia-hosted Cu deposits also occur in the volcanoplutonic rocks of the eastern Abitibi greenstone belt. For example, the St. Jude breccia-hosted mineralization and Don Rouyn deposit are associated with different trondhjemite phases in the Flavrian-Powell pluton. Similarly, the Croxall breccia-hosted mineralization is associated with the Clifford stock which intrudes the Ben-Nevis volcanic complex. The Clifford stock consists of amphibole-bearing equigranular tonalite to granodiorite that formed at ~2.68 Ga.

Porphyry Cu deposits are associated with oxidized, sulfur-rich, and hydrous magma that characterizes the subduction of oxidized and hydrous oceanic lithosphere in Phanerozoic arc settings. In contrast, such deposits are rare in the Precambrian, which has been ascribed to poor preservation of tectonically active plate margins and hypothesized different tectonomagmatic conditions. To test this hypothesis, this project focuses on constraining the redox state and volatile element abundances of the magma associated with rare reported ArcheanPaleoproterozoic porphyry Cu deposits in the Abitibi greenstone belt in Canada. These parameters will be further constrained for TTG-diorite intrusion and volcanism (ca. 27402680 Ma) across the Abitibi greenstone belt, to test whether the same tectonomagmatic setting occurs locally or regionally (such as in the belt).

PROGRESS YEAR 3

In Year 1 of this project, fieldwork in these areas was completed before September 2018 and representative samples of these intrusive rocks have been collected. Subsequently, thin section polishing, zircon separation and mounting, and mineral searching have been conducted; and a preliminary petrographic observation has been finished.

FUTURE WORK

Sample preparation and analytical work are the main tasks of the next step, although visits to drill cores of the Côté and Croxall deposits are also planned. U-Pb-Hf-O isotopes and trace elements of zircon and major elements of primary amphibole, biotite, and apatite will be analyzed at Laurentian University, the University of Alberta, and Ontario Geological Survey. Apatite S6+/S ratio will be analyzed using XANES (X-ray near-edge spectrometry) at the Advanced Photon Source, Argonne National Laboratory in Illinois.

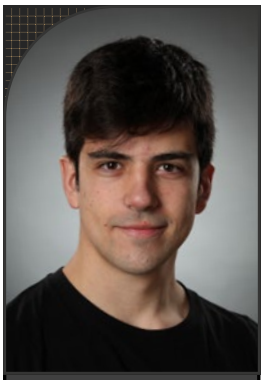
Zircon separates for TTG magmatism and associated volcanism across the Abitibi greenstone belt have been collected

from the Ontario and Québec Geological surveys for Hf-O isotopic mapping by Dr. David Mole. Inclusion-rich grains will be selected and mounted. Primary minerals that are hosted in robust zircon crystals will be used to constrain the oxygen fugacity and volatile element abundances. This work will enhance understanding of crustal evolution, metallogeny, and atmospheric change in the Neoarchean.

This thematic project aims to:

1. Examine the metal endowment (or apparent lack of it, in the case of porphyry Cu deposits) in Archean terrain;
2. Test whether metallogenic processes for Phanerozoic porphyry Cu systems operated in the Archean, or whether key geodynamic or geochemical differences reduced the fertility of Archean magmas; and
3. Contour spatial and temporal variability of oxygen fugacity and volatile element abundances of Neoarchean tonalite-trondhjemite-granodiorite-diorite plutonism and associated volcanism in the Abitibi subprovince, Superior province.

TECTONOTHERMAL EVOLUTION



Nicolas Estrada

Nicolas Estrada, Ph.D. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on Tectonothermal evolution of the middle-lower Abitibi-Wawa crust and the role of melt mobility on metal transport, Kapuskasing uplift, Ontario. He is supervised by Dr. Douglas K. Tinkham, Dr. Taus R. C. Jørgensen, and Dr. Jeffrey H. March.

SCOPE OF PROJECT

One of the goals of Metal Earth is to identify fundamental processes leading to the formation of metal endowed belts, and the measurable criteria to distinguish them from belts with less potential for ore deposit formation. However, some processes like fluid behavior and partial melting of the lower-crust are not directly observable. Their evolution may be a critical factor in the interpretation of processes forming and modifying the continental crust, and thus, the formation of ore deposits.

The Kapuskasing structural zone (KSZ) extends over 500 km in length and close to 50 km in width. It cuts across the east-striking metal endowed Abitibi Subprovince to the east and the Wawa Subprovince to the west. This fault-bounded structure has been interpreted to represent mid to lower crustal levels of the Abitibi-Wawa belts that can be traced downdip on seismic reflection profiles to 25-35 km depths (Percival and West, 1994). The rocks observed in the KSZ experienced an extended period of high-grade metamorphism that was later exposed through uplift events in the Neoarchean (Krogh and Moser, 1994). These metamorphic rocks show a gradational change from amphibolite to granulite facies metamorphism towards the northeast (i.e. change in chemical and physical conditions), and offer a unique opportunity to investigate partial melting processes and metal behavior in the mid to lower Archean crust.

This project will further constrain the tectonothermal evolution of portions of the mid to lower Abitibi-Wawa crust using exposures in the Kapuskasing uplift. This will be achieved by understanding the metamorphic conditions of the area and the evaluation of the potential for partial melting and melt extraction of the mid to lower crust to mobilize metals of economic interest.

Collaborator Dr. Manuel Duguet, Ontario Geological Survey.

PROGRESS YEAR 3

During the first year of the project (2018) fieldwork was undertaken on the southern part of the KSZ. Detailed bedrock mapping was conducted, with the objective of collecting appropriate samples to gain insight into the tectonometamorphic evolution of the KSZ (**Figure 32**), and identifying partial melting characteristics through detailed observations along traverses guided by previously determined distribution of metamorphic grades. The majority of outcrops observed are located within the Borden Lake Greenstone Belt.

Approximately 100 samples from several geological units of interest were collected including samples with migmatitic characteristics (i.e., leucosome, melanosome and mesosome). Representative samples of mafic and felsic rocks with optimal mineral assemblages for phase equilibria and geochronology studies were selected for petrography and whole rock geochemistry analyses.

Field observations and preliminary petrographic work indicate that migmatitic mafic gneiss is characterized by a variation in modal mineralogy at outcrop scale presence of migmatitic features including leucosomes (melt), melanosomes (residue), mesosome (partially altered rock) and paleosome (unaltered rock). The variety of migmatitic textures observed suggest that melt was not only generated in situ but has also migrated, although the extent of the migration has not been entirely constrained.

The mineralogical and textural relationships between minerals (e.g., garnet, feldspar, calcite, scapolite, amphibole, pyroxene) provide a good first approximation into the range of the pressure-temperature conditions as well as the nature of fluids involved in the metamorphic processes. Preliminary SEM-EDS analyses of accessory minerals, including titanite, indicate that some of the samples are suitable for U-Pb geochronology to provide information on the timing of metamorphism.

Two abstracts were prepared by N. Estrada, D.K. Tinkham and T.R.C. Jørgensen for conference presentations. Results from fieldwork were published in a Summary of Fieldwork paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2019.

FUTURE WORK

Fieldwork during the summer of 2019 will continue to focus on detailed bedrock mapping. The first half of the season will be spent in the northern part of the KSZ. This will be crucial for establishing field observations and relations of higher-grade metamorphic rocks that have experienced higher pressure metamorphism in comparison with the ones observed in the southern part of the KSZ. The second part of the field season will be spent on key outcrops in the southern KSZ to refine past observations and allow further interpretation of the tectonothermal history. In addition, additional samples of mafic and felsic rocks, including migmatitic features like leucosome, melanosome, and paleosome will be collected.

After the field season, research activities will concentrate on reconstructing the metamorphic reaction history and P-T-t conditions of metamorphism to elucidate the tectonothermal history of portions of the KSZ, as well as investigate the behavior of metals in the formation of leucosome-melanasome pairs to understand the behavior of metals during high-grade metamorphism of the middle-lower crust. This will be achieved by analysing the migmatitic components separately using high-precision geochemistry, scanning electron microscopy, energy-dispersive X-ray spectrometry (EDS) mapping, microprobe analysis and laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) analysis. Subsequent phase equilibria modelling and geochronology will help constrain the P-T conditions of metamorphism and the tectonometamorphic history of the area. Geochronology will include U-Pb and trace element analyses of zircon and titanite from characteristic metamorphic features (e.g., leucosome, restite and pegmatite) found in representative lithological packages from each unit. Analyses comparing mafic and felsic rocks that have undergone partial melting

and those that have undergone melting extractions, along with their trace metal chemistry, will be used to understand the mobilization of metals. Mesosome, melanosome and leucosome components will be analyzed separately using high-precision geochemistry.

A constrained tectonometamorphic history of portions of the mid to lower Abitibi-Wawa crust exposed in the Kapuskasing uplift of the Superior Province, will provide an understanding of the role that anataxis plays in remobilizing metals from the mid to lower crust.

Figure 32: Nicolas Estrada in the southern part of the Kapuskasing structural zone, between the towns of Chapleau and Foleyet, during field season 2018.

FUTURE WORK:
BUILDING ON FOUNDATIONAL KNOWLEDGE

This section highlights upcoming Metal Earth projects that will be conducted in future years of the program. These research projects will build upon the knowledge gained from fieldwork, data compilation and analysis during Metal Earth's start up years.

CRATON SCALE PROJECTS

FLUID SOURCE AND PATHWAYS

Through an academic collaboration with Metal Earth, Université Laval is conducting four transect scale subprojects (3 Ph.D. and 1 M.Sc.) related to Metal Earth research themes which represent the potential for significant impacts on collective understanding of fluid and metal source. Beginning in the summer 2019, these projects will deal with complementary problematics which could help to provide new insights in the understanding of the generation, the circulation and the interactions of auriferous fluids into the crust leading to the formation of orogenic gold deposits.

SOURCE TO SINK: TOWARD AN INTEGRATED UNDERSTANDING OF THE AURIFEROUS FLUID FLOW SYSTEM(S) PH.D. TOPIC 1

Michael Herzog

Dr. Crystal Laflamme

Michael Herzog, Ph.D. Candidate, Université Laval, to complete his thesis on *Monitoring fluid composition through multiple hydrothermal pulses in the Val d'Or camp.* Supervised by Dr. Crystal Laflamme, and Dr. Georges Beaudoin.

SCOPE OF PROJECT

This project deals with the multiple-sulfur isotopes analyses of sulfur genetically associated to orogenic gold deposits and with geochronology of accessory mineral(s) in order to constrain the source(s) of mineralizing fluid(s) and their dynamic of circulation through time and space at a camp scale. In the summer of 2019, field work and sampling in the Val d'Or camp will be conducted, in collaboration with industry partners Canadian Malartic Mine Corp.; Eldorado Gold Lamaque, Eldorado Gold Corp.; Goldex Mine, Agnico Eagle Mines Ltd.; and Probe Metals Inc.

Samples collected will be prepared and detailed petrographic study will be undertaken. This project will involve use of multiple sulfur isotopes; U-Pb geochronology on accessory minerals, and XRF. The anticipated outcomes of this work are to improve understanding of auriferous fluids from source to sink, and to build a framework for ore vectoring criteria at the camp-scale.

SOURCE TO SINK: TOWARD AN INTEGRATED UNDERSTANDING OF THE AURIFEROUS FLUID FLOW SYSTEM(S) PH.D. TOPIC 2

Vivek Raj

Dr. Christian J. Dupuis

Vivek Raj, Ph.D. Candidate, Université Laval, to complete his thesis on *Physical properties of hydrothermal alteration halo along the Augmitto-Bouzan segment.* Supervised by Dr. Christian J. Dupuis, and Dr. Richard Smith.

SCOPE OF PROJECT

The aim of this project is to determine if gold bearing formation have specific physical properties and if differences exist between endowed and less endowed areas.

The second outcome of this work is to acquire VSP data from selected boreholes in order to help to the inversion of seismic data acquired along transects. Pending immigration procedures currently in progress, V. Raj will arrive in late summer or early fall of 2019. The field campaign will be conducted in the summer of 2019, initiated by Dr. Christian J. Dupuis and a team of student researchers.

This project will involve use of spectral gamma, magnetic susceptibility, full waveform sonic, electrical conductivity, induced polarization, and optical televiewer. The logging data acquired during this field campaign will be processed, logs for all well visited, and velocity models will be provided by the end of 2019.

SOURCE TO SINK: TOWARD AN INTEGRATED UNDERSTANDING OF THE AURIFEROUS FLUID FLOW SYSTEM(S) PH.D. TOPIC 3

Isaac Siles Malta

Dr. Carl Guilmette

Isaac Siles Malta, Ph.D. Candidate, Université Laval, to complete his thesis on *Modelling the composition, volume and timing of fluid generation from Pontiac metasediments.* Supervised by Dr. Carl Guilmette, Dr. Crystal Laflamme, and Dr. Georges Beaudoin.

SCOPE OF PROJECT

This project deals with the modelling of the composition, volume and timing (P-T-t-X and O, H stable isotopes) of fluid generation from Pontiac metasediments in order to test the hypothesis of a metamorphic origin for the auriferous fluid at the origin of the gold endowment in Abitibi. In the summer of 2019, field work and sampling will be conducted in the Pontiac of the Rouyn- Noranda and Val d'Or areas.

This project will involve use of P-T-X modelling, stable isotopes (C, O, H, S), trace elements geochemistry, U-Pb and Lu-Hf geochronology on prograde minerals, XRF. Samples collected during the 2019 field campaign will be prepared, and their detailed petrographic study will be initiated. Additionally, a detailed geological map of the studied area will be produced. The anticipated outcome of this work is to determine if local metamorphic rocks could be the source of mineralizing fluid at the origin of the gold endowment in the Abitibi.

SOURCE TO SINK: TOWARD AN INTEGRATED UNDERSTANDING OF THE AURIFEROUS FLUID FLOW SYSTEM(S) M.SC. TOPIC 1

Guillaume Raymond

Guillaume Raymond, M.Sc. Candidate, Université Laval, to complete his thesis on ***Spatial variation of fluid flow along the Augmitto-Bouzan segment.*** Supervised by Dr. Georges Beaudoin, and Dr. Crystal Laflamme.

SCOPE OF PROJECT

This project focuses on the characterization of variations of fluid circulation conditions along a 12 km segment of the Cadillac-Larder Lake Fault Zone. By using stable isotopes (O, C, H) this project will determine if spatial variations of fluid circulation conditions mimic the erratic distribution of gold mineralization at pluri-kilometric scale. In the summer of 2019, field work and sampling will be conducted along the Augmitto-Bouzan segment of the Rouyn-Noranda transect, in collaboration with Yorbeau Resources Inc.

Carbonates samples collected during the 2019 field campaign will be prepared and their detailed petrographic study will be initiated. This clumped isotope thermometry project will involve use of stable isotopes (C, O, H, 47), XRF, and 3D fluid flow modelling using HydroGeoSphere software.

TRANSECT SCALE PROJECTS

BEN-NEVIS – LARDER LAKE TRANSECT M.SC. TOPIC 3

Stefanie Kisluk

Stefanie Kisluk, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences. Thesis topic *Lithostratigraphic, geochemical and geochronological controls on VMS mineralization in the Ben Nevis Volcanic Complex: implications for understanding regional metal endowment of the Blake River Group, Abitibi Subprovince, Ontario.* Supervised by Dr. Kate E.L. Rubingh and Dr. Ross L. Sherlock.

SCOPE OF PROJECT

The Ben Nevis – Larder Lake transect, is located in the Abitibi Subprovince of the Superior Province in northeastern Ontario. The Ben Nevis Volcanic Complex (2696.6 ± 1.3 Ma) is hosted by the Archean rocks of the Blake River Group (2701 ± 3 –2698.5 ± 2Ma) (Péloquin et al., 2008). The Blake River Group in Québec is well documented and is host to 33 volcanogenic massive sulphide (VMS) deposits totalling 125 Mt. However, the Ben Nevis Volcanic Complex, despite its similarities in age, lithology,

geochemical characteristics and styles of synvolcanic mineralization, hosts subeconomic VMS deposits (Ayer, 2005).

This research project will commence in May 2019. Focus will be on understanding the lithostratigraphic, geochemical, and geochronological controls on VMS mineralization in the Ben Nevis Volcanic complex. This research is intended to develop a model for regional metal endowment of the Blake River Group. Details of this project will be further defined accordingly, during the 2019 field season.

COBALT TRANSECT M.SC. TOPIC 1

Louise Rush

Louise Rush, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences. Thesis topic Effective exploration targetting in the Cobalt Camp, tracing the origin of metals and fluids, Cobalt, Ontario. Supervised by Dr. Shawna Elizabeth White, Dr. Ross L. Sherlock, and Dr. Daniel J. Kontak.

SCOPE OF PROJECT

The first season of fieldwork for this project will be conducted in Cobalt from June-August 2019. Thesis project Effective exploration targetting in the Cobalt Camp, tracing the origin of metals and fluids, Cobalt, Ontario will address questions including:

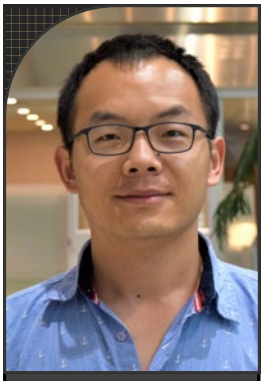
1. Is there systematic metal zoning in the Cobalt Camp?
2. Is there zoning in the hydrothermal fluid composition?
3. What are the metal contents of the fluids?
4. Where are the fluids sourced from?
5. What is the timing of fluid flow and ore generation?

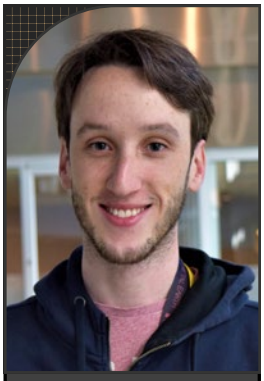
Sampling of mineralized veins will include core samples provided by Metal Earth industry partner First Cobalt Corp., local abandoned mine sites, and museum collections. From this suite, select samples will be used to constrain all relevant aspects of ore formation (i.e. alteration, mineral paragenesis) using detailed petrographic study at different scales combined with state-of-the-art imaging and in situ analysis (SEM-EDS, EMPA).

Subsequently, in situ analysis using various micro-beam methods (e.g., LA-ICPMS, SIMS) will be used to geochemically fingerprint the fluids, hence source reservoirs, using trace elements and both radiogenic (Pb, Sr) and stable (C, S, O, D) isotopes. In addition, fluid inclusions will be used to evaluate the PT evolution of the mineralization and constrain fluid chemistry. The temporal aspect will be constrained through dating of hydrothermal phases (e.g., monazite, carbonate).

STURGEON TRANSECT

Transect lead Dr. Chong Ma, RA; Marius Etienne, Ph.D. Candidate Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences. Thesis topic *Volcanic stratigraphy and metallogeny of the Handy Lake Assemblage,* Sturgeon Lake. Supervised by Dr. Robert Lodge.


Dr. Chong Ma


Marius Etienne

SCOPE OF PROJECT

The Sturgeon transect (**Figure 33**) is the easternmost line of the three north-south transects across the western Wabigoon subprovince (Superior province) of the Metal Earth project. It is ~60 km long along Highway 599 and goes through the interpreted Winnipeg River terrane and the Sturgeon Lake greenstone belt from south to north. The goals of the Sturgeon transect are to understand (1) the stratigraphy of the Archean metavolcanic rocks of the various volcanic assemblages (southern Sturgeon, central Sturgeon, Handy Lake, and Fourbay Lake); (2) structural or stratigraphic relationships between the assemblages; (3) nature and timing of deformation; (4) origin and timing of granitic magmatism; (4) origin and timing of volcanism; (5) sedimentary provenances of successor basins; (6) amalgamation of the metavolcanic assemblages and their accretion to the Winnipeg River terrane; and (7) controls of metal endowment.

The Sturgeon transect will examine the regional controls of the Mattabi Mine and the origin, evolution and metallogeny of the supracrustal rocks throughout the greenstone belt. Mapping and sampling along this transect will start with the Handy Lake assemblage, part of the North Sturgeon supracrustal assemblage, in June 2019. The primary dataset will be based on structural and kinematic analyses of deformation, whole rock and isotopic fingerprinting, zircon U-Pb and Lu-Hf analyses, Titanium-in-zircon thermometry, and seismic-gravity-magnetotelluric mapping of the lithosphere and upper mantle. All acquired data will be integrated into the regional context on the basis of previously reported data from the region. A preliminary understanding of the 4D geology along the Sturgeon transect is expected by April 2021.

DRYDEN-STORMY LAKE TRANSECT M.SC. TOPIC 3


Amokelani Mavundza

Amokelani Mavundza, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences. Thesis topic *Characterizing the magnetic response of felsic to intermediate intrusions of the western Wabigoon subprovince.* Supervised by Dr. Stéphane Perrouty and Dr. Ben M. Frieman.

SCOPE OF PROJECT

A. Mavundza joined the Metal Earth research initiative at the beginning of the 2018-19 academic year. As a result, no fieldwork was conducted in relation to this subproject during Year 3. Initial work has focused on delineating felsic to intermediate intrusion of interest to this study and the compilation of high resolution airborne magnetic imagery.

Fieldwork associated with this project will be carried out during the summer of 2019, focused on conducting field transects across the intrusions of interest. Field transects will include the collection of representative samples at regular intervals, and taking a series of magnetic susceptibility measurements using a handheld device (KT-10). Representative rock samples will be analyzed by optical and scanning electron microscopy during the winter of 2019 to establish how the textural arrangement and mineralogy is manifested as variable magnetic signatures. These results will be paired with whole rock geochemical analysis to establish rock type variations within and among the intrusions investigated.

This project seeks to link the observed airborne magnetic signatures of felsic to intermediate intrusions to ground-based magnetic susceptibility measurements and the physical properties of the intrusive complexes. These results will be used to establish guiding parameters that will aid in the interpretation of magnetic signatures in other, lesser studied areas

of the Superior Province. Additionally, felsic to intermediate intrusions are commonly genetically linked to a variety of economically significant deposit types such as rare earth element, lithium, and/or gold deposits. Thus, it is expected that these results will aid in greenfield exploration sectors.

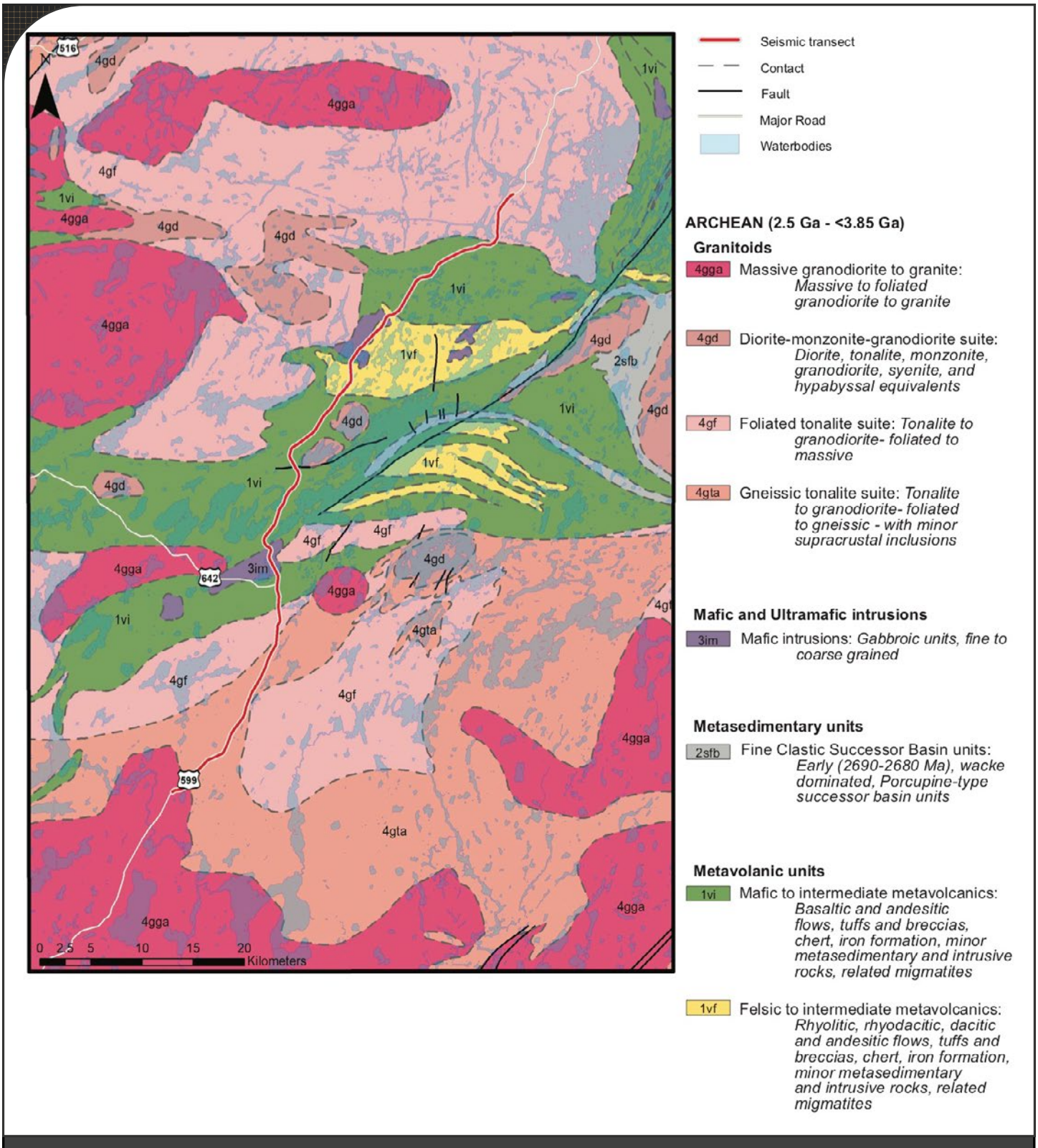


Figure 33: Map of Sturgeon Transect.

RAINY RIVER TRANSECT


Dr. Gaetan Launay

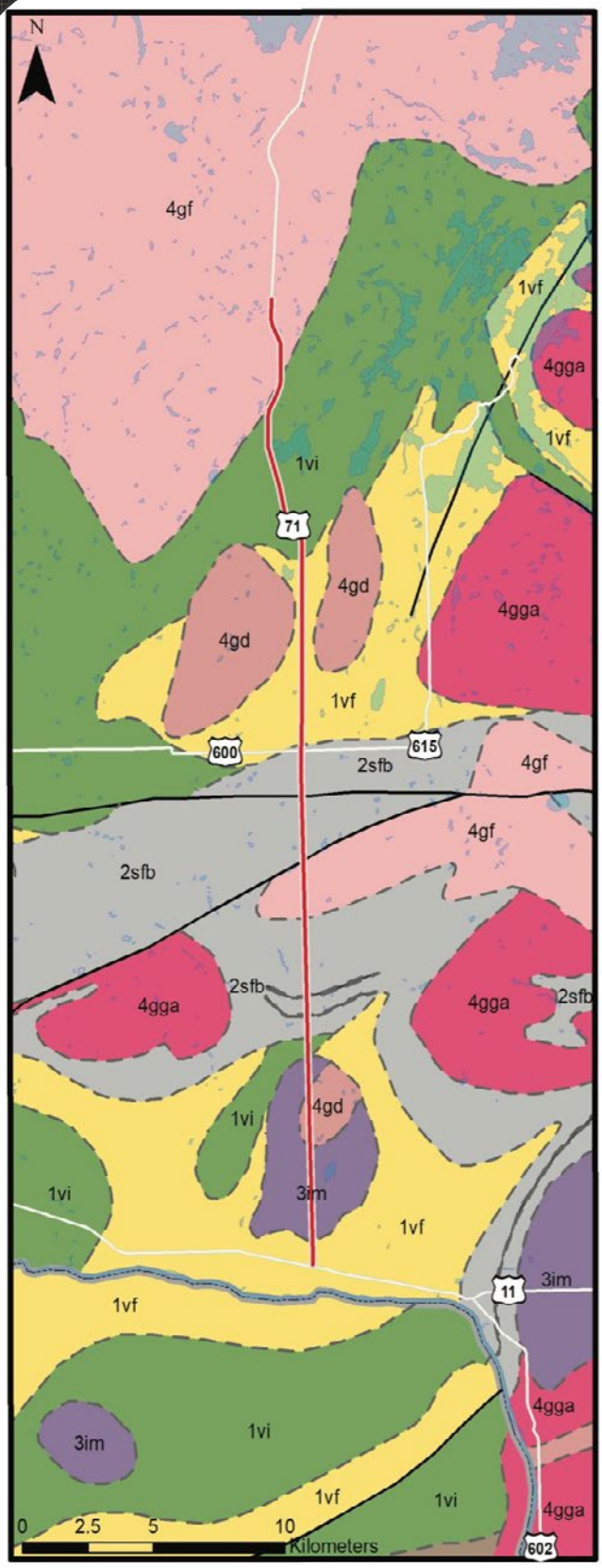

Mattea MacRae

Transect lead Dr. Gaetan Launay, RA; and Mattea MacRae, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences. M. MacRae's thesis topic is *Stratigraphic and structural characteristics of the Rainy River area (Western Wabigoon - Quetico subprovinces).* Supervised by Dr. Ross L. Sherlock and Dr. Doug Tinkham and Dr. Patrick Mercier-Langevin.

SCOPE OF PROJECT

The Rainy River transect (**Figure 34**) is part of the larger Metal Earth project led by MERC. The main objective is to constrain factors controlling the metal endowment within Archean greenstone belts. The Rainy River transect area lies within the western Wabigoon and the Quetico subprovinces that form part of the Archean Superior Province and include the Rainy River gold deposit (3.7 Moz Au; New Gold report, 2014).

The purpose of this transect work is to (i) constrain the stratigraphic and the structural frameworks of the Rainy River greenstone belt (RRGB) and the Quetico subprovince, (ii) constrain the geodynamic evolution of the Rainy River - Quetico crustal blocks, and (iii) to place the formation of mineral deposits in complete crustal-scale geological processes. To address these topics, a multi-disciplinary approach combining geological mapping, geochemistry and geochronology will be applied. The geologic interpretation of seismic, magnetotelluric and gravity data sets will extrapolate the revised surface geology through lithosphere. Ultimately, the compilation of these results will constrain the metallogenic evolution of the RRGB and identify the factors controlling the metal endowment in the western Wabigoon subprovince.



Seismic transect
Contact
Fault
Major Road
Waterbodies
International Border

ARCHEAN (2.5 Ga - <3.85 Ga)

Granitoids

4gga Massive granodiorite to granite: *Massive to foliated granodiorite to granite*

4gd Diorite-monzonite-granodiorite suite: *Diorite, tonalite, monzonite, granodiorite, syenite, and hypabyssal equivalents*

4gf Foliated tonalite suite: *Tonalite to granodiorite- foliated to massive*

Mafic and Ultramafic intrusions

3im Mafic intrusions: *Gabbroic units, fine to coarse grained*

Metasedimentary units

2sua Clastic and chemical metasedimentary units: *Clastic and chemical metasedimentary rocks with or without komatiites*

2sfb Fine Clastic Successor Basin units: *Early (2690-2680 Ma), wacke dominated, Porcupine-type successor basin units*

2si Iron formation: *Dominantly oxide facies minor sulfide, carbonate and silicate facies*

Metavolanic units

1vi Mafic to intermediate metavolcanics: *Basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

1vf Felsic to intermediate metavolcanics: *Rhyolitic, rhyodacitic, dacitic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites*

Figure 34: Map of Rainy River Transect.

APPENDIX A: BACKGROUND

METAL EARTH WILL FILL THE KNOWLEDGE GAP TO HELP MEET FUTURE GLOBAL NEEDS

Metals are essential to society (e.g. agriculture, shelter, health, communication, transportation). In the developing low carbon energy economy, metals will be required for energy and infrastructure. Secure supply underpins economic and social sustainability and must meet future demands of rapidly growing world population.

Metals are a principal driver of Canada's economy, constituting 19% of Canada's total domestic exports and $88.6 billion in GDP in 2016, according to Natural Resources Canada. Mining and metal production will underpin Canada's Far North development and our sovereignty. Metals are a finite resource, and deposits must be continually discovered to meet growing global need.

Metals are ultimately derived from Earth's mantle during differentiation, episodic periods of crustal development, and have been continuously supplied at sub-economic contents to the crust by magmas and fluids. To be exploitable, metals must be concentrated through natural processes into ore deposits.

Our understanding of metal endowment stems from the characterization of individual mineral deposits and on metallogeny (i.e., placing deposit types in the context of geodynamic environments). This has resulted in sophisticated ore deposit models that link deposits to local - or district-scale processes, but only a broad, vague understanding of how deposits relate to their larger geological environments. Such research has substantially improved our understanding of the controls localizing ore deposits, and ore districts. However, since 2005, a decrease in exploration success, despite a marked increase in exploration expenditures indicates that: 1) Rates of discovery within mining districts (the number and size of deposits within a given area) have decreased as metal deposits represent a finite resource within the currently known areas of endowment. 2) Discoveries in new areas are insufficient to meet future needs as existing models, based on deposit-scale characteristics, cannot differentiate areas with higher metal endowment vs. geologically similar, but vast areas of lower endowment. Current exploration models are simply at the wrong scale.

Ore deposits and ore districts are smaller-scale expressions of processes that operate within much larger, terrane-scale, "ore systems". In the latter, metal endowment is related to the evolution and interplay of larger tectonic elements including deep crustal structures, fluid (magma/heat) pathways, and connection and interaction with the mantle. It is at the scale of ore systems that metals are sourced, mobilized, transported, concentrated and preserved. Differences in these elements and processes result in the differential endowment of geologically similar areas.

Thus, research at the scale of ore systems is required to develop the criteria needed to target the small, better endowed areas from the vast areas of low endowment – leading to greater exploration success, and ensuring that modern society has a stable, sustainable supply of metals into the future.

FOUNDATION FOR METAL EARTH'S RESEARCH PROGRAM

Metal Earth rests on four points: 1) It will build on existing knowledge of ore deposits and their districts, but differs in its approach to resolving the fundamental scientific issues posed by system-scale controls on metal endowment [16]. This requires an integrated, multidisciplinary approach at a much broader scale than previous efforts. 2) Entire ore systems will be imaged at full crust-mantle scale [16] to identify key geological, geochemical and geophysical attributes that explain the processes responsible for the extraction of metals from sources, transport pathways, and their economic concentration. 3) In contrast to previous lithospheric-scale studies, e.g., Canada's LITHOPROBE (1990-2004) Metal Earth will relate deep earth features to the specific distribution of ores. 4) Metal Earth also places equal emphasis on less endowed areas, which have been explored but largely ignored by research, to refine comparison with well-endowed areas, thereby identifying -fingerprinting- measurable differences that resulted in contrasting metal endowment.

Metal Earth will research, develop, and deploy new 3D & 4D data integration, analysis and visualization tools [17] to aid in the discovery of new deposits through quantitative interpretation at a larger spatial scale than previously done, addressing the significant challenges of deposit-to-craton scale data integration.

Metal Earth will initially focus on Archean volcano-sedimentary greenstone belts, constituting 80% of Earth history, 30% of Canada's Far North rock exposure and 48% of Canada's metal wealth to determine what processes are responsible for early Earth's differential metal endowment. The answer to this fundamental question will require a new understanding of secular changes in the evolution of Earth's atmosphere, hydrosphere, lithosphere, mantle, and geodynamic environments [18, 19]. These differences should be recognizable at the Earth's surface.

To achieve this, Metal Earth comprises four integrated activities; 1) Broad, craton-scale research to better understand the architecture and interaction of greenstone belts with their surrounding granitoids during terrane assembly and ore district formation; 2) Transect research where more detailed studies will aim to resolve the lithospheric-crustal architecture and fluid (magma/heat) pathways, providing a geological framework to resolve the differential endowment of terranes and structures; 3) Thematic research at the craton scale will address specific processes or questions on metal endowment; and 4) Development of data integration, analysis and interpretive tools to predict metal endowment.

CRATON SCALE RESEARCH

Metal Earth's craton scale studies will focus on acquiring new data from which an understanding of the 4D architecture of the Superior and Slave cratons will develop.

The first step is to compile, and interpret existing regional geological, geochemical, isotopic and geophysical data (seismic reflection, seismic tomography, magnetic, and gravity).

These databases will be supplemented by new U-Pb radiometric ages and isotopic data, available in high volume due to recent, analytical advances. Recent research conducted by Macquarie U. (Australia), by Global Lithospheric Architecture Mapping (GLAM) [18] a private consortium, and by the Centre for Exploration Targeting (one of our Australian partners) have demonstrated the usefulness of Hf isotopes (zircon) to unravel the architecture and assembly of cratons. For example, in the Yilgarn Craton in Australia, Hf isotopic data for zircons and whole rock Nd data was used to produce time-slice maps that track the assembly and evolution of the craton [6].

A similar approach is proposed for the Superior and Slave cratons where the archived zircon separates from ~3000 zircon samples, the rock powder database for whole rock Nd analysis [20], and the potential for adding hundreds of new data

through in situ Nd measurement, will provide much larger and more extensive coverage. This, coupled with an arguably better understanding of the shield geology, will produce 3D images tracking secular variation in the assembly of the Superior and Slave cratons, and will identify regional, deep mantle-crustal paths for mineralizing fluids, magma, and heat.

A mantle contribution to crustal metal endowment will be investigated using various geochemical tools. While magmatic and hydrothermal processes that accompany crustal differentiation concentrate the metals to form extractable resources, these processes can also obscure evidence of mantle to crust pathways.

Geochemical tools will be deployed in both mantle (i.e. xenoliths) and crustal rocks that probe the mantle (i.e. komatiites) [21] to peer through crustal differentiation to determine mantle conditions. This approach, combined with new data from other components of Metal Earth, will be integrated to reveal the ultimate source of metals before concentration in crustal deposits.

New techniques and instruments will be used. For example, at the Univ. of Alberta, a newly developed analytical method will determine the precious metals inventory (Au, PGE) of mantle xenoliths and komatiites [22]. A split-stream laser ablation (LASS) system [23, 24], which is the only one of its kind in Canada, will measure 'live' radionuclide isotopes (Hf and Nd) in individual minerals (i.e. zircon, titanite, monazite, apatite).

A new approach to measuring Pb isotopes in situ on feldspars and sulfides [25] will be used to obtain chronological and fingerprinting information about base metal sources. At the Carnegie Institution for Science, isotopes from extinct isotopic systems (e.g. 142Nd, 182W) (e.g., [26]) will be measured to test for the past presence of metal reservoirs in the deep mantle.

These techniques and approaches will identify craton scale metal endowment differences, which are related to larger-scale geologic processes that took place in the mantle early during Earth's history.

TRANSECT SCALE RESEARCH

Transects will be conducted in the Abitibi and Wabigoon Subprovinces [27] as type examples of endowed and less endowed terranes, respectively, characterizing differential endowment at the terrane scale in the Superior Craton (Figure 2). These areas are easily accessible and have up-to-date geoscience databases. More remote transects are also planned for the Ring of Fire area in the northern Superior Craton [28, 29] and the Yellowknife and Hope Bay greenstone belts of the Slave Craton [30], which differ from the Superior Craton in its tectonic evolution and metallogeny. Transects will cross productive gold-rich ancestral fault systems and volcanic centres that host gold, Cu-Zn, or Ni- Cu-PGE deposits, and less endowed faults and volcanic centres with similar geology. Geological, geochemical and geophysical data, including seismic, magnetotelluric, and gravity surveys, will be collected and integrated for each transect and combined with seismic cross lines to capture the 3D effects. Reflection seismic surveys can detect lithological contacts, sills or dikes as well as major structures and thus providing images from mantle to surface. Magnetotelluric (MT) surveys can detect mineralization and evidence of past fluid flow preserved as carbon films along major discontinuities and provide resistivity/conductivity images of the crust [31]. As these surveys measure different properties of the crust, modeling and integration of MT and gravity data will provide new profiles through the crust, detailing its architecture and crustal scale structures. Transects will take advantage of existing LITHOPROBE and later seismic data (e.g., [32]), craton-scale zircon Hf isotopic data and mantle xenolith information.

Targeted surface mapping will be done along each transect in concert with regional scale sampling for geochemical (major, trace, REE), isotopic (Nd, Hf, Pb, O, H, S) and geochronological analysis (U-Pb TIMS, LA-ICP-MS on zircons, rutile

and monazite). Geophysical properties (magnetic susceptibility, density, porosity, resistivity, chargeability or spectral complex conductivity) of hydrothermally altered and unaltered rocks will be measured to constrain the interpretation of the geophysical data. Geochemistry including stable isotopes will characterize and define fluid pathways (e.g., [33]). Kinematic interpretation of surface structures, reconstructions of the stratigraphy and architecture of volcanic and sedimentary rocks, together with petrogenetic and geochronological studies, will provide an understanding of the history and architecture of endowed and less endowed segments of major breaks and volcanic centres within the greenstone belts. Mapping will constrain interpretation of the geophysical data.

THEMATIC RESEARCH

Thematic research will seek to answer fundamental questions about the features and processes that result in metal endowment by understanding: (1) the subcontinental lithospheric mantle (SCLM) and crustal-scale fluid pathways, (2) fluid and metal sources, (3) Archean tectonics and metallogeny.

Crustal scale fluid/magma/heat pathways: Are there differences in the SCLM beneath endowed and less endowed greenstone belts? Mantle xenoliths can be used to constrain the depth and thermal state of the lithospheric mantle at the time of sampling, which affect the potential of this reservoir to control melting and allow heat conduction and advection. Chemical fingerprints of the xenoliths will be used to track the time integrated metasomatic history of craton roots. Within Archean cratons, Neoarchean terranes (2.80-2.5 Ga) typically contain more mineral deposits than Mesoarchean terranes (3.2 -2.8 Ga) [34]. However, orthomagmatic Ni-Cu-PGE (+/- Cr) deposits [35] and orogenic Au deposits [36] are commonly proximal to the boundaries between these terranes. Are such boundaries major pathways for the upward migration of magmas and fluids? Is there a crustal- or SCLM-scale control on the location of magmatic Ni-Cu-PGE-Cr-Ti deposits (e.g. Ring of Fire, Bird River [37])? Other questions to be addressed include: 1) Do the linear belts of younger sedimentary rocks that unconformably overly older volcanic rocks [36, 38] and are associated with younger orogenic gold deposits Au deposits delineate long-lived synorogenic structures? Although gold-rich VMS deposits are interpreted to be syngenetic and syn-volcanic, in the Abitibi they are spatially associated with younger orogenic gold deposits and the linear belts of younger sedimentary rocks [36, 37]. Do the "Au-breaks/structures" and the preservation of younger linear belts of sedimentary rocks indicate that these structures were originally extensional and synvolcanic in origin [38, 40]? Can sedimentological and volcanological facies analysis of rocks along these Au-structures determine if they are old synorogenic and/or synvolcanic structures? 2) As hydrothermal alteration can drastically change rock properties, does the geophysical expression of endowed upper crustal pathways differ from the less endowed? 3) What are the near- surface expressions (geological, geochemical, geophysical) of endowed crust-mantle pathways? 4) Within an ore district, do endowment processes responsible for "giant or world class" deposits differ from those for deposits of average size/grade?

Fluid and metal sources: Hydrothermal fluids can be metamorphic, magmatic, or meteoritic in origin. Contributions from metamorphic devolatilization [41], magmas [42, 43], and meteoric sources may change and evolve during the evolution of the crust and structural pathways. Several fundamental questions arise with respect to endowment: 1) Is mid-crustal metamorphic devolatilization a source for Archean gold-bearing hydrothermal fluids, gold [39, 40] and CO_2. Is the CO_2, manifest now as ubiquitous carbonate alteration within and along some ancestral faults [44] genetically related to gold transport and deposition, or is it solely a product of mid-crustal devolatilization along a major crustal structure? 2) What is the role of tonalite-trondhjemite-granodiorite intrusive suites (TTG), and alkaline magmatism e.g., [43]? The alkaline magmas may be the earliest expressions of small-scale convective erosion of the SCLM yielding small-degree, fluid-rich melts from metasomatised basal lithospheric mantle. Such melts have the ability to channel deep mantle C-H-O-halogen rich volatiles into the crust where they may become very effective agents of metal scavenging and

transport. Are the fluids produced from these magmas key to the initiation and focusing of mineralization or do the melts simply represent a mantle crust-connection (pathway)? Deep-seated alkaline melts are abundant yet highly localized within and around the Slave [30] and the Superior [27, 45] cratons, and offer unique windows into deep mantle volatile sources. Radiogenic isotope and stable isotope tracers can track the action of these fluids and their source, and may provide key fingerprints for those with metal potential and those without. 3) Is gold also leached from sulfides in shales or from sulphides in mafic volcanic and sedimentary rocks [46]? 4) What is the absolute timing of Au-mineralizing events and how does it differ amongst different fault systems within and between greenstone belts. 5) Within ore district, do the endowment processes responsible for "giant or world class" deposits differ from those for deposits of average size/grade?

Archean tectonics and metallogeny: Many of the world's presently exploited metal deposits formed in ancient submarine and subaerial volcanic environments, the majority by processes related to extension (rifting) of intraoceanic or continental arc crust above subduction zones. High heat flow, in these settings, is ultimately responsible for the production of metal-enriched crustal and mantle melts and deeply penetrating basement faults that focus magmas, fluids and heat into mineralized corridors. Current models for endowment are based on Phanerozoic subduction-driven geodynamic processes, which represent only 10% of Earth's history and they do not explain variability in endowment among nominally similar geodynamic environments.

During the Archean era, the planet was hotter due to the decay of heat producing isotopes e.g., [42, 47] and refs. therein) and accumulated latent heat from early meteorite bombardment [48]. Although Archean tectonic processes were likely dominated by plume activity and the migration and collision of plates, the evidence for large-scale ocean plate subduction similar to that evident in the Phanerozoic is controversial [49, 50, 51]. Do profound differences between Archean and Phanerozoic metallogeny reflect the accretion and/or sagduction of more reduced, altered oceanic plateau or crust and the subsequent metasomatic enrichment of the SCLM [52]?

By working in collaboration with researchers at the University of Ottawa and GEOMAR (Germany), Metal Earth will benefit from a parallel study directed at understanding the geodynamics and metallogeny of modern arcs to determine the link between deep structures and mineral endowment using high-quality reflection/refraction seismic surveys and deep electromagnetics to identify the key structures related to microplate evolution e.g., [53, 54]. Of relevance to Metal Earth is better understanding of the geodynamics of microplate interactions, their boundaries and their metallogeny, which may be analogous to geodynamic processes that operated during the Archean era. Collaboration with the Centre of Excellence for Ore Deposits Research (CODES) at U. Tasmania [54] will also facilitate comparison of the geological, geophysical and geochemical signature of magma, fluid, and heat conduits (structure) in modern and Phanerozoic endowed environments.

Other Questions of Relevance: The hydrosphere and atmosphere underwent drastic changes during Earth's evolution, and these had profound effects on metal availability or mobility [19, 52]. Did a more reduced Archean atmosphere and hydrosphere affect the behavior of sulphur and thus the formation of metal deposits [55]? Can we track oxygen levels in the Archean hydrosphere-atmosphere by ***in situ*** analysis of C in banded iron formation? Can the oxidation state and sulphur content of Archean magmas be tracked by the analysis of mineral inclusions (Fe-Ti oxides, apatite, etc.) preserved in robust accessory minerals such as zircon? Komatiite-hosted Ni-Cu deposits peaked at 2.7 Ga and disappeared by 1.9 Ga. The cessation of komatiitic volcanism corresponds to the global stabilization of thick cratonic mantle roots and seems linked to secular cooling of the mantle. Did cooling of our planet affect the formation of other metal deposit types (e.g. [19])?

DATA INTEGRATION, ANALYSIS, VISUALIZATION AND INTERPRETATION

Geoscience data from the craton-scale, transect and thematic research activities will be integrated, processed and interrogated using a goCAD Common Earth model [17, 51, 53] approach in which all data are situated within 3D (or 4D where possible) quantitatively self-consistent models. To potentially see deeper and to time-stamp data sets (4D), software with spherical coordinate systems are required, such as Geon IDV, which was developed for the large EarthScope of Project/US Array project [56]. Data and models will be managed at the Centre for Excellence in Mining Innovation's new Mining Observatory Data Control Centre (MODCC) at the SNOLAB in Sudbury. Mira Geosciences, a world leader in data management and earth modeling innovation and capability, and Laurentian's new Chair in Exploration Targeting and a new tenure-track Professor in Earth Systems Modeling will provide leadership and training in the use of the appropriate technology, software and workflows based on their collective experience and the scientific needs of the research program. Mira Geosciences (**www.mirageoscience.com**) will implement best practices developed during their leadership role in the data integration component of the $13M NSERC-CMIC;CRD project (www.cmic-ccim.org), which was directed at establishing the "footprints" of three deposit types. The data will be visualized and interpreted in 4D using LU's Virtual Reality Lab (VRL) at MIRARCO where MRI-like slices from surface to mantle will be examined to identify key geological, geochemical and geophysical differences between endowed and less endowed areas. These differences will establish a "fingerprint" for ore systems, which will define areas of endowment based on newly recognized patterns of measurable data, and to determine the processes and controls on metal endowment. Innovative technologies, modeling algorithms, software tools and techniques will be developed to aid exploration by predicting the metal endowment of greenstone belts and cratons. These will be further developed into commercial products aimed at the mineral industry and government; the latter to aid resource evaluation and policy decisions. Metal Earth will transform how multidisciplinary, often sparse multi-dimensional geoscience data is integrated, analyzed, visualized and interpreted.

APPENDIX B: LAURENTIAN UNIVERSITY, PARTNERS, AND COLLABORATORS

METAL EARTH TEAM, MERC, HARQUAIL SCHOOL OF EARTH SCIENCES

METAL EARTH ADVISORY BOARD

Dr. Rodney Allen, Consultant Geologist and CEO, Volcanic Resources, Hedemora, Sweden

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Dr. Richard Tosdal, Consultant, Past Director of Mineral Deposit Research Unit (MDRU) and Adjunct Professor, University of British Columbia, Past Chairman of the Board, NSERC-CMIC Footprints project

Dr. Dominique Weis, Canada Research Chair in Geochemistry of the Earth's Mantle and Professor, Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia

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Dr. Bruno Lafrance, Professor of Structural Geology; Metal Earth Associate Director

Dr. Ross L. Sherlock, University Research Chair in Exploration Targeting, Director, MERC and Metal Earth

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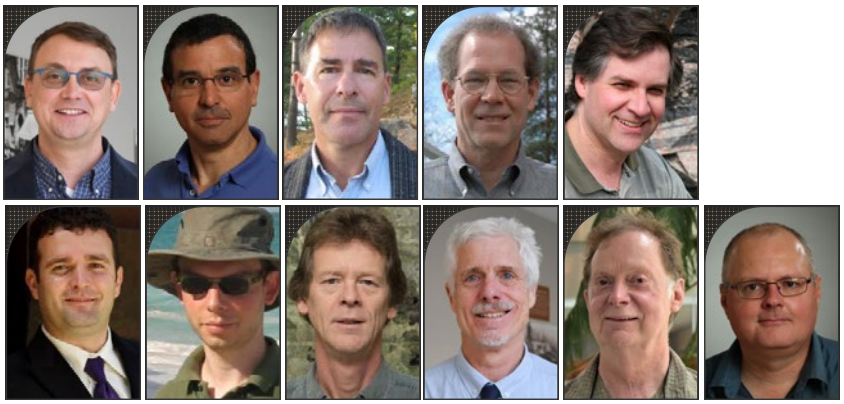

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APPENDIX D:
PUBLICATIONS AND PRESENTATIONS

CRATON SCALE PROJECTS

Isotopic Mapping of the Superior Craton

Mole, D.R., Barnes, S.J., Le Vaillant, M., Martin, L.A.J., Hicks, J., 2018: Timing, geochemistry and tectonic setting of Ni-Cu sulfide-associated intrusions of the Halls Creek Orogen, Western Australia. Lithos. 314-315: 425-446.

Mole, D.R., Barnes, S.J., Yao, Z., White, A.J.R., Maas, R., Kirkland, C.L., 2018: The Archean Fortescue large igneous province: A result of komatiite contamination by a distinct Eo-Paleoarchean crust. Precambrian Research. 310: 365-390.

Mole, D.R., Thurston, P.C., and Gibson, H.L., 2018: Isotopic terrane mapping and intra-cratonic architecture: The underlying control on all mineral systems? Resources for Future Generations (RFG) Conference 2018, Vancouver, British Columbia, 16-21 June, 2018. Oral presentation.

Mole, D.R., Marsh, J.H., Thurston, P.C., and Ayer, J.A., 2019: Crustal architecture of the south-east Superior Craton. Society for Geology Applied to Mineral Deposits (SGA) 2019 Biennial Meeting, Glasgow, UK. Oral presentation.

Metal Oceans: Modern Ocean Crust

Barckhausen, U., Heyde, I., Kopp, H., and **Hannington**, M.D., 2019: Seafloor spreading and crustal ages of the Central and Northern Lau Basin from magnetic data. Annual Meeting of the German Geophysical Society. Jahrestagung der deutschen geophysikalischen Gesellschaft 2019. Marine Geophysik Poster, Abstract Nr. A287.

Barckhausen, U., Heyde, I., Kopp, H., and **Hannington**, M.D., 2019: Seafloor spreading and crustal ages of the Central and Northern Lau Basin from magnetic data. Volcanic versus non-volcanic rifts and passive margins, from rift to ridge. European Geosciences Union (EGU) General Assembly 2019. Geophysical Research Abstracts Vol. 21: Session TS6.5/GD5.8/GMPV7.9.

Hannington, M.D., Kopp, H., and Schnabel, M., 2019: Cruise Report SO267: ARCHIMEDES I: Arc Rifting, Metallogeny and Microplate Evolution – an Integrated Geodynamic, Magmatic and Hydrothermal Study of the Fonualei Rift System, NE Lau Basin, Suva (Fiji) – Suva (Fiji). 11.12.2018 – 26.01.2019: Open Access GEOMAR Report, No. Ser. 049, GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Germany, DOI 10.3289/GEOMAR_REP_NS_49_2019.

Peterkin, B., Jamieson, J., Kwasnitschka, T., and **Hannington**, M.D., 2018: Formation of hydrothermal sulfide deposits on the Niua South Volcano, Northeast Lau Basin. Resources for Future Generations (RFG) 2018, Vancouver, British Columbia, 06 June, 2018. Poster presentation.

Schmid, F., Dannowski, A., Kopp, H., Petersen, F., Schnabel, M., Schramm, B., Riedel, M., Beniest, A., Brandl, P., Weber, M., and **Hannington**, M.D., 2019: Formation and rifting of backarc crust in the Lau Basin: First results of a recent seismic experiment. Jahrestagung der deutschen geophysikalischen Gesellschaft 2019. Marine Geophysik Poster, Abstract Nr. A.

Modern Ocean Crust Project (Metal Oceans) Topic 1

Stewart, M.S., Hannington, M.D., Emberley, J., Baxter, A., Breker, K., Petersen, S., Brandl, P., Kraetschell, A., Anderson, M.O., and Mercier-Langevin, P., and members of the Marine Mineral Resources Group at GEOMAR and Metal Oceans, 2019: University of Ottawa and University of Toronto. Geological Map of the Lau Basin, 1:1 million scale: Toronto Metal Earth Board Meeting, Toronto, Ontario, 1 March, 2019.

Modern Ocean Crust Project (Metal Oceans) Topic 3

Anderson, M.O., Hannington, M.D., McConachy, T.F., Jamieson, J.W., Anders, M., Wienkenjohann, H., Strauss, H., Hansteen, T., Petersen, S., 2018: Mineralization and alteration of a modern seafloor massive sulfide deposit hosted in primary volcaniclastic rocks. Economic Geology. Submitted 25 October, 2018, in review.

Anderson, M.O., Hannington, M.D., McConachy, T.F., 2019: Geological interpretation of volcanism and segmentation of the Mariana back-arc spreading center between 12.7˚N and 18.3˚N. Advancing Earth and Space Science (AGU100). 18(6): 2240-2274.

Anderson, M.O., Hannington, M.D., McConachy, T.F., and Jamieson, J.W., 2018: Integrating geophysical and geochemical data to understand the relationships between geodynamics, volcanism, and massive sulfide formation in back-arc basins. Society of Economic Geologists. Conference Keystone Colorado, USA, 22-25 September, 2018. S09.03. Oral presentation.

Anderson, M.O., Chadwick, W.W. Jr., Merle, S.G., Resing, J.A., Baker, E.T., Walker, S.L., Hannington, M.D., Augustin, N., 2017: Relationship between tectonism, volcanism, and hydrothermal venting along the Mariana back-arc spreading center between 12.7˚N and 18.3˚N. AGU Chapman Conference on Submarine Volcanology, Hobart, Australia, 29 January - 3 February 2017. Invited.

Anderson, M.O., Hannington, M.D., and McConachy, T.F., 2019: Metallogeny of modern back-arc basins from regional to local scales. Annual Prospectors and Developers Convention, Special Session on Seafloor Mining, Metro Toronto Convention Centre, Toronto, Ontario, 6 March 2019. Invited.

Anderson, M.O., Hannington, M.D., McConachy, T.F., and Jamieson, J.W., 2019: Subseafloor alteration of a modern seafloor massive sulphide deposit hosted in primary volcaniclastic rocks. Geological Association of Canada Annual Meeting, Québec City, Québec, 12-15 May 2019.

Baker, E.T., Walker, S.L, Resing, J.A., Chadwick, W.W. Jr., **Anderson**, M.O., Merle, S.G., and Butterfield, D.A., 2018: Hydrothermal activity along back-arc spreading centers: The importance of arc proximity. Ocean Sciences Meeting, Portland, Oregon, USA, 11–16 February 2018. Poster presentation.

Haase, K., Haase, K.M., Beier, C., Bach, W., Kleint, C., **Anderson**, M., et al., 2018: RV Sonne, Cruise SO263 Tonga Rift, Suva, Fiji – Suva, Fiji, 01.06.2018-27.06.2018, GeoZentrum Nordbayern, Friedrich-Alexander Universität Erlangen-Nürnberg, p. 222.

Anderson, M.O., 2018, Relationships Between Tectonics, Volcanism, and Hydrothermal Venting in the New Hebrides and Mariana Back-Arc Basins, Western Pacific. University of Ottawa, 363 p. (with Appendices 1036 p.) Unpublished Ph.D. Thesis.

Modern Ocean Crust Project (Metal Oceans) Topic 6

Fassbender, M.L., Hannington M.D., and Stewart, M.S., 2019: Volcanic rock geochemistry of the Lau Basin: Unexpected complexity of active back-arc spreading centres. PDAC-SEG Student Minerals Colloquium, Toronto, Ontario, 5 March 2019. Poster presentation.

Fluid Source and Pathways Project

Quesnel, B., Scheffer, C., Beaudoin, G., LaFlamme, C., Guilmette, C., Dupuis, C., 2018: Metal Earth: Vers une réévaluation pluridisciplinaire des modèles de genèse des gisements métallifères précambriens. Québec Mines, Québec City, Québec, 19-22 novembre 2018. Poster presentation.

Mantle Group

Luguet, A., Pearson, D.G., 2019: Dating mantle peridotites using Re-Os isotopes: The complex message from whole rocks, base metal sulfides and platinum group minerals. American Mineralogist. 104: 165-189. February 2019.

Nicklas, R.W., Puchtel, I., Ash, R.D., Piccoli, P.M., Hanski, E., Nisbet, E.G., Waterton, P., Pearson, D. G., Anbar, A., 2019: Secular mantle oxidation across the Archean-Proterozoic boundary: Evidence from V partitioning in komatiites and picrites. Geochimica Cosmochimica Acta, 250: 49–75. February 2019.

Reimink, J. R., Pearson, D.G., Shirey, S.B., Carlson, R.W., Ketchum, J.W.F., 2019: Onset of new, progressive crustal growth in the central Slave craton at 3.5 Ga. Geochemical Perspectives Letters, 10, 7-12. February 2019.

Vezinet, A., Pearson, D.G., Thomassot, E., Stern, R.A., Luo, Y., Sarkar, C., 2018: Generation of early continental crust: A billion years of TTG evolution from the Eoarchean Saglek Block, Canada. Goldschmidt Conference, Boston, USA, August 2018. Oral presentation.

Reimink, J., Shirey, S.B., Carlson, R.W., Pearson D.G., 2018: The diverse origins of cratonic nuclei-a perspective from the Slave Craton. Goldschmidt Conference, Boston, USA, August 2018. Oral presentation.

Luguet, A., Pearson D.G., 2018: Dating mantle peridotites: What do whole rock and mineral Re-Os isotopic signatures tell us? Goldschmidt Conference, Boston, USA, August 2018. Oral presentation. Invited.

Mantle Group PDF Topic 1

Vezinet, A., Pearson, D.G., Thomassot, E., Stern, R.A., Sarkar, C., Luo, Y., Fisher, C.M., 2018: Hydrothermally-altered mafic crust as source for early Earth TTG: Pb/Hf/O isotope and trace element evidence in zircon derived from TTG of the Eoarchean Saglek Block, N. Labrador. Earth & Planetary Science Letters, 503: 95-107.

Vezinet, A., Pearson, D.G., Thomassot, E., Stern R.A., Luo. Y., Sarkar, C., 2018: Generation of early continental crust: A billion years of TTG evolution from the Eoarchean Saglek Block, Canada. Goldschmidt Conference, Boston, USA, August 2018. Oral presentation.

Chibougamau Transect

Mathieu, L., Racicot, D., 2019: Petrogenetic study of the multiphase Chibougamau pluton: Archaean magmas associated with Cu–Au magmato-hydrothermal systems. Minerals – Multidisciplinary Open Access Journal (MDPI). 9(3): 174-209.

Mathieu, L., 2019: Origin of the vanadiferous serpentine–magnetite rocks of the Mt. Sorcerer area, Lac Doré layered intrusion, Chibougamau, Québec. Geosciences – MDPI. 9(3): 110-146.

Mathieu, L., 2018: The structure of composite volcanoes unravelled by analogue modeling: A review. Journal of Structural Geology. SI:JSG - 40th Anniversary.

Mathieu, L., 2018: Quantifying hydrothermal alteration: A review of methods. Geosciences – MDPI. Special Issue. 8(245).

Mathieu, L., Lafrance, B., Sherlock, R.L., Gibson, H.L., Ayer, J., Thurston, P.C., Daigneault, R., Bédard, L.P., Gaboury, D., Naghizadeh, M., Perrouty, S., Feltrin, L., Smith, R., Beaudoin, G., Hamilton, M.A., Hannington, M.D., Pearson, D.G., 2018: Le projet Metal Earth: une initiative de recherche en exploration minérale en 4D. Géologues, revue de la SGF.

de Souza, S., Mathieu, L., 2018: Éléonore et Canadian Malartic, exemples de découvertes et défis en exploration minérale au Québec. Géologues, revue de la SGF. (198): 46-51.

Mathieu L., Trépanier S., Daigneault R., Jébrak M., 2017: Quantifying hydrothermal alteration in exploration contexts. Proceeding of the 14th SGA Biennial Meeting, Québec City, Québec, 20-23 August 2017. p 1143-1146.

Mathieu, L., Trépanier, S., 2018: Quantifier l'altération hydrothermale: Outils théoriques et pratiques. Xplor - Congrès de l'exploration minière du Québec, Montréal, Québec, octobre 2018. Short course. Invited.

Mathieu, L., Bedeaux, P., Boucher, A., Youssoufou, Y. A., Keiffer, M., Huguet, J., Madon, B., Daigneault, R., Gaboury, D., Bédard, P., 2018: Metal Earth à Chibougamau. Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Poster presentation.

Mathieu, L., 2018: Contamination of layered intrusions: The Lac Doré Complex example. Goldschmidt Conference. Boston, États-Unis, 12-17 août 2018. Oral presentation.

Mathieu, L., Sherlock, R.L., Lafrance, B., Gibson, H.L., Daigneault, R., Bédard, P., Gaboury, D.; 2018: Le projet Metal Earth à Chibougamau. Forum Technologique Consorem-Divex, Val d'Or, Québec, mai 2018. Oral presentation. Invited.

Mathieu, L., Lafrance, B., Gibson, H.L., Ayer, J., Thurston, P.C., Sherlock, R.L., Daigneault, R., Bédard, P., Gaboury, D., Goutier, J., Pilote, P., 2018: Le projet Metal Earth: Facteurs influant sur la distribution de l'or à l'Archéen. Congrès de l'ACFAS, Chicoutimi, Québec, 7-11 mai 2018. Oral presentation.

Mathieu, L., Daigneault, R., 2017: Optimisation des mailles de forages pour les besoins du calcul de ressources. Conférence Québec Mines, Québec, Québec, novembre 2017. Poster presentation.

Goutier, J., Mathieu, L., Beauchamp, A.M., 2017: Minéralisations et altérations en terrains métamorphisés: Exemple de la Baie-James. Conférence Québec Mines, Québec, novembre 2017. Poster presentation.

Mathieu, L., Trépanier, S., Daigneault, R., Jébrak, M., 2017: Quantifying hydrothermal alteration in exploration contexts.

SGA - Society for Geology Applied to Mineral Deposits (SGA), abstract 173-R3un-272, Québec, 20-23 août 2017. Poster presentation.

Chibougamau Transect PDF Topic 1

Bedeaux, P., Mathieu, L., Daigneault, R., 2018: Metal Earth à Chibougamau: Cartographie du transect de Chibougamau: projet Metal Earth: styles structuraux de la Faille de Barlow et du bassin de Chébistuan. Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Poster presentation.

Chibougamau Transect M.Sc. Topic 1

Boucher, A., Mathieu, L., Daigneault, R., 2018: Metal Earth à Chibougamau: Stratigraphie, chimie et age de la formation d'Obatogamau. Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Poster presentation.

Chibougamau Transect M.Sc. Topic 2

Kieffer, M., Mathieu, L., Gaboury, D., 2018: Metal Earth à Chibougamau: Synthèse cartographique de l'indice Moly-Desgagné: Déformation et métamorphisme (Complexe à l'Eau Jaune, région de Chibougamau, Québec). Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Poster presentation.

Chibougamau Transect M.Sc. Topic 3

Huguet, J., Mathieu, L., Bédard, P., 2018: Metal Earth à Chibougamau: Pluton de Chevrillon, homogénéité et relation à la déformation (Chibougamau, Québec). Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Poster presentation.

Chibougamau Transect M.Sc. Topic 4

Youssoufou, Y. A., Mathieu, L., Gaboury, D., 2018: Metal Earth à Chibougamau: Origine du sodagranophyre du Complexe du Lac Doré (CLD) et minéralisations associées, région de Chibougamau, Abitibi (Québec). Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Poster presentation.

Malartic Transect

Zhou, X., Lafrance, B., 2018: Stratigraphic and structural investigations near major deformation zones in the Malartic transect area, southern Abitibi Subprovince and Pontiac Subprovince, Québec. Metal Earth 2018 Fieldwork Summary.

Zhou, X., Lafrance, B., 2018: Fault kinematics and structural evolution along the Amos-Malartic transect in the Southern Abitibi and Pontiac Subprovinces, Québec. Canadian Tectonics Group Meeting, Victoriaville, Québec. Poster presentation.

Malartic Transect M.Sc. Topic 1

Samson, B., Lafrance, B., Zhou, X., 2018: Regional folding, quartz veining and gold mineralization in a successor basin in the Abitibi greenstone belt, Malartic, Québec. Canadian Tectonics Group meeting. Victoriaville, Québec. Oral presentation.

Samson, B., Lafrance, B., Zhou, X., 2018: Structural geology of the Timiskaming and Cadillac groups along the Malartic segment of the Larder Lake-Cadillac deformation zone and implications for gold mineralization, Abitibi greenstone belt, northwestern Québec. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation.

Samson, B., Lafrance, B., and Zhou, X., 2019. The implications of a granodiorite intrusion within the Cadillac – Timiskaming

basin and the effects of regional folding. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation.

Malartic Transect M.Sc. Topic 2

Shirriff, D., Lesher, C.M., Lafrance, B., Zhou, X., 2019: Mobilization of Ni-Cu-(PGE) mineralization at the Cubric showing in the La Motte-Vassan Formation, La Motte, Québec. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation.

Shirriff, D., Lesher, C.M., Lafrance, B., Zhou, X., 2019: Mobilization of Ni-Cu-(PGE) mineralization at the Cubric showing in the Southern Manneville fault zone, southern Abitibi Subprovince, Québec. GAC-MAC-IAH Québec 2019 Joint Meeting. Québec City, Québec, 12-15 May, 2019. Oral presentation.

Rouyn-Noranda Transect

Jørgensen, T.R.C., Gibson, H.L., Hamilton, M.A., 2018: U-Pb zircon geochronology and geochemistry of volcanic rocks in the Deguisier Formation, Abitibi Greenstone Belt, Québec: Implications for gold and VMS mineralization. Society of Economic Geology (SEG) Conference 2018 – Metals, Minerals and Society, Keystone, USA, 22-25 September 2018. MERC-ME-2018-042. Poster presentation.

Jørgensen, T.R.C., Tinkham, D.K., and Lesher, C.M., 2018: The origin of inclusions in the contact sublayer of the Sudbury Igneous Complex, Ontario. Society of Economic Geology (SEG) Conference 2018 – Metals, Minerals and Society, Keystone, USA, 22-25 September. MERC-ME-2018-044. Poster presentation.

Schofield, M.A., Rehm, A., Sutton, J.C., Bradley, A.M., Paleczny, A.T., Jørgensen, T.R.C., Gibson, H.L., 2018: Rouyn-Noranda – A look at old and new styles of mineralization. MERC-ME-2018-043.

Rouyn-Noranda Transect Ph.D. Topic 1

Schofield, M.D., Lafrance, B., Poulsen, K.H., Gibson, H.L., 2019: The Powell fault, Rouyn-Noranda, Québec: Evidence for a synvolcanic origin. 10th annual PDAC - SEG Student Minerals Colloquium, Toronto, Ontario, 5 March, 2019. MERC-ME-2019-158. Poster presentation.

Schofield, M.D., Gibson, H.L., Lafrance, B., Poulsen, K.H., 2018: Preliminary results from detailed geological mapping of the Powell Block, Rouyn-Noranda area, Québec. Society of Economic Geology (SEG) Conference 2018 – Metals, Minerals and Society, Keystone, USA, 22-25 September 2018. MERC-ME-2018-045. Poster presentation.

Schofield, M.A., Rehm, A., Sutton, J.C., Bradley, A.M., Paleczny, A.T., Jørgensen, T.R.C., Gibson, H.L., 2018: Rouyn-Noranda – A look at old and new styles of mineralization. MERC-ME-2018-043.

Rouyn-Noranda Transect M.Sc. Topic 1

Schofield, M.A., Rehm, A., Sutton, J.C., Bradley, A.M., Paleczny, A.T., Jørgensen, T.R.C., Gibson, H.L., 2018: Rouyn-Noranda – A look at old and new styles of mineralization. MERC-ME-2018-043.

Rouyn-Noranda Transect M.Sc. Topic 2

Sutton, J.C., Gibson, H.L., Jørgensen, T.R.C., Hamilton, M.A., 2018: Volcanic reconstruction of the ca. 2701 Ma Duprat-Montbray formation: Implications for targeting new volcanogenic massive sulfide (VMS) deposits in the Lower Blake River Group, Rouyn-Noranda, Québec. 10th annual PDAC - SEG Student Minerals Colloquium, Toronto, Ontario, 5 March,

2019. MERC-ME-2019-111. Poster presentation.

Sutton, J.C., Gibson, H.L., Jørgensen, T.R.C., Hamilton, M.A., 2018: Volcanic reconstruction of the ca. 2701 Ma Duprat-Montbray formation: implications for targeting new volcanogenic massive sulfide deposits in the Lower Blake River Group, Rouyn-Noranda, Québec. Association for Mineral Exploration (AME) Roundup 2019, Vancouver, British Columbia, Jan 28-31 January 2019. MERC-ME-2019-107. Poster presentation.

Schofield, M.A., Rehm, A., Sutton, J.C., Bradley, A.M., Paleczny, A.T., Jørgensen, T.R.C., Gibson, H.L., 2018: Rouyn-Noranda – A look at old and new styles of mineralization. MERC-ME-2018-043.

Ben-Nevis – Larder Lake Transect

Cheraghi, S., Naghizadeh, M., Snyder, D., Haugaard, R., Rubingh, K.E., and Gemmell, T., 2019: High resolution seismic imaging of crooked 2D profiles in Greenstone Belts of the Canadian Shield: Preliminarily results from the Swayze and Larder Lake areas, Ontario, Canada. Journal of Geophysical Prospecting. Manuscript accepted, in review.

Sherlock, R.L., and Rubingh, K.E., 2018: Geologic and geophysical expression of variably metal endowed fault systems in the Larder Lake area of the southern Abitibi, Ontario, Canada: Preliminary results of the Metal Earth project. Society of Economic Geology (SEG) Conference 2018 – Metals, Minerals and Society, Keystone, USA, 22-25 September 2018. Oral presentation.

Sherlock, R.L., Rubingh, K.E., and the Metal Earth research team, 2018: Geologic architecture and precious metal mineralization in the Southern Abitibi: New insights from the Larder Lake area. MERC-ME-2018-104. Association for Mineral Exploration British Columbia (AME) Mineral Exploration Roundup 2019, Vancouver, British Columbia, 28-31 January 2019. Oral presentation.

Sherlock, R.L., Rubingh, K.E., and the Metal Earth research team, 2019: Variably metal endowed fault systems in the Larder Lake area. MERC-ME-2018-105. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Oral presentation.

Brace, S., St-Jean, N., and Rubingh, K.E., 2018: Ben Nevis – Larder Lake field trip guide. MERC-ME-2018-043_B.Mineral Exploration Research Centre, Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada.

Rubingh, K.E., 2018: Structural and stratigraphic framework of the Larder Lake area: Insights from new mapping, geochronology, and geophysics. Northeastern Ontario Mines and Minerals Symposium, Kirkland Lake, Ontario, 16-18 October, 2018. Oral presentation.

Rubingh, K.E., 2019. Structural and stratigraphic framework of the Larder Lake area: Insights from new mapping, geochronology and geophysics. Metal Earth Advisory Board Meeting, Toronto, Ontario, March 25, 2019. Oral presentation.

Ben-Nevis – Larder Lake Transect M.Sc. Topic 1

St-Jean, N., Sherlock, R.L., Lafrance, B., 2018: Volcanic stratigraphy and structural framework of the Kerr–Addison deposit: Implications for gold mineralization. Society of Economic Geology (SEG) Conference 2018 – Metals, Minerals and Society, Keystone, USA, 22-25 September 2018. Poster presentation.

Brace, S., St-Jean, N., Rubingh, K.E., 2018: Ben Nevis – Larder Lake field trip guide. MERC-ME-2018-043_B. Mineral Exploration Research Centre, Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario.

Ben-Nevis – Larder Lake Transect M.Sc. Topic 2

Brace, S., St-Jean, N., and Rubingh, K.E., 2018: Ben Nevis – Larder Lake field trip guide publication. MERC-ME-2018-043_B. Mineral Exploration Research Centre, Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario.

Cobalt Transect

White, S.E., **Thurston, P.C.**, Santaguida, F., 2018: Stratigraphic and structural history of the Cobalt region, Ontario: Controls on mineralized veins. Congrès Québec Mines et Énergie, Québec City, Québec, 19-22 novembre 2018. Oral presentation.

White, S.E., Sherlock, R.L., 2018: Structure and stratigraphy of Archean volcanic units and the Paleoproterozoic Cobalt Group near Cobalt, Ontario. Canadian Tectonics Group (CTG). Poster presentation.

Swayze Transect

Hill, G., Roots, E., Frieman, B., Haugaard, R., Smith, R., 2019: An integrated approach to characterising the mantle and lower crustal conditions and processes responsible for the distribution of mineral endowment within Archean greenstone belts. Association for Mineral Exploration British Columbia (AME) Mineral Exploration Roundup 2019, Vancouver, British Columbia, 28-31 January 2019. Oral presentation.

Haugaard, R., Gemmell, T., Ayer, J., Thurston, P., 2018: The nature and provenance of the sedimentary basins of the Swayze Area, Abitibi Greenstone Belt. Society of Economic Geology (SEG) Conference 2018 – Metals, Minerals and Society, Keystone, USA, 22-25 September. Poster presentation.

Haugaard, R., 2019: Sedimentary basins of the Swayze area, Abitibi Greenstone Belt: provenance, timing and facies association. GAC-MAC-IAH Québec 2019 Joint Meeting. Québec City, Québec, 12-15 May, 2019. Oral presentation.

Haugaard, R., Gemmell, T., Ayer, J., Thurston, P., March, J., Hamilton M.A., 2018: Lithological and stratigraphic constraints through the Swayze Area, Abitibi Greenstone Belt. Ontario Prospectors Association (OPA) 2018 Northeastern Ontario Mines & Minerals Symposium. Kirkland Lake, Ontario, 16-18 October, 2018. Oral presentation of MERC short course.

Swayze Transect Ph.D. Topic 1

Gemmell, T., Haugaard, R., Gibson, H., 2019: Metavolcanic evolution of the Swayze area, Abitibi greenstone belt: Observations. 10th annual PDAC - SEG Student Minerals Colloquium, Toronto, Ontario, 5 March, 2019. Poster presentation.

Geraldton-Onaman Transect

Strongman, K.R., Gibson, H.L., **Tóth, Z.**, 2018: Preliminary Results from geological mapping of the volcanic stratigraphy of the Elmhirst– Rickaby and Humboldt Assemblages, Onaman–Tashota greenstone belt; in Summary of Fieldwork and Other Activities, 2018. Ontario Geological Survey, Open File Report 6350; pp. 33-1 – 33-7. MERC-ME-2018-083.

Tóth, Z., Strongman, K.R., 2018: Geraldton-Onaman transect – Deformation and mineralization styles. Publication #MERC-ME-2018-043_E; 16p.

Geraldton-Onaman Transect Ph.D Topic 1

Strongman, K.R., Gibson, H.L., Lafrance, B., 2019: The metallogeny, volcanic stratigraphy, and geodynamic evolution of the Elmhirst-Rickaby episode: An Archean andesitic package. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation. Publication # MERC-ME-2019-160.

Dryden-Stormy Lake Transect

Perrouty, S., NSERC-CMIC Footprint Team, CFREF Metal Earth Team, 2019: Innovations for gold exploration in Precambrian greenstone belts: Highlights from the Footprints and Metal Earth programs and potential applications to the Guiana Shield. 11th Inter Guiana Geological Conference, Paramaribo, Suriname, 19-20 February 2019. Extended abstract. 4 p. Oral presentation.

Dryden-Stormy Lake Transect Ph.D. Topic 1

Montsion, R.M., Perrouty, S., Frieman, B.M., 2019: Optimization of GIS-based structural variability analysis for Archean greenstone belts: A case study in the western Wabigoon subprovince, Ontario. PDAC-SEG Student Minerals Colloquium, Toronto, Ontario, 5 March 2019. Poster presentation.

Dryden-Stormy Lake Transect M.Sc. Topic 1

Downie, D., Frieman, B.M., Perrouty, S., 2019: Raiders of the lost lake: New perspective for intrusion-related gold exploration in the western Wabigoon subprovince, Ontario. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Abstracts with Programs. Oral presentation.

Dryden-Stormy Lake Transect M.Sc. Topic 2

Zammit, K., Frieman, B.M., Perrouty, S., 2019: Preliminary results from regional mapping and petrographic analysis of mineralized and barren deformation zones in the western Wabigoon subprovince. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Abstracts with Programs. Abstracts with Programs. Poster presentation.

Dryden-Stormy Lake Transect M.Sc. Topic 3

Mavundza, A., Perrouty, S., Frieman, B.M., 2019: Characterizing the magnetic responses of felsic-intermediate intrusions in the western Wabigoon subprovince. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Abstracts with Programs. Poster presentation.

GEOPHYSICS PROJECTS

Gravity and Magnetics

Hill, G., Roots, E., Frieman, B., Haugaard, R., Smith, R., 2019: An integrated approach to characterising the mantle and lower crustal conditions and processes responsible for the distribution of mineral endowment within Archean greenstone belts. Association for Mineral Exploration (AME) Roundup, Vancouver, British Columbia, Jan 28-31 January 2019.

Smith, R., Eshaghi, E., Cheraghi, S., Naghizadeh, M., Roots, E., Hill, G., 2018: La géophysique dans le cadre du projet Metal Earth pour mieux comprendre l'enrichissement en métaux des roches précambriennes. Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Invited.

Eshaghi, E., Haugaard, R., Jørgensen, T.R.C., Zhou, X., Gibson, H.L., Sherlock, R.L., Lafrance, B., Ayer, J., Thurston, P.C., and Smith, R.S., 2018: Metal Earth: A multidisciplinary ore deposit research project to improve our understanding of metal endowment in Precambrian rocks. Resources for Future Generations (RFG) Conference 2018, Vancouver, British

Columbia, 6 June, 2018. Oral presentation.

Smith, R., Mir, R., Perrouty, S., 2018: Geophysical exploration for mineral systems: Highlights from the NSERC-CMIC Footprints Project and CFREF Metal Earth Project. British Columbia Geophysical Society Fall Symposium, Vancouver, British Columbia, 12 October 2018. Oral presentation.

Gravity and Magnetics M.Sc. Topic 1

Maleki, A., Eshaghi, E., Smith, R., Altwegg, P., Snyder, D., Mathieu, L., Naghizadeh, M., 2019: Potential field data modelling along Metal Earth's Chibougamau transect using geophysical and geological constraints. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation.

Gravity and Magnetics M.Sc. Topic 2

McNeice, W., Eshaghi, E., Smith, R., 2019: Comparing magnetic susceptibilities derived from aeromagnetic data and outcrop scale measurements in the western Abitibi greenstone belt. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation.

McNeice, W., Eshaghi, E., Smith, R., 2019: Comparing magnetic susceptibilities derived from aeromagnetic data and outcrop scale measurements in the western Abitibi greenstone belt. Condor Consulting Ltd. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Oral presentation.

Magnetotellurics

Hill, G., Roots, E., Frieman, B., Haugaard, R., Smith, R., 2019: An integrated approach to characterising the mantle and lower crustal conditions and processes responsible for the distribution of mineral endowment within Archean greenstone belts. Association for Mineral Exploration (AME) Roundup 2019, Vancouver, British Columbia, Jan 28-31 January 2019.

Smith, R., Eshaghi, E., Cheraghi, S., Naghizadeh, M., Roots, E., Hill, G., 2018: La géophysique dans le cadre du projet Metal Earth pour mieux comprendre l'enrichissement en métaux des roches précambriennes. Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Invited.

Eshaghi, E., Haugaard, R., Jørgensen, T.R.C., Zhou, X., Gibson, H.L., Sherlock, R.L., Lafrance, B., Ayer, J., Thurston, P.C., and Smith, R.S., 2018: Metal Earth: A multidisciplinary ore deposit research project to improve our understanding of metal endowment in Precambrian rocks. Resources for Future Generations (RFG) Conference 2018, Vancouver, British Columbia, 06 June, 2018. Oral presentation.

Smith, R., Mir, R., Perrouty, S., 2018: Geophysical exploration for mineral systems: Highlights from the NSERC-CMIC Footprints Project and CFREF Metal Earth Project. British Columbia Geophysical Society Fall Symposium, Vancouver, British Columbia, 12 October 2018. Oral presentation.

Geophysics Ph.D. Topic 1

Lawley, C., Kjarsgaard, B., Jackson, S., Yang, Z., Petts, D., Roots, E., 2018: Trace metal and isotopic depth profiles through the Abitibi cratonic mantle. Lithos 314–315, 520–533.

Roots, E., Craven, J.A., Rainbird, R., Smith, R., 2018: Structurally constrained inversion in geochron space. Prospectors & Developers Association of Canada (PDAC) Conference, Toronto, Ontario, 3-6 March 2019. Poster presentation.

Roots, E., Hill, G.J., Frieman, B.M., Craven, J.A., 2018: Preliminary results of the Metal Earth magnetotelluric survey. American

Geophysical Union, Fall General Assembly, Washington, USA, 10-14 December 2018. Oral presentation.

Hill, G.J., Roots, E., Frieman, B., Haugaard, R., Smith, R., 2019: An integrated approach to characterising the mantle and lower crustal conditions and processes responsible for the distribution of mineral endowment within Archean greenstone belts. Association for Mineral Exploration (AME) Roundup 2019, Vancouver, British Columbia, Jan 28-31 January 2019. Oral presentation.

Seismic R1 and R2 Processing and Interpretation

Naghizadeh, M., Snyder, D., Cheraghi, S., Foster, S., Cilensek, S., Floreani, E., Mackie, J., 2019: Acquisition and processing of wider bandwidth seismic data in crystalline crust: Progress with the Metal Earth project. Minerals – Multidisciplinary Open Access Journal (MDPI). No.3, 145.

Naghizadeh, M., 2019: The Metal Earth project: Crustal scale reflection seismic study of the Archean Superior Province of Canada. Recorder, Canadian Society of Exploration Geophysicists. Vol. 44:4.

Haghshenas L.H., **Naghizadeh**, M., Sacchi, M., Gholami, A., 2019: Adaptive singular spectrum analysis for seismic denoising and interpolation. Geophysics. 84(2): V133-V142.

Eshaghi, E., Smith, R., **Naghizadeh**, M., Hill, G., Root, E., Maleki, A., Cheraghi, S., Ayer, J., 2019: Metal Earth: Role of multidisciplinary geophysical methods to improve knowledge of mineral deposition across Precambrian rocks. Australian Society of Exploration Geophysicists (AEGS) Conference, Perth, Australia, 18-21 February 2018. Oral presentation.

Jodeiri, A.F.H., **Naghizadeh**, M., 2018: Multi-focusing stacking using the very fast simulated annealing global optimization algorithm. GeoConvention 2018, Calgary, Canada, 7-11 May 2018. Oral presentation.

Seismic R2 Processing

Cheraghi, S., Naghizadeh, M., Snyder, D., Haugaard, R., Rubingh, K.E., Gemmel, T., 2019: High resolution seismic imaging of crooked 2D profiles in Greenstone Belts of the Canadian Shield: Preliminarily results from the Swayze and Larder Lake areas, Ontario, Canada. Geophysical Prospecting. Under review.

Cheraghi, S., Naghizadeh, M., Snyder, D., 2018: Crustal-scale seismic investigation in Chibougamau, Canada. European Association of Geoscientists & Engineers (EAGE). Workshop: Worldwide Mineral Exploration Challenges and Cost-effective Geophysical Methods. Porto, Portugal, 9-13 September 2018. Oral presentation.

Seismic Ph.D. Topic 1

Yilmaz, O., Mavko, G., **Jodeiri, H.**, 2018: Seismic response of soft water-bottom sediments. Society of Exploration Geophysicists, The Leading Edge. 37(10): 746–751.

Jodeiri, H., Naghizadeh, M., 2019: Multi-focusing stacking technique: A robust method of improving subsurface seismic imaging. PDAC-SEG Student Minerals Colloquium, Toronto, Ontario, 5 March 2019. Poster presentation.

Yilmaz, O., Mavko, G., **Jodeiri, H.**, 2018: Seismic response of soft water-bottom sediments. PDAC-SEG Student Minerals Colloquium, Toronto, Ontario, 5 March 2019. SEG Technical Program Expanded Abstracts 2018: pp. 4753-4757. Oral presentation.

Localization of Ni-Cu-(PGE) Mineralization

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2019: Volcanology, geochemistry, and petrogenesis of the Expo-Raglan magmatic system in the Eastern Cape Smith Belt, Nunavik, northern Québec. Targeted Geoscience Initiative: 2018 report of activities. Geological Survey of Canada, Open File 8549, Volume 1: 393–401.

McKevitt, D.J., Houlé, M.G., Lesher, C.M., 2018: Investigation of ultramafic to mafic komatiitic units within the Raglan Block within the Cape Smith Belt, Nunavik, northern Québec. Targeted Geoscience Initiative: 2017 report of activities. Geological Survey of Canada, Open File 8358, Volume 1: 169–172.

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2019: Geology, geochemistry and petrogenesis of the Expo-Ungava–Raglan dike, sill and lava-channel system in the Paleoproterozoic Cape Smith Belt, Northern Nunavik, Québec. Metal Earth Summary of Fieldwork. Submitted for publication.

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2018: Geology and geochemistry of mafic-ultramafic sills in the Northern Permits, Raglan Ni-Cu-(PGE) District, Cape Smith Belt, Nunavik, Québec. Geological Survey of Canada, Scientific Presentation 90.

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2019: Anatomy of the Ni-Cu-(PGE) mineralized Expo-Raglan magmatic system in the Early Proterozoic Cape Smith belt, Québec, Canada. GAC-MAC-IAH Québec 2019 meeting, No. SS-RE14-O13. Abstract accepted for oral presentation.

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2018: Geology and geochemistry of the Raglan-Expo magmatic Ni-Cu-(PGE) system, Cape Smith Belt, Nunavik, Québec. Congrès Québec Mines et Énergie, Québec, 19-22 novembre 2018. Abstracts of oral presentations and posters. Poster presentation.

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2018: Anatomy of the Ni-Cu-(PGE) mineralized Expo-Raglan dike-sill-lava channel system in the early Proterozoic Cape Smith Belt, Nunavik, Québec. Geological Society of America. Abstracts with Programs, Vol. 50(6), Paper #151-7. Oral presentation.

McKevitt, D.J., Lesher, C.M., Houlé, M.G., 2017: Geology and geochemistry of mafic-ultramafic sills in the northern permits, Raglan Ni-Cu-(PGE) District, Cape Smith Belt, Nunavik, Québec. Congrès Québec Mines et Énergie, Québec, 20-23 novembre 2017. Abstracts of oral presentations and posters. Poster presentation.

Mineralogical Indicators of Oxidation / Reduction

Small, C.R., McDonald, A.M., Hastie, E.C.G., 2019: The Rundle Intrusive Complex: Investigating oxidation processes related to gold mineralization in an Archean alkaline intrusive setting. 10th annual PDAC - SEG Student Minerals Colloquium, Sudbury, Ontario, 5 March, 2019. Poster presentation.

Tectonothermal Evolution

Estrada, N., Tinkham, D.K., Jørgensen, T.R.C., 2019: Preliminary investigation of partial melting relationships to identify the behavior of metals during high-grade metamorphism, Kapuskasing Structural Zone, Ontario, Canada. 10th annual PDAC - SEG Student Minerals Colloquium, Sudbury, Ontario, 5 March, 2019. MERC-ME-2019-151. Poster presentation.

APPENDIX E: RESOURCES

DOWNLOADABLE REPORTS AND PAPERS

TRANSECT SCALE PROJECTS

Project: CHIBOUGAMAU TRANSECT PDF TOPICS 1 AND 2
Title: *Preliminary results of summer 2018 fieldwork focused on the Chibougamau transect area as part of the Metal Earth project*
Link: https://merc.laurentian.ca/sites/default/files/paper_9_bedeaux_final_english.pdf

Project: CHIBOUGAMAU TRANSECT M.SC. TOPIC 1
Title: *Mapping in the southern part of the Chibougamau transect, focusing on the stratigraphy of the Obatogamau Formation*
Link: https://merc.laurentian.ca/sites/default/files/paper_5_boucher_final_english.pdf

Project: CHIBOUGAMAU TRANSECT M.SC. TOPIC 2
Title: *Geometry, geochemistry and manner of emplacement of the Eau Jaune Complex, Chibougamau region, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_8_kieffer_final_english.pdf

Project: CHIBOUGAMAU TRANSECT M.SC. TOPIC 3
Title: *Mineralogical and chemical characterization of the Chevrillon pluton and relationship with its sedimentary host, Chibougamau area, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_6_huguet_final_english.pdf

Project: CHIBOUGAMAU TRANSECT M.SC. TOPIC 4
Title: *Origin of the Lac Doré Complex 'sodagranophyre' and related mineralizations, Chibougamau Region, Abitibi Subprovince, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_7_ahmadou_final_english.pdf

Project: MALARTIC TRANSECT
Title: *Stratigraphic and Structural Investigations near Major Deformation Zones in the Malartic Transect Area, Southern Abitibi and Pontiac Subprovinces, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_3_zhou_final_english.pdf

Project: MALARTIC TRANSECT M.SC. TOPIC 1
Title: *Regional Folding, Quartz Veining and Gold Mineralization in a Metasedimentary Basin along the Malartic Segment of the Larder Lake–Cadillac Deformation Zone, Abitibi Greenstone Belt, Quebec*

Link: https://merc.laurentian.ca/sites/default/files/paper_2_samson_final_english.pdf

Project: MALARTIC TRANSECT M.SC. TOPIC 2
Title: *Lithological and Structural Setting of the Cubric Ni-Cu- (PGE) Showing, Southern Abitibi Subprovince, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper1_shirriff_final_english.pdf

Project: ROUYN-NORANDA TRANSECT PH.D. TOPIC 1
Title: *Quartz-Sulphide Mineralization and Associated Spotted Alteration within the Powell Block, Rouyn- Noranda, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_10_schofield_final_english.pdf

Project: ROUYN-NORANDA TRANSECT M.SC. TOPIC 2
Title: *Preliminary Description of the Volcanic-Intrusive Setting of the Duprat–Montbray Formation, Lower Blake River Group, Rouyn-Noranda, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_4_sutton_final_english.pdf

Project: BEN-NEVIS – LARDER LAKE TRANSECT
Title: *Preliminary Results from Detailed Geological Mapping of the Stratigraphic and Structural Framework of the Hearst Assemblage, and the Nature of the Lincoln-Nipissing Shear Zone, Skead Township, Northeastern Ontario*
Link: https://merc.laurentian.ca/sites/default/files/6350-40_rubingh_et_al_me.pdf

Project: BEN-NEVIS – LARDER LAKE TRANSECT M.SC. TOPIC 1
Title: *Regional and Detailed Structural Mapping of the Timiskaming Assemblage–Larder Lake Group Contact Between the Kerr–Addison and Cheminis Mine Sites, Northeastern Ontario*
Link: https://merc.laurentian.ca/sites/default/files/6350-41_st-jean_et_al_me.pdf

Project: BEN-NEVIS – LARDER LAKE TRANSECT M.SC. TOPIC 2
Title: *Geological Mapping of Timiskaming-age Intrusions Along the Lincoln–Nipissing Shear Zone, Larder Lake, Ontario*
Link: https://merc.laurentian.ca/sites/default/files/6350-39_brace_et_al_me.pdf

Project: MATHESON TRANSECT
Title: *Lithological and Stratigraphic Relationships of the North Swayze and Matheson Areas, Abitibi Greenstone Belt*
Link: https://merc.laurentian.ca/sites/default/files/6350-43_haugaard_et_al_me.pdf

Project: SWAYZE TRANSECT
Title: *Lithological and Stratigraphic Relationships of the North Swayze and Matheson Areas, Abitibi Greenstone Belt*
Link: https://merc.laurentian.ca/sites/default/files/6350-43_haugaard_et_al_me.pdf

Project: SWAYZE TRANSECT M.SC. TOPIC 1
Title: *Base Metal Mineralization Associated with the Woman River Iron Formation, with a Focus on the Jefferson and Stackpool Prospects, Marion and Genoa Townships, Swayze Area, Abitibi Greenstone Belt*
Link: https://merc.laurentian.ca/sites/default/files/6350-44_mowbray_et_al_me.pdf

Project: GERALDTON-ONAMAN TRANSECT
Title: *Preliminary Results from the Assessment of the Structural Evolution of the Southern Geraldton–Onaman Transect*
Link: https://merc.laurentian.ca/sites/default/files/6350-32_toth_lafrance_me.pdf

Project: GERALDTON-ONAMAN TRANSECT PH.D. TOPIC 1

Title: *Preliminary Results from Geological Mapping of the Volcanic Stratigraphy of the Elmhirst– Rickaby and Humboldt Assemblages, Onaman–Tashota Greenstone Belt*
Link: https://merc.laurentian.ca/sites/default/files/6350-33_strongman_et_al_me.pdf

Project: DRYDEN-STORMY LAKE TRANSECT M.SC. TOPIC 1
Title: *Preliminary Results from Detailed Geological Mapping of the Lost Lake Area in the Western Wabigoon Subprovince, Ontario*
Link: https://merc.laurentian.ca/sites/default/files/6350-35_downie_et_al_me.pdf

Project: DRYDEN-STORMY LAKE TRANSECT M.SC. TOPIC 2
Title: *Preliminary Observations from Structural Mapping of Regional Deformation Zones in the Dryden–Stormy Lake Area of the Western Wabigoon Subprovince*
Link: https://merc.laurentian.ca/sites/default/files/6350-34_zammit_et_al_me.pdf

GEOPHYSICS PROJECTS

Project: GRAVITY AND MAGNETICS
Title: *Potential Field Data Acquisition and Compilation Across Metal Earth's Areas of Interest*
Link: https://merc.laurentian.ca/sites/default/files/6350-46_maleki_et_al_me.pdf

Project: MAGNETOTELLURICS
Title: *Magnetotelluric Data Collection in the Superior Province, Canada*
Link: https://merc.laurentian.ca/sites/default/files/6350-47_roots_hill_me.pdf

THEMATIC RESEARCH PROJECTS

Project: FACTORS CONTRIBUTING TO METAL ENDOWMENT PH.D TOPIC 1
Title: *Preliminary Regional Interpretation and Sampling for Modelling and Prospectivity Analysis of the Western Wabigoon Subprovince*
Link: https://merc.laurentian.ca/sites/default/files/6350-37_montsion_et_al_me.pdf

Project: LOCALIZATION OF NI-CU-(PGE) MINERALIZATION
Title: *Geology, geochemistry and petrogenesis of the Expo- Ungava–Raglan dike, sill and lava-channel system in the Paleoproterozoic Cape Smith Belt, Northern Nunavik, Quebec*
Link: https://merc.laurentian.ca/sites/default/files/paper_11_mckevitt_english.pdf

Project: MINERALOGICAL INDICATORS OF OXIDATION / REDUCTION
Title: *The Rundle Intrusive Complex: Investigating Oxidation Processes Related to Gold Mineralization in an Archean Alkalic Intrusive Setting*
Link: https://merc.laurentian.ca/sites/default/files/6350-45_small_et_al_me.pdf

Project: TECTONOTHERMAL EVOLUTION
Title: *Identification of Partial Melting Relationships in the Southern Kapuskasing Structural Zone, Ontario*
Link: https://merc.laurentian.ca/sites/default/files/6350-31_estrada_et_al_me.pdf

CONTACT INFORMATION

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