Laurentian University
Université Laurentienne

HARQUAIL School of Earth Sciences
École des sciences de la Terre

PROCEEDINGS

of the

Harquail School of Earth Sciences

2019 GRADUATE SYMPOSIUM

December 2–3, 2019

Auditorium of the Willet Green Miller Centre

Edited by

D. McKevitt, H. Seibel, F. Justina, and S. Perrouty

HARQUAIL EARTH SCIENCES
(705) 675-1151 x6575;
HES@laurentian.ca
hes.laurentian.ca

MERC
Mineral Exploration Research Centre
at the HARQUAIL School of Earth Sciences

METAL EARTH

Laurentian University
Université Laurentienne

GOODMAN SCHOOL OF MINES
ÉCOLE DES MINES

Canada's Mining University

PROGRAM

Monday, December 2nd

Ni-Cu-PGE Systems

*10:20 AM – **COFFEE BREAK***

Base Metals and Polymetallic Systems

Environmental Geosciences

*12:00 PM – **LUNCH BREAK***

Geophysics and Modelling

*02:40 PM – **COFFEE BREAK***

Tuesday, December 3rd

Porphyry and Intrusion-related Systems

*10:20 AM – **COFFEE BREAK***

Precambrian Geology

Monday, December 2nd

Dustin Peters (PhD student) *9:00 AM* *02/12/2019*

A Review on the General Characteristics and Formation of Sublayer in the Sudbury Igneous Complex, Ontario

Approximately 50% of the Ni-Cu-PGE ores associated with the Sudbury Igneous Complex (SIC) are hosted by or associated with Sublayer norite, a magmatic breccia restricted to embayments and troughs along the lower contact of the complex. It has been the subject of numerous studies to better understand its origin and link to sulfide mineralization. Sublayer is characterized by abundant mafic to ultramafic and lesser intermediate to felsic inclusions in an igneous textured, noritic to sulfidic matrix. There are three different inclusion types: (1) anteliths (cognate inclusions) originating from the melt sheet itself, (2) local inclusions derived from surrounding footwall rocks, and (3) exotic inclusions without nearby equivalents. Sublayer matrix moreover varies significantly in trace element composition around the SIC, indicating contamination by assimilation of local country rocks and inclusions. Three processes have been proposed to form Sublayer and embayments: 1) convective sweeping, 2) gravity flow of impact-generated inclusions and exsolved sulfides into embayments along the crater floor and 3) thermomechanical erosion of local footwall rocks to form inclusions and embayments. Variations in the S-Pb isotopic compositions of the ores require significant contribution from local footwall rocks, but exotic inclusions preclude an entirely thermomechanical erosion and there are fluid dynamic limitations on convective sweeping and gravity flow. Solving these questions is essential for defining better constrained mineralization vectors around the SIC.

Sandra Baurier Aymat (PhD student) *9:20 AM* *02/12/2019*

Footwall breccia in the Cryderman area, Sudbury Igneous Complex, Ontario

Footwall breccia (FWBX) occurs, together with Sublayer norite (SLNR), discontinuously along the basal contact of the Sudbury Igneous Complex (SIC) and hosts a significant portion of the Ni-(Cu-PGE)-bearing contact ores. Both are well developed on the North and East Ranges, but FWBX occurs only locally on the South Range. The two rock types are polymictic, matrix-supported breccias containing heterometric fragments of mostly local footwall lithologies and minor exotic lithologies, but FWBX is characterized by an anatectic to sulfidic matrix, whereas SLNR is characterized by a noritic to sulfidic matrix. Coarsening of FWBX matrix grain sizes occurs towards the contact with the SIC, and mineralogy and bulk composition vary with proximity to the footwall and to the sulfide mineralization. In the Cryderman area, located along the SE margin of the SIC, mineralization is dominantly hosted in FWBX, which typically occurs adjacent to weakly to non-brecciated metabasaltic-metasedimentary footwall rocks. SLNR is much less abundant in this area than in other mineralized contact environments, including the nearby Falconbridge and Garson deposits, which have been interpreted as subvertical tectonized embayments and troughs of mineralized SLNR. Defining the characteristics of FWBX and lesser SLNR in the Cryderman area will better constrain the formation, timing, and spatial relationships between the different rock types in contact-ore environments in the SIC.

Henning V. L. Seibel (PhD student) *9:40 AM* *02/12/2019*

Models of Offset Dike Formation in the Sudbury Igneous Complex, Ontario

Offset dikes contain approximately 50% of the total ore reserves and resources in the Sudbury Igneous Complex (SIC) and their margins are generally thought to represent the initial impact melt composition. Thus, they play an important part in understanding the formation of the SIC and represent desirable exploration targets for mining companies. Despite the fact that some of these dikes have been studied in great detail and have been mined for over 100 years, there is still uncertainty and debate about their genesis. The most proposed model for offset dike formation involves injection of two temporally distinct melts: emplacement of sulfide-poor, inclusion-poor quartz-diorite melt (QD) was followed by injection of sulfide-rich, inclusion-rich quartz-diorite (MIQD) in the center of the dikes. An alternative model involves emplacement of one sulfide-rich, inclusion-rich quartz-diorite melt with flowage differentiation producing a sulfide-poor, inclusion-poor marginal zone and a sulfide-rich, inclusion-rich interior zone. These two models have very different implications for (a) the timing and mechanism of offset dike emplacement within the evolution of the SIC, (b) the timing of inclusion generation and sulfur saturation in the SIC, and (c) exploration vectors for targeting mineralization in offset dikes. Therefore, a detailed understanding of the exact processes involved in their formation is needed.

Dylan J. McKevitt (PhD student) *10:00 AM* *02/12/2019*

Petrology and architecture of the magmatic plumbing system for the Expo-Delta-Raglan Ni-Cu PGE deposits, Circum-Superior Large Igneous Province, Nunavik, Québec

The eastern half of the Cape Smith Belt's Southern Domain in Nunavik (Québec) contains a world-class nickel district and displays one of the best-exposed and least-metamorphosed sections through the Circum-Superior Large Igneous Province. Rocks are generally metamorphosed to lower-middle greenschist facies and only locally deformed, so igneous structures and textures are generally well preserved. Two volcano-sedimentary groups comprise the stratigraphic sequence. The Povungnituk Group consists of the lowermost Nituk Formation sedimentary rocks that directly overlie Archean Superior Province basement, 2.04-1.96 Ga Beauparlant Formation tholeiitic basalts, and the uppermost sedimentary Nuvilic Formation. Komatiitic-tholeiitic basalts of the ca. 1.88 Ga Chukotat Group conformably overlie the Povungnituk Group. Differentiated olivine pyroxenite\meso-leucogabbro sills ("Delta" units) intrude the major sedimentary horizons and contain subeconomic reef-style PGE-(Cu)-(Ni) sulfide mineralization. Poorly-differentiated blade-shaped dikes with olivine pyroxenite to peridotite cores and melagabbroic margins ("Expo" units) intrude Povungnituk basalts and associated sedimentary horizons and host significant Cu-Ni-PGE mineralization along their lower margins and keels. Poorly-differentiated lava channels and invasive channels ("Raglan" units) composed mainly of peridotite with pyroxenitic margins represent the basal part of the Chukotat sequence and contain world-class Ni-Cu-PGE mineralization localized in embayments at the bottoms of flows. The petrology and mineralization in each part of the system reflects the degree of channelization, magma flux, and proximity to S-rich sedimentary horizons.

Louise V. Rush (MSc student) *10:40 AM* *02/12/2019*

Recent models addressing the ambiguous nature of five-metal association type vein deposits

The polymetallic "five-element" (Ag-Ni-Co-As-Bi) veins of arsenides and sulfarsenides are well known for their high tenors as much as their ambiguous genetic models. Although a paragenesis from sulfide to native metal to arsenide and back to sulfide is established, the deposits are known to occur in varying rocks types of different geologic settings and age. The present study focuses on the polymetallic veins in Cobalt, Ontario, which is Canada's premier Ag producer (400+ Moz). At present a modern genetic model that accounts for deposit formation and sources of metals and hydrothermal fluids is lacking. More recent models based on studies in European equivalents address (i) conspicuous ore textures, (ii) complex mineralogy, (iii) discontinuous mineralization, and (iv) lack of significant wall-rock alteration to better constrain chemical controls and mechanics of vein formation. These models conclude that the unusual ore textures imply far-from-equilibrium conditions of mineral formation and a redox control. "Natural fracking", or tectonically controlled liberation of reduced hydrocarbon bearing fluids, allowed a sudden influx and mixing with oxidized metal-rich fluids, which facilitated native metal and arsenide precipitation. In-situ S-C-O isotope signatures from deposits formed in similar geologic settings to Cobalt provide case-by-case indications of metal and fluid sources. These models will be applied to Cobalt veins in hopes of determining the metal, sulfur, and reducing agent source(s), and mobilization mechanism for fluid mixing.

Chaneil Wallace (PhD student) *11:00 AM* *02/12/2019*

Geology of the carbonate-hosted Navan Zn-Pb deposit, Ireland

The Irish Midlands contain numerous carbonate-hosted Zn-Pb deposits and many past producing mines hosted by Lower Carboniferous carbonate strata that accumulated in rift basins. Navan (17.4 Mt at 5.6% Zn + 1.5% Pb), Europe's largest Zn mine, is the only currently active Zn mine in Ireland and contains an unusual new ore-zone (Tara deep) that is currently being delineated. Developing a better understanding of Navan is pressing because current exploration in Ireland seeks to find the "next Navan". The original Navan deposit, in Courceyan (Tournaisian) strata, consists of stratiform mineralisation in multiple shallow-marine carbonate layers, and is cross-cut by an erosion surface overlain by the 'boulder conglomerate', a deposit of presumed Chadian (early Viséan) age that contains mineralised clasts indicating very early, sub-seafloor, hydrothermal mineralisation, and resedimentation of mineralised clasts in the late Courceyan – early Chadian. Tara deep's mineralisation, in contrast, is hosted by the matrix of unrelated, younger carbonate conglomerate units intercalated in deep-water Chadian-Arundian (Viséan) calciturbidites >1.5 km from the original ore-zone, and hence records yet another, later episode of mineralisation. The origin of and controls on Tara deep mineralisation remain to be deciphered.

Christian Frost (MSc student) *11:20 AM* *02/12/2019*

A literature review on the textural characteristics, reaction pathways and formation mechanisms of framboidal pyrite

A 'framboid' is a characteristic shape and texture of syngenetic and diagenetic sedimentary pyrite, defined as microscopic, sphaeroidal to sub-sphaeroidal clusters of equidimensional, equimorphic pyrite crystals. Framboidal pyrite formation takes place through three possible reaction pathways: 1) initial formation of mackinawite (poorly ordered Fe sulphide) as an intermediary; 2) reaction of FeS, either as pyrrhotite or mackinawite, with H_2S to form pyrite; and 3) the addition of a polysulphide to the reaction series, increasing the rate of pyrite formation. The morphological characteristics of framboidal pyrite indicate 1) a lag phase before nucleation becomes significant, regarded as a metastable phase interval, 2) burst nucleation, in which nucleation rate increases exponentially and can finish in seconds, and 3) a short growth phase in which nucleation becomes insignificant as a result of the limitation in the supply of components. Framboidal pyrite displays elevated trace element content (Ni, Co, As, Se, Cu, Zn, Pb, Bi, Sb, Tl, Mo, Ag, Cd, Mn, Hg, Te and Au), which is postulated as the metal source for Carlin-type and orogenic gold deposits. Zn/Ni and Tl/Co ratios in framboidal pyrite can be used as an exploration vector towards SEDEX mineralisation, because hydrothermal vent-fluid (ore-forming) increases the Zn and Tl content of pyrite but decreases Ni and Co, producing spatial gradients in the concentrations of these trace elements in pyrite.

Brittaney Courchesne (MSc student) *11:40 AM* *02/12/2019*

X-ray absorption spectroscopy:
A powerful tool to pre-characterize arsenic-rich tailings material prior to their bioleaching

Knowledge of arsenic (As) mineralogy and geochemistry in tailings is of great importance prior to their remediation or bioleaching as the solubility, stability, and reactivity of primary and secondary As-bearing minerals vary based on pH and redox conditions. In nature, As predominantly occurs in primary ore minerals as As(-3) and As(0), and as As(+3) and As(+5) in secondary phases. To deduce the abundance of primary versus secondary As-mineral phases, we looked at the average valence state of arsenic from three weakly alkaline tailings sites in Northeastern Ontario by means of a subset of X-ray absorption spectroscopy, known as X-ray absorption near-edge structure (XANES). XANES is one of two energy regions within the X-ray absorption spectrum that is used to ascertain valence state data of a specific element, in this case arsenic. The average valence of As found in each study site was: 4.4 (site A), 4.1 (site B) and 3.27 (site C). Therefore, pentavalent (+5) As was the most dominant form, implying that secondary As-mineral phases are more abundant than primary As-minerals. Arsenic speciation is essential in: a) providing insight into the geochemical behaviour of As; b) determining whether the microbial communities present vary based on arsenic speciation; and c) aiding in the development of an efficient, site-specific bioleaching model, when combined with chemical, mineralogical and microbial data.

Neal McClenaghan (MSc student) *1:00 PM* *02/12/2019*

Mineral-nanomineral relationships in Cr deposits and their effect on the fate of Cr in the environment

Recent studies indicate that naturally occurring environmental nanoparticles can play a key role in the chemical characteristics and overall quality of natural waters. Despite this knowledge, environmental risk assessments are based on the total concentrations of elements in natural waters, ignoring that a significant proportion of the elements are associated with nanoparticles. Recent nanoscale examinations of Cr-rich silicates show that Cr occurs in silicates of ultramafic rocks in the form of chromite ($FeCr_2O_4$) nanoparticles. Leaching experiments of the silicates and subsequent TEM (transmission electron microscope) examinations of the colloidal fraction of the leachate indicate the occurrence of chromite nanoparticles in highly altered amorphous Al-silicates, suggesting that these nanoparticles do not necessarily dissolve during weathering of the silicates. The release of chromite nanoparticles during dissolution of Cr-rich mafic silicates will thus affect the long-term environmental fate of Cr in natural waters. To assess the long-term environmental fate of Cr, a set of experiments are designed in order to examine the oxidation kinetics and particle interactions of chromite nanoparticles with strongly oxidising agents of Mn_3O_4. Preliminary TEM examinations indicate that Mn^{3+} in Mn_3O_4 oxidize Fe^{2+} in $FeCr_2O_4$ resulting in the formation of Fe^{3+} and Cr^{3+} hydroxides.

Phathutshedzo M. Nethavhani (MSc student) *1:20 PM* *02/12/2019*

A review of kriging as an optimal interpolator in geostatistical analysis and its implications for the Sudbury soil study

Greater Sudbury has been historically crucial for the mining of Nickel, leading to significant environmental impact, including extensive heavy metal soil contamination. This research considers geospatial, continuous, interpolation (kriging) to evaluate the geographic distribution of Sudbury's contamination with a variety of kriging methods. Kriging helps with planning, risk, and area assessment, which are all part of the decision making in various disciplines, including environmental geoscience. Acquiring data to produce regional scale surveys such as the Sudbury soil study can be costly and usually results in sparse sampling grids. Kriging can partly mitigate this lack of information using predictions. The spatial distribution of geochemical values is often stationary. Observations that are close in geographic space are more related than those further apart, displaying autocorrelation, which is a pre-requisite for the application of kriging techniques together with constant variance and mean over specific distances (variograms). Kriging is often challenging to parametrize, requiring cross-validation strategies to evaluate interpolation quality. A review of kriging methods and a series of case studies are proposed to illustrate some of the foundations of geostatistics and its potential application to soil geochemistry in Sudbury.

Lawraine Lerato Mogashoa (MSc student) *1:40 PM* *02/12/2019*

A review of the concept of 3D geological modelling: Example from the Sandstone greenstone belt

With the recent development of computer technology, geological modelling programs have evolved from 2D approaches to 3D approaches. This provides an effective way of integrating multi-disciplinary data and visualising subsurface geology. 3D geological modelling can be described as the construction of a volumetric model comprising a collection faults, lithologies, contacts and their topological relationships that define the subsurface geology. This talk aims to review the concept of 3D geological modelling and presents an example from the Archean Sandstone greenstone belt (north-central Yilgarn Craton) to highlight how various datasets can be used to construct a model in sparse data environments. This includes data such as cross sections, seismic reflection profile and 2D forward models. From a computational perspective, integration of these datasets can be done through explicit or implicit modelling techniques. Explicit modelling is a technique that relies on manual digitisation of geological sections that are then linked by a wireframing process to create models. Implicit modelling uses a single mathematical function such as a radial basis function to reconstruct interpolated surfaces and volumes. By integrating various datasets and 3D modelling techniques, insight into the distribution of lithology and structure (in the Sandstone greenstone belt) was determined. 3D geological modelling is beneficial in mineral exploration to enhance the knowledge of the geology and mineralization at greater depth.

Sahibzada H. Ali (MSc student) *2:00 PM* *02/12/2019*

Implicit 3D modelling: exploring for deeper volcanogenic massive sulphide (VMS) deposits, Noranda Central Camp

The Noranda mining camp (NC) is an economically significant part of the Abitibi subprovince. This research focuses on developing a 3D model of the central part of the NC to facilitate a re-evaluation of the relationship of VMS deposits with fault structures and exhalites as well as representing updated 3D geochemical patterns. Recently developed, deeper drillholes and assayed multielement geochemical data support exploration for VMS deposits at greater depths. Thus, 3D structural modelling will assist with the interpretation of integrated synvolcanic faults and better establish their relationship to the exhalites. These structures represent plausible hydrothermal and magmatic conduits, which led to metal deposition in the Blake River Group. By quantifying hydrothermal alteration/mineralization in 3D and contrasting it with the structural modelling, potential new prospective domains will be highlighted, where further economic Cu-Zn-(Au) mineralization may be found. Earlier 3D models used an explicit modelling approach to integrate multidisciplinary datasets. However, geochemical vectors were not analyzed in detail and coupled with a 3D representation of geochemical mobility (mass-balance calculations). Proposed 3D reconstructions are rather based on implicit modelling (Leapfrog Geo™) in concert with multivariate geochemical data integration (ioGAS™) to leverage updated targeting technology. Preliminary results based on relatively simple vectors have shown similar relationships of alteration with synvolcanic faults and exhalites, as reported in earlier contributions.

Anthony Zamperoni (MSc student) *2:20 PM* *02/12/2019*

Modelling the airborne electromagnetic response of a sphere beneath conductive overburden

Electromagnetic geophysical methods are used in mineral exploration for the ability to detect conductors at depth. It is important to consider the interaction between the target conductor and any thin, conductive overburden than might exist above the half-space. The overburden is often comprised of glacial tills and clays or the conductive weathering of basement rocks. This situation can be approximated using a discrete conductor model consisting of a "dipping sphere" in a resistive half-space underlying conductive overburden. A semi-analytical solution that considers the first-order interaction of the sphere and overburden has been derived to calculate the airborne electromagnetic response. The simplicity and efficiency of this solution makes it well suited to be implemented when computation time and immediacy of results are desirable. To this end, we have developed a graphical user interface which generates the electromagnetic response for this sphere overburden model. The program allows users to change the parameters of the survey and target body and quickly view the resulting changes in the electromagnetic response. The newly developed program was used to model the response of a known anomaly at the Forrestania test site in Australia, the results are compared with models generated using existing plate modelling software.

Hossein Jodeiri Akbari Fam (PhD student) *3:00 PM* *02/12/2019*

High-resolution Multi-Focusing seismic imaging

A recently introduced Multi-focusing (MF) time imaging method can considerably improve the quality of seismic imaging in the complex geologic areas with the poor signal-to-noise ratio. This method is a sophisticated alternative method for conventional stacking and provides very detailed and high-resolution images based on a transformation of multi-coverage pre-stack data into a zero-offset stack section. The implementation of Multi-focusing is technically challenging, computationally expensive, and comprises several isolated steps and lacks an efficient optimization component. In a two-dimensional case, the MF time correction operator depends on three wavefront parameters. The main problem of this approach is the simultaneous determination of these parameters optimally for each image point and time location. In this research, we address the optimization problem using multidimensional constrained Very-Fast-Simulated-Annealing (VFSA) and Differential-Evolution (DE) global optimization algorithms. We have also designed an efficient signal processing sequence for pre-stack data enhancement. We examined our developed algorithm and codes on 2D complex synthetic seismic data. The results indicate that both mentioned optimization algorithms are computationally cost-effective, however, the DE algorithm was more accurate than the VFSA algorithm. The MF method focuses the sub-vertical faults and steeply dipping reflections at their right location and images them clearly compared to the conventional method. Our approach leads to high-resolution seismic images with a significant impact on interpretation ability for the seismic section.

Christopher Mancuso (MSc student) *3:20 PM* *02/12/2019*

Imaging cross-dipping events in Metal Earth's reflection seismic surveys

High amplitude reflections in crustal seismic surveys are often credited to shear zones, underplating or more complex 3D structures. A 3D seismic survey could effectively image these structures, however, most of the Metal Earth surveys were acquired along the available roadways resulting in crooked 2D seismic geometries. Fortunately, a 2D crooked line acquisition provides a swath 3D data configuration that can illuminate out-of-plane structures. By applying Cross-Dip Moveout (CDMO) correction on the data, one can image cross-dipping events on 2D profiles. Traditionally, CDMO correction is implemented by applying time shifts to the traces along straight processing lines to mitigate the midpoint dispersal in the final stack. However, for crooked lines, the Common Mid Point (CMP) locations are often picked by carefully fitting a curved processing line through the prestack data-space in order to get a consistent fold. Therefore, we propose a new CDMO operator by utilizing two, instead of one, free parameters representing the decomposed dip components within the Cartesian space that is more suitable for curved processing lines. The proposed method can be more easily applied to any processing geometry (flat, curved, disparate, etc). After examining the performance of proposed method on synthetic data, the algorithm was applied to the Metal Earth's Larder Lake transect.

Robert Rapolai (MSc student) *3:40 PM* *02/12/2019*

Integrated geophysical interpretation and modeling of the Rouyn-Noranda transect

The main objective of geophysical interpretation and modeling is to produce a consistent and reliable model of the subsurface using available data sets. Integrated interpretation of geophysical data for Rouyn-Noranda area has been carried out using seismic attribute analyses and integration with Gravity and Magnetotelluric (MT) data to find correlations between seismic reflectivity, density, and electrical resistivity. Two types of inverted gravity models, constrained and unconstrained inversions, and a regional scale MT resistivity model were analyzed in this study. The seismic reflection character of the upper crust (~10km) is poor, characterized by weak scattered reflections, marked by the base of the Blake River Group. The 3D constrained gravity inversion reveals the depths and extends of intrusive and plutonic bodies along the transect. The middle crust (~10-24km) is characterized by regionally sub-horizontal and east-ward dipping reflections. This part represents the most complex reflection character of the crust with major break in reflectivity and high electrical resistivity. The high reflectivity character of the middle crust is attributed to several geological factors which will be discussed. The deeper crust (~24-36km) is characterized by horizontal, laterally discontinuous, subparallel reflections, suggesting possible mantle penetrating shear zones. As the seismic line overlaps with the Lithoprobe regional line 21, the overall resolution of the Metal Earth seismic data is higher, and more details about crustal structure have been revealed by integration with legacy geophysical data sets.

Elton Mpongo (MSc student) *4:00 PM* *02/12/2019*

Integrated Quantitative Seismic Interpretation of Metal Earth's Larder Lake Transect

The Larder Lake area is characterized by a series of complex metavolcanic and metasedimentary rocks intruded by granitic plutons and batholiths, which makes the area to be referred to as hardrock environment. These stratigraphic units are truncated by two major breaks, the Lincoln Nipissing Shear Zone (LNSZ) and Cadillac-Larder Lake Deformation Zone (CLLDZ) which are trending NE-SW and E-W respectively. Seismic imaging and interpretation in hardrock environment is challenging due to lack of continuity of reflections mainly due to smaller acoustic impedance contrasts between different stratigraphic units. This study aims to determine the structural architecture and evolution of the area using seismic data and other depth resolving geophysical methods using quantitative modeling approach. Seismic interpretation in the area will be based on the Lithoprobe and Metal Earth's seismic data sets to better understand the structural controls of the reflections. Lithoprobe transects will be used in conjunction with the Metal Earth's transect for the interpretation. Seismic data in the area show steeply dipping reflections on the upper crust which correlates to the structural orientation of rock units on the surface geology. However, the middle to lower crust is characterized by subhorizontal reflections which are "preliminary" interpreted to be intrusive or tectonic contacts.

Fabiano D. Justina (PhD student) *4:20 PM* *02/12/2019*

2.5D Forward Gravity and Magnetic Modelling of the Matheson Transect

The Abitibi greenstone belt (AGB) contains some of the most important gold and base metal mining camps in Canada, and as a consequence of this significance, an excellent knowledge of its geology has been acquired over the years. Nonetheless, most of this understanding relates to the surface geology and drilling focussed on prospective zones. In face of that, a 2.5D forward modelling of gravity and magnetic data has been carried out in the Matheson transect to resolve the structure at depth, which is located in the southern part of AGB. Two seismic sections, a petrophysical data compilation, and as well as geological maps have been utilized to construct the initial model and provide bounds on the physical properties of the lithologies. The modelling provides a check on the validity of the seismic interpretation and can also be used to infer interfaces which are not visible on the seismic sections, due to either subvertical orientation or weak acoustic impedance contrast. For example, there are two main faults present in our study area, and the Porcupine-Destor Fault has been visualized on the seismic section and validated on the gravity modelling, while the Pipestone Fault has a dip that is only resolved with assistance of the gravity modelling.

Tuesday, December 3rd

Ijaz Ahmad (PhD student) *9:00 AM* *03/12/2019*

Quantification of platinum group elements in micron scale sulfide-inclusions using LA–ICP–MS

Micron-scale sulfide melt inclusions trapped in early-crystallizing minerals can reveal the compositions of the parental sulfide melt in magmatic systems. In-situ trace element analysis of sulfide melt inclusions is complicated by recrystallization to discrete mineral phase upon cooling. In addition, platinum group elements (PGE) combine with semimetals and exsolve as platinum group minerals, causing extreme heterogeneity of metals within the inclusion. Thus, the analysis of exposed inclusions suffers from fractionation and partial sampling after cutting and polishing, and will not be representative of the whole inclusion. Homogenization of unexposed sulfide inclusions by heating and rapid quenching prior to polishing, and analysis of unexposed inclusions using LA-ICP-MS spot sizes larger than the inclusion and removing the composition of the host mineral from the analysis can potentially solve this problem. Heating and quenching reduces heterogeneity, but sulfide melt inclusions are difficult to quench and suffer from contamination and leaking when the melting temperature of the host mineral is lower than sulfide. Analysis of whole unexposed inclusions does not suffer from this problem, but only inclusions close to the surface can be analyzed to avoid down-hole fractionation, and the method is difficult to apply to unexposed inclusions in opaque minerals. An analysis of the strengths and weaknesses of these techniques indicates that both techniques can reliably quantify primary PGE contents depending on the mineralogy of the host mineral.

Colin Ross (MSc student) *9:20 AM* *03/12/2019*

Controls on Cu/Au ratio in Porphyry-style Cu-Au ± Mo Deposits

Cu-Au ± Mo porphyry deposits are defined by a Cu/Au ratio of 4.0×10^4, and are formed from hydrothermal fluids exsolved from cooling, calc-alkaline magmas. The Au-rich calc-alkaline magmas responsible for the formation of Cu-Au deposits are genetically related to oxidized magmatism from the partial melting of the metasomatized asthenospheric mantle wedge. The original metal content of this partial melt is the main control of the proportion of Cu/Au in porphyry deposits. Although it is understood that the Cu/Au ratio is controlled by magma source, the source magma cannot solely account for trends in metal association and zonation within Cu-Au porphyries. Other factors such as crystal-chemistry, and density-dependent precipitation of Cu-Fe sulfides play a role in the formation of Cu-Au porphyry deposits. The crystal-chemical control on the formation of Au-rich porphyry deposits is a decisive factor in ore formation where high Au concentrations can be accounted for by the preferential incorporation of Au into a bornite solid-solution at high temperatures (>600°C). Furthermore, density-dependent precipitation of Cu-Fe sulfides where Cu-Fe sulfides cannot stabilize at low pressure results in the sole precipitation of Au, leading to increased Au grades and the shallow depths of Au-rich deposits. Thus, magma source is not likely the sole control on Cu/Au ratio and additional controls must be invoked.

Well-Shen Lee (PhD student) *9:40 AM* *03/12/2019*

Finding a porphyry in a core stack: Copper potential at the Klaza Epithermal Deposit, Yukon

The Late Cretaceous Klaza Au-Ag-Pb-Zn-(Cu-Au) deposit is an intermediate sulfidation epithermal deposit located in the historic Mt. Nansen mining district, Yukon. The limitations of a three-lithology logging code have hindered the promotion of a porphyry-epithermal deposit model long advocated for the site. Field and analytical work conducted in 2019 reveals a protracted and complex magmatic-hydrothermal system typical of porphyry deposits. The pre-ore Whitehorse plutonic suite (105 Ma) of granodiorite to tonalite composition is cut by the multi-generational Kelly dyke swarm (80-76 Ma) consisting four distinct monzonite to diorite magmatic pulses, followed by a syenite dyke swarm at 71 Ma. Hydrothermal activity is typical of porphyry settings: early halo micaceous (EDM) veins, sinuous and planar A-type veins, B-type, and D-type veins, and molybdenite-quartz veins. ^{187}Re-^{187}Os molybdenite ages constrain porphyry mineralization to two events: 77 Ma and 71 Ma. High-T Cu-Au-Mo mineralization associated with phyllic and lesser potassic alteration assemblages is cut by composite, 2 m-wide epithermal sulfide veins with a 5 m-wide halo of illite-epidote-Fe-carbonate. These field observations integrated with Cu-Au-assay data suggest the Klaza veins are located in the phyllic alteration shell of a two-stage Cu-Au-Mo composite porphyry system. These results have implications to: (1) the continued exploration potential at the Klaza deposit; and (2) the understanding of Yukon Cu-Au porphyry metallogeny in the Late Cretaceous.

Xuyang Meng (PhD student) *10:00 AM* *03/12/2019*

Oxidized, sulfur-rich arc-like magmatism in the Paleoproterozoic Richtersveld Magmatic Arc, Namibia

Phanerozoic arc magmas are typically more oxidized, sulfur-rich, and hydrous than those formed in mid-ocean ridges, which may reflect metasomatism of the sub-arc mantle wedge by oxidizing slab-derived fluids or magmatic differentiation processes. However, it remains poorly constrained as to whether magma with such features formed in the Precambrian, when slab material is thought to have been relatively reduced. To constrain the magmatic conditions of Precambrian arc magmas, the igneous phases of the Haib porphyry Cu deposit in the Paleoproterozoic Richtersveld Magmatic Arc of southern Namibia is being investigated. The deposit area contains pre-mineralization andesitic feldspar porphyry, mineralized granodiorite porphyries, granodiorite batholith, and later aplite dike. Zircon from these lithologies have been dated to 1893 ± 9 Ma (2σ, MSWD = 3.1). Estimates of whole-rock trace element data indicate the melts with moderate to high magmatic water content (~3–4 wt %), reflected by hornblende and variable plagioclase fractionation. The average magmatic fO_2, calculated from zircon geochemistry, ranges from ΔFMQ + 0.2 to 1.4 and sulfur contents of primary apatite inclusions in zircon and titanite are SO_3 = 0.35 ± 0.16 wt % (n = 66), attesting to relatively oxidized and high magmatic sulfur contents. The preliminary results reveal that formation of moderately oxidized, sulfur-rich hydrous magmas typical of many Phanerozoic arcs was already possible in the late Paleoproterozoic.

Keaton Strongman (PhD student) *10:40 AM* *03/12/2019*

Geology of the Vent Prospect, a 2718 Ma High Sulfidation Epithermal System

High sulfidation epithermal deposits are formed from highly acidic, sulfur-rich fluids that leach their host volcanic rocks resulting in characteristic advanced argillic alteration. Epithermal deposits are extremely susceptible to erosion and the majority are Tertiary in age. No clear examples of high sulfidation deposits have been documented in the Archean rock record. The ca. 2722-2718 Ma Metcalfe-Venus assemblage, within the Superior Province in Ontario contains a Au-Ag prospect named “the Vent” that possesses many characteristics of high sulfidation epithermal systems. This study’s results show that the Vent consists of a decimeter scale, zoned, discordant, metamorphosed alteration system consisting of a) pods of residual quartz-pyrite; b) kyanite-quartz-pyrite; c) kyanite-sericite-quartz; d) sericite with minor kyanite; and e) sericite without kyanite. Mineralisation occurs as Au- and Ag-bearing pyrite and arsenopyrite as replacement and stringer styles. The vent is hosted within a series of dacitic flows and porphyry intrusions. These dacitic flows show spine-like structures and contain blocky flow-top breccias that lack hyaloclastite. Cutting these units is a swarm of pebble dikes. This setting is consistent with a subaerial volcanic edifice into which acidic hydrothermal fluids were pumped, periodically over-pressuring and brecciating the edifice. We propose that this is consistent with modern high sulfidation systems, and that the Vent may represent the oldest identified high sulfidation epithermal system on the planet.

Connor R. Small (MSc student) *11:00 AM* *03/12/2019*

Evaluating the relationship between oxidation processes and gold mineralization in an archean alkaline intrusive setting

Recent research suggests a possible correlation exists among depleted $\delta^{34}S$ values, high fO_2 and Au distribution in alkaline intrusive settings, but there are very few studies that have investigated these relationships. The Rundle deposit, located in the southern Abitibi greenstone belt, represents a unique opportunity to examine redox controls on high-grade Au mineralization hosted in alkaline intrusive rocks, along with their mineralogical attributes, on the deposit scale. Samples which comprised of mineralized and non-mineralized SiO_2-undersaturated rocks along with mafic to ultramafic rocks, were collected in 2018 for host-rock identification, whole-rock lithogeochemistry, and S-isotopic analyses, in order to assess the spatial and temporal relationships of Au mineralization with oxidation. Gold is associated with both disseminated and fracture-controlled pyrite within the felsic alkaline rocks. In-situ SIMS analysis of pyrite grains suggests a strong correlation between depleted $\delta^{34}S$ values (-5 to -15 ‰) and high-grade gold zones (1 to 100 ppm). Preliminary SEM-EDS analyses show gold inclusions (3 to 5 µm) hosted within hematite and goethite rims that have replaced pyrite, suggesting a strong positive relationship between development of Au mineralization and oxidation. The observations made in this current study have many important implications not only for ore forming processes, but also for targeting and exploring new gold deposits in oxidized settings.

David Downie (MSc student) *11:20 AM* *03/12/2019*

The potential for intrusion-related gold systems in the western Wabigoon subprovince: A case study of the North Boyer Lake area, Ontario

Intrusion-related gold systems represent a relatively under-explored deposit type in the western Wabigoon subprovince despite an abundance of intrusive complexes with spatially associated gold occurrences. The North Boyer Lake area, located approximately 55 km SE of Dryden, Ontario, is a poorly documented domain with great outcrop exposure, well-preserved igneous relationships, and recently reported anomalous gold values. New detailed mapping and sampling for structural, petrographic, and whole-rock lithogeochemical analyses were conducted in the area. This work aims to investigate the mineralogy, deformation, and alteration pattern associated with a large intermediate intrusion as a vector for exploration. Supracrustal exposures are dominated by metavolcanic rocks of the Boyer Lake and Kawashegamuk groups and intruded by the 15 km^2 Lost Lake porphyry. Hydrothermal alteration assemblages are observed throughout the study area. An intrusion-related phyllic alteration characterized by an assemblage of sericite, quartz and pyrite is overprinted by carbonatization associated with localized deformation zones. Mineralization is associated with hydrothermal breccias proximal to the contact between mafic volcanic rocks and intrusive rocks. Field relationships and lithogeochemical analyses from the North Boyer Lake area shows similarities with intrusion-related gold systems of the Abitibi Subprovince, such as the world-class Côté Gold deposit, suggesting that there is potential for a similar type of deposit in the western Wabigoon subprovince.

Amokelani Mavundza (MSc student) *11:40 AM* *03/12/2019*

Using flat-floored and wedge-shaped granitic pluton geometries to understand the emplacement history of granitic batholiths

Granite plutons make up a substantial volume of the Earth's crust, thus understanding deformational processes during the emplacement granitic plutons help interpret the evolution of the Earth's mechanical processes. The shape and size of a pluton reflects deformational processes during its emplacement. Two main geometries; (1) flat-floored and (2) wedge-shaped plutons are recognised from multiple studies of different granite plutons using mapping, fabric measurements and geochemistry as well as indirect geophysical methods such as gravity inversions for investigating the geometry at depth. This is a review of the characteristics of these two main geometries explaining the occurrence of large granitic plutons and the processes that lead to the emplacement. Flat-floored shaped plutons tend to be 2-3 km in depth, extend about 30-40km in each direction and have a sub horizontal floor of gently dipping feeder zones. The wedge-shaped plutons have a thickness of over 10km with a vertical feeder system and usually elongate in map view. The geometries suggest that emplacement is mainly controlled by crustal rheology where the dip of the pluton floor marks the transition from gentle dipping to vertical feeder system and that deformation controls the mechanism of magma ascent and segregation from lower to upper crust through the interaction of magma and the regional stress field.

Kendra Zammit (MSc student) *1:00 PM* *03/12/2019*

Relative timing of deformation and orogenic gold mineralization in the western Wabigoon Subprovince, Ontario

Orogenic gold deposits are commonly associated with late-stage deformation accommodated by crustal-scale deformation zones. Spatial and temporal constraints on orogenic gold mineralization are well established in the Abitibi Subprovince, which produces most of Canada's orogenic gold, but remain poorly documented in the western Superior Province. The objective of this work is to characterize the relative timing of regional deformation and gold mineralization in the Dryden area of the western Wabigoon Subprovince (WWS). Results of regional- to outcrop-scale mapping and microstructural observations indicate two primary stages of deformation in the WWS. D_1 is marked by regional-scale isoclinal folds (F_1) and a penetrative E-W trending axial-planar foliation (S_1) associated with E-trending deformation zones. D_2 is marked by asymmetric Z-shaped refolding of F_1 folds (F_2), which are interpreted as dextral-sense shear indicators, and a penetrative NE-SW trending foliation (S_2) that is associated with sinistral-sense shear indicators along NE-trending deformation zones. These observations suggest N-S shortening occurred during D_1 and NW-SE shortening occurred during D_2. Field observations indicate orogenic gold mineralization is related to D_2. Monazite and titanite U/Pb geochronology will provide absolute age constraints on deformation and gold mineralization in the WWS (work in progress). Ultimately, this study will contribute to proposing a new structural and metallogenic history of the WWS, which will assist future gold exploration in the area.

Nicolas Estrada (MSc student) *1:20 PM* *03/12/2019*

Assessing metal behavior during lower crustal evolution, Kapuskasing Structural Zone, Ontario

The majority of ore deposits in Precambrian systems formed close to the Earth's surface or were emplaced at middle-upper crustal levels; however, the mantle is a major source of metals that form these deposits. The behaviour and chemical evolution of fluids and partial melting, which are not directly observable, are critical in the interpretation of the formation and modification of the continental crust and, therefore, understanding the development of related ore deposits. The Archean Kapuskasing Structural Zone provides a unique opportunity to study the behavior of metals during lower-crustal evolution by understanding the tectonothermal history of the area. This intracontinental portion of the lower-crust was uplifted and thrusted eastward upon the metal-endowed Abitibi Subprovince, exposing metamorphic rocks that show an increasing metamorphic grade from amphibolite to granulite facies toward the northeast. Field-based and petrographic observations of the mafic gneisses indicate a widespread assemblage of amphibole + plagioclase + quartz ± clinopyroxene ± garnet ± titanite characterized by a variation in modal mineralogy at outcrop scale that defines different migmatite components (i.e., melanosome, mesosome, leucosomes). Further characterization of metamorphic reactions and mineral association with sulphides (e.g. pyrite, chalcopyrite, pyrrhotite) within the different migmatite components may lead to the identification and explanation of the extraction, transport, deposition, and concentration of metals during high-grade metamorphism.

Thomas Gemmell (PhD student) *1:40 PM* *03/12/2019*

Iron Formations and their significance in the Abitibi Greenstone Belt

Iron formations are iron-rich (15-40 wt% Fe_2O_3) and siliceous (40-60 wt% SiO_2) chemical sedimentary rocks that precipitated from seawater throughout the Precambrian Era (predominantly between 2.80 and 1.85 Ga). The source of Fe (II) is likely from submarine hydrothermal processes, however, the mechanisms of how the Fe (II) is oxidized are still under debate. The two major types of iron formations are Banded Iron Formation (BIF), which form in deep marine settings, and Granular Iron Formation (GIF), which form in shallow water proximal to continental crust. BIFs can be further subdivided into Algoma-type and Superior-type. The former is typically a less-extensive deposit hosted in volcanic rocks or greywackes and forms in deep basins influenced by pulses of magmatic and hydrothermal activity. The latter is a regionally extensive deposit found interbedded with carbonates, black shales and arenites with only minor volcanic rocks, and typically forms on continental shelves during periods of high sea level. Within the Abitibi greenstone belt, Algoma-type BIFs represent key marker horizons and gaps in the volcanic stratigraphy. Some of these BIFs are conducive to exhalative VMS style mineralization making them important targets for base metal exploration.

Adrian Rehm (MSc student) *2:00 PM* *03/12/2019*

Origin of mafic-ultramafic volcanic rocks in the Northern Pontiac subprovince, Quebec

The Pontiac subprovince is an Archean metasedimentary terrane located south of the Abitibi subprovince in Quebec, comprising ~2682 Ma turbidites, felsic to intermediate plutons, and mafic-ultramafic volcanic rocks. The volcanic horizons are localized successions of basaltic-komatiitic flows and sills, previously interpreted as allochthonous slices, unrelated to the Pontiac Group sediments. Detailed mapping of the area around Bellecombe, Quebec, identified peperite in the contact zone between the volcanic and sedimentary packages. The peperite comprises fluidal and blocky clasts of mafic-ultramafic igneous rock within bedded and non-bedded sedimentary rocks. This texture suggests that mafic-ultramafic magma was emplaced into wet, unconsolidated sediments. Intercalated basaltic flows and sedimentary beds were also observed at the margins of the volcanic package. The volcanic-sedimentary contact zones that lack these features display, for the most part, no localized shearing and are interpreted as primary contacts. These field relationships, supported by whole-rock geochemistry and petrographical observations, suggest a synsedimentary, autochthonous emplacement of the mafic-ultramafic volcanic rocks, and thus, the presence of a mantle-penetrating structure in the Pontiac subprovince. This interpretation is compatible with a plume-related or back-arc model for the Pontiac subprovince, and may provide insight into the formation of other similar, understudied Archean metasedimentary terranes such as the Quetico and English River subprovinces in Northern Ontario.

George Gilchrist (MSc student) *2:20 PM* *03/12/2019*

Kamoa-Kakula copper deposit

The Kamoa-Kakula Copper Deposit is the first major copper discovery in the Central African Copperbelt in decades, an area renowned for its stratiform copper deposits. Defying conventional wisdom and established exploration models, drilling targeted a far higher stratigraphic interval, progressively delineating a deposit that has become the largest copper deposit ever discovered in Africa. Mineralisation is hosted within reducing diamictites and siltstones close to, or on a thick sequence of coarse sandstones, marking a distinct deepening in the rift basin to sub-wave base sedimentation. The pyrite contained in these units acted as a reductant to the oxidised Cu-bearing fluids moving through the basin. Although broadly mineralised across an area of 25km by 10km, distinct high grade zones have been identified controlled by the rift structures responsible for focussed fluid flow and graben formation within which the pyrite-rich siltstones formed. Subtle differences in basin architecture have led to a number of different styles of mineralisation across the deposit. Developing an understanding of the evolution of the broader rift basin, and features indicative of reductant formation (rather than timing of mineralisation) are driving ongoing exploration activities.

Charlotte Stone (MSc student) *3:00 PM* *03/12/2019*

Lithostratigraphy of the mid-Neoproterozoic Ram Head Formation, Mackenzie Mountains, NWT

The mid-Neoproterozoic Ram Head Formation is the uppermost formation of the Mackenzie Mountains Supergroup and records intracratonic shallow-marine carbonate sedimentation in northeastern Laurentia immediately preceding the dispersal of supercontinent Rodinia. The 700-m-thick Ram Head Formation is important because it records the enigmatic 811 Ma Bitter Springs stage anomaly – the first substantial carbon isotope excursion since the GOE, is temporally equivalent to strata containing the oldest known mineralised eukaryotes, was deposited during the poorly understood Neoproterozoic oxygenation event, and forms the footwall of the Redstone copperbelt, but no detailed study has yet been conducted on the formation. Based on field work, the type section can be broadly divided into lower and upper members composed of repeated upward-shallowing cycles. Two major exposure surfaces are present – one in the lower member and one at the base of the upper member. The upper member begins with an upward-deepening episode that terminates in a massive, mineralised, 85-m-thick thrombolitic unit. Above this microbial unit, upward-shallowing cycles resume. A range of indicators suggest possible tectonic activity during deposition. This study's field work is followed by comparing petrographic information with a chemostratigraphic study to investigate the cause of the Bitter Springs excursion and address marine geochemistry at the time of deposition.

Patrick Bovingdon (MSc student) *3:20 PM* *03/12/2019*

Geochronology of Archean rocks in the Fury and Hecla area, Northwestern Baffin Island, Canada: Results from the 2018 Gifford River Area

The Gifford River and Jungerson River (Admiralty Inlet), located in the Western Churchill Province (Rae Domain) in northwestern Baffin Island, represent Archean to Paleoproterozoic crust that has been exposed to multiple tectonothermal events. These rocks record enigmatic events prior to 2.7 Ga and subsequent region wide orogenic events, though crustal influence and inheritance is largely unknown. Previously, the tonalitic-granodioritic basement, later granitic intrusions and metasedimentary units were unknown in age and correlated regionally by lithology. Now, with new U-Pb zircon geochronology, temporal correlation of these granitoids in the Fury and Hecla area can be done with other blocks within the Committee Bay Belt area. Later work includes understanding the formation of the Archean crust within the Rae craton and the mechanisms involved in crustal formation and investigate the nature of the melts present during crustal formation. Additionally, stable isotopes are used to investigate origins of the basement and intrusion melts, indicate inheritance from older sources and understand the geological formation of this area. The Fury and Hecla area is understudied in comparison to adjacent areas, but can provide key information about the geological history of the Committee Bay belt and the Western Churchill Province via a detailed look into whole-rock and zircon geochemistry of the tonalitic-granodioritic-monzogranitic basement, late quartz-syenite, monzogranite, porphyritic intrusions and a metasedimentary package.

Mollie Patzke (PhD student) *3:40 PM* *03/12/2019*

Detrital zircon provenance of the Mesoproterozoic Fury and Hecla Basin, Nunavut, Canada

The Fury and Hecla (F&H) Basin (Nunavut, Canada) is part of the Mesoproterozoic Bylot basins, which record deposition during the amalgamation of Rodinia and contain the first photosynthesizing eukaryote microfossil. Provenance analysis of sedimentary basins uses detrital zircon geochronology to help identify source-to-sink pathways and infers regional tectonic settings. Seven samples of fluvial and marine sandstones represent the overall fill of the F&H Basin. Sixty detrital zircon grains from each sample were analyzed for U-Pb ages on the sensitive high-resolution ion microprobe (SHRIMP) at the Geological Survey of Canada, Ottawa. Samples from F&H stratigraphy yield ages that span from 3.3 to 1.7 Ga. Preliminary interpretation of statistical-distribution age peaks are attributed to Rae province orogenic and/or magmatic events including (from youngest to oldest): the Trans-Hudson (1.9–1.8 Ga), Taltson-Thelon (2.0–1.9 Ga), Arrowsmith (2.5–2.3 Ga), Snow Island (2.6–2.5 Ga) and Mary River (2.8– 2.7 Ga). Notably, there is a 600-million-year gap between the absolute depositional age in the middle F&H stratigraphy (whole-rock, black shale Re-Os dated ~1.1 Ga) and the youngest detrital zircon grain age (~1.7 Ga). The detrital zircon age data does not reflect the contemporaneous Grenville orogen (~1.1 Ga). Detrital zircon geochronology provides context for a larger study to understand basin formation during supercontinent amalgamation and discern the depositional setting conducive for the evolution of life.