METAL EARTH

ANNUAL REPORT

2017 - 2018

METAL EARTH

Annual Report **2017-2018**

Metal Earth: A Global Initiative

This annual report represents the work completed in Years 1 and 2 (March 2017-April 2018), the period marking the beginning of Metal Earth, a seven-year, $104 million applied R&D program. This global initiative is 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 Corporation (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.

Year 1 and 2 activities included the hiring of a Chair in Exploration Targeting; faculty science leaders in Precambrian geology, earth systems modelling, and exploration geophysics; 6 international postdoctoral fellows, 1 Canadian and 4 international research associates; and 2 GIS visualisation specialists, an information technologist, and a database manager, all of which reside at Laurentian University. Metal Earth also facilitated the hiring of a faculty member at Université du Québec à Chicoutimi, one of our partner institutions.

Projects undertaken from March 2017-April 2018 were led by research associates, postdoctoral fellows, Ph.D. and M.Sc. students supervised by Metal Earth faculty and science leaders. This report contains scientific background and progress reviews of all Metal Earth research activities conducted during Year 1 and 2, followed by an overview of upcoming research projects.

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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HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

THE HARQUAIL FAMILY

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METAL EARTH:
A GLOBAL INITIATIVE

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 Metal Earth 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 CORE GOALS AND OBJECTIVES

1 Fundamental Science

- transform our understanding of Earth's early evolution and processes that govern differential metal endowment,
- directly translates into improving the science for targeting and finding new orebodies.

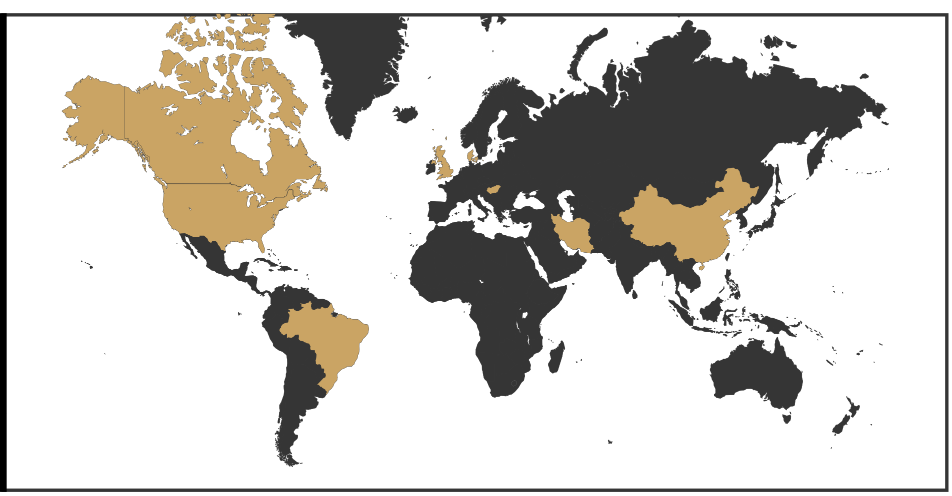
2 Applied Innovation and Commercialization

- 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.

PROGRAM STATISTICS

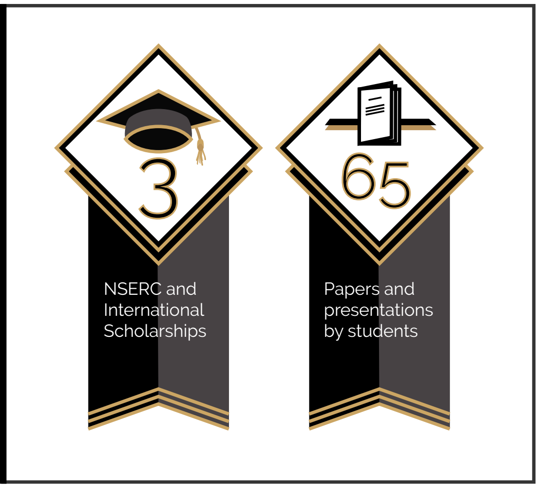
Global Reach

8 countries represented by research associates and student researchers.
Canada, USA, UK, Iran, Denmark, Hungary, China and Brazil.



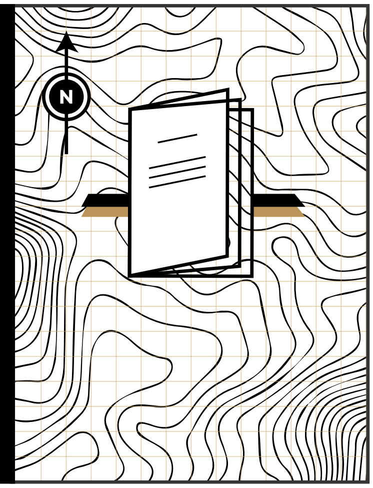
Student Successes

68



Information Sharing

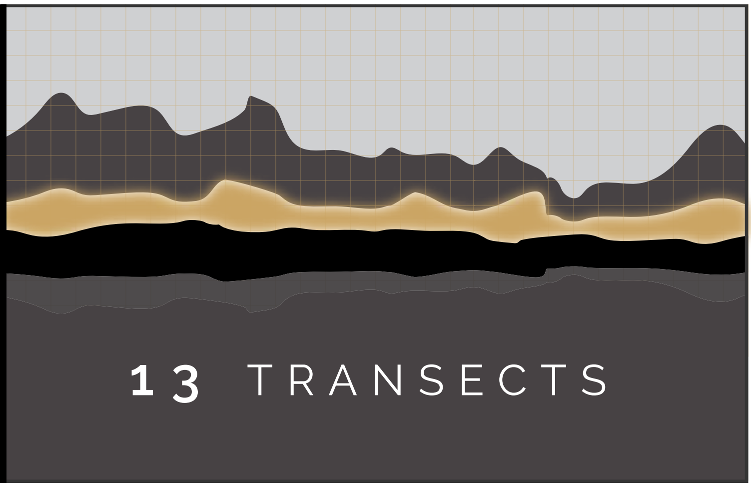
16 reports and maps published in government survey publications



Field Work

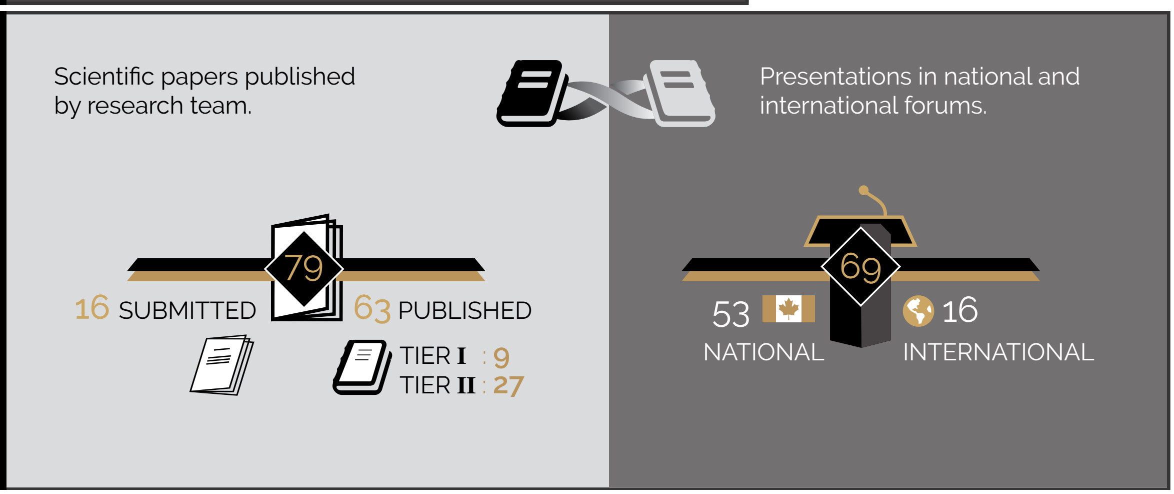
1000kms

13 transects totalling approximately 1,000 line km



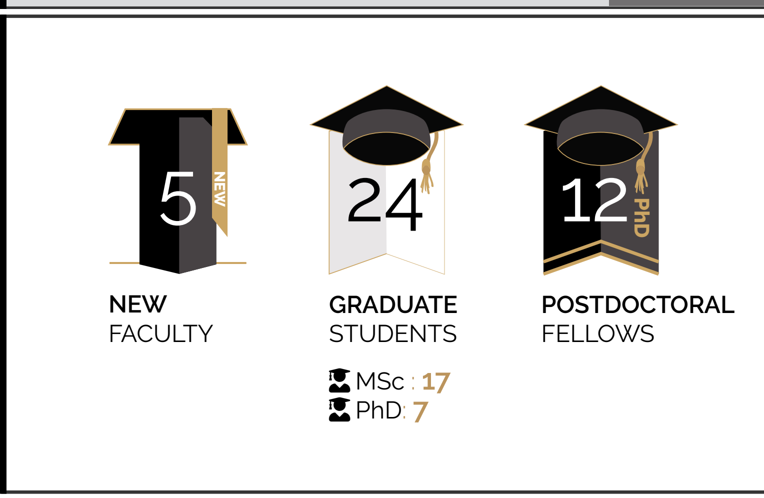
Knowledge Transfer

145 scientific papers / presentations : both national and international.



HQP and Job Training

26 PERSON YEARS of employment created.



WELCOME MESSAGE

MESSAGE FROM Interim President and Vice-Chancellor, Laurentian University

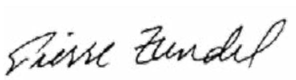

Dr. Pierre Zundel

Laurentian University is proud to be the lead institution for Metal Earth, a $104 million, seven-year applied research and development program. Following an extensive two-year, two-tier application process, Laurentian University was selected as one of only 13 Canadian universities, and the only proposal in the Earth Sciences, receiving $49.2 million in funding from the Canada First Research Excellence Fund (CFREF).

The largest geoscience program in the world, Metal Earth is a strategic consortium of 25 outstanding Canadian and international researchers from academia, research centres, government and industry. This massive undertaking will cement Canada's reputation as a world leader in mining and mineral exploration research, and will directly impact industry on a global scale through open source delivery of new knowledge and the implementation of new or adapted technology.

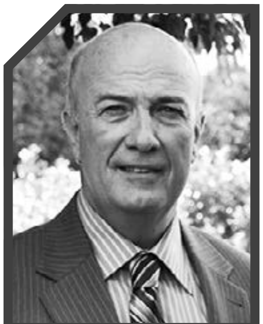
Laurentian looks forward to making a significant impact in Northern Ontario through thoughtful consultation with Indigenous communities; provincially and nationally with other Canadian institutions, research centres and government surveys; and internationally through the collaborative efforts of researchers spanning three continents and four countries. Laurentian University is also 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.

As Interim President and Vice-Chancellor, Laurentian University, it is my privilege to introduce this inaugural annual report outlining the work completed on the Metal Earth project in Year 1 and 2.



Dr. Pierre Zundel
Interim President and Vice-Chancellor, Laurentian University

MESSAGE FROM the Former MERC and Founding Metal Earth Director



Dr. Harold Gibson

As former Director of the Mineral Exploration Research Centre (MERC), I have seen MERC grow from a Sudbury-focused research centre to a global research centre with a focus on mineral exploration research. Metal Earth was a natural evolution for MERC, and as Founding Director of Metal Earth, it has been my honour to lead our team of Dr. Bruno Lafrance, Dr. John A. Ayer, Dr. Phillips C. Thurston and the Harquail School of Earth Sciences in developing the concept, research plan and establishing the connections which propelled Metal Earth from a bold concept to a geoscience research program of unparalleled scale. Since the letter of intent phase, to implementation, Metal Earth has attracted enthusiastic support from industry and governments that has snowballed into a global list of researchers.

Metal Earth represents a shared commitment to bringing together the best minds, the most experienced researchers, and the most advanced technology and state-of-the-art equipment to transform our understanding of the processes responsible for metal endowment and ore localization during early Earth's evolution. By researching ore systems at unprecedented scales, crust to mantle and craton to deposit, compiling databases and sharing research findings and analysis, our world-wide network of researchers will help Metal Earth provide the knowledge and tools that industry needs to discover the metals required to sustain society.

This extraordinary cooperation within the Earth Sciences has been groundbreaking. The momentum created by funding provided by the Canada First Research Excellence Fund (CFREF) has driven this project forward and has resulted in early scientific gains that have outpaced many of the original goals of this seven-year program.

As Founding Director, I'm proud to have implemented and led the first two years of Metal Earth, and have every confidence in Dr. Ross Sherlock's ability to advance Metal Earth's global research objectives. Dr. Sherlock brings a wealth of industry and academic experience and connections established during a 30-year career with global mining and exploration companies and government. His professional focus on resource exploration and delineation for Canada's mining and mineral exploration sectors includes training and mentoring young geoscientists in the field and training numerous grads and undergrads.

I look forward to contributing to Metal Earth's future scientific advancements and to Metal Earth's continued success and growing accomplishments.

Harold Gibson

Dr. Harold Gibson
Past Director, MERC and Metal Earth

MESSAGE FROM Director, MERC and Metal Earth

Dr. Ross Sherlock

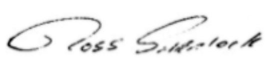
Under the formative direction of Dr. Harold Gibson, former Director, Mineral Exploration Research Centre (MERC) and Metal Earth, Laurentian University amassed an outstanding team of researchers within MERC and the Harquail School of Earth Sciences. Their expertise has been strengthened by the profound global collaborations Metal Earth established with researchers across multiple sectors of academia, government, and industry during the first two years of this program.

As Director of MERC since August 2017 and Metal Earth since July 2018, I am honoured to take a leadership role for this global research initiative.

After more than 30 years in the mineral exploration sector, I understand the importance of economic geology on the mining industry, and recognize the value of Metal Earth's scientific research. Metal Earth is poised to make significant strides in geoscience literature and contributions to the world's body of knowledge relating to metal endowment across the globe.

I look forward to advancing the field work and data compilation already accomplished and facilitating the powerful impacts Metal Earth is set to achieve in the next few years. The value of this research has global reach through the program's capacity to develop and train earth science students and junior researchers, to accelerate the development of tools and services with far reaching commercialization potential, and to drive massive economic and job creation impacts by transforming how the mineral exploration industry recognizes markers that lead to locating new deposits and ultimately opening new mines.

On behalf of the entire Metal Earth program, I am pleased to work with our national and international industry and academic partners, and mentor and develop students as they prepare to make their mark on the world.



Dr. Ross Sherlock
Director, MERC and Metal Earth

PARTNERS

ACADEMIC INSTITUTIONS

- Université du Québec à Chicoutimi, UQAC
- University of Alberta
- Université Laval
- University of Ottawa
- University of Toronto
- Carnegie Institution for Science
- University of Maryland
- University of New South Wales
- Centre for Exploration Targeting, University of Western Australia
- Centre for Ore Deposit and Earth Sciences (CODES), University of Tasmania
- MIRARCO Mining Innovation, Laurentian University
- Smart Exploration, Uppsala University, Sweden

PUBLIC SECTOR

- Ministry of Energy and Natural Resources, Quebec (MERN)
- Ontario Geological Survey
- Geological Survey of Canada
- Canada Nunavut Geoscience Office
- Northwest Territories Geological Survey
- Manitoba Geological Survey

INDUSTRY

- Agnico Eagle Mines Limited
- BonTerra Resources
- Entreprises minières Globex | Globex Mining Enterprises Inc.
- Falco Resources
- GFG Resources Inc.
- Gold Candle Ltd.
- IAMGOLD Corporation
- Keast, Todd, P. Geo.
- Mortimer, Charlie
- Pershimex Inc.
- Pioneer Aviation Ltd.
- Services GFE Inc.
- SpaceKnow
- Sphinx Resources Ltd.
- Transition Metals Corporation
- Yorbeau Resources Inc.

PEOPLE

METAL EARTH, MERC, HARQUAIL SCHOOL OF EARTH SCIENCES

DIRECTORS

- Dr. John A. Ayer, Adjunct Professor, Associate MERC Director
- Dr. Harold Gibson, Professor, Past Director, MERC and Metal Earth
- Dr. Bruno Lafrance, Professor, Metal Earth Associate Director
- Dr. Ross Sherlock, Professor. Director, MERC and Metal Earth, University Research Chair in Exploration Targeting

FACULTY

- Dr. C. Michael Lesher, Professor, University Research Chair in Mineral Exploration
- Dr. Jeremy P. Richards, Professor, Canada Research Chair in Metallogeny
- Dr. Richard Smith, Professor, Industrial Research Chair in Exploration Geophysics
- Dr. Leonardo Feltrin, Associate Professor, Earth Systems Modelling
- Dr. Pedro Jugo, Associate Professor, Igneous Petrology
- Dr. Daniel J. Kontak, Professor, Ore Deposit Geology
- Dr. Mostafa Naghizadeh, Assistant Professor, Seismic Geophysics
- Dr. Stéphane Perrouty, Assistant Professor, Precambrian Geology
- Dr. David B. Snyder, Geological Survey of Canada (retired), Science Leader
- Dr. Phillips C. Thurston, Adjunct Professor, Precambrian Geology

RESEARCH ASSOCIATES (RA) AND POSTDOCTORAL FELLOWS (PDF)

- Dr. Saeid Cheraghi, PDF, Metal Earth, Geophysics Seismic project
- Dr. Esmaeil Eshaghi, PDF, Metal Earth, Geophysical potential field data and petrophysics
- Dr. Ben Frieman, PDF, Metal Earth, Stormy-Dryden Transect
- Dr. Graham James Hill, Senior RA, Metal Earth, Magnetotellurics
- Dr. Taus Jørgensen, RA, Metal Earth, Rouyn-Noranda Transect
- Dr. Jeffrey Marsh, PDF, Metal Earth, LA-ICP-MS
- Dr. David Mole, PDF, Metal Earth, Craton Scale project
- Dr. Rasmus Haugaard, PDF, Metal Earth, Swayze Transect

- Dr. Benoit Quesnel, RA, Metal Earth subproject, Fluid Source and Pathways
- Kate Rubingh, RA, Metal Earth, Ben-Nevis – Larder Lake Transect
- Margaret Stewart, RA, University of Ottawa, Metal Earth subproject, Metal Oceans
- Zsuzsanna Tóth, RA, Metal Earth, Geraldton-Onaman Transect
- Dr. Xiaohui Zhou, RA, Metal Earth, Malartic Transect

PH.D. STUDENT RESEARCHERS

- Thomas Gemmell, Ph.D. Candidate in Mineral Deposits and Precambrian Geology, Swayze Transect
- Eric Roots, Ph.D. Candidate in Mineral Deposits and Precambrian Geology, Magnetotellurics
- Marina Schofield, Ph.D. Candidate in Mineral Deposits and Precambrian Geology, Rouyn-Noranda Transect
- Keaton Strongman, Ph.D. Candidate in Mineral Deposits and Precambrian Geology, Geraldton-Onaman Transect

M.SC. STUDENT RESEARCHERS

- Sean Brace, M.Sc. Candidate Geology, Ben-Nevis – Larder Lake Transect
- Fabiano Justina, M.Sc. Candidate Geology, Geophysical Gravity and Magnetics
- Amir Maleki, M.Sc. Candidate Geophysics, Geophysical Gravity and Magnetics
- William McNeice, M.Sc. Candidate Geophysics, Geophysical Gravity and Magnetics
- Blake Mowbray, M.Sc. Candidate Geology, Swayze Transect
- Adrian Rehm, M.Sc. Candidate Geology, Rouyn-Noranda Transect
- Brendon Samson, M.Sc. Candidate Geology, Malartic Transect
- Danielle Shirriff, M.Sc. Candidate Geology, Malartic Transect
- Nadia St-Jean, M.Sc. Candidate Geology, Ben-Nevis – Larder Lake Transect
- Jonathan Sutton, M.Sc. Candidate Geology, Rouyn-Noranda Transect

TECHNICIANS

- Jacqueline Edwards, GIS Visualisation Specialist, Metal Earth
- Kipp Grose, Information Technologist, Metal Earth
- Rebecca Montsion, GIS Visualisation Specialist, Metal Earth and Ph.D. Candidate in Mineral Deposits and Precambrian Geology
- Ryan Paquette, Database Manager, Metal Earth

ADMINISTRATION

- Lindsay Cooper, Communications & Promotions Manager, Harquail School of Earth Sciences
- Chantal Duval, Executive Assistant, MERC
- Courtney Foltz, Administrative Coordinator
- Natalie Lafleur Roy, Finance Manager

ACADEMIC PARTNERS

- Dr. Mark D. Hannington, Goldcorp Chair in Economic Geology, University of Ottawa, and Helmholtz Professor, GEOMAR - Helmholtz Centre for Ocean Research Kiel, Modern/Ancient Ocean Crust project
- Dr. Graham Pearson, Canada Excellence Research Chair Laureate, U of Alberta, Mantle Group, Analyze mantle xenolith samples: Kirkland Lake and Wawa Suites project
- Dr. Steven B. Shirey, Staff Scientist, Carnegie Institution for Science, Mantle Group, Analyze mantle xenolith samples: Kirkland Lake and Wawa Suites project
- Dr. Richard Carlson, Director of Terrestrial Magnetism, Carnegie Institution for Science, USA, Analyze mantle xenolith samples: Kirkland Lake and Wawa Suites project
- Dr. Richard J. Walker, Chair, Department of Geology, University of Maryland, USA, Analyze mantle xenolith samples: Kirkland Lake and Wawa Suites project
- Dr. Georges Beaudoin, NSERC-Agnico-Eagle Industrial Research Chair in Mineral Exploration, Université Laval, Fluid Sources and Pathways
- Dr. Réal Daigneault, Director, Center for Mineral Resources Research (CERM), Université du Québec à Chicoutimi (UQAC), Mapping of the Chibougamau Transect project
- Dr. Lucie Mathieu, Institutional Research Chair on Archean metallogenic processes, CERM, UQAC, Mapping of the Chibougamau Transect project
- Dr. Michael A. Hamilton, Associate Professor, Jack Satterly Laboratory, University of Toronto, Evolution of the Canadian Shield Geochronology project

PRIVATE SECTOR COLLABORATORS

- Dr. K. Howard Poulsen, international consultant and globally recognized expert in Greenstone Gold deposits and Precambrian Geology

PROGRESS STATUS UPDATE:
YEAR 1 AND 2

| CRATON SCALE PROJECTS

ISOTOPIC MAPPING OF THE SUPERIOR CRATON

Dr. David Mole

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

SCOPE

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 [1, 2]. Methods such as seismic tomography, Sm-Nd and Lu-Hf analyses will map the lithospheric architecture and constrain large-scale intracratonic controls on magmatism, crustal evolution, and mineralization in the Superior Craton; the Earth's largest Archean terrane [3].

PROGRESS YEAR 1 - 2

The protocol for this project was the use of existing zircon samples from across the craton that were archived from U-Pb geochronology samples. This reduced the need for re-sampling on a large scale and minimized the need for further field work.

Subsequently, the first 4-6 months of this project involved building a single database from geochronology records of the Geological Survey of Canada (GSC), Ontario Geological Survey (OGS), Ministry of Energy and Natural Resources, Quebec (MERN), and the Manitoba Geological Survey (MGS). Using the new database, 202 samples were selected for further work, from a total of 1,168 potential samples.

FUTURE WORK

The geochronology database, now in place, requires work to capture further data and to be internally consistent and error free. This will be completed by the end of 2018 and will be released to the public as a supplement to the Superior compilation (Figure 1). This will be updated as additional results warrant.

Initially zircon mounts will be made and imaged at CSIRO in Perth, Western Australia. Laser ablation analyses of these samples will begin in July 2018 at Laurentian University.

The anticipated outcome of this work is a craton-scale Hf-isotope map of the Superior Craton, which will highlight the age, evolution and source of the crust in space and time. This large new dataset will allow the investigation of craton evolution and Archean tectonics at a previously unseen scale and detail, and will facilitate the coupled understanding of large-scale metallogenesis and crustal evolution – one of the primary aims of the Metal Earth project.

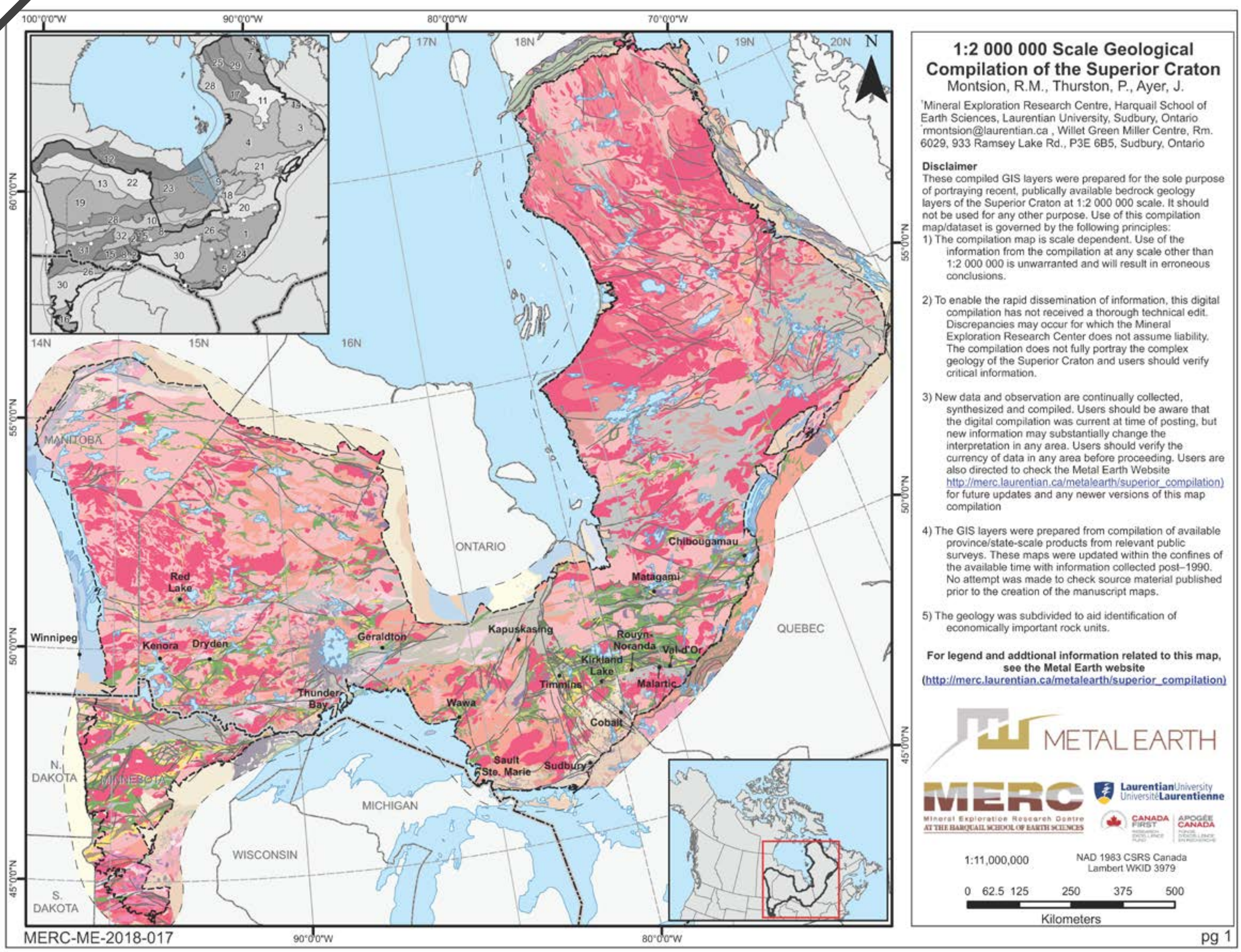


Figure 1: The Superior Craton geologic compilation map presents standardized descriptive lithological units throughout the Superior Craton, the location of craton- and sub province-scale faults, and tectonic subdivisions.

METAL OCEANS

Dr. Mark D. Hannington

Project lead Dr. Mark D. Hannington, University of Ottawa, and GEOMAR - Helmholtz Centre for Ocean Research Kiel; Margaret Stewart, RA, University of Ottawa; Melissa Anderson, Assistant Professor, University of Toronto; Patrick Mercier-Langevin, Geological Survey of Canada; Justin Emberley, GIS Technician, University of Ottawa.

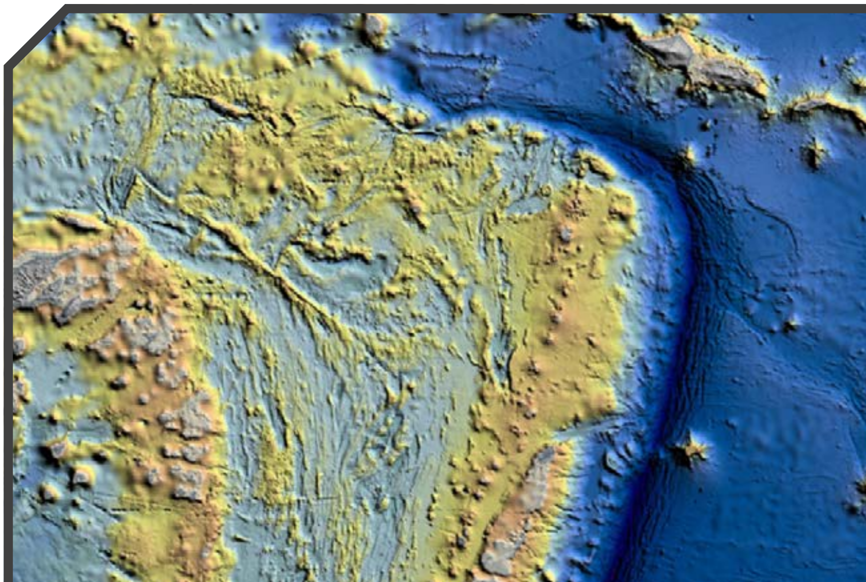


Figure 2: Bathymetric map of the northern Lau Basin showing its complex geology and structure. (Source: Global Multi-Resolution Topography Data Synthesis)

SCOPE

Metal Oceans is a subproject of Metal Earth focusing on the comparison of modern ocean crust and its evolution with the structure and composition of Archean greenstone belts. The primary objective is to investigate the relationship between microplate formation and the emergence of magmatic-hydrothermal systems in modern convergent-margin settings. Metal Oceans is aimed at revealing the geodynamic and magmatic complexity at a very fine scale (10's to 100's km) for three sub-regions of the Indo-Australian margin (Lau Basin, New Hebrides and Eastern PNG) which host spectacular concentrations of metals and hydrothermal activity. The complex microplate interactions in these regions will be tested in a series of crustal imaging experiments, directly analogous to those being performed in Metal Earth.

PROGRESS YEAR 1 - 2

During 2017-18, two proposals for large-scale marine transects were submitted and approved (ARCHIMEDES I, 20-267 and ARCHIMEDES II, DynaMet) and team participation on a third transect was also approved (TongaRIFT, SO-263).

Project-related meetings and workshops were held in Ottawa and Kiel, from June 2017 to March 2018, including interviews for the RA/PDF and Ph.D. positions, workshops on the development of the Microplate Atlas, and cruise planning. By February 2018, Metal Earth Research Associates, M. Stewart, and M. Anderson and J. Emberley, GIS Technician were established in a new office in ARC405 (Advanced Research Complex) University of Ottawa.

Metal Earth has developed and signed a Memorandum of Understanding with Natural Resources Canada's Geological Survey of Canada (GSC). GSC scientist, Patrick Mercier-Langevin, is participating in the Metal Oceans research project with Metal Earth academic partner, University of Ottawa.

Metal Earth and the GSC have developed a strong working relationship. Senior GSC scientist, Benoit Dubé, is the science advisor to MERC, and GSC Director, Mike Villeneuve, is an ex-officio Advisory Board member. MERC and Metal Earth Director, Dr. Ross Sherlock, is an ex-officio member of NRCan Targeted Geoscience Initiative (TGI 5) Advisory Board.

FUTURE WORK

The first marine transect ARCHIMEDES I is scheduled for December 12, 2018 to January 27, 2019. This 6-week survey of the NE Lau Basin is the first time that the full complement of ocean-going geophysical survey equipment available through GEOMAR and its partners will be deployed in a single mission. Forty personnel will participate, including four Metal Earth researchers (M. Hannington, M. Stewart, P. Mercier-Langevin, TBD). An initial report of the results, including multichannel reflection and refraction seismics, ocean-bottom magnetotellurics, magnetics, heat flow, AUV-based sidescan, and sampling, will be available before March 31, 2019.

Metal Earth researcher M. Anderson will participate on the TongaRIFT transect (SO-263) in June 2018. The project is focused on the primitive arc assemblages of the northernmost Tonga arc, including recently discovered boninitic volcanoes. The project will have 26 days of shiptime on R/V SONNE with the GEOMAR ROV (K. Haase, Chief Scientist, GeoZentrum Nordbayern).

ANTICIPATED OUTCOMES

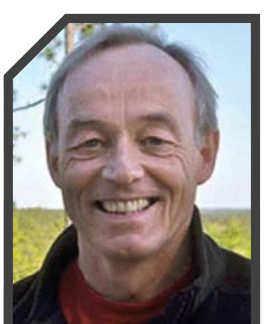
The major outputs of Metal Oceans will include 1) a new Marine Microplate Atlas of the Western Pacific region, with a focus on the Melanesian archipelago from PNG to Tonga, 2) a geophysical and lithogeochemical compilation of the study areas, and 3) microplate models for comparison with ancient greenstone belts.

The marine transects will include high-resolution seismic, electromagnetic, magnetic, and heat flow together with volcanic geochemistry and geochronology at a scale that will be directly comparable to the Metal Earth transects. An important outcome of the crustal imaging experiments will be the identification of critical melt- and fluid-ascent pathways, how they are organized, and their spatial and temporal link to large-scale magmatic-hydrothermal systems. Metal Oceans wants to identify specific types of microplate boundaries that connect with translithospheric faults and evolve into major corridors for fluid transport through the crust – a fundamental part of fertility and mineral endowment. The project will also train new Canadian researchers in the application of regional geodynamics to mineral exploration.

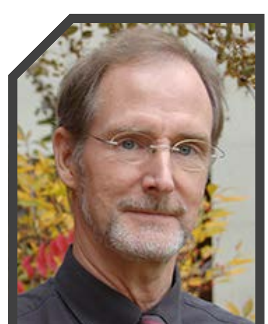
MANTLE GROUP

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


Dr. Graham Pearson


Dr. Steven B. Shirey


Dr. Richard Carlson


Dr. Richard J. Walker

SCOPE

The Mantle Group research, for this subproject of Metal Earth, focuses on the generation and evolution of sub-continental mantle underpinning both the Superior and Slave cratons and its relationship to the formation and evolution of the greenstone belts and Archean crust. Researchers will analyse mantle samples from as many of the kimberlite fields across the Superior Craton as possible (Figure 3). The group will also examine the location and nature of precious metal enrichment and depletion in samples of modern mantle from regions such as the Bismark Trough, an area of interest for Metal Ocean. The group will focus on how the early crust of the Superior and Slave cratons formed and evolved, prior to craton stabilisation. These studies will reveal the potential role of the continental lithospheric mantle in the formation or protection of metal endowed and lesser endowed terranes.

PROGRESS YEAR 1 - 2

The Mantle Group has: 1) created the majority of the laser ablation split-stream (LASS) reference materials needed for in situ Hf and Nd isotope studies to be performed at both Laurentian University and University of Alberta, 2) successfully developed and tested bespoke software for LASS, and 3) trained Laurentian staff in LASS methods and data reduction. This is an enormous component of technology transfer to Laurentian University.

Additionally, 1) full major and trace element characterisation of mantle xenoliths from Kirkland Lake has been completed; 2) initial measurements have been made on Kirkland Lake mantle xenoliths; 3) rutiles from lower crustal xenoliths from Victor, Attawapiskat have been separated; and, 4) a manuscript on Eoarchean crust of the Saglek Block (Labrador), based on work done by Dr. Adrien Vezinet under G. Pearson's Canada Excellence Research Chairs funding has been submitted.

FUTURE WORK

Mantle Group research will include U-Pb, Hf and O isotope characterisation of the oldest Superior crust – Assean Lake, Manitoba. This crustal block, being the oldest in the Superior Craton, forms the reference point for all other Hf isotope work on the Superior Craton, providing a baseline measurement of Meso/Eoarchean crust.

Future work also includes: 1) completing Re-Os and PGE measurements on Kirkland Lake mantle xenoliths, 2) making solution Hf isotope measurements of rutiles from Victor lower crust to estimate age of crust from model age constraints; 3) beginning Re-Os isotope and PGE measurements on Wawa mantle xenolith samples from a collection made by J. Ayer and S. Shirey in 2010; and 4) precious metal measurements on Slave mantle and Bismark trough peridotites.

ANTICIPATED OUTCOMES

U-Pb, Hf and O isotope characterisation of the crustal block – Assean Lake, Manitoba, will provide both a stand-alone piece of research on the genesis of the oldest crust, and a critical part of the Isotopic mapping of the Superior Craton project.

Completion of the Kirkland Lake mantle xenoliths Re-Os and PGE measurements will result in a paper on the formation of the southern Superior lithospheric mantle and the impact of the mid-continent rift on Superior lithosphere.

Rutile work will provide the only estimate of the basement age beneath Attawapiskat and will contribute a key piece of data towards the *Isotopic mapping of the Superior Craton* project.

Precious metal laser ablation work integrates TGI-5 initiatives of the Geological Survey of Canada with Metal Earth. This will provide a fundamental understanding of 1) the location of precious metals in mantle peridotites, 2) their inter-phase budget, and 3) how Archean and modern mantle lithosphere becomes enriched or depleted in precious metals. This research will also directly integrate with the Metal Oceans project.

CRATON SCALE MAPPING – GEOLOGIC COMPILATION OF THE SUPERIOR CRATON

Map authored by Rebecca Montsion, Ph.D. Candidate, Metal Earth, MERC, Harquail School of Earth Sciences. Supervised by Dr. Phillips C. Thurston and Dr. John A. Ayer.

SCOPE

The compilation of integrated and standardized geospatial geological data within the Superior Craton, for the purpose of providing a platform for geoscientists to seamlessly visualize, interrogate, and investigate geological information across jurisdictional boundaries.

In March 2018, Metal Earth released its first stand-alone map (Figure 1). This is the fundamental underlying database to be used in the *Isotopic mapping of the Superior Craton* project.

The intention of Metal Earth is to continue to release digital geologic products. These products will include results of the transect scale mapping as well as the geophysical datasets. Metal Earth will also compile and release geologic maps of selected areas through the Superior and Slave cratons. The Superior map and its database can be downloaded **HERE.**

TRANSECT SCALE PROJECTS

SCOPE 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 [4]. 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 [5, 6].

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 collect geological data (lithological, structural, geochemical, geochronological, mineralization, and alteration) and to compile previous work. By integrating newly acquired geological and geophysical (seismic 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 field work 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 two years in duration, although Ph.D. students who are working on these transects will require additional field work in the third year. In 2017 (Year 2), four transects were active including Malartic, Rouyn-Noranda, Larder Lake, and Swayze. In 2018, (Year 3), the same four transects were active with the addition of Matheson, Geraldton-Onaman and Dryden Stormy. New additions are described under Future Work.

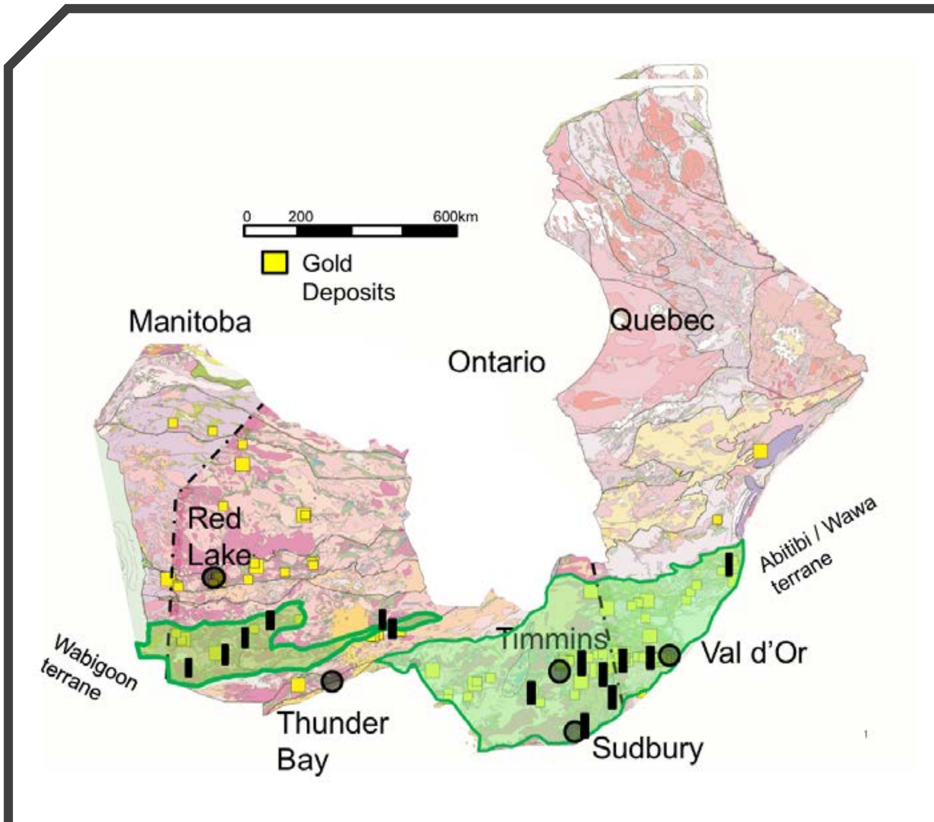


Figure 3: Geological compilation showing the Metal Earth transects (black bars) in the Superior Craton along with selected communities (circles).

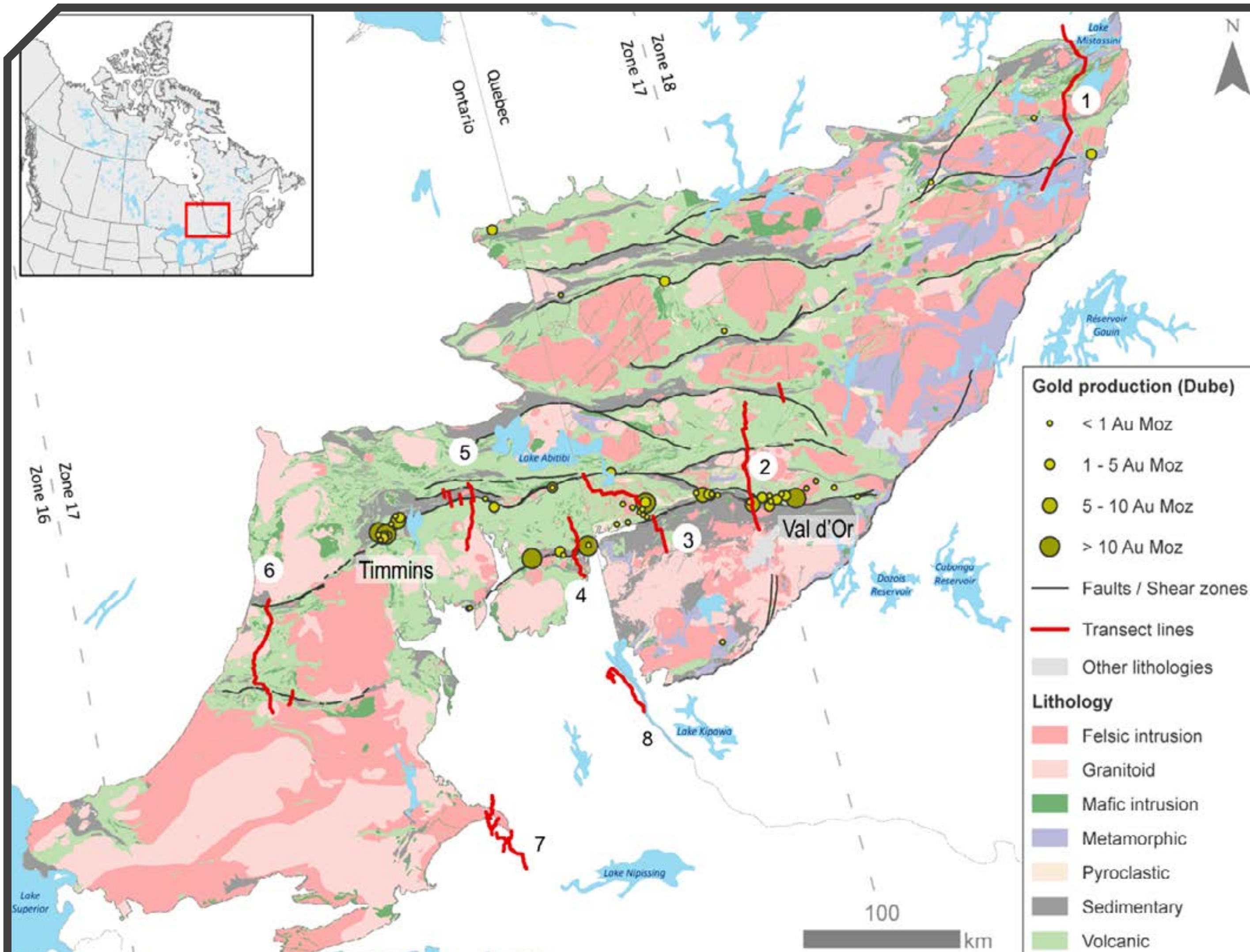


Figure 4: Geological compilation of the Abitibi Subprovince with locations of transects. 1. Chibougamau, 2. Malartic, 3. Rouyn-Noranda, 4. Ben Nevis-Larder Lake, 5. Matheson, 6. Swayze, 7. Sudbury, 8. Cobalt

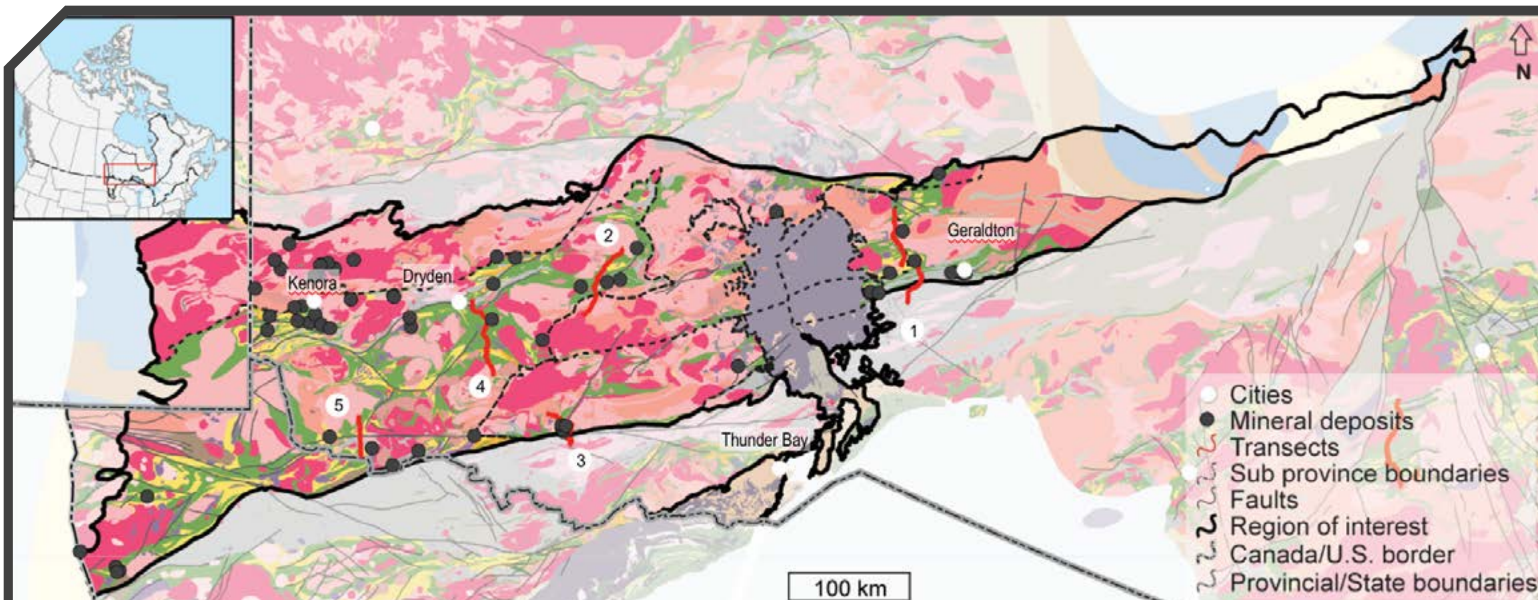


Figure 5: Geological compilation of the Wabigoon Subprovince with locations of the transects. 1. Geraldton-Onaman, 2. Sturgeon River, 3. Atikokan, 4. Dryden-Stormy, 5. Rainy River

MALARTIC TRANSECT

Project lead, Dr. Xiaohui Zhou, RA; Metal Earth, MERC, Harquail School of Earth Sciences.

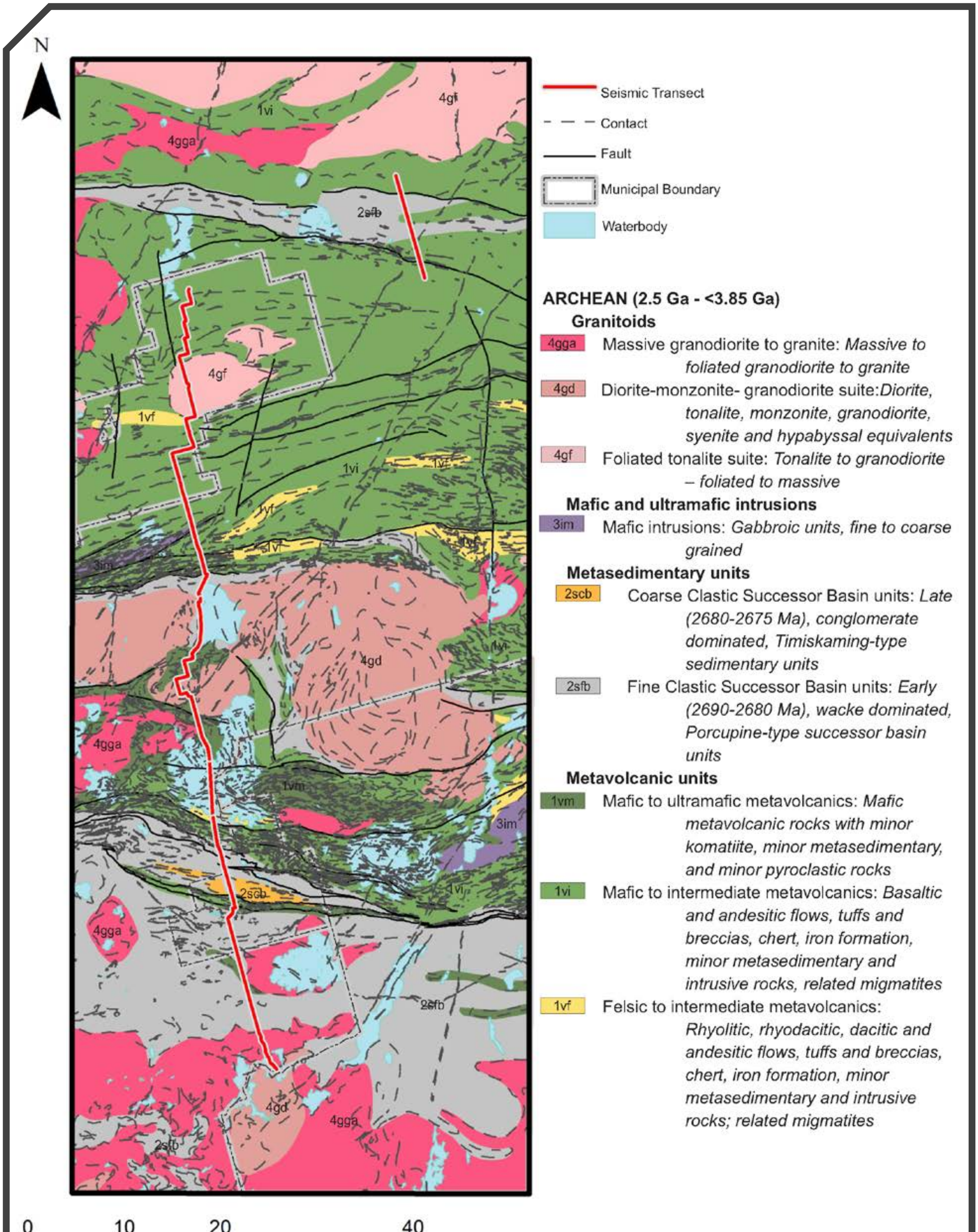


Figure 6: Geological compilation of the Malartic Transect.

Dr. Xiaohui Zhou

SCOPE

The Malartic transect is roughly 100 km across the highly endowed Malartic area, which covers Neoarchean volcano-sedimentary and plutonic rocks in the southern Abitibi and Pontiac Subprovince. Major scientific topics include:

- Stratigraphic and structural setting of nickel (e.g. Cubric showing) and gold deposits (e.g. lode gold occurrences near Canadian Malartic gold deposit),
- Provenance and age of Cadillac and Timiskaming Group sedimentary rocks,
- Fault kinematics and timing of generally west-northwest–striking regional faults subparallel to Cadillac-Larder Lake break, and
- Evolution of La Motte pluton and Northern and Southern Manneville faults.

Multi-disciplinary (stratigraphy, structure, geochemistry, geochronology and geophysics) research on these topics will further our understanding of early Earth evolution and place formation of mineral deposits in a crustal scale geological context.

PROGRESS YEAR 1 – 2

Field work on the Malartic transect began in 2017, led by X. Zhou, B. Samson, and D. Shirriff. During the first year, an initial map of the transect was compiled. Targeted mapping was completed to address specific geologic complexities along the transect.

In Year 2, 1) mapping was more focused along the transect for stratigraphic and structural setting of nickel mineralization in the Marbridge and Cubric areas, in collaboration with Globex Mining Enterprises; 2) contact relationships were studied between Piche, Cadillac, Timiskaming and Blake River Group – in collaboration with Agnico-Eagle, IAMGOLD, Dundee Precious Metals Inc. and Midland Exploration Inc.; 3) investigations of several key outcrops were undertaken to interpret fault kinematics and determine timing of generally west-northwest–striking regional faults subparallel to the Cadillac-Larder Lake break in collaboration with Monarques Gold Corp.; 4) timing of deformation of La Motte pluton and Northern and Southern Manneville faults was gathered/assessed; and, 5) stratigraphic and structural control was analyzed on lode gold occurrences near the Castagniers Fault, in collaboration with Kenorland Minerals and Madex Exploration.

X. Zhou completed a Summary of Field Work paper *Stratigraphic and structural setting of gold and nickel deposits in the La Motte–Malartic area* which can be downloaded **HERE.**

FUTURE WORK

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 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. Two Master of Science theses will be completed with the Malartic transect project.

MALARTIC TRANSECT; M.Sc. TOPIC 1

Brendon Samson

Brendon Samson, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences, is completing his thesis *Structural geology of the Timiskaming and Cadillac group along the Malartic segment of the Larder Lake–Cadillac deformation zone and implications for gold mineralization as part of the Malartic transect*. Supervised by Dr. Bruno Lafrance and Dr. Xiaohui Zhou.

PROGRESS YEAR 1 - 2

The purpose of this study is to examine the style of deformation of two sedimentary successions, Timiskaming and Cadillac groups, and the relationship to gold mineralization along the Cadillac-Larder Lake break. The study area is situated along the NW-trending Malartic segment of the E-trending Cadillac-Larder Lake deformation zone. It straddles ultramafic and mafic flows of the Piché Group, turbidites with local iron formation and conglomerates of the Cadillac Group (ca. < 2686 Ma), and polymictic conglomerates, sandstones and argillites of the Timiskaming Group (ca. < 2672 Ma). The metamorphic grade that has affected these rocks is from lower to upper greenschist facies.

At least two deformation events (D1 and D2) occurred after the deposition of the sedimentary rocks of the Cadillac and Timiskaming groups. Gold mineralization is hosted by the D1 extensional quartz veins and their associated alteration halos. The wall rocks to the veins are altered over 10-20 cm by chlorite, carbonate, tourmaline, biotite, and arsenopyrite.

Results from the first year's field work were published in a Summary of Field Work paper. Samson SoFW 2017, which can be downloaded **HERE.** A similar paper will be completed in the fall of 2018. B. Samson's thesis will be completed in the spring of 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 the *Lithologic and structural controls on the Cubric nickel prospect, on the Malartic transect*. Supervised by Dr. C. Michael Lesher, Dr. Bruno Lafrance and Dr. Xiaohui Zhou.

PROGRESS YEAR 1 - 2

The Marbridge deposit and Cubric Nickel Showing are hosted in ca. 2714 ± 2 Ma ultramafic to mafic volcanic rocks of the La Motte-Vassan Formation of the Malartic Group, located approximately 25 km north of Malartic, QC. The current interpretation for the nickel mineralization was that it formed in the ultramafic rocks and was later mobilized into a nearby gabbro dyke. Using geochemical analysis, the thesis will establish a fingerprint for mobilized sulfide minerals which can be used to help characterize other deposits.

Results from the first year's field work were published in a Summary of Field Work paper Shirriff SoFW 2017, which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. D. Shirriff's thesis will be completed in the spring of 2019.

Figure 7: Malartic Team from left to right Luc Roy, Sam Battye, Naomi Welt, Brendon Samson, Danielle Shirriff and Dr. Xiaohui Zhou.

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

SCOPE

The ~80 km, Rouyn-Noranda transect in Quebec straddles the Abitibi and Pontiac Subprovinces of the southern Superior Province, including two E-W trending subvertical crustal-scale faults, i.e., the Porcupine-Destor and the Cadillac-Larder Lake fault zones (Figure 8). The transect has high metal endowment across the Noranda gold-base metal camp, as well as gold mineralization associated with the Porcupine-Destor and Cadillac-Larder Lake breaks.

The Abitibi greenstone belt comprises seven broadly E-W trending volcanic assemblages (~2750 to ~2695 Ma) unconformably overlain by the sedimentary-rock-dominated Porcupine (~2690-2685 Ma) and Timiskaming (~2679-2669 Ma) assemblages [7, 8]. The Pontiac Subprovince hosts the Canadian Malartic mine, one of Canada's largest producing gold mines, but otherwise, only a few metallic deposits, architectural stone quarries, and industrial mineral deposits were mined previously. The Pontiac Subprovince comprises dominantly monotonous turbiditic greywacke successions of the Pontiac Group with a depositional age constrained at ~2682 Ma [9, 10] and minor ultramafic- to mafic volcanic units. The Abitibi and Pontiac Subprovinces also contain numerous syn-volcanic (~2750-2695 Ma), syn-deformational (~2695-2670 Ma), and post-deformational (~2670-2650 Ma) intrusions [11, 12].

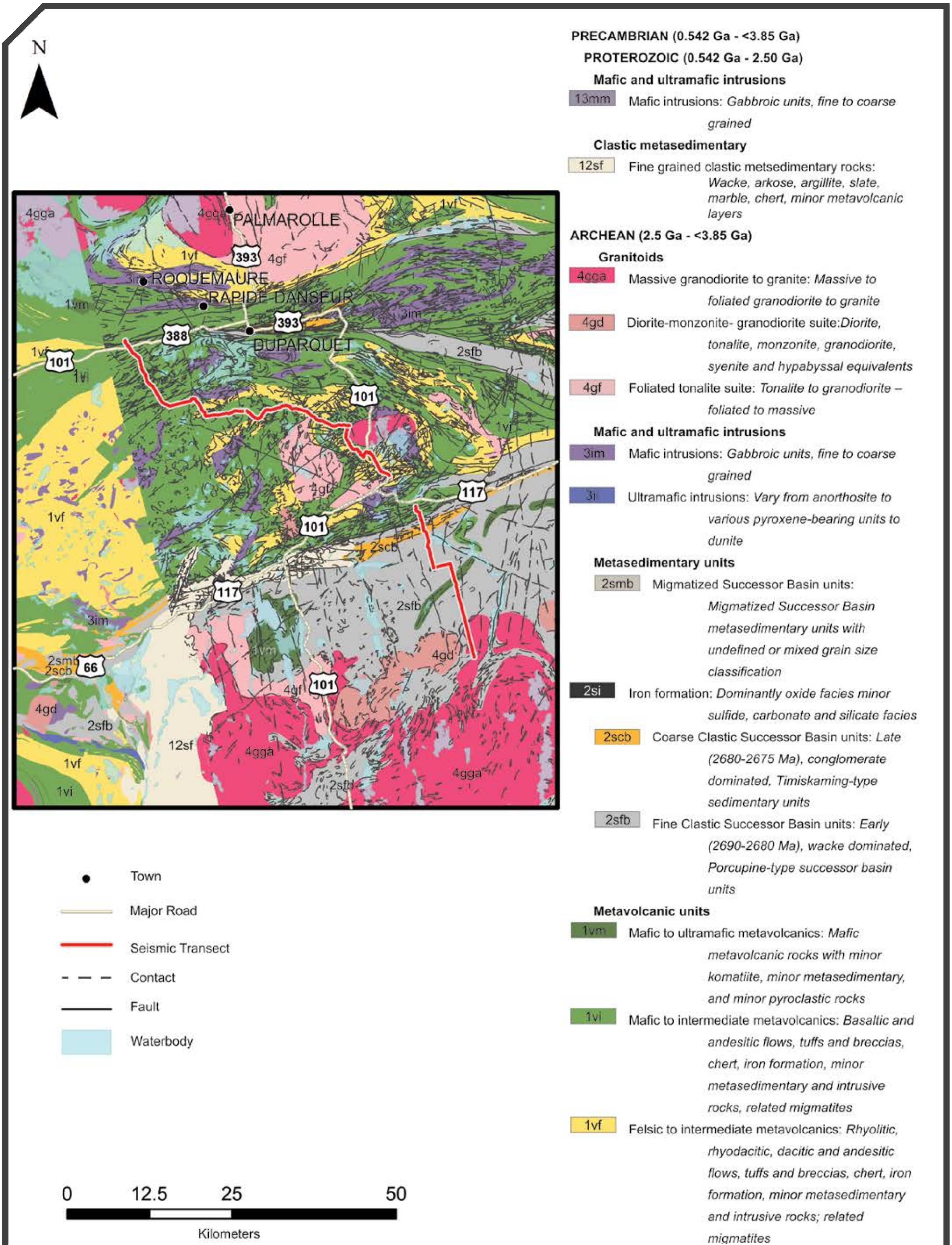


Figure 8: Geological compilation of the Rouyn-Noranda Transect.

P R O G R E S S   Y E A R   1 - 2

The Rouyn-Noranda transect had its first year's field work in 2017, led by T. Jørgensen (T.R.C.J.), along with Ph.D. candidate Marina Schofield and two M.Sc. candidates, Jonathan Sutton and Adrian Rehm. The first field season was focused on establishing the regional stratigraphic-structural context and outlining significant research directions where Metal Earth could contribute.

The second year's field work has expanded upon this and focused on outstanding research questions including 1) petrogenesis and U-Pb geochronology of volcanic rocks in the Deguisier Formation, Kinojevis Group; 2) characterization of alteration systems associated with subvolcanic intrusions and VMS mineralization in the Duprat-Montbray formation, lower Blake River Group; 3) metallogeny of the Powell Block, Blake River Group; 4) tectonic vs. syn-sedimentary emplacement history of ultramafic- to mafic volcanic rocks in the Pontiac Group sedimentary rocks, Pontiac Subprovince; and, 5) detailed provenance study of Pontiac Group sedimentary rocks and their contact relationship with the overlying Timiskaming sedimentary rocks.

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 Ph.D., two M.Sc. theses, as well as two Hons. B.Sc. theses will be completed with the Rouyn-Noranda transect. T.J.C.J. completed a Summary of Field work paper in 2017, titled *Preliminary results from transect mapping in the Abitibi greenstone belt and Pontiac Subprovince, Rouyn-Noranda area*, Quebec, which can be downloaded **HERE**.

ROUYN-NORANDA TRANSECT; Ph.D. TOPIC 1

Marina Schofield, Ph.D. Candidate in 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, Quebec*. Advisors are Dr. Harold Gibson, Dr. Bruno Lafrance, and Dr. K. Howard Poulsen.

P R O G R E S S   Y E A R   1 - 2

Marina Schofield

This project is focused on the Powell Block, a ~32 km² wedge-shaped fault block; one of several that comprise the Rouyn-Noranda mineral district. The Powell Block is bounded by the Beauchastel fault to the north and the Horne Creek fault to the south, both of which are interpreted as second order splays off the Cadillac-Larder Lake fault zone. The Powell Block hosts the Au-rich Quemont VMS deposit (14 Mt at 5.5 g/t Au, 331 g/t Ag 1.32% Cu, and 2.44% Zn) and separates the Horne deposit, a world class Au-rich VMS deposit (54 Mt at 6.1 g/t Au, 13 g/t Ag, and 2.2% Cu), from conventional VMS deposits (≤ 1 g/t Au) north of the Beauchastel fault. In addition, orogenic style quartz-carbonate-Au vein mineralization is found along the Horne Creek Fault and cross-cutting the Powell intrusion (e.g. Silidor, New Marlon, Powell-Rouyn).

The main objective of this project will be to document the spatial relationship between these two overlapping hydrothermal systems (syn-orogenic and syn-volcanic) and characterize the mineralization and alteration, chemically and petrographically, in order to understand the likely hydrothermal fluid source(s) and conditions that led to mineralization.

The research project will comprise geological mapping and compilation of the Powell Block at a scale of 1: 2,400, over an area of about 24 km^2. Ultimately this project aims to further our understanding of the structural, stratigraphic evolution of the area and how the mineralization and alteration events fit within that chronological sequence. Findings from this research project will have implications on our understanding of Au-enrichment processes and for exploration models in the Abitibi and globally.

Results from the first year's field work were published in a Summary of Field Work paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. M. Schofield's thesis will be completed in the spring of 2021.

ROUYN-NORANDA TRANSECT; M.Sc. TOPIC 1

Jonathan Sutton

Jonathan Sutton, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences, is completing his thesis *Characterization of hydrothermal systems using whole-rock oxygen isotopes to constrain synvolcanic intrusions and VMS deposits in the Duprat-Montbray formation*. Advisors are Dr. Harold Gibson and Dr. Taus R. C. Jørgensen.

PROGRESS YEAR 1 - 2

This research is conducted in the 2704-2695 Ma Blake River Group, a volcanic terrane that, in the Noranda area, is highly endowed in volcanogenic massive sulphide deposits. The lower stratigraphy of the Blake River Group incorporates the Duprat-Montbray formation, which is characterized by alternating andesitic pillowed and massive flows and coherent to volcanoclastic rhyolitic units. These stratigraphic units are intruded by ca. 2701 Ma synvolcanic Fabie pluton, a quartz-feldspar porphyritic tonalite with quartz-diorite xenoliths. This pluton is located below the ca. 2701 Ma upper rhyolite unit that hosts two volcanogenic massive sulphide deposits (Fabie and Magusi). Often synvolcanic intrusions, such as Fabie, are enplaced into the shallow crustal near active hydrothermal systems and contribute heat and possible metals to the mineralizing hydrothermal system.

This project aims to determine the spatial-temporal relationship between the stratigraphy of the Duprat-Montbray formation, Fabie pluton and nearby volcanogenic massive sulphide deposits. The relationship between the Fabie pluton and the volcanic stratigraphy will be documented by producing a detailed geological map of the main lithologies, alteration profiles and contact relationships.

In order to constrain the ore-forming hydrothermal system to the intrusion, the hydrothermal alteration system is mapped by combining whole-rock geochemistry and δ^{18}O-isotopic data in collaboration with our partners at Université Laval. Results of this research will enable a comparison to more prolific VMS mineralized stratigraphy in the Noranda camp.

Results from the first year's field work were published in a Summary of Field Work paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. J. Sutton's thesis will be completed in the spring of 2019.

Figure 9: Rouyn-Noranda Transect M.Sc. thesis 1: J. Sutton viewing outcrops to be mapped along transect.

ROUYN-NORANDA TRANSECT; M.Sc. TOPIC 2

Adrian Rehm

Adrian Rehm, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on ***Detailed geological mapping of the mafic-ultramafic volcanic package in the Pontiac Subprovince in the Lac Bellecombe area, Quebec***. Advisors are Dr. Phillips C. Thurston and Dr. Taus R. C. Jørgensen.

PROGRESS YEAR 1 - 2

A narrow (~50-200 m) but laterally extensive (~25 km) interval of mafic and ultramafic volcanic rocks is located in the Pontiac Subprovince about 20 km south of Rouyn-Noranda. The objective of the research is to characterize the stratigraphy and deformation history of the volcanic succession and to determine whether emplacement of the volcanic rocks occurred during deposition of the sedimentary succession or was a later structural event. Initial indications from the first year's field work, have recognized peperitic textures along the contact. Peperite is a textural term referring to igneous rocks intermixed with sedimentary rocks interpreted to have occurred while the sediments were unconsolidated. The resulting rock contains jigsaw-fit, amoeboid or wispy clasts of isolated igneous material in a sedimentary matrix.

Results from the first year's field work were published in a Summary of Field Work paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. A. Rehm's thesis will be completed in the spring of 2019.

BEN-NEVIS - LARDER LAKE TRANSECT

Kate Rubingh

Project team lead, Kate Rubingh, RA, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE

The Ben Nevis – Larder Lake transect is approximately 45 km long, located in the Abitibi Subprovince of the Superior Province in northeastern Ontario. This transect is focused on three main areas; the Ben Nevis volcanic complex, part of the Blake River Group, the Timiskaming assemblage and the associated Cadillac-Larder Lake break, and Larder Lake Group (Piché Group) 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) [13]. The Blake River Group in Quebec 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 will build 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 also crosses the Timiskaming assemblage (ca. 2680 – 2670 Ma) [14] with fluvial-alluvial-marine sedimentary facies 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) [15] equivalent to the Piché Group in Quebec. 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 Quebec 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 fault 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.

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 Ph.D. and two M.Sc. theses will be completed with the Ben-Nevis Larder Lake transect.

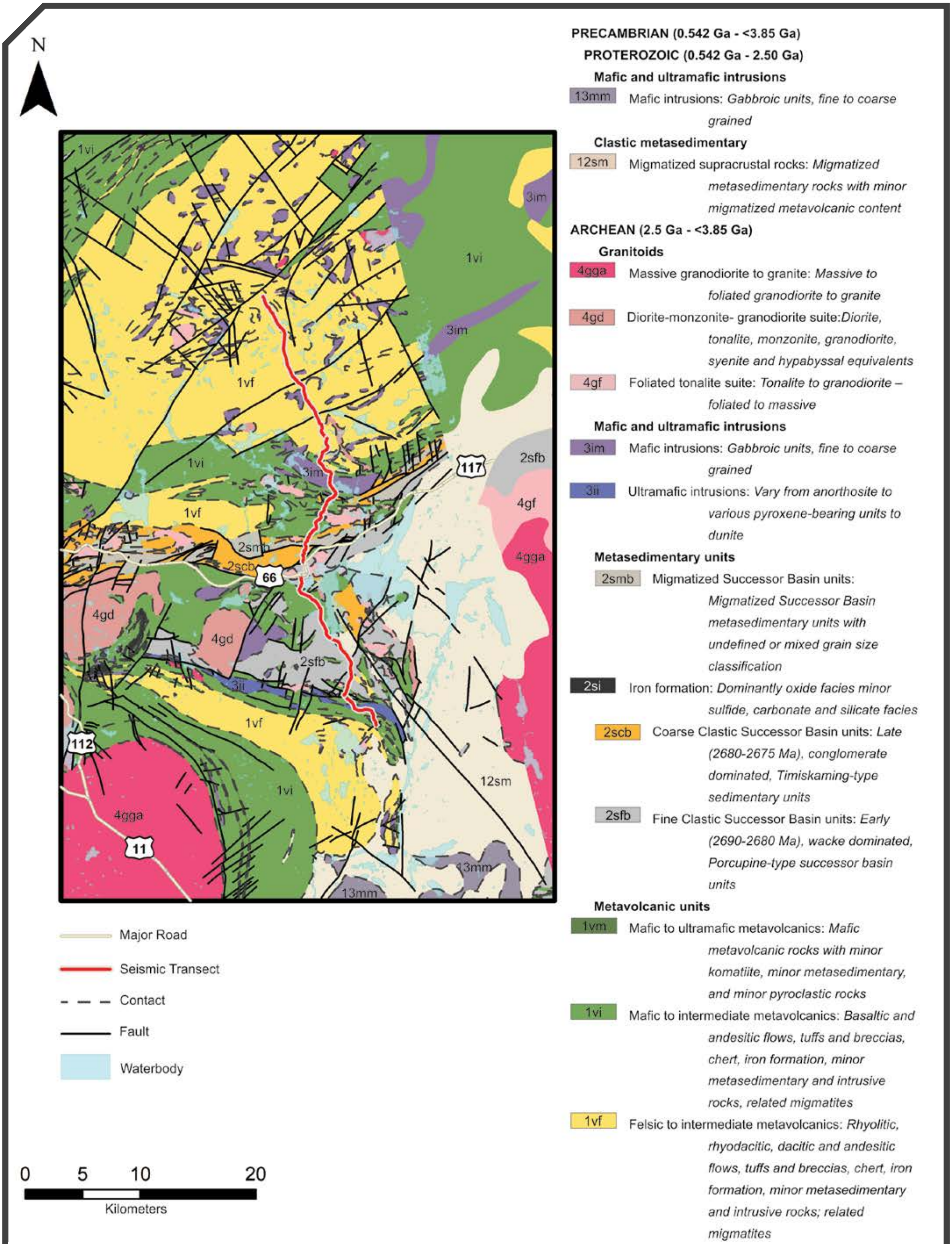


Figure 10: Geological compilation of the Ben-Nevis - Larder Lake Transect.

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

Nadia St-Jean

Nadia St-Jean, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing her thesis 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)*. Supervised by Dr. Bruno Lafrance and Dr. Ross Sherlock.

PROGRESS YEAR 1 - 2

The study location is in northeast Ontario, approximately 10 km from the Quebec border, and within the footprint of the ~11 million ounce Kerr-Addison gold deposit. At this locality, there is a thick package of Larder Lake group ultramafic and mafic volcanic rocks which hosts the Kerr-Addison gold deposit, in contact with younger Timiskaming sedimentary rocks.

The contact between these two groups is defined by a major regional-scale fault, the Cadillac - Larder Lake break. Typically, the contact relationship is considered to have been a complex structural juxtaposition of the two units. However, in the area of the transect, lower strain windows support the potential of an original unconformity between the two units which will be examined in this thesis. The results of this study have implications, with respect to the overall nature of the Larder Lake Cadillac break and the origins of the Larder Lake Group, as it occurs along this major structural trend.

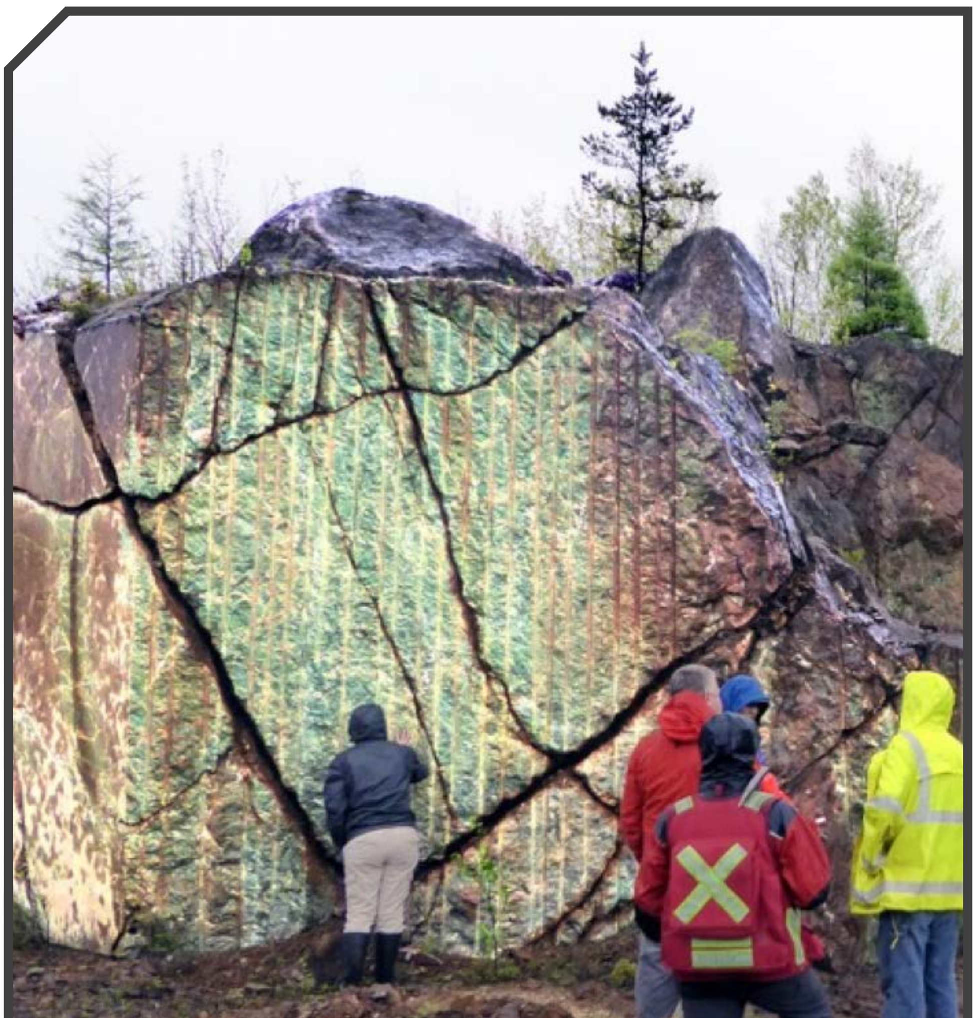


Figure 11: Slabs of fuchsite alteration at Kerr-Addison.

Results from the first year's field work were published in a Summary of Field Work paper which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. N. St-Jean's thesis will be completed in the spring of 2019.

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

Sean Brace

Sean Brace, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences is completing his thesis on *Igneous petrochemistry of small volume intrusions enplaced into the Lincoln Nipissing shear zone and their relationship to gold mineralization*. Supervised by Dr. Pedro Jugo, Dr. Daniel J. Kontak and Kate Rubingh.

PROGRESS YEAR 1 - 2

This project is being conducted in the southern portion of the transect and consists of detailed geological mapping on composite intrusive bodies that are associated with gold prospects along the west-northwesterly trending Lincoln–Nipissing shear zone, approximately 11 km south of Larder Lake. This study is using a combination of methods including mapping and detailed petrography of the intrusions focused on the compositional domains, alteration of the intrusions and host rocks and their relationship to regional structural framework.

This study provides an excellent opportunity to examine the relationship between a cluster of gold prospects, a significant regional-scale fault system and a chain of felsic to intermediate intrusive rocks [16, 17].

Results from the first year's field work were published in a Summary of Field Work paper, which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018. S. Brace's thesis will be completed in the spring of 2019.

SWAYZE TRANSECT

Dr. Rasmus Haugaard

Project lead, Dr. Rasmus Haugaard, PDF, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE

The Swayze area is located within the western Abitibi Subprovince and is likely the westward extension of the Abitibi greenstone belt. The area has long been considered the poor cousin to the Abitibi greenstone belt, as a result of lower metal endowment. Rather than being a collage of unrelated volcanic fragments that were amalgamated, Heather (2001, unpublished Ph.D. thesis) proposed a model that the greenstone belt in Swayze represents continuous lava flows that can be correlated throughout not only the Swayze area but also to the rest of the Abitibi.

PROGRESS YEAR 1 - 2

The older part of the lava flows is found toward the margins of the granite intrusions with younger volcanic ages toward the centre of the greenstone keels. However, crystallization and depositional ages of important volcanic and sedimentary units is poorly constrained relative to other parts of the Abitibi greenstone belt. For example, large uncertainties exist in the depositional ages of the two successor basins in the Swayze area - the Timiskaming-type conglomerate basin and the Porcupine-type greywacke dominated basin.

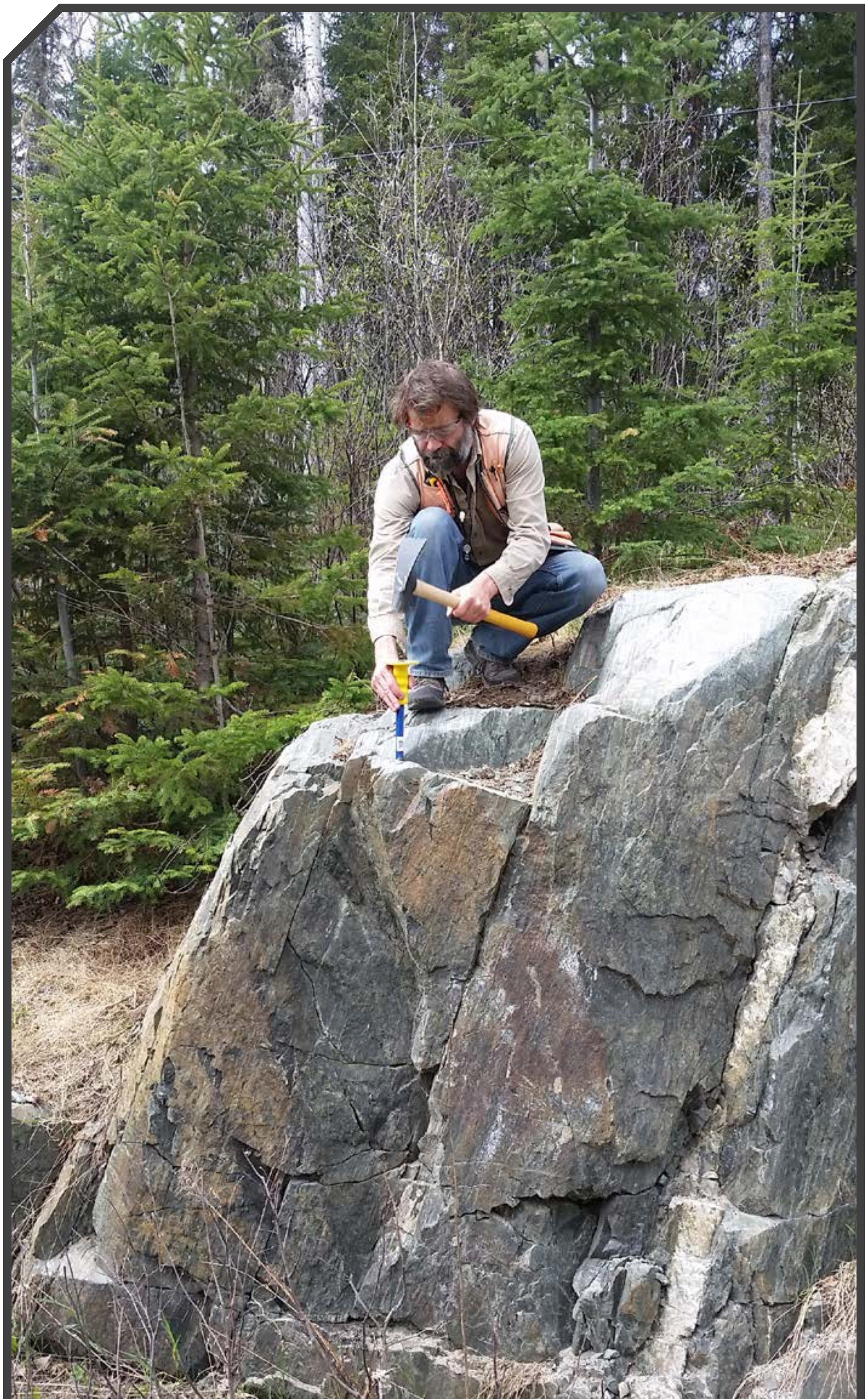


Figure 12: Dr. Rasmus Haugaard sampling in the Swayze belt.

The scope of the Swayze project is therefore to test if the greenstone belt rocks are part of the same continuous stratigraphy by 1) improving the stratigraphy and the existing 1:50,000 scale geological map by detailed mapping of key rock units and their internal relationships, 2) establishing a cross-section along a N-S transect (Figure 13), 3) mapping sedimentary interface zones and depositional gaps between and within volcanic units that can help constrain the stratigraphy and the evolution of the Swayze area, and, 4) evaluating the mineral potential of the area.

The first year of field work was focused on mapping and sampling of key volcanic and sedimentary rock units in the southern, central and partly northern part of the transect. Field work focused on a previously unrecognized conglomerate in the south and a regionally significant banded iron formation. R. Haugaard completed a Summary of Field Work paper in 2017, titled *Lithological and Stratigraphic Relationships of the Swayze Area, Abitibi Greenstone Belt* which can be downloaded **HERE**.

SWAYZE TRANSECT; M.Sc. TOPIC 1

Blake Mowbray

Blake Mowbray, M.Sc. Candidate Geology, Metal Earth, MERC, Harquail School of Earth Sciences, is completing his thesis on *The Jefferson base metal prospect, Genoa Township part of the Swayze belt*. Supervised by Dr. Harold Gibson, and Dr. Rasmus Haugaard.

PROGRESS YEAR 1 - 2

This project will provide a detailed characterization of the stratigraphy, alteration and mineralization at the Jefferson prospect. The Jefferson prospect is hosted within and proximal to the ca. 2735 Ma Woman River banded iron formation. It has been interpreted as volcanic massive sulphide (VMS) style mineralization by previous workers. Mineralization was reported to consist of massive sulphides enriched in Zn and Pb over a strike length of 150 m and to a depth of 30 m. The Jefferson prospect is underlain by a basal bimodal volcanic sequence, principally the Chester group and overlying Rush River basal mafic unit.

Recent work by Red Pine Exploration identified massive and semi-massive polymetallic mineralization, hosted primarily within banded iron formation and stringer type mineralization, observed in felsic volcanic units of the hanging wall.

B. Mowbray will author a Summary of Field Work paper in 2018 and his thesis will be completed in the spring of 2019.

FUTURE WORK

The Ontario Geological Survey will be supporting a Ph.D. project by Thomas Gemmell on the *Volcanic Stratigraphy and Base Metal Metallogeny of the Swayze Belt*. Although having worked with the Ontario Geological Survey, mapping in the Swayze belt for the last several field seasons, T. Gemmell will start as a graduate student, part of Metal Earth, in the fall of 2018.

Field work will continue to focus on detailed mapping in the northern part of the Swayze transect, particularly within the inferred Porcupine (~2690 Ma) sedimentary basin where mapping sedimentary lithofacies (e.g., conglomerate, sandstone, mudstone) will be crucial to establish the depositional environment (e.g., fluvial vs. marine type environment). In addition, sampling of sedimentary beds for detrital zircon dating will be carried out.

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 M.Sc. thesis will be completed with the Swayze transect.

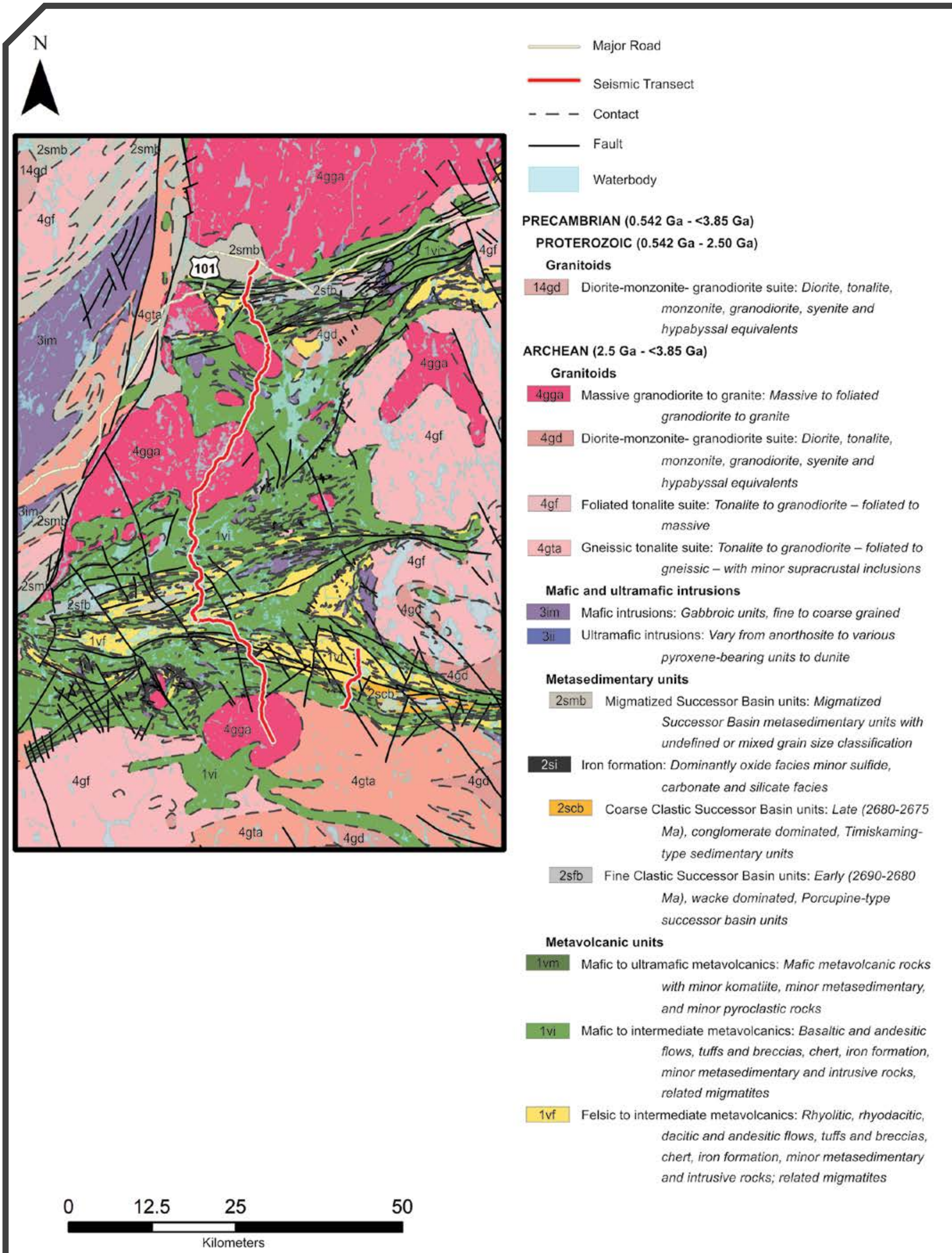


Figure 13: Geological compilation of the Swayze Transect.

GEOPHYSICS

SEISMIC

Dr. Mostafa Naghizadeh

Dr. Saeid Cheraghi

The seismic subproject of Metal Earth is led by Dr. Mostafa Naghizadeh, Dr. David B. Snyder, and Dr. Saeid Cheraghi, PDF, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE

Metal Earth is aiming to reveal detailed subsurface images of geological structures using active seismic reflection data sets. Seismic reflection is the most accurate and intuitive geophysical prospecting method, and the final migrated seismic sections will help to understand the tectonic history of Abitibi and Wabigoon regions. The seismic sections will also provide answers to the questions related to the deep geological structures and whether these structures are factors relating to metal endowment.

Detailed processing, imaging and interpretation of seismic data will be carried out by Laurentian University seismic research staff and students in collaboration with non-seismic geophysicists and geologists involved in the Metal Earth program.

Imaging algorithms such as the multi-focusing method are crucial for high-resolution imaging of seismic data in a hard rock environment. The interpretation of seismic sections will be carried out in collaboration with Metal Earth's experienced geologists in their respective study areas.

Due to the unique nature of the acquired seismic data (crooked lines, wide-offset recordings, irregular shots distributions, and intersecting and parallel 2D seismic line), researchers will be able to investigate various data processing and imaging techniques to create high-resolution seismic sections. These innovative methods can generate 2.5D/3D seismic sections on parts of the study areas.

The seismic sections will be used for joint inversion of non-seismic geophysical data in order to reduce the inversion uncertainties. Seismic interpolation and reconstruction methods will be used to mitigate the irregular distribution of the seismic traces caused by seismic lines which followed irregular road networks. Proper reconstruction of seismic data will lead to artifact-free seismic images.

More than 30 long-offset dynamite-source seismic records will be used for full waveform inversion (FWI) study in order to build high-resolution velocity models for Metal Earth traverses.

PROGRESS YEAR 1 - 2

Field work for the reflection seismic method involved acquiring over 1,000 line km of seismic R1 acquisition scenario (50 m shot spacing, 25 m receiver spacing, 15 km offset, and 12 seconds record length) and 200 km of seismic R2 acquisition scenario (25 m shot spacing, 12.5 receiver spacing, 15 km offset, and 12 seconds record length), that was acquired during summer and fall 2017 by SAExploration using 4 of the company's vibroseis trucks.

Initial processing of the acquired seismic data is currently underway by Absolute Imaging, a third party contractor to allow the field teams to use the data during the summer of 2018.

FUTURE WORK

The reflection seismic work is fundamental to extrapolating the surface geology, as being refined on the Metal Earth transects, to the subsurface, down to the mantle-crust interface, the Moho discontinuity.

The seismic (reflectivity) sections will show the boundaries between geological layers with distinct acoustic impedance properties and will reveal, with a high degree of certainty, the boundaries of the geological units. The reflectivity response of geological layers in the seismic sections will be interpreted by connecting corresponding layers to surface geology and integrating with the tectonic history of the region.

In addition, Metal Earth is collaborating with Dr. Gerhard Pratt, Western University, to develop for full waveform inversions of R3 scenario seismic data. This is a separate research project – an example of how further innovative research will be developed out of Metal Earth. MERC has also signed a Memorandum of Understanding (MOU) with the Smart Exploration project based at Uppsala University, Sweden. The EU-funded Smart Exploration is a three-year €5.2M project primarily focused on developing new, innovative methods and technologies for deep exploration targets. A link to their website is here: **smartexploration.eu**.

Figure 14: Photo of the seismic vibroseis trucks at the start of the Chibougamau transect.

Metal Earth researchers are investigating the possibility of passive seismic data acquisition and processing along Larder Lake traverse as a proof of concept study. The seismic image generated using passive seismic methods could be compared to the active seismic image. If consistent and comparable images are observed, researchers can deploy cost effective passive seismic methods for imaging hard to access regions, such as areas in the Slave Craton.

GRAVITY AND MAGNETICS

Dr. Richard Smith

The gravity and magnetics subproject at Metal Earth is supervised by Dr. Richard Smith, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE

The geophysical work involving non-seismic / MT 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 be built, that is consistent with the known geology (surface mapping and any drill holes) and the geophysical data, including the seismic data?
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 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 Ontario Geological Survey (OGS), the Geological Survey of Canada (GSC), the Minnesota Geological Survey (MGS), and the Footprint project databases.

The geophysical data includes magnetic data, available from the OGS, Ministry of Natural Resources, Quebec (MERN) and the GSC. 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 give an idea of how variable the susceptibility is spatially within the lithology. For example, a gneiss is expected to have considerable variation.

PROGRESS YEAR 1 - 2

The Year 2 (summer 2017) data collection covered the Chibougamau, Malartic and Noranda transects. Survey methodology was published in a Summary of Field Work which can be downloaded **HERE**. A similar paper will be completed in the fall of 2018.

FUTURE WORK

Year 3 (summer 2018), data collection will cover the active Ontario transects including Sudbury, Cobalt, Larder Lake, Swayze, Matheson, Geraldton-Onaman and Stormy-Dryden. 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.

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 about 0.1 milligals. This requires knowing the station elevation to approximately a third of a meter, using a differential Trimble GPS system.

GEOPHYSICAL M.Sc. THESIS 1

Amir Maleki

Amir Maleki, M.Sc. Candidate Geophysics, is completing his M.Sc. on the *Collection and interpretation of gravity data along the Chibougamau transects*. Supervised by Dr. Richard Smith, Metal Earth, MERC, Harquail School of Earth Sciences.

PROGRESS YEAR 1 - 2

Thesis research includes 1) gravity data acquisition along the Metal Earth transects, 2) incorporating the acquired gravity data along the Chibougamau transect with regional gravity data, and 3) combining gravity data with available magnetic data from the Quebec Government or the Geological Survey of Canada (GSC) to perform geologically constrained 2D integrated modelling. A. Maleki's thesis will be completed in the spring of 2019.

GEOPHYSICAL M.Sc. THESIS 2

William McNeice

William McNeice, M.Sc. Candidate Geophysics, is completing his thesis on *The use of magnetic susceptibility, a physical rock property, for potential field modelling of magnetic data*. Supervised by Dr. Richard Smith, Metal Earth, MERC, Harquail School of Earth Sciences.

PROGRESS YEAR 1 - 2

An area of 100km × 100km was chosen on the Ontario side of the Abitibi greenstone belt which has both publicly accessible high resolution airborne magnetic data and magnetic susceptibility data measured from rock outcrops; with the goal to compare the two datasets.

The airborne magnetic data is the sum of the magnetic responses from rocks on the surface, rocks under the surface, and ground cover. While the magnetic susceptibility obtained from the outcrop consists of the responses from only the surface rocks. The focus of this research is to compare the measured magnetic susceptibility values and the apparent magnetic susceptibility, which is derived from the airborne data using a series of filters, on Geosoft's Oasis montaj®.

The goal of this work will be to perform 2D line modelling, using a module in Oasis montaj®, to determine if magnetic susceptibility data collected from outcrops does, or does not, help with potential field modelling. W. McNeice's thesis will be completed in the spring of 2019.

Figure 15: William McNeice (standing) and Brandon Hume collecting gravity data.

GEOPHYSICAL DATA COMPILATION/MODELLING

Dr. Esmaeil Eshaghi

Project lead, Dr. Esmaeil Eshaghi, PDF, Metal Earth, MERC, Harquail School of Earth Sciences.

PROGRESS YEAR 1 - 2

An integral part of Metal Earth is the compiling and modelling of geophysical and geological data. In any geological modelling, some fundamental geological problems arise due to a lack of subsurface information. These problems raise significant questions for the research and exploration communities to tackle. A credible geophysical modelling exercise can enhance the understanding of geometry and properties of major subsurface geological units and boundaries associated with mineralization or tectonic evolution, to potentially direct the activities of mineral explorers or researchers.

Modelling of geophysical data (e.g. gravity and magnetic data) is limited due to the non-uniqueness of the solutions. Constraining these solutions with geologic observations and physical properties can limit the range of possibilities. Therefore, in order to reduce the ambiguity inherently associated with geophysical inversions, Metal Earth is using geological and geophysical constraints to limit the possibilities for non-unique solutions.

While geological observations provide surficial constraints of the initial models, seismic and magnetotelluric models provide information on the subsurface. In addition, systematic petrophysical characterisation defines the average and range of density and magnetic susceptibility values of major geological/stratigraphic units which help constrain the gravity and magnetic inversions.

Final inverted models reliably present depth sections that can be used to better evaluate components and structures contributing to mineralization, and differentiate areas associated with similar surficial geology but different levels of mineral enrichment. These models allow for the potential to either revalidate existing mineral endowment scenarios, modify existing models, or develop new models.

E. Eshaghi is the lead researcher on modeling and compiling the multiparameter geologic and geophysical data sets from the transect work. He is responsible for geophysical and petrophysical data compilation, contributing with management of data acquisition, potential field and petrophysical data processing and modeling. This is an ongoing iterative process and will continue through the course of the Metal Earth program. E. Eshaghi works closely with the other geologic and geophysical researchers to link the otherwise disparate datasets and produce internally consistent and coherent models.

FUTURE WORK: LOOKING FORWARD TO DISCOVERY

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 field work, data compilation and analysis during Metal Earth's start up years.

TRANSECT PROJECTS

GERALDTON-ONAMAN TRANSECT

Zsuzsanna Tóth

Keaton Strongman

Project Lead, Zsuzsanna Tóth, RA, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

The Geraldton-Onaman transect covers the northern part of the metasedimentary Quetico Subprovince, the Beardmore-Geraldton and Onaman-Tashota granite-greenstone belts of the eastern Wabigoon Subprovince.

Orogenic gold deposits across the Beardmore-Geraldton belt produced over 4.1 Moz Au over the past century and significant resources remain (e.g. Hardrock deposit, Geraldton, ca. 6.4 Moz) in this belt. In contrast, numerous precious and base metal occurrences were discovered in the Onaman-Tashota greenstone belt to the north, however, none of them have proven to be economic. Therefore, although it has geological evolution similar to the Beardmore-Geraldton belt, the Onaman-Tashota greenstone belt is a less endowed area.

During the summer of 2018, traverses will be completed to better understand the evolution of the Onaman-Tashota greenstone belt and to compare it to that of the Beardmore-Geraldton belt and the Abitibi greenstone belt.

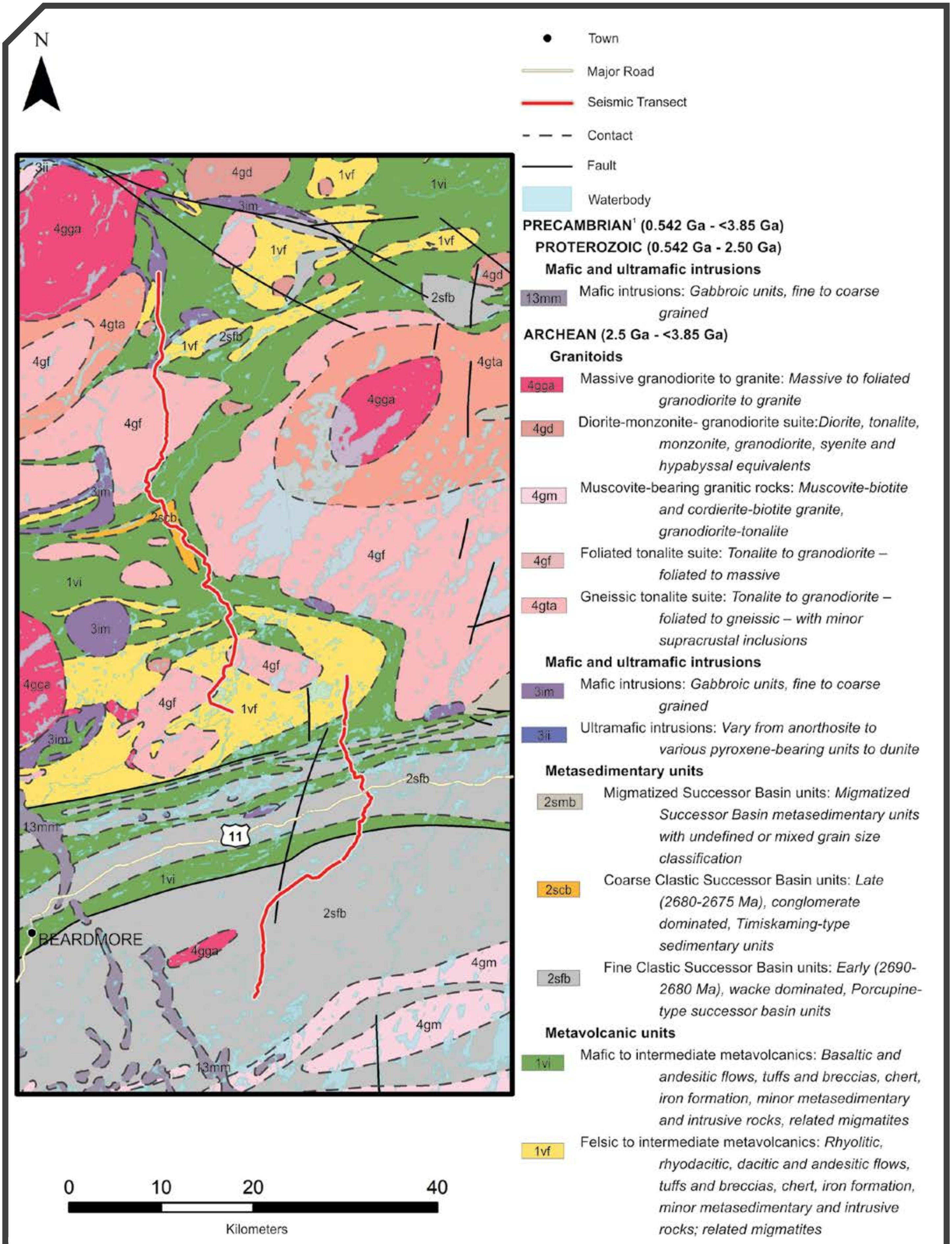


Figure 16: Geological compilation of the Geraldton-Onaman Transect.

Figure 17: The Geraldton-Onaman team ready for take-off to visit the Marshall Lake area along the northern boundary of the Onaman-Tashota greenstone belt. From left to right: Dr. Bruno Lafrance, Dr. Harold Gibson, Greg Stott, Jason Orloff, Anna Haataja, Keaton Strongman, Zsuzsanna Toth.

As part of his Ph.D. thesis, Keaton Strongman will study the geology of mineral occurrences across the Onaman-Tashota greenstone belt to determine what type of ore systems they represent, how they fit in the greenstone belt evolution, and what implications they carry in terms of geodynamic setting.

Z. Toth will assist in determining the relative timing of the mineralization, with respect to the structural evolution of the Onaman-Tashota greenstone belt, and attempt age dating the mineralization events in the Beardmore-Geraldton greenstone belt.

STORMY-DRYDEN TRANSECT

Dr. Ben Frieman

Stormy-Dryden transect lead, Dr. Ben Frieman, RA, Metal Earth, MERC, Harquail School of Earth Sciences.

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 metal endowment. As a consequence, the supracrustal stratigraphy, intrusive history, structural evolution, and metamorphic development are largely under-investigated, and their relationships with economic resource distribution are unknown. This project aims to investigate and integrate these topics to propose a revised Precambrian and metallogenic evolution model of the Western Wabigoon.

This study is focused on the central portion of the Western Wabigoon Subprovince, along the Stormy-Dryden transect, 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. These include the well-endowed Abitibi and the poorly endowed Western Wabigoon greenstone belts. The heterogeneity of metal endowment among these belts suggests there were factors contributing to mineralization that acted on a regional scale. Fundamental research questions to be investigated in this project include:

Figure 18: Stormy-Dryden team members at Kakabeka Falls. From left to right: Dr. Ben Frieman, Austin Goncalves, David Downie (standing), Dr. Stéphane Perrouty, Alec Graham, Katharine Holt, Rebecca Montsion and Kendra Zammit.

1. What were these factors?
2. How did these belts vary at the district- and craton-scales?
3. What were the associated geological processes?

To address these research questions, field work and 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 better mineralized belts in the Superior Province.

During the summer of 2018, Year 3 for Metal Earth, field work on the Stormy-Dryden transect will begin and focus initially on constraints on regional contact relationships (e.g. unconformable, tectonic), geochemical, and geochronological relationships between these volcanic groups.

These results will be compared to similar volcanic rocks in the Winnipeg River and Marmion terranes, and will be integrated with the broad knowledge of the magmatic evolution and Precambrian tectonics of the Superior Province. A number of graduate research topics will be developed over the course of the summer field work.

Ph.D. THESIS 1

Rebecca Montsion, Ph.D. Candidate in Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences. Thesis topic *Prospectivity Modelling Approach for Archean Greenstone Belts*. Supervised by Dr. Stéphane Perrouty and Dr. Ross Sherlock.

Rebecca Montsion

A Ph.D. thesis will be initiated in 2018 to develop a mineral prospectivity approach to determine if the integration of geological knowledge and prospectivity modelling can contribute to determining reasons for the poor metal endowment of the Western Wabigoon Subprovince.

A new 3D-GIS-based prospectivity and data analytics approach, which includes uncertainty analysis, will be developed and tested to characterize and understand the variables that control the spatial distribution of the alteration.

By integrating geological knowledge, data from multiple geoscientific disciplines (volcanic and

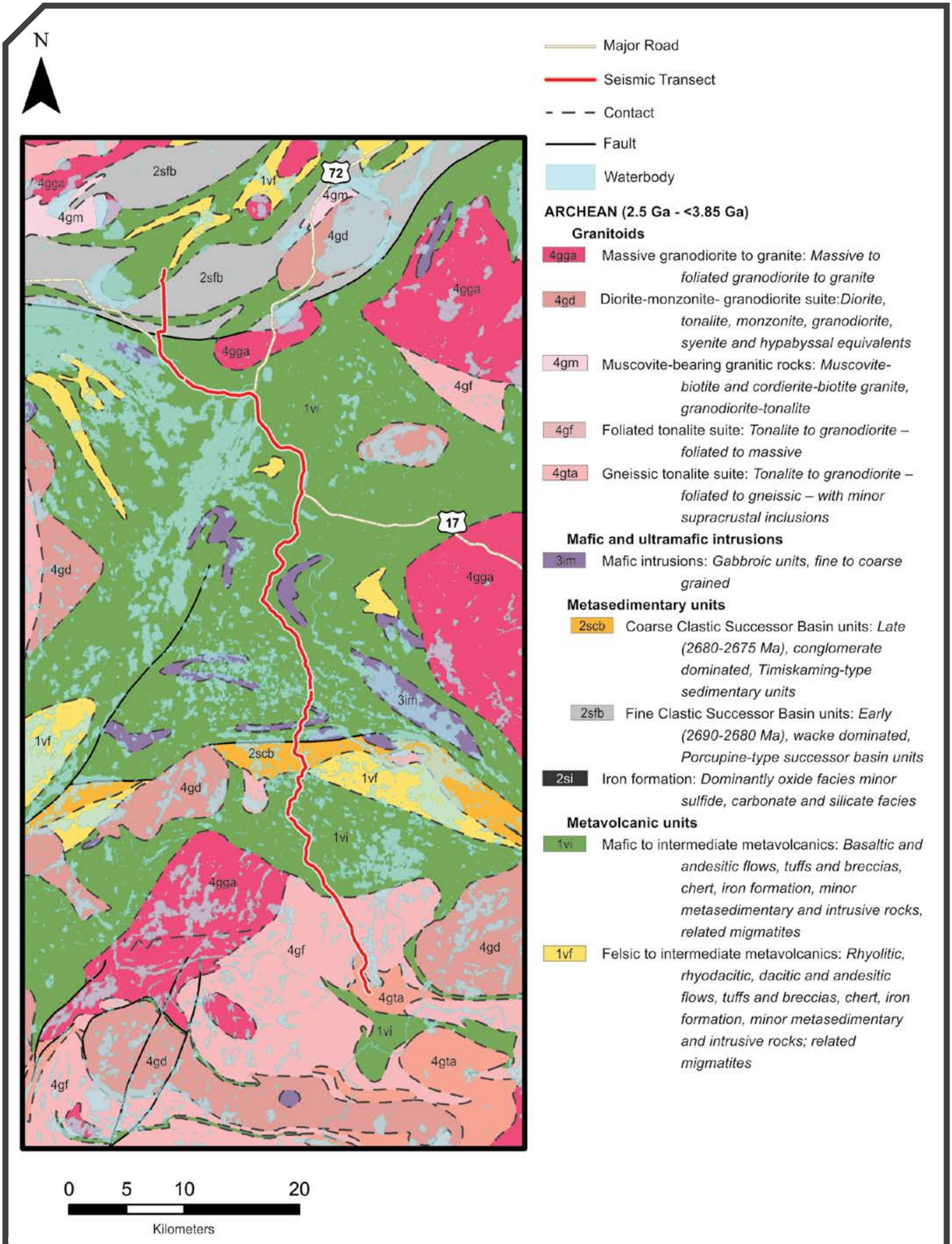


Figure 19: Geological compilation of the Stormy-Dryden Transect.

intrusive stratigraphy, structures, and metamorphism), 3D modelling, uncertainty analysis, and predictive mapping tools, results will provide new insight on the metallogeny and economic exploration of Archean greenstone belts, worldwide.

CHIBOUGAMAU TRANSECT

Dr. Lucie Mathieu, Faculty at Université du Québec à Chicoutimi (UQAC), Institutional Research Chair on Archean metallogenic processes, Center for Mineral Resources Research (CERM), and Metal Earth collaborator. Dr. Réal Daigneault, Director, CERM, Université du Québec à Chicoutimi (UQAC), Mapping of the Chibougamau Transect project.

Dr. Lucie Mathieu

Dr. Réal Daigneault

SCOPE OF PROJECT

The Chibougamau area, when compared to the rest of the Abitibi Subprovince, has several unique characteristics: fold-dominated architecture, lack of komatiites, unusual intrusions (layered complex and polyphased pluton), and a large amount of "intrusion-related" copper dominated mineralization.

Research will focus on the geologic architecture of deformation corridors, the Chibougamau pluton, the Abitibi-Opatica contact, as well as the contact between Formations.

Field work on the Chibougamau transect will be initiated in Year 3 of Metal Earth, in summer 2018. The project goals will be addressed over a period of several years. Four M.Sc. candidates and one PDF have been hired to work on the transect. These student researchers will assist in the construction of a 3D model that will be necessary to interpret the geophysical profiles. This documentation will also provide keys to the initial geometry and deformation history of the studied area.

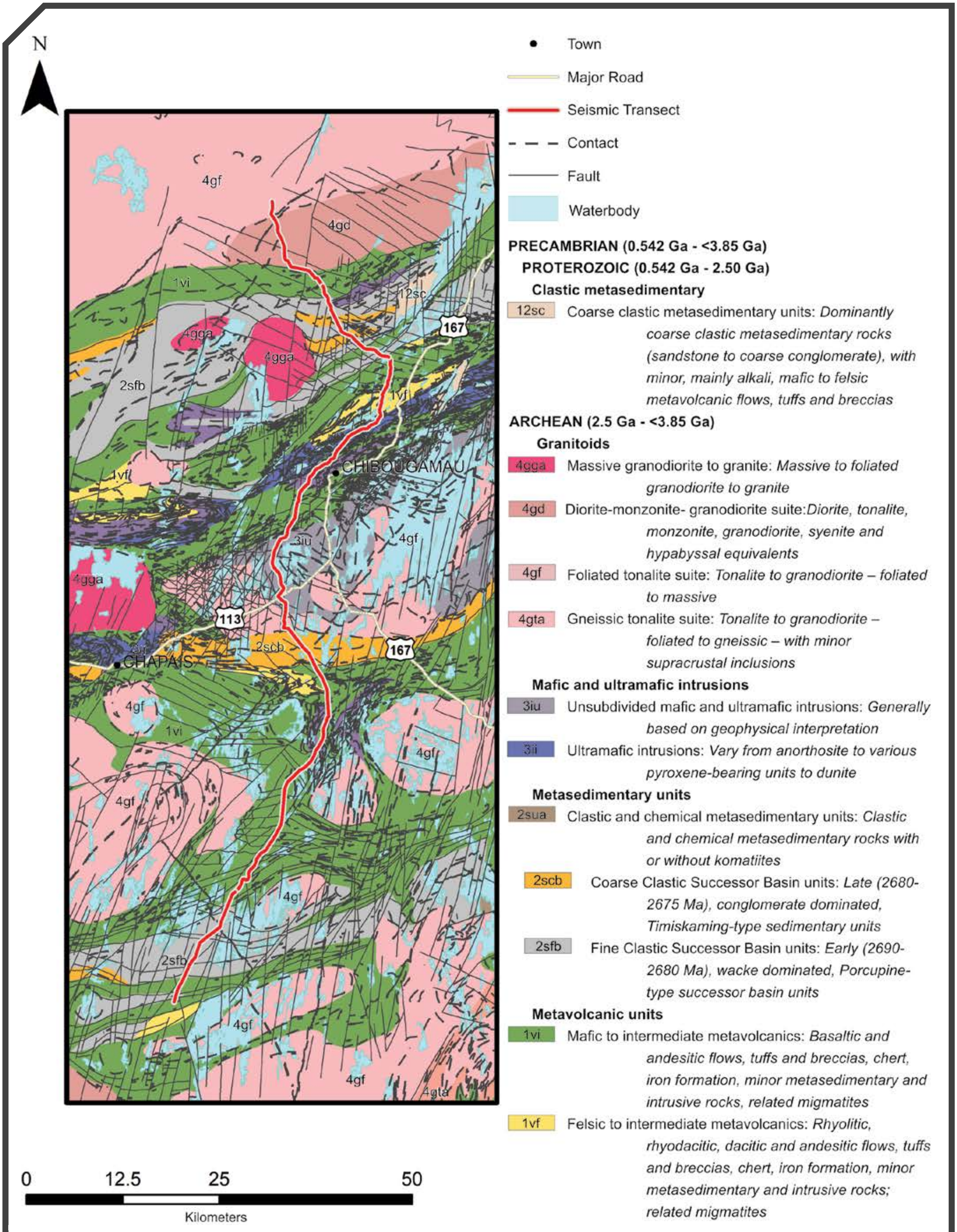
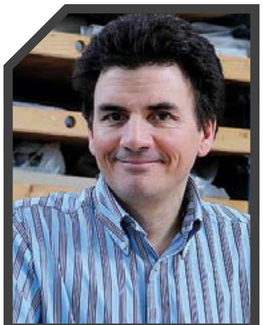


Figure 20: Geological compilation of the Chibougamau Transects.

FLUID SOURCE AND PATHWAYS



Dr. Georges Beaudoin

Project lead, Dr. Georges Beaudoin, NSERC-Agnico Eagle Industrial Research Chair in Mineral Exploration; and Dr. Benoit Quesnel, RA, Université Laval.

SCOPE OF PROJECT

This Metal Earth subproject will be a research collaboration with Université Laval where stable isotope analysis will provide information on fluid-rock interaction within selected areas of the transects. Stable isotopes of H, B, C, O, N, and S are very efficient tracers of geological phenomena in the lithosphere. The isotopic composition of these elements provides unique information about the source of fluids and their interactions with rock units. Within the Metal Earth research program, stable isotopes will allow researchers to track the sources of fluids and their fluid flow paths, and to decipher the conditions favorable for the formation of mineral deposits. This research will integrate with the transect scale work and add a critical piece of information to understand fluid flow and water / rock interaction.

GEOCHRONOLOGY

Dr. Michael A. Hamilton

Project lead, Dr. Michael A. Hamilton, Associate Professor, Jack Satterly Laboratory, University of Toronto.

SCOPE OF PROJECT

Geochronology is integral to the understanding of Archean geology. All of the transects will rely heavily on geochronological constraints to help resolve geologic problems and correlate geology across the subprovinces. The Jack Satterly Laboratory is one of the premier geochronology labs in the world, and this partnership with the University of Toronto will provide high resolution age dates to constrain stratigraphy and improve our understanding of the transect geology.

MT SURVEY

Eric Roots

Project lead, Dr. Graham James Hill, Senior RA, Metal Earth, MERC, Harquail School of Earth Sciences; Eric Roots, Ph.D. Candidate in Mineral Deposits and Precambrian Geology, Metal Earth, MERC, Harquail School of Earth Sciences.

SCOPE OF PROJECT

Magnetotelluric (MT) is a geophysical survey which resolves the bulk electrical resistivity (inverse of conductivity) of the crust. Metal Earth's MT survey will estimate the electrical resistivity of the Earth's crust and upper mantle using naturally occurring electromagnetic (EM) fields as sources. The MT responses from a number of measurements will be combined to create models of resistivity which constitute a proxy for geochemical and structural history of the study area.

The MT survey will be conducted during Year 3 of the project through a third party contractor, Complete MT Solutions [**complete-mt-solutions.com**]. This survey will be conducted along the same transects as the seismic survey and the geologic transects, using similar resolutions.

Understanding of the deeper structure and processes associated with mineralization remains unresolved in terms of deep magmatic staging at the boundary between the crust and the mantle, and conduit(s) permitting the passage of magmas and volatile streams toward the surface. However, these features are expected to possess a strong electrical resistivity contrast with the surrounding country rock, so MT resistivity imaging is an appropriate method to attempt to confirm or challenge existing models.

In settings where significant basaltic underplating appears to occur, mafic magmas ponded near Moho levels may hybridize with crustal materials, cool, and exsolve vertically mobile fluids of high solute content. As melt passage is intermittent, sub-vertical conduits of low resistivity should represent traces of separated hypersaline brine which have accumulated over time and formed large-scale interconnection. Moreover, the brittle regime crustal faults are likely to have become fluidised and also stand out in the resistivity structure. These are the features Metal Earth will be looking for as they represent potential migration paths through the crust for enriched fluids.

Each transect will have a MT survey conducted along its length using parameters that produce similar resolution to the seismic surveys conducted in 2017. These MT sections will be utilized in a similar manner to extrapolate surface geology to depth and combined with other geologic and geophysical constraints to produce a fully integrated geological/ geophysical section along the transects.

THEMATIC RESEARCH

PROPOSALS RESULTS

In January 2018, Metal Earth put out a call for proposals for thematic projects. These projects could be at any scale and needed to address fundamental questions pertaining to metal endowment. The general themes of the projects include:

1. Fluid/magma/heat pathways,
2. SCLM variations/differences in endowed and less endowed areas,
3. Fluid and metal sources in mantle and crust, and
4. Archean tectonics and metallogeny.

Metal Earth initiated a review process to assess the proposals and the fit with Metal Earth. The reviewers consisted of a subset of the MERC advisory board who were independent of Metal Earth. Each proposal was ranked according to 1) scientific merit of proposal, 2) excellence of researchers (do they have the expertise to do the project?), and, 3) fit with the goals of Metal Earth. The reviewers were Dr. Andy Wurst, Barrick Gold Corporation (Au); Dr. Andrew Davies, Teck Resources Limited (Cu); Dr. Frank Santaguida, First Cobalt Corporation (Ni); and Dr. Benoît Dubé (Geological Survey of Canada). Each proposal was ranked, and revisions were suggested to better conform with the goals of Metal Earth. The proposals were submitted to a budget committee, which assessed the appropriateness of budget and were then ranked and approved by the Metal Earth's Executive team.

The following six projects were funded in Year 2 and the results will be reported upon in subsequent reports:

1. The nature of Archean porphyritic rocks associated with copper mineralization in the Superior Province, Canadian Shield (PI: Jeremy P. Richards, 1 Ph.D.)
2. Factors contributing to metal endowment in the Western Wabigoon Subprovince: A mineral prospectivity modelling approach for Archean Greenstone Belts (PI: Stephane Perrouty. 1 Ph.D.)
3. Localization of Magmatic Cr and Ni-Cu-PGE Mineralization within and along the margins of the Superior Craton (PI: Mike Lesher, 1 Ph.D., 2 M.Sc.)
4. Chemical and temporal characterization of gold mineralized and barren fluid pathways (PI: Daniel J. Kontak, 1 Ph.D.)
5. Tectonothermal evolution of the middle-lower Abitibi-Wawa crust and its relation to the Borden Lake gold deposit, Kapuskasing Uplift, Ontario (PI: Doug Tinkham, 1 Ph.D.)
6. Mineralogical indicators of oxidation/reduction and relationship to Syenite-hosted Au Mineralization, Rundle deposit, Swayze area, Abitibi Greenstone Belt, ON (PI: Andy MacDonald, 1 MSc)

DOWNLOADABLE REPORTS AND PAPERS

Project: CRATON SCALE MAPPING – GEOLOGIC COMPILATION OF THE SUPERIOR CRATON
Title: Superior Data Compilation
Link: **https://merc.laurentian.ca/research/metal-earth/superior-compilation**

Project: MALARTIC TRANSECT
Title: Stratigraphic and structural setting of gold and nickel deposits in the La Motte–Malartic area, southern Abitibi and Pontiac subprovinces, Superior Province, Quebec
Link: **https://merc.laurentian.ca/news-standard/stratigraphic-and-structural-setting-gold-and-nickel-deposits-the-la-motte–malartic**

Project: MALARTIC TRANSECT; M.SC. TOPIC 1
Title: 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 Quebec
Link: **https://merc.laurentian.ca/news-standard/structural-geology-the-timiskaming-and-cadillac-groups-along-the-malartic-segment-the**

Project: MALARTIC TRANSECT; M.Sc. TOPIC 2
Title: Lithological and structural setting of the Cubric nickel showing, Southern Manneville fault, southern Abitibi Subprovince, Quebec
Link: **https://merc.laurentian.ca/news-standard/lithological-and-structural-setting-the-cubric-nickel-showing-southern-manneville**

Project: ROUYN-NORANDA TRANSECT
Title: Preliminary results from transect mapping in the Abitibi greenstone belt and Pontiac Subprovince, Rouyn-Noranda area, Quebec
Link: **https://merc.laurentian.ca/news-standard/preliminary-results-from-transect-mapping-the-abitibi-greenstone-belt-and-pontiac**

Project: ROUYN-NORANDA TRANSECT; Ph.D. TOPIC 1
Title: Reconnaissance mapping of the geology and mineral deposits of the Powell block, Rouyn-Noranda area, Quebec
Link: **https://merc.laurentian.ca/news-standard/reconnaissance-mapping-the-geology-and-mineral-deposits-the-powell-block-rouyn-noranda**

Project: ROUYN-NORANDA TRANSECT; M.Sc. TOPIC 1
Title: Volcanic stratigraphy and intrusions in the Renault–Dufresnoy and Duprat–Montbray formations: implications for metal endowment in the lower Blake River group, Rouyn-Noranda, Quebec
Link: **https://merc.laurentian.ca/news-standard/volcanic-stratigraphy-and-intrusions-the-renault–dufresnoy-and-duprat–montbray**

Project: ROUYN-NORANDA TRANSECT; M.Sc. TOPIC 2
Title: Preliminary results from detailed geological mapping of the contact zone between metavolcanic and metasedimentary rocks in the Pontiac Subprovince, Lac Bellecombe area, Quebec Published Tuesday, 19 December 2017
Link: **merc.laurentian.ca/news-standard/preliminary-results-from-detailed-geological-mapping-the-contact-zone-between**

Project: **BEN-NEVIS - LARDER LAKE TRANSECT; M.SC. TOPIC 1**
Title: Preliminary Results from Detailed Geological Mapping and Core Logging of Volcanic and Sedimentary Rocks in the Footprint of the Kerr–Addison Mine, Virginiatown, Ontario
Link: https://merc.laurentian.ca/news-standard/preliminary-results-from-detailed-geological-mapping-and-core-logging-volcanic-and

Project: **BEN-NEVIS - LARDER LAKE TRANSECT; M.SC. TOPIC 2**
Title: Preliminary Results from Detailed Geological Mapping of Syenite-Associated Gold Mineralization Along the Lincoln–Nipissing Fault, Larder Lake, Ontario
Link: https://merc.laurentian.ca/news-standard/preliminary-results-from-detailed-geological-mapping-syenite-associated-gold

Project: **SWAYZE TRANSECT**
Title: Lithological and Stratigraphic Relationships of the Swayze Area, Abitibi Greenstone Belt Published Tuesday, 19 December 2017
Link: https://merc.laurentian.ca/news-standard/lithological-and-stratigraphic-relationships-the-swayze-area-abitibi-greenstone-belt

Project: **GRAVITY AND MAGNETICS**
Title: Metal Earth Geophysics Report - Summer 2017
Link: https://merc.laurentian.ca/news-standard/metal-earth-geophysics-report-summer-2017

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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 [18] on metal endowment. 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 [18] 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 thoroughly 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 [19] 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 [20, 21]. 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) [1, 2, 20], 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 [5].

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 [22], 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) [23] 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 [24]. A split-stream laser ablation (LASS) system [25, 26], 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 [27] 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., [28]) 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 [29] as type examples of endowed and less endowed terranes, respectively, characterizing differential endowment at the terrane scale in the Superior Craton (Figure 1). 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 [30, 31] and the Yellowknife and Hope Bay greenstone belts of the Slave Craton [32], 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 (MT), 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 surveys (MT) can detect mineralization and evidence of past fluid flow preserved as carbon films along major discontinuities and provide resistivity/conductivity images of the crust [33]. 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., [34]), 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., [35]). 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) [36]. However, orthomagmatic Ni-Cu-PGE (+/- Cr) deposits [37] and orogenic Au deposits [38] 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 [39])? Other questions to be addressed include: 1) Do the linear belts of younger sedimentary rocks that unconformably overly older volcanic rocks [38, 40] 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 [38, 41]. 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 [40, 42]? 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 [43], magmas [44, 45], 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 [41, 42] and CO_2. Is the CO_2, manifest now as ubiquitous carbonate alteration within and along some ancestral faults [46] 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., [45]? 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 [32] and the Superior [29, 47] 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 [48]? 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., [44, 49] and refs. therein) and accumulated latent heat from early meteorite bombardment [50]. 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 [51, 52, 53]. 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 [54]?

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., [55, 56]. 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 Center of Excellence for Ore Deposits Research (CODES) at U. Tasmania [56] 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 [21, 54]. Did a more reduced Archean atmosphere and hydrosphere affect the behavior of sulphur and thus the formation of metal deposits [57]? 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. [21]?

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 [19, 53, 55] 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/US Array project [58]. Data and models will be managed at the Center 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.

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