Ni-Cu-PGE deposits of the Sudbury Basin and Archean Precious and Base Metal Deposits of the Abitibi Greenstone Belt, Ontario and Québec

Field Trip Report – April 29-May 7 2019

Memorial University of Newfoundland, Canada (MUN)

Participants (left to right): Nikola Denisová, Gabriel Sindol, Dennis Sánchez Mora, Robert King, Carly Mueller, Maciej Pawlukiewicz
Contents
Participants........................................................................................................................................... 2
Itinerary.................................................................................................................................................... 2
Budget.................................................................................................................................................... 3
Acknowledgements and Sponsorships.................................................................................................... 4
Sudbury basin geology and Ni-Cu-PGE deposits...................................................................................... 5
Orogenic gold deposits in Timmins.......................................................................................................... 8
Au-rich VMS ........................................................................................................................................... 14

Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Degree</th>
<th>Nationality</th>
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<tr>
<td>Dennis Sánchez Mora</td>
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<td>Costa Rican</td>
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<td>Nikola Denisová</td>
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<td>Robert King</td>
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<td>Gabriel Sindol</td>
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<td>Maciej Pawlukiewicz</td>
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<td>Carly Mueller</td>
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Itinerary

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Acknowledgements and Sponsorships

We would like to thank the people who had a hand in making this field trip possible by providing the advice, contacts, financial, and organizational support needed. Specifically, we would like to thank John Jamieson, Elliott Burden, and Mike Babechuk for advice and contacts; the Society of Economic Geologists Wallace Fund and the Mineral Deposits Division of the Geological Society of Canada for financial support; the School of Graduate Studies at MUN for providing promotional items.

Special thanks to the government, exploration, and mining companies who not only gave us their time but allowed us to visit their projects. Everyone made us feel welcome in as were introduced to the operations we were at; it was an invaluable experience. We would like to extend a special thank you to:

David Smith and the Wallbridge Mining staff for their project overview, outcrop visit, and core discussion.

Shirley Peloquin and Clayton Kennedy of the Ontario Geological Survey for leading a field trip across the Sudbury Igneous Complex.

Paul Levesque, John Howson, Andrew Lapierre and others for the mine tours, discussion and lunch at their operations. Special thank you to Theresa Rycaj for organizing both days with staff at both operations.

Jackie Long and Kevin Montgomery for the exploration overview, introduction to their core, and discussion of their Golden Highway Project.

Roxanne Jacobs, David Pitre, David Fortin, Guy Gosselin and staff for the deposit overview and core discussion of the LaRonde project.
Sudbury basin geology and Ni-Cu-PGE deposits
By: Maciej Pawlukiewicz

Sudbury has been an interest to geologists since the discovery of the meteorite impact crater that has hosted numerous mines and outcrops of economic interest. Our group had the opportunity to look at the geology of the Ni-Cu-PGE deposits of the Sudbury Igneous Complex (SIC), metamorphism, and associated features of impact structures (Figure 1; Rousell and Brown, 2009). The Sudbury district exceeds 1648 million metric tonnes of Ni-Cu-PGE magmatic sulphide deposits with grades of 1.2% Ni and 1.1% Cu (Lightfoot et al., 1997). The area hosts numerous deposit types: (1) SIC-footwall contact deposits; (2) footwall vein deposits’ (3) offset dike deposits; and (4) sheared deposits (Rousell and Brown, 2009).

Figure 1. Geological map of the Sudbury base metal mining district showing the main units. Offset dykes are labelled in bold (Ames et al., 2005). Abbreviations: PCDZ = Pumphouse Creek deformation zone, SCF = Sandcherry Creek fault, FLF = Fecunis Lake fault, MF = Murray fault, CF = Creighton fault, SRSZ = South Range shear zone, GBF = Grenville Front boundary zone

Basic, simplified model for the creation of the Sudbury Igneous Complex
The Sudbury impact structure (1.85 Ga) (62km x 30 km x 15km) is located between the Superior Province of the Canadian Shield to the NW, and the Grenville Province to the SE. The Sudbury Structure represented the roots of an ancient meteorite impact crater or “astrobleme”. The sequence of events in the Sudbury Structure is interpreted to be as follows:

1) major impact
2) excavation of a crater
3) deposition of the Onaping Formation as a fallback breccia or “suevite”
4) intrusion of the SIC as an impact-generated, but probably mantle-derived

The geology and metallogeny of the Sudbury area are already well summarized in the paper – *Geology of the Giant Sudbury Polymetallic Mining Camp, Ontario, Canada* (Ames et al., 2008). Additional information can be found in *A Field Guide to the Geology of Sudbury, Ontario* (Rousell and Brown, 2009).

Sudbury Major Deposit Types

**SIC-footwall Contact deposits:** These deposits occur at or near the contact between the base of the SIC and the underlying footwall rocks. The mineralization occurs as disseminated sulphides in the Contact Sublayer, which increase in concentration downward, and as massive to semi-massive sulphides along the Sublayer–footwall contact or in the underlying Footwall Breccia.

**Footwall vein deposits:** Mineralization in the footwall occurs as veins and disseminations as much as 700 m from the base of the SIC. There is considerable evidence of hydrothermal activity in and around these systems, however, it is still uncertain as to what proportion of the mineralization is magmatic or hydrothermal or some combination of the two.

**Offset dyke deposits:** Dykes that radiate outward from the base of the SIC. The radial Offset dykes consist of fine-grained quartz diorite that was intruded in two phases. The first phase, preserved along the margins of the dykes, contains no sulphide minerals. The second phase, generally preserved in the dyke cores but locally present along the margins, contains sulphide mineralization. Angular fragments, consisting of quartz diorite with disseminated sulphide minerals, locally occur in massive sulphide ore.

**Sheared deposits:** SIC–footwall contact deposits in the eastern third of the South Range were strongly affected by ductile shear. The Falconbridge deposit best illustrates the form of the sheared deposits. The original deposit, which was probably more irregular in shape, has been remobilized to form tabular bodies localized along the shears.

**Day 1 (April 29)**
Travel day, arrived to Sudbury.

**Day 2 (April 30)**
- Location: Sudbury, Ontario, Canada.
• Activity: Geologist David Smith presented an overview of the geology of Sudbury and Ni-Cu-PGE prospects owned by Wallbridge Mining. Students saw highlights of drill core (Figure 2A) from the various projects the company owns. Afterwards, students examined trenches showing exposed massive sulfide mineralization and host rocks (quartz diorite and inclusion-rich quartz diorite) at the Parkin Offset project (Figure 2B).

• Company: Wallbridge Mining Company Limited

Figure 2. A) Drill core from the Cu-PGE Hammer deposit, part of an offset dike, one of the three main deposit types in Sudbury, Ontario. B) Trench exposing an outcrop of massive sulfide Ni-Cu-PGE mineralization at the Parkin deposit, owned by Wallbridge Mining Company Limited.

Day 3 (May 1)

• Location: Sudbury, Ontario, Canada.

• Activity: Geological tour looking at key outcrops that define the stratigraphy of the Sudbury basin. The Sudbury basin is interpreted to be the product of a bolide impact, which is thought to be one of the key controls on the prolific Ni-Cu-PGE mineralization. Evidence
for the impact includes shatter cones (Figure 3A) and the Sudbury breccia (Figure 3B) that has a pseudotachylite matrix and polymictic clasts. The tour stops followed through the lower contact of the Sudbury Igneous Complex up through it to the overlying metasedimentary formations and back into the Sudbury breccia on the other side of the Sudbury Basin.


**Figure 3.** A) Shatter cones in Sudbury, evidence of a meteor impact. B). Sudbury breccia, matrix is a pseudotachylite.

**Orogenic gold deposits in Timmins**

By: Dennis Sánchez Mora

The Porcupine district located in and around the city of Timmins has produced >67 million ounces of gold since 1910 (Newmont Goldcorp, 2019). The Hoyle Pond underground mine, currently (2019), provides 60% of the gold and the Hollinger open pit mine provides the rest of the ore for Newmont Goldcorp operations in the Porcupine district (Newmont Goldcorp, 2019). The Porcupine gold camp is located in the Archean Abitibi subprovince of the Superior province in northern Ontario (Dinel et al., 2008). Gold mineralization is associated with fault-fill and extensional quartz-carbonate veins that are generally second order structures associated with the Porcupine-Destor fault (Dinel et al., 2008), this mineralization is typical of orogenic gold deposits. The Abitibi subprovince hosts several styles of gold mineralization that formed at different times and at different crustal levels (Bateman et al., 2008), furthermore this subprovince has experienced
several deformation events (up to D_7). The Hollinger-McIntyre-Coniaurum mines are hosted by mafic lavas of the Tisdale assemblage and mineralization consists of a Cu-Au-Ag-Mo orebody and quartz-carbonate Au-veins (Bateman et al., 2008). The Dome mine mineralization is also hosted in the Tisdale assemblage and consists of several vein types; ankerite (±quartz ±tourmaline-low gold) sheeted vein arrays (Bateman et al., 2008). Multiple gold mineralization events have been documented (Stromberg et al., 2019). Hoyle Pond mine is hosted also in the Tisdale assemblage in folded mafic-ultramafic volcanic rocks (Bateman et al., 2008). Three types of veins have been identified at Hoyle Pond that include quartz-albite-tourmaline-hydromuscovite-carbonate-coarse gold, quartz-chlorite-muscovite-carbonate-pyrite-gold and late quartz veins (Bateman et al., 2008). Mineralization at Hoyle Pond is associated with isoclinal folding and trusting associated with D_3 and D_4 events (Dinel et al., 2008; Bateman et al., 2008).

Day 4 (May 2)

- Location: Timmins, Ontario, Canada.
- Activity: Underground mine tour at Hoyle Pond mine. The students took part in several different activities in the mine. After a safety induction, the students used the series of underground shafts to get down to the 1580m level (Figure 4A). There they visited different drives to observe two of the main quartz veins that host high-grade gold mineralization (Figure 4B). An exciting and interesting part of the tour was a review of underground mining techniques and innovations, such as the use of drones in underground surveys and reaching inaccessible part of the mine. Following the underground tour, the exploration geologists gave the students an overview of the regional geology, Newmont-Goldcorp operations in the area and the exploration tools used by the team. The students then discussed the drill core (Figure 4C, D) and geological cross sections with the exploration geologists at the site. The exploration group highlighted the importance of oriented drill core in understanding the complex structural history in the camp. See Dinel et al., (2008) for an overview of the deposit geology and structural geology.
- Company: Newmont Goldcorp
Figure 4. Hoyle Pond mine. A) The group at level 1580 where our tour guides explained the underground operations. B) High-grade bearing-gold quartz carbonate vein. C) Students looking at drill core. D) Newmont Goldcorp’s core shack.
Day 5 (May 3)

- Location: Timmins, Ontario, Canada.
- Activity: The group visited two open pit gold mines operated by Newmont Goldcorp: Hollinger mine (in operation) and Dome mine (inactive). The students observed operations in the Hollinger mine (Figure 5A) and learned about the social programs that the company has in place. These programs are extremely important as the town of Timmins is only a few meters (Figure 5B) from the main operations. These include live noise monitoring and seismic monitoring (https://sentinel.bksv.com/goldcorp/porcupine#Live%20Monitoring) that can be accessed at any time by anyone. The tour also included a view of the Dome pit that is scheduled for expansion (Figure 5C). The group was also shown new technology that the company is implementing, such as remotely operated and automated drilling equipment (Figure 6A, B), as well as the use of drones to calculate stockpile volumes. See (Stromberg et al., 2019) for details on the interpreted multiple mineralization events at the Dome mine.
- Company: Newmont Goldcorp

![Figure 5. A) Group at the Hollinger gold mine. B) Overlook of the Hollinger pit where the town of Timmins can be seen to the right (directly next to the open pit). C) View of the Dome mine.](image-url)
Figure 6. A) Newmont Goldcorp’s station that controls automated drilling. B) Part of the drills that are either remotely operated or automated at the Hollinger mine.

Day 6 (May 4)
- Location: Timmins, Ontario, Canada.
- Activity: The exploration company Moneta Porcupine provided an overview of the local geology and their exploration projects in the Timmins-Matheson golden corridor (Figure 7A, B). The senior geologist, Kevin Montgomery, explained the stratigraphy and highlighted important structural and geochemical controls on the gold mineralization.
- Activity: Students also saw some spectacular gold samples at the Timmins Museum (Figure 8A, B), that have been collected from the Timmins gold camp.

Company: Moneta Porcupine Mines Inc.

Figure 7. A) Senior geologist Kevin Montgomery from Moneta Porcupine explains the local geology. B) Iron formation, functioning as trap for the gold mineralization.
Figure 8. Gold samples from the Timmins camp at the Timmins Museum. A) Quartz vein with visible gold. B) Gold nugget.

Day 7 (May 5)

- Location: Malartic, Québec, Canada
- Activity: The group visited the Canadian Malartic open pit gold mine that is operated by Agnico Eagle and Yamana Gold. Although a tour was not possible, the group discussed the local geology and deposit type (Figure 9A, B). This high tonnage and low grade gold deposit is proposed to be an Archean intrusion-related style deposit (Helt et al., 2014).
- Activity: The students also explored some outcrops in the area, where they found an excellent exposure of komatiites (Figure 9C) with spinifex texture (Lajoie and Gélinas, 1978).
- Company: None.
Figure 9. A) View of the Canadian Malartic open pit mine, part of the town of Malartic had to be moved for the operation and is currently very close to the mine operations. B) Students discuss the geology of Canadian Malartic deposit. C) Student very excited to look at the spinifex textures of the komatitites at Spinifex Ridge.

Au-rich VMS
By: Nikola Denisova

The area around Rouyn-Noranda is world class VMS district. The Late Archean Noranda Volcanic Complex hosts around 20 VMS deposits in the Doyon-Bousquet-LaRonde mining camp, which include the Au-rich La Ronde Penna deposit and Horne deposit. The deposits are hosted by submarine volcanic rocks of the Blake River Group of the Abitibi greenstone belt (Kerr and Gibson, 1993). The Noranda volcanic complex hosting the deposits is composed of five cycles, each consisting of a basaltic basal unit and a bimodal upper unit with the Flavian pluton at the core of the volcanic complex (Kerr and Gibson, 1993). Outcrops in the area show examples of typical volcanic and volcano-sedimentary rocks, alteration types and textures associated with bimodal-mafic VMS. The LaRonde deposit is currently owned by Agnico Eagle and is part of the LaRonde-Penna complex that also includes the LaRonde Zone 5 underground mine and the now inactive
Lapa mine. The deposit has been in operation since 1988 and in 2016 it has produced 5 million ounces of gold (Agnico Eagle, 2019). The current reserves contain 2.6 million gold ounces. The deposit is made up of steeply dipping massive to semi-massive sulfide lenses containing Au-Zn-Ag-Cu-Pb (Mercier-Langevin et al., 2007). The massive sulfide lenses are stacked, a result of multiple cycles of hydrothermal activity, and not all of them are economic, although the mineralized zones associated with felsic rocks are more likely to be economic (Agnico Eagle, 2019). The lenses have been further flattened and stretched during regional deformation (Agnico Eagle, 2019).

**Day 8 (May 6)**

- **Location:** Rouyn-Noranda, Québec, Canada
- **Activity:** Visit to the gold-rich volcanogenic massive sulfide LaRonde Penna mine. Exploration geologist Roxanne Jacobs gave an presentation on the underground mine operation for the students and provided an overview of the local geology (Figure 10A, B). Students also viewed drill core from the LaRonde deposit (Figure 10C). See Mercier-Langevin et al., (2007) for an overview of the geology of the deposit.
- **Company:** Agnico Eagle

**Day 9 (May 7)**

- **Travel day, flight back to St. John’s, Newfoundland.**
Figure 10. A) Exploration geologist Roxanne Jacobs from Agnico Eagle shows a 3D model of their LaRonde underground mine. B) Copper-Au ore from LaRonde mine, massive chalcopyrite. C) Students examining drill core from the LaRonde volcanogenic massive sulfide deposit.
References


