UNIVERSITÉ LAVAL
Département de géologie et génie géologique

Call for candidates for research projects on

The metallogeny of orogenic gold deposits

The Agnico Eagle – Eldorado Research Chair in Mineral Exploration

AGNICO EAGLE | eldorado gold Québec | Ressources naturelles et Forêts Québec | CRSNG NSERC

The Agnico Eagle – Eldorado Research Chair in Mineral Exploration is a 5-year major research initiative funded by NSERC and partners Agnico Eagle, Eldorado Gold and Ministère des Ressources Naturelles et des Forêts (MRNF) to study the metallogeny of orogenic gold deposits. The team comprises researchers from Université Laval (Profs G. Beaudoin, C. Guilmette, C. LaFlamme, and B. Rottier), and INRS-ETE (Prof. R. Soucy La Roche). The Chair offers a dynamic and collaborative training environment comprising more than thirty graduate students and research associates. Université Laval is amongst the top-ranked universities in Canada. Recognized for its leadership and high achievements in education and research, it offers a welcoming and diverse environment in the heart of Quebec City, a UNESCO World Heritage City (http://www.quebecregion.com/en/). The university community comprises over 50,000 students and offers an engaging work environment in an outstanding quality of life setting.

We are calling for applications to undertake **five** PhD projects. The projects comprise **1)** regional scale studies of orogenic gold districts, **2)** studies to date and determine the origin of auriferous fluid events in important orogenic gold deposits, and **3)** development of new indicator mineral methodologies to fingerprint the origin, vector towards ore and assess metal endowment of orogenic gold deposits. The project titles are listed below, and detailed descriptions are appended.

1. **Regional scale studies** – Understanding the regional geological setting of gold deposits is a critical component for targeting of regions with higher potential to host orogenic gold deposits.
   a. **Bonnefond corridor (PhD1)** – The Bonnefond corridor is a sector of the Val-d'Or orogenic gold vein field, in the Neoarchean Abitibi sub-province (Québec), south and southwest of the Bourlamaque batholith.
2. **Dating gold mineralization events and source of fluids** – deposit scale studies to date fluid flow events and to understand the source and flow of hydrothermal fluids forming gold deposits.
   a. **Meliadine (PhD2):** Meliadine (Nunavut) hosts a series of orogenic gold deposits located along the Pyke Fault, with a complex history.
   b. **Hope Bay (PhD3):** this study will construct on the ongoing regional-scale study of the greenstone belt. The age of mineralization in relation to metamorphism and deformation remains speculative.
3. **Indicator minerals** – The projects will continue to develop fingerprinting provenance, vectoring and fertility exploration tools.
   a. **Chalcopyrite Fingerprinting (PhD4):** Ongoing study on chalcopyrite major and trace element composition has focused on orogenic, Ni-Cu and VMS deposits, in addition to

more limited data on other chalcopyrite sources, including porphyry copper deposits. Chalcopyrite in porphyry copper deposits will be the major focus of this study.

b. **Ormaque (PhD5):** a case-study at Ormaque (Val-d'Or) quartz-tourmaline-carbonate veins to devise innovative indicator mineral vectoring and fertility assessment tools to target gold oreshoots.

The **PhD projects** are supported with a scholarship of 27 500$ per year for 3 years. PhD candidates can receive up to $8,500 from the University of achieving milestones in their training program in addition to their scholarship. Foreign PhD students receive a waiver of international tuition fees to the level of students residing in Québec. This scholarship can be cumulated with another excellence award. The candidates will have the opportunity to conduct original research and to present it at national and international conferences. Projects will start in January or May 2024. Positions are open until filled. Fluency in spoken and written English is mandatory whereas proficiency in French is beneficial, but not required. The team will supervise students in their preferred language (English or French).

Valuing equity, diversity and excellence, Université Laval is strongly committed to provide an inclusive work and living environment for all its members. **We subscribe to equal access and encourage qualified individuals** of all origins, sexes, sexual orientations, gender identities or expressions, as well as persons with disabilities, to apply.

Candidates should send their curriculum vitae, a letter of motivation indicating which project(s) are of interest, and the names of 3 references to:

Professor Georges Beaudoin
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Université Laval
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Appendix – Detailed description of projects

1. **Regional scale studies** – Understanding the regional geological setting of gold deposits is a critical component for targeting of regions with higher potential to host orogenic gold deposits.
   - **i) Bonnefond corridor (PhD1)** – The Bonnefond corridor is a sector of the Val-d'Or orogenic gold vein field, in the Neoarchean Abitibi sub-province (Québec), south and southwest of the Bourlamaque batholith. The volcanic country rocks are intruded by several intrusive bodies, both syn- and post-volcanic, including the Bonnefond South tonalitic to dioritic complex and the New Louvre tonalite sill. The intrusions and their immediate host rocks are cut by second- and third-order shallow-dipping (15 and 45º) shear zones that host gold-bearing quartz-carbonate-tourmaline veins. Efficient exploration requires a better understanding of the relations between the intrusion age, petrology and geochemistry, and that of the volcanic host rocks and the overlapping VMS (e.g., Louvicourt) and orogenic gold mineralized systems. **Objectives**: i) characterize the petrological and geochemical evolution of the volcanic and intrusive rocks; ii) constrain the chronology of intrusive activity; iii) establish the paragenetic sequence of mineralization and alteration; iv) define the structural framework of the shear zones and veins; v) compare with other gold deposits hosted in tonalitic and dioritic intrusions. **Activities:** detailed field mapping and core logging, followed by petrography, microstructural analysis, lithogeochemistry, mineral chemistry and geochronology of intrusions. **Anticipated results:** i) a framework explaining the petrochronologic evolution of the intrusions, their geochemical affinity and conditions during emplacement; ii) the structural evolution of the vein-hosting shear zones; iii) the paragenetic evolution on mineralization and alteration; iv) constraints on the timing and role of the intrusions for gold mineralization; v) improved map of the Bonnefond corridor and new exploration guides.
2. **Dating gold events and source of fluids** – deposit scale studies to date fluid flow events and to understand the source and flow of hydrothermal fluids forming gold deposits.
   - **i. Meliadine (PhD2):** Meliadine hosts a series of Banded-Iron Formation (BIF) associated orogenic gold deposits located along the Pyke Fault, in Nunavut. Dating of arsenopyrite by Re/Os yields a range of model ages from 2.3 to 1.8 Ga (Lawley et al. 2015). Late xenotime in quartz veins and altered host rocks yielded SHRIMP ages of 1858±10 Ma (Lawley et al. 2015) similar to monazite 1854±6 Ma (Carpenter et al. 2005), but the relationship of the dated phosphate grains with gold mineralization is

equivocal. Thus, the age of gold mineralization is uncertain, and the source of fluids has not been investigated, such that the origin of the gold mineralization hosted in Archean rocks, overprinted by Paleoproterozoic events, remains mysterious, thus hampering efficient exploration in similar terranes. **Objectives**: i) date auriferous hydrothermal fluid flow events using phosphate U/Pb geochronology on grains related to gold deposition; ii) establish the source of fluids, gold ligands, and metals; iii) present a framework relating the auriferous fluid events to the tectonometamorphic evolution of the country rocks. **Activities:** detailed paragenetic sequence of gold mineralization and deformation, geochronology of phosphate minerals, stable isotope geochemistry of sulfides and vein minerals (bulk and in situ). **Anticipated results:** i) age of gold mineralization and other hydrothermal events; ii) source and evolution of hydrothermal fluids, gold ligands and metals; iii) improved understanding of potentially polyphased orogenic gold deposits; iv) implications and new guides for gold exploration.

ii. **Hope Bay (PhD3):** this study will construct on the regional-scale study of the greenstone belt. The age of gold mineralization in the Hope Bay belt is constrained only by dominant D2 deformation (Sherlock et al. 2012). An intriguing feature of the Hope Bay greenstone belt is the lack of terrane bounding crustal shear zones (Sherlock et al. 2012), commonly interpreted to control flow of hydrothermal fluids. The age of mineralization in relation to metamorphism and deformation remains speculative, whereas no information exists on the origin and evolution of the hydrothermal fluids for this region where the greenstone belt rests on an old, metamorphosed crystalline basement. **Objectives**: i) date auriferous hydrothermal fluid flow events using phosphate U/Pb geochronology on grains related to gold deposition; ii) establish the source of fluids, gold ligands, and metals; iii) present a framework relating the auriferous fluid events to the tectonometamorphic evolution of the country rocks. **Activities:** detailed paragenetic sequence of gold mineralization and deformation, geochronology of phosphate minerals, stable isotope geochemistry of sulfides and vein minerals (bulk and in situ). **Anticipated results:** i) age of gold mineralization and other hydrothermal events; ii) source and evolution of hydrothermal fluids, gold ligands and metals; iii) improved understanding of potentially polyphased orogenic gold deposits; iv) implications and new guides for gold exploration.

3. **Indicator minerals** – The Chair as established itself as the international leader in indicator mineral research. The proposed research will continue to develop our leadership in fingerprinting the provenance of indicator minerals, on indicator mineral vectoring and fertility exploration tools.

   i. **Chalcopyrite Fingerprinting (PhD4):** A recent study on chalcopyrite major and trace element composition (E. Caraballo) has focussed on orogenic, Ni-Cu and VMS deposits, in addition to more limited data on other chalcopyrite sources, including porphyry copper deposits. The limited dataset on porphyry copper deposits limits the use of chalcopyrite in provenance studies. **Objectives:** i) measure the major and trace element composition of chalcopyrite in representative porphyry Cu-Mo-Au deposits; ii) define chemical criteria to fingerprint chalcopyrite sourced from orogenic gold and porphyry deposits; iii) methodology to use chalcopyrite for orogenic gold deposits exploration. **Activities:** acquire a set of representative samples from stages in evolution of porphyry deposits and of sub-types of porphyry deposits, measure the

major and trace element composition of chalcopyrite, statistical analysis of chemical composition using multivariate and machine learning methods. **Anticipated results:** i) a database of chalcopyrite major and trace element composition; ii) chemical criteria to discriminate the source of chalcopyrite; iii) methodology to use chalcopyrite in exploration for orogenic gold deposits.

ii. **Ormaque (PhD5):**

Orogenic Au veins are associated with alteration halos characterized by chlorite, sericite, carbonate, pyrite and tourmaline. In contrast to other deposit types (e.g., VMS, Porphyry Cu-Au deposits) the extent of the alteration footprint surrounding orogenic Au veins and the spatial chemical evolution of the alteration minerals in the alteration halo are not well defined. This knowledge gap is partly due to the difficulty to recognize the distal portion of the alteration halos of orogenic Au veins in contrast to greenstones of similar mineralogy. The Ormaque deposit (Val-d'Or) contains sub-horizontal quartz-tourmaline-carbonate veins that represent a perfect case study to better understand the extent of the alteration and the chemical evolution of alteration minerals surrounding the mineralized veins. **Objectives:** i) define the paragenetic sequence of successive gold mineralization events and associated alteration; ii) detail the major and trace elements composition of alteration minerals as function of distance to gold-rich and -poor veins; iii) define vectoring criteria to target gold oreshoots. **Activities:** field and underground mapping, and core logging, petrography, mineral chemical analyses (micro-XRF, EPMA, LA-ICP-MS), SWIR and XRD analyses, statistical data analysis. **Anticipated results:** i) Spatial mineralogical and chemical characterization of the alteration haloes associated to gold-rich and -poor orogenic veins; ii) Tracking the chemical evolution of chlorite, sericite, and tourmaline as function of the distance of the gold-rich and -poor veins; iii) Development of indicator mineral methodologies to vector toward mineralized orogenic Au veins.