Gold Deposits of Abitibi-Timiskaming

September 2nd-7th, 2019

Queen`s University
Society of Economic Geology Student Chapter

By: Colin Aldis

Executive Summary

Six students from the Department of Geological Sciences and Geological Engineering at Queen's University toured the historical mining region of the Abitibi Greenstone Belt from September 2^{nd} to 7^{th}, 2019. The field trip included tours of legacy and current mining operations, smelters and processing plants, and regional geology.

The second day, participants toured Glencore's Horne Cu Smelter in Rouyn-Noranda. The Horne Smelter process copper concentrates and metal-bearing recyclable materials, primarily old electronics. A 99.1% pure Cu anode is produced before being shipped to Montreal, where the anode is purified to 99.99% Cu cathodes and are marketable.

The President of Yorbeau Resources, and Queen's alumnus, Dr. Gérald Riverin, led a regional geology tour of Rouyn-Noranda. We spent the day examining the geological requisites for favourable VMS and orogenic style gold that make the Abitibi a world-class gold camp. Activities included examining auriferous drill-core, Archean meta-sedimentary and volcanic sequences, primary structural controls within the region, and identifying ore minerals and alteration haloes.

We toured two different styles and operations of gold mines on the fourth and fifth days: the historic orogenic Au Lamaque mine and disseminated Au-rich pyrite Canadian Malartic Mine. Students explored the underground shafts of Lamaque Mine, and gained insight on how the mining industry shaped the community. This contrasted with Canadian Malartic Mine, which is the largest operating mine in Canada, and offered a unique perspective on the scale and challenges associated with modern mining.

Our chapter very gratefully acknowledges the Stewart Wallace Fund Committee, Glencore, Yorbeau Resources, and Agnico Eagle-Yamana for the funding, opportunity, and time to visit the largest greenstone belt in the world.

Acknowledgements

We gratefully acknowledge the Society of Economic Geologists for their generous donation from the Steward R. Wallace Fund to support this trip. Thank you to Hannah Lang, Colin Aldis, and Collette Pilsworth for helping prepare proposals, logistics, and the guidebook for this trip. Thank you to the Dr. Gérald Riverin, President of Yorbeau Resources, who showed us around Rouyn-Noranda, shared geological and empirical knowledge with kindness and enthusiasm, and allowed access to their collection of drill-core and properties.

Objectives

The Queen's University Chapter of the Society of Economic Geologists (QSEG) has organized a field trip to the Abitibi region from September 2nd to September 7th, 2019. This trip is a student organized and the participants are undergraduate and graduate students from the Department of Geological Sciences and Geological Engineering at Queen's University. Arrangements have been made with Yorbeau Resources, Glencore, and Canadian Malartic to have their geologists lead tours of different operations in the district and with experts in the local geology to lead a regional geology tour.

The goal of this trip is to introduce students to the geology of the world-class Abitibi gold and volcanogenic massive sulphide (VMS) camp, and to provide exposure to active mining operations to promote a better understanding of the mining cycle.

The team was based out of Val d'Or as that provides a central location for access to several different mines and easily accessible outcrops for understanding the regional geology of the Abitibi. The scope of the field trip includes regional geology, VMS deposits, orogenic gold deposits, and orogenic and intrusion related gold deposits. The tour will cover both underground and open pit mining techniques. Additionally, this trip aims to bring together a diverse mix of graduate and undergraduate students in geology, geological engineering and mining engineering to promote the exchange of ideas between different groups and to encourage interest in economic geology and mining at Queen's University.

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Trip Participants

Students

Name	Program
Colin Aldis	Ph.D. Geology
Callum Walter	Ph.D. Geological Engineering/Geophysics
Fouad Faraj	MASc. Geological Engineering/Geophysics
Elizabeth Hemlin	B.Sc. Geology
Lingjia Cao	BA
Richard Barrette	B.Sc. Geology

Mining Partners

Itinerary

Date	Activities
September 2nd, Monday	Depart for Val d`Or
September 3rd, Tuesday	Tour of Glencore Horne Smelter
September 4th, Wednesday	Regional Geology Tour with Dr. Gérald Riverin
September 5th,Thursday	Tour of La Cité de l`Or Lamaque Mine Musuem
September 6th, Friday	Tour of Canadian Malartic Mine
September 7th, Saturday	Depart for Kingston

September 3rd: Glencore Horne Smelter

This section is edited from Glencore's Recycling webpage (http://www.glencorerecycling.com) and the Fondrie's homepage (http://www.fonderiehorne.ca)

The Horne Smelter is located in Rouyn-Noranda, Quebec, and is the world's largest processor of electronic scrap containing copper and precious metals. The Horne smelter, named after the original Noranda prospector, Edmund Horne, opened in 1927 at the site of the Horne mine. While the mine was closed in 1976, the smelter grew to become the largest and most advanced recycling plant of its kind in North America, with a unique ability to process complex feeds.

The smelter is a custom copper smelter which uses both copper concentrates and precious metal-bearing recyclable materials as its feedstock to produce a 99.1% copper anode. The anode is shipped to the Canadian Copper Refinery (CCR) in Montreal to be converted into 99.99% copper cathodes which are sold on world markets.

The annual production capacity is 215,000 tonnes of copper and 640,000 tonnes of sulphuric acid (H_2SO_4). The copper is shipped from all over Canada and internationally to be processed. The concentrates have an average content of 26% Cu.

Sulphuric acid is a by-product of the smelting process. It is a useful by-product as it is used in the food, pharmaceutical, and fertilizer industries and helps prevent harmful contamination of the environment. The process began in 1989, when sulphuric acid smelting was commissioned. There has been a steady decline in SO_2 emissions since the processes introduction. Today, 96% of the sulphur is converted to sulphuric acid.

Detailed below are the processing steps to convert copper concentrate or recyclable materials into an anode (Fig. 4):

1) **Unloading:** Upon arrival at the plant, a cross-check system is put in motion to ensure that the materials received are in compliance with the authorizations. After sampling, sorting, and shredding, batches of recycled material, depending on size, grade, and nature, are shipped primarily to the Noranda reactor. The approximately 740,000 tonnes of copper concentrated and other materials containing copper and precious metals, combined with recycled materials are conveyed to the reactor via conveyors.
2) **Reactor – Continuous Smelting:** The melting is carried out in the reactor where the concentrate and the flux are heated to 1200°C. After reaching a 70% copper content, the matte is transferred to the Noranda converter. The oxygen enrichment of the air used generates enough heat to virtually eliminate the need for fuel.
3) **The Noranda Converter:** Operating on a semi-continuous basis, the converter increases the copper content of the matte from the reactor to 98%.
4) **The Concentrator:** It receives the slag produced by the reactor and Noranda converter. After crushing, it is reduced to fine particles in ball mills and pumped to the flotation cells. Copper will be recovered by physically separating it from its impurities.
5) **The Sulphuric Acid Plant:** There are three sections: 1) the wet gases are cleaned, cooled and dried; 2) dry gases, sulphur dioxide, are converted to sulphuric anhydride (SO_3); 3) the SO_3 is adsorbed in strong acids to produce quality sulphuric acid (H_2SO_4).
6) **The Converters:** The copper from the Noranda converter is transferred to pyro-refining furnaces where the remaining impurities are removed by oxidation and slagging.
7) **Anode Furnaces:** natural gas is used to remove the excess oxygen in copper from pyro-refining furnaces. The copper is 99.1% pure and is moulded into 340 kg anodes.

8) **Transport:** The copper anodes are transported by railcar or truck to the CCR refinery in east Montreal for final processing. The copper is purified to 99.99% and sold on the market.

September 4th: Regional Geology Tour

Stop 1: Jardin Geologique
(325, avenue Principale, Rouyn-Noranda, QC, J9X 4R8)

This geological garden and Botanical Park is in the heart of Rouyn-Noranda and commemorates the region's rich mining history. Local companies (current and former) have donated rock samples that decorate the park. The *Jardin Geologique* is separated into themes: gold and silver samples, base metals, industrial rocks, and fossils. The park introduces visitors to the Abitibi region and provides an excellent evolution of the Archean geology within a beautiful, floral park.

Stop 2: The Larder Lake-Cadillac Break at the Augmitto gold deposit, Rouyn-Noranda
(48.195N, -79.096E - 4039 Rang Hull, Rouyn-Noranda, QC J9Y 1B4)
This section is from Poulsen (2017).

The hanging-wall sedimentary rocks are well-exposed near the headframe at Stop 8A (Fig. 13A). Although Z-shaped minor folds and a well-defined striped axial planar cleavage (similar to that at Stop 5) are ubiquitous, graded bedding suggests that the sedimentary succession as a whole faces southward. The rocks are moderately carbonate altered, and meter-wide sericite-carbonate bedding-parallel shear zones containing gray quartz veins are common. These veins and related alteration are overprinted by the Z-shaped folds.

Both contacts of the Piché Group (Figs. 13A, B, 27) are arguably faults. The southern contact is locally marked by graphitic and calcite-chlorite phyllonites and the northern one is a zone of intense foliation, which is locally overprinted by late folds (Figs. 17F, 27). The Piché Group is composed mainly of ultramafic komatiite that is variably carbonate altered and foliated. Primary volcanic textures, including spinifex, are preserved (Trench 4) where deformation and alteration are weak, but most rocks show the effects of progressive carbonate alteration. Distinctive calcite-chlorite-quartz alteration results in a banded rock, which also contains an Mn-bearing phase (possibly the pyroxene namansilite). This banded, Ca- and Mn-enriched, metasomatic rock is found along the southern, footwall of the Piché Group and, along with local graphitic phyllonite, defines the Larder Lake-Cadillac Break as a shear zone in this sector.

Albitite dikes (Fig. 27) are typically deformed to produce distinctive boudins the long axes of which tend to be aligned on an azimuth of 070°–080°. The dikes form a swarm which can be traced obliquely across the volcanic rocks of the Piché Group. At surface, the albitite dikes are distinguished by their red-brown oxidation in contrast to the orange-weathering ultramafic rocks but in drill core they appear to be distinctively pink to beige and are difficult to scratch. The mineral assemblage is albite-ankerite-quartz-pyrite-arsenopyrite and several channel samples indicate grades of 0.5 to 1 g/t Au. Whole-rock and trace element geochemical data suggest that the albitite dikes are derived from a mafic to intermediate igneous protolith, in places distinguished only by a higher than normal content of P_2O_5. Addition of both Na_2O and $CO_2$is required to explain their current compositions.

Although gold is locally found in Timiskaming sedimentary rocks in the immediate foot- or hanging-wall at Augmitto, ore is mostly composed of ankerite-magnesite assemblage carbonate rocks, particularly in the southern, structurally lower, part of the Piché Group. The highest gold grades tend to occur where green mica (fuchsite) is part of the assemblage. Arsenopyrite and dravite tend to mark the gold-bearing zone and visible gold is common in the deposit. In detail, visible gold is commonly associated with arrays of centimeter- to millimeter-thick buckled gray quartz veins and veinlets which tend to form irregular stockwork zones.

Stop 3: The Astoria Deposit, Granada (48.195N, -79.035E -2039 Avenue Granada, Rouyn-Noranda, QC J9Y 1K7)
This section is from Poulsen (2017).

The Astoria deposit was one of the first gold prospects to be discovered along the Larder Lake-Cadillac Break, likely because gold ore was exposed on a prominent hill where two intersecting Proterozoic dikes relatively resistant to glacial erosion are exposed. The dikes provide a degree of geologic complication in that they not only disrupt and displace the surrounding Archean rocks (Fig. 28) but also impart a contact metamorphic aureole of calc-silicate hornfels along their margins. Furthermore, as illustrated at Stop 9A (Fig. 28) the rocks in the Astoria sector as a whole are strongly deformed. Another notable feature is in the abundance of conglomerate in the Timiskaming section, particularly along the northern, hanging-wall contact of the Piché Group (Stop 9B). Clasts in the conglomerate, both north and south of the volcanic rocks of the Piché Group, are highly flattened with a local downdip lineation. On average, the foliation is intense and dips steeply northward but, at the local scale, it varies considerably in strike, displaying the same S-shaped curvature described above. Within the central part of the Piché Group, the foliation strikes ENE, but toward both margins this curves into an E-W orientation. The same is true of the strongly carbonate-altered zone within the Piché Group (Fig. 28).

Gold at Astoria is found mainly in two zones. The A zone is located along the southern contact of the Piché Group (Stop 9C) at is in contact with the footwall sedimentary rocks (Fig. 28). In places the sedimentary rocks are mineralized. The Aw zone is the westward extension of the A zone down-plunge and beyond the western margin of the Proterozoic diabase dike. Most of the 1 t (~30,000 oz) Au production between 1986 and 1995 came from underground mining in the Aw zone. The B zone occurs toward the structural top of the altered volcanic rocks of the Piché Group.

September 5th: Cité de l'Or Lamaque Mine and Bourlamaque Mining Village

(90 Perrault Avenue, Val-d'Or, QC, J9P 7B9)
Edited from Sigma-Lamaque Technical Report (2018)

In 1923, gold was discovered in a quartz vein in a shear zone zone vein, which lead to the Lamaque Mine. The mine opened in 1935 and operated from until 1985, and became a national historical monument in 2012. The mine produced 4.5 Moz Au at an average grade of 5.86 g/t. The capacity of milling production peaked in 2,100 tons a day in 1953, and was demolished in 1992.

The mine is hosted within the Val d'Or Formation, which is composed of intermediate to felsic volcaniclastic and minor flows. The volcaniclastic rocks have been intruded by a porphyritic diorite. The diorite is composed of an amphibole-rich mafic zone and a biotite felsic diorite.

Gold is hosted within quartz-tourmaline-carbonate and pyritic gold veins and structurally controlled in shear zones. The most continuous auriferous veins are hosted in E-W striking brittle-ductile reverse shear zones that dip 50-70° southwards. Gold may also be found within sericite-carbonate-pyrite selvage zones along the veins.

During the tour of the facilities, visitors see the No. 7 shaft, go underground to examine the mining techniques, and see the metallurgical processes involved in concentrating gold ore.

September 6th: Canadian Malartic Mine Tour

(100 Chemin du Lac Mourier, Malartic, QC J0Y 1Z0)

Canadian Malartic Mine, Malartic, QC is a low-grade gold deposit (13.4 Moz Au at 1.02 g/t; Helt et al., 2014) that is one of Canada's largest operating open-pit mines. The mine is hosted in Archean (2680-2672 Ma; Robert, 2001) quartz porphyritic monzodiorite intrusions and clastic metasedimentary rocks of the Pontiac Group and mafic-ultramafic rocks of the Piché Group. Mineralization is disseminated within pyrite in quartz-carbonate stockwork. The pyrite is enriched in Au-Te-W-S-Bi-Ag±Pb±Mo (De Souza et al., 2015).

The mine produces can produce up to 55,000 tonnes of rock per day. Annually, the mine produces 640,000 oz of gold.

References

De Souza, S., Dubé, B., McNicoll, V. J., Dupuis, C., Mercier-Langevin, P., Creaser, R. A., & Kjarsgaard, I. M. (2015). Geology, hydrothermal alteration, and genesis of the world-class Canadian Malartic stockwork-disseminated Archean gold deposit, Quebec, Canada. *Targeted Geoscience Initiative 4: Contributions to the understanding of Precambrian Lode Gold Deposits and Implications for Exploration*, p. 113-126.

Eldorado Gold. (2018). *Technical Report Lamaque Project, Québec, Canada.*

Helt, K. M., William-Jones, A. E., Clark, J. R., Wing, B. A., & Wares, R. P. (2014). Constraints on the Genesis of the Archean oxidized, intrusion-related Canadian Malartic gold deposit, Québec, Canada. *Economic Geology*, v. 109, p. 713-735.

Poulsen, H. (2017). The Larder Lake-Cadillac Break and Its Gold Districts. *Economic Geology*, v. 19, p. 137-166.

Robert, F. (2001). Syenite-associated disseminated gold deposits in the Abitibi greenstone belt, Canada. *Mineralium Deposita*, v. 36, p. 503-516.

Photo Highlights

Figure 1: At the Glencore Horne Cu Smelter – Tuesday September 3rd

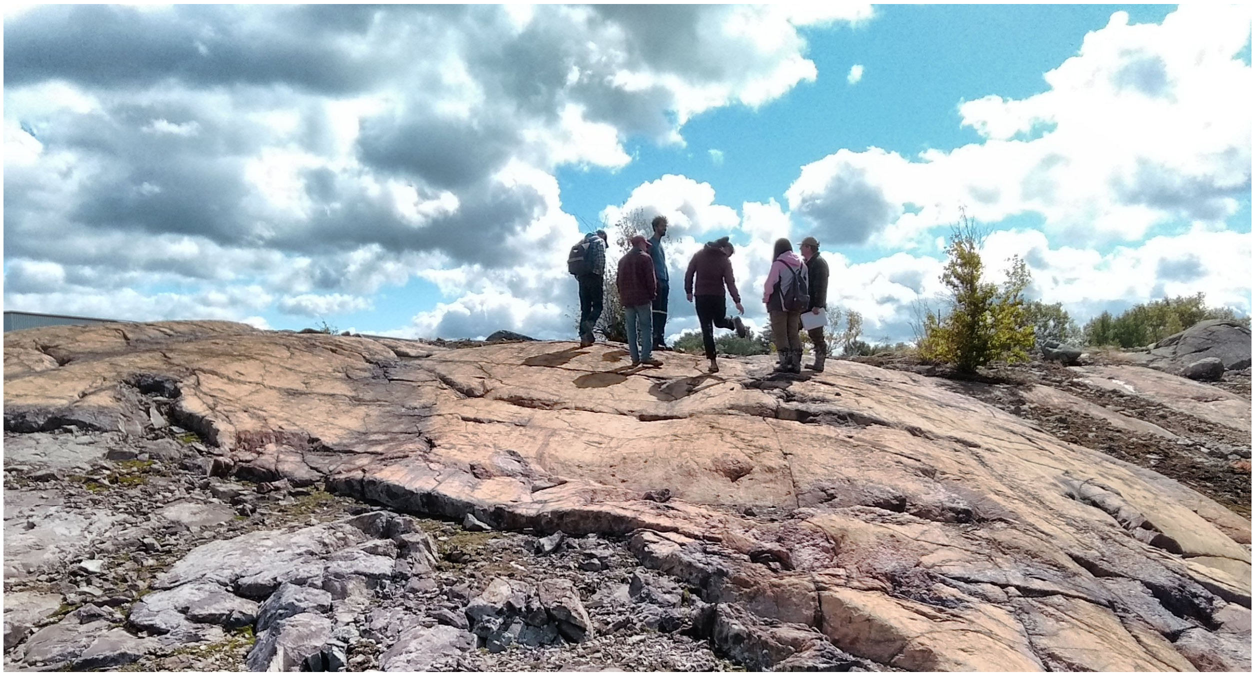

Figure 2: Regional geology tour with Dr. Gérald Riverin – Wednesday September 4th

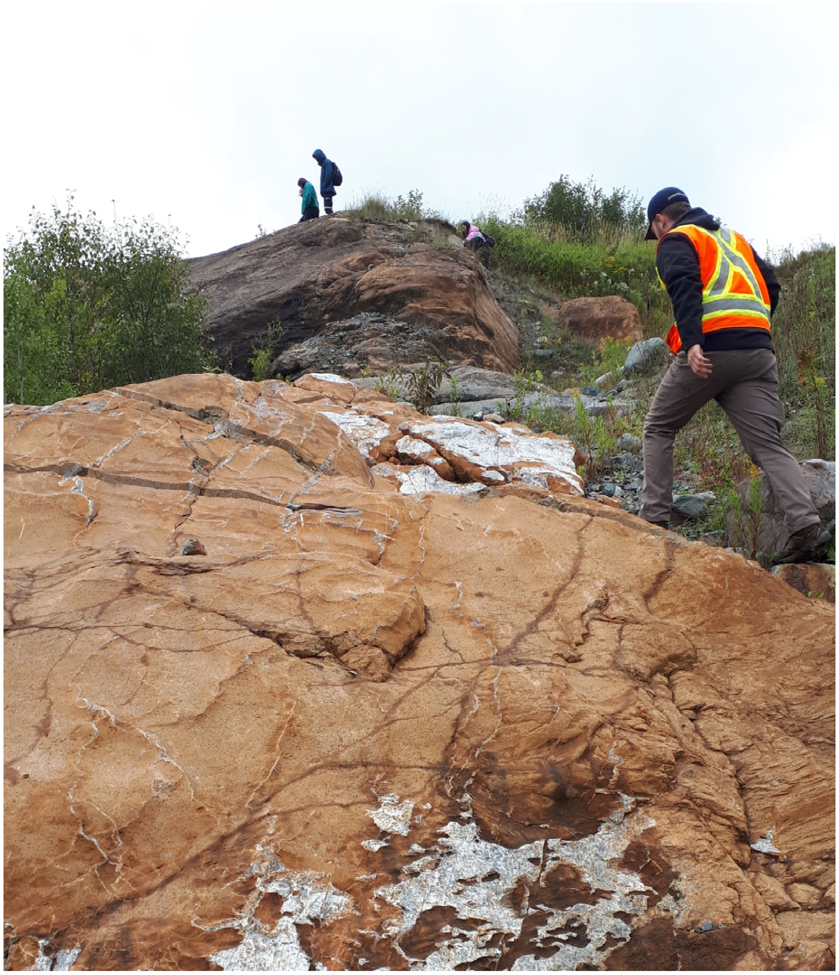

Figure 3: Regional geology tour - Wednesday September 4th

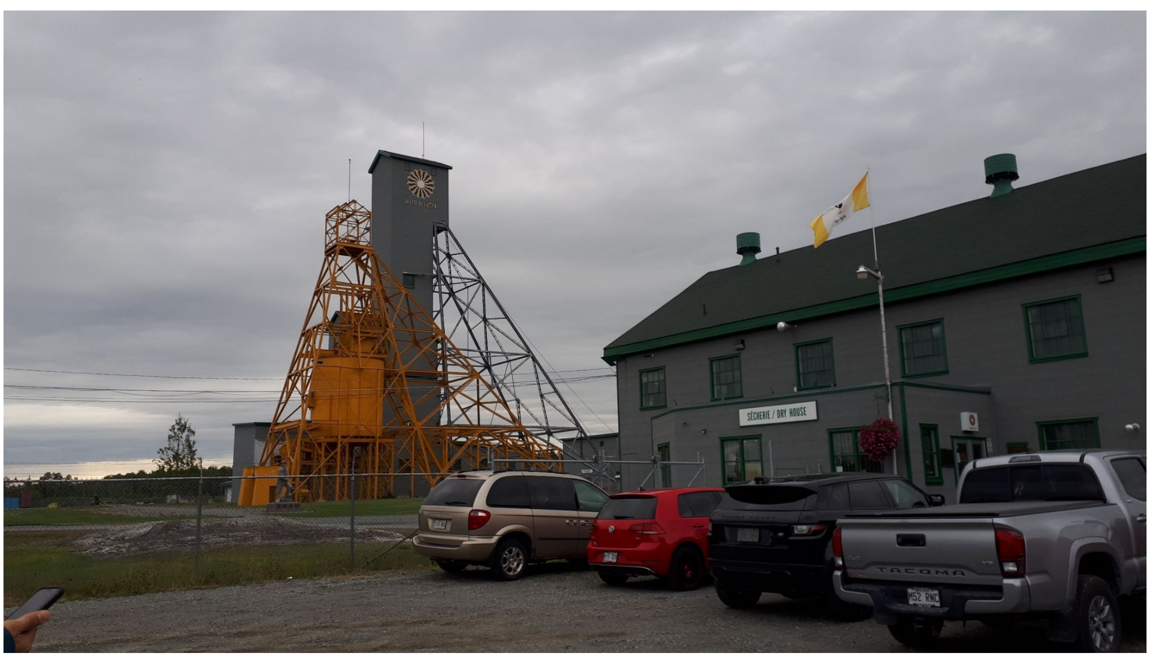

Figure 4: At La Cité de l`Or Lamaque Mine Musuem - Thursday September 5th

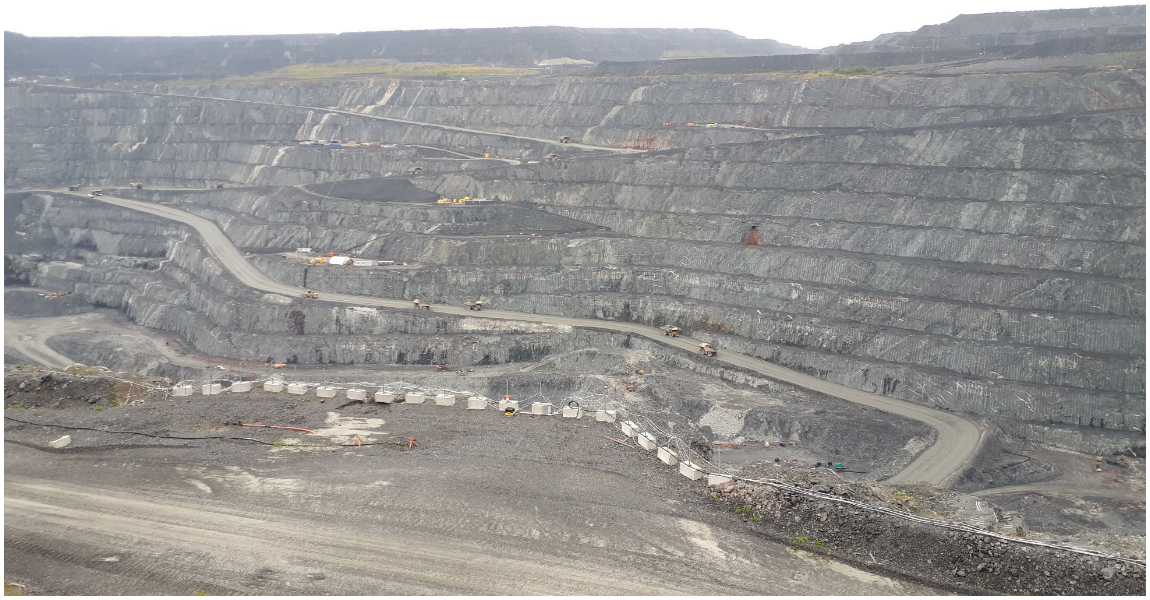

Figure 5: Canadian Malartic open-pit mine - Friday September 6th

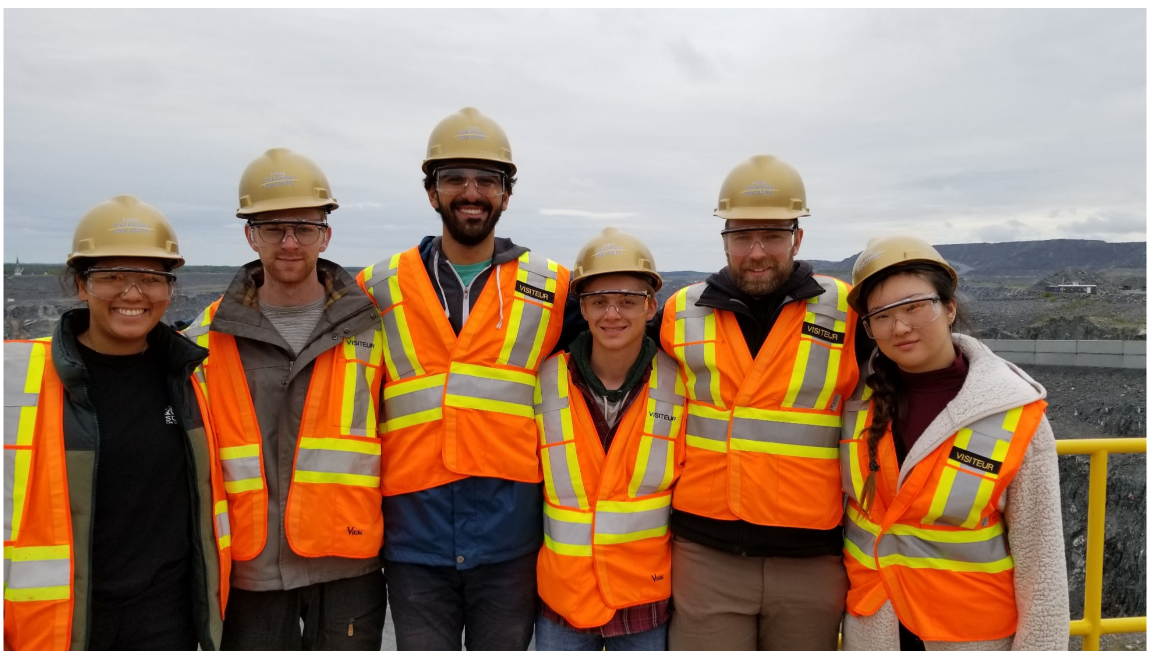

Figure 6: Overlooking the Canadian Malartic open-pit mine - September 6th