Field-based investigation of structural and geochemical variability of gold-bearing veins in the Klondike Gold District, Yukon, Canada

Dr Taija Torvela, Dr Rob Chapman, Dr David Banks (Leeds)

CASE partner: Peter Tallman (Klondike Gold Corp.)

Contact email: t.m.torvela@leeds.ac.uk

Late-orogenic hydrothermal activity results in the formation of quartz and carbonate vein systems in the upper crust. It is an enigma why only certain hydrothermal pulses are associated with economic gold mineralization but others are not. Even in the same vein system, early veins are commonly barren whereas later vein generations carry significant gold mineralization. This project aims at understanding the variability in barren vs. gold-bearing vein generations, and how this variability might control gold deposition. You will compare the different vein generations in the Klondike Gold District in Yukon, using detailed geochemical and structural geology approaches. The project is expected to elucidate the formation of orogenic gold systems in general, and also increase our understanding of the overall hydrothermal evolution of late-orogenic crust.

Background

Gold formed in orogenic belts is typically classified as ‘orogenic’ if it has no association with magmatic fluids. One of the most distinct features of orogenic gold is its strong structural control: it is hosted in veins and fractures which are in turn typically located in second- and third-order structures such as splays, adjacent to major crustal shear zones (e.g. Sibson et al. 1988; Cox et al., 2001). Orogenic gold deposits form due to late-orogenic hydrothermal fluid activity, the exact nature of which is still debated (e.g. Goldfarb and Groves, 2015; Yardley and Cleverley, 2015).

Commonly, these ore-bearing vein systems show multiple generations of vein quartz (±carbonates), but typically only one or two of these contain gold whereas other hydrothermal veining events within the same vein system are barren. For example, Wilkinson and Johnston (1996) describe the evolution of the high-grade Croagh Patrick deposit, Ireland, showing that the second veining event was the most significant one for gold deposition. They further hypothesise that this was due to the second event linking the en-echelon tension gashes, thereby enhancing permeability of the rock above a threshold that allowed fluid phase separation and effective gold deposition. Wilkinson et al. (1999) also show how cathodoluminescence (CL) techniques can be used to identify different vein generations.

The importance of pressure-temperature-composition evolution (PTx) of hydrothermal fluids to gold deposition has been later investigated by e.g. Micklethwaite et al. (2010). They concluded that drastic PTx changes have important implications to both fault (re)activation and mineralization. However, further work on specific case and experimental studies is needed to improve our understanding of these systems, specifically in terms of the detailed PTx conditions (e.g. magnitudes of pressure drop, effect of undercooling of hydrothermal fluids, mineralization rates, etc), the scaling properties of the vein systems, and how the stress and strain evolution within and around the faults underpin these. Further understanding of these issues will contribute to development for better exploration strategies for orogenic gold, while also increasing our fundamental scientific understanding of the hydrothermal evolution of the orogenic crust.

Fig. 1. View to the Tomb Stone Range from King Solomon's Dome, Klondike Gold District, location of one of the quartz vein systems of interest.

This project aims at understanding the variability in barren vs. gold-bearing vein generations, and how this variability might control gold deposition. You will use a holistic approach, combining detailed structural and geochemical investigations in a field study area in the Klondike Gold District, Yukon (Fig. 1). There, recent discoveries and drilling programmes by Klondike Gold Corp. of several vein systems, many of which show significant gold endowment, provide an ideal platform for this study. Recent studies in the University of Leeds (Grimshaw, 2018) and elsewhere have further established the suitability of the area for this type of study. Especially Grimshaw (2018) shows that the quartz vein system within the Nugget zone of the Lone Star deposit formed by at least four separate fluid pulses, and that gold is mostly associated with the third fluid pulse (Fig. 2).

Apart from the Nugget Zone, the other discovered gold occurrences in the Klondike Gold District, including the new prospect Gold Run, c. 30 km SE from the Lone Star area, offer a unique opportunity to expand from the previous work by conducting a detailed compare-contrast study of the various gold-bearing vein systems.

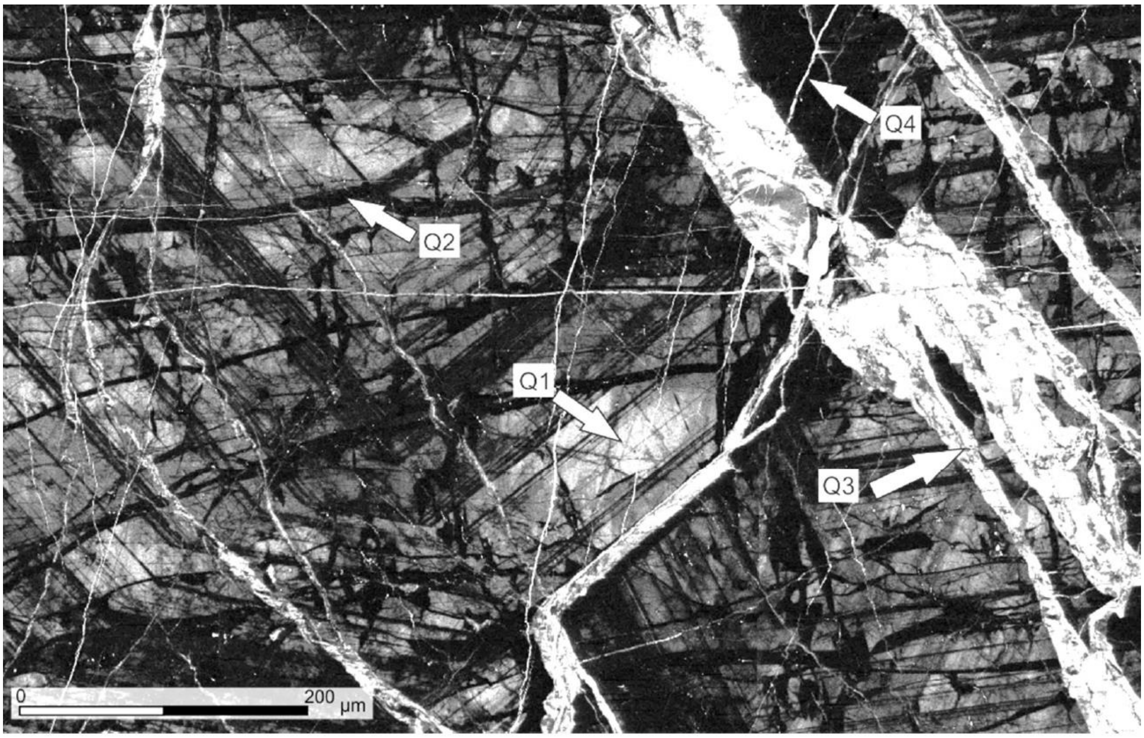

Fig. 2. Cathodoluminescence (CL) CL image from a quartz vein in the Nugget Zone, Lone Star deposit, Yukon. The vein shows at least four distinct fluid phases (Q1-Q4). From Grimshaw (2018).

Aims, objectives, and methodology

You will construct structural models for the vein systems in the Lone Star and the Gold Run prospects, investigate both gold-barren and gold-bearing veins and vein generations using microanalytical methods and fluid inclusions studies, and tie these together in order to understand the hydrothermal and mechanical evolution of the system. This approach will allow determining the characteristics of each vein system and of the vein generations within them, address the similarities vs. differences, and hypothesize on the controls on the gold deposition.

The project aims to establish whether the variations within in the vein systems are systematic through time, with respect to e.g. the number of fluid pulses, association of gold with these, vein mineralogy and parageneses, structural and mechanical evolution, geochemistry (e.g. trace elements, oxygen isotopes), vein ages, fluid composition, and microchemistry of individual gold grains. Leeds is world-leading in gold microchemistry which has already shown high potential in differentiating between gold sources and deposit types (e.g. Chapman et al., 2010a,b).

The specific research questions are:

i) Are the structural styles of veining replicated in the various deposits?
ii) Are the vein mineralogies, ages, fluid compositions, and trace element/isotope geochemistries in each vein system similar or different? Is the vein evolution similar or different - how many fluid pulses?
iii) Is the gold systematically associated with a certain hydrothermal pulse? Are the gold grains microchemically similar?
iv) Are any differences resulting from different fluid sources or interactions with host rock?
v) Are any patterns or features unique to the study area; can we say something about the evolution of similar deposits worldwide, or about the evolution of late-orogenic hydrothermal systems in general?

These main objectives will aim at answering the above questions:

i) Understand the structural and lithological framework (i.e. the fault and deformation model) for the study area, using existing geological and geophysical maps and literature, supplemented by additional mapping where needed;

ii) Characterise populations of vein generations (representing fluid pulses) in each vein system from samples collected from drill core;
iii) Identify dateable material (such as mica) from the veins and its association to the different vein/gold generations, and attempt dating these veins and, hence, the gold mineralization;
iv) Identify any commonality in signatures within the vein generations (e.g. mineralogy, geochemistry, fluid chemistry);
v) Tie any patterns into the structural model, in order to establish any commonalities or differences in fluid pathways;
vi) If possible, conduct a regional or global comparison study of similar deposits described in the literature.

The ultimate aim is, in other words, to generate a better, more detailed understanding of the variations in the gold metallogeny in the Klondike area, leading to a development in our understanding of late-orogenic, gold-bearing hydrothermal vein and fluid systems through time.

The specific methodology involves field work and analytical aspects. You will make extended visits (core sampling and field work, minimum 3 months in total) to the Klondike Gold District in Yukon. The project will also benefit from a detailed structural mapping campaign conducted in the Klondike Gold District during summer 2018 by SRK Exploration and the University of Leeds (report pending). The structural model can be built using e.g. MOVE or Leapfrog, depending on the scale of the model. Both are available at the School of Earth and Environment under academic licence. Vein paragenetic, geochemical, fluid inclusion, and the microchemical characterization of gold is achieved by use of the state-of-the-art facilities at Leeds: cathodoluminesence (CL) for indentifying the different vein and fluid inclusion generations, scanning electron microscope (SEM) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) to characterize detailed mineral geochemistries, and the electron microprobe (EMP) facilities for gold microchemistry analysis. Combining the structural modelling results with the detailed vein and gold analyses will allow a more holistic approach to any regional patterns in fluid flow and vein formation.

The novel combination of methodologies and data means that the study has significant potential to elucidate the questions about the structural, mechanical, and geochemical variability of the hydrothermal system during late orogenesis, including the implications to orogenic gold deposition.

Ideally, if time allows, the study can be extended along the orogenic strike into other nearby areas, in order to investigate possible regional patterns. Recent work in e.g. the Coffee deposit will support the possible expansion and regional considerations (MacWilliam, 2018).

NERC remit and potential for high impact outcome

The project maps directly into the NERC strategic research areas “benefiting from natural resources” of the “Societal Challenges” remit, which “address key societal challenges, helping business, government and society benefit from natural resources”.

Scientifically, the genesis of gold in orogenic is a hotly debated subject: the fluid sources, fluid pathways, gold source, timing of mineralization, and trap mechanisms are all active research topics worldwide. Regardless of the fluid or gold source, all “orogenic” gold deposits are strongly structurally controlled, but the linkage between the structures, the tectonic evolution, and the fluid and gold sources (i.e. geochemistry) are poorly understood. Therefore, this project will be a significant contribution to the understanding of orogenic gold systems as it aims at a detailed analysis of the tempo-spatial evolution of this type of gold mineralization in the context of an evolving tectonic system. We anticipate the project will generate several papers with wide interest, and at least one will be suitable for submission to a high impact journal.

Training and employability

You will work under the supervision of Dr Taija Torvela, Dr Rob Chapman, and Dr David Banks within the Ores and Mineralization Group (OMG: https://www.facebook.com/Ores-and-Mineralization-Research-Group-OMG-1155557114600278) of the Institute of Applied Geosciences. This project provides specialist scientific training in: (i) structural analysis and field work; (ii) state-of-the-art microanalytical and/or geochemical techniques; and (iii) industry-standard software skills. In addition, you will have access to a broad spectrum of training workshops both externally and internally, and participate in the regular OMG research meetings and events. The OMG involves a range of academic staff whose interests and expertise overlap ore deposits. Crucially, OMG research staff have a history working in the Klondike Gold District and nearby areas (e.g. Chapman et al., 2010a,b; Grimshaw, 2018). In addition, the project will be supported by the existing post-graduate research projects at OMG addressing the detailed aspects of gold deposit genesis in the Scottish and Irish Caledonides and in Newfoundland. We anticipate that you will be able to publish up to three research papers, and attend both national conferences (e.g. MDSG) and international academic/ industry facing conferences (e.g. SEG, SGA, PDAC, Roundup) according to your career trajectory.

The PhD study is equally suited to career pathways in academia or industry. The expected outputs of the project have global significance for understanding of an economically important mineralization type where deposit models and deposit classification are still the subject of intense academic debate. At the same time, exposure to industry-facing aspects through relevant conferences and other interactions e.g. through the CASE partner provides non-academic vocational experience. The student would also be expected to contribute substantially to the activities of the buoyant Leeds Chapter of SEG, with all the associated benefits of networking across industry and academia. Finally, the School has close links with the Minerals Deposit Research unit at UBC Vancouver, and Leeds postgraduate students regularly present their work at the annual Vancouver Exploration Roundup. Consequently the student will benefit from wide ranging and established institutional links with the Canadian exploration industry and academia.

Student profile

The successful candidate will have at least a BSc with a high 2:1 or a 1st from a Geological Sciences or similar programme; an MSc/MGeol qualification is highly advantageous, as is experience of publication or other extra-curricular research activities. Strong structural geology skills, including field work, and the ability to clearly communicate results are essential. Previous experience of ore deposit geology, especially gold deposit geochemistry, in either an academic or industrial context is desirable; additional specific experience in GIS, statistical analysis, microanalytical techniques, fluid inclusions, and/or numerical modelling is desirable but not essential.

References

Chapman RJ, Mortensen JK, LeBarge WL, Crawford EC, 2010a. Microchemical Studies of Placer and Lode Gold in the Klondike District, Yukon, Canada: 1. Evidence for a Small, Gold-Rich, Orogenic Hydrothermal System in the Bonanza and Eldorado Creek Area, Economic Geology 105,1369-1392.

Chapman RJ, Mortensen JK, LeBarge WL, Crawford EC, 2010b. Microchemical Studies of Placer and Lode Gold in the Klondike District, Yukon, Canada: 2. Constraints on the Nature and Location of Regional Lode Sources, Economic Geology 105,1393-1410.

Cox SF, Knackstedt MA, Braun J, 2001. Principles of structural control on permeability and fluid flow in hydrothermal systems. In: Richards JP and Tosdal RM, Structural Controls on Ore Genesis. Reviews in Economic Geology 14, 1-24.

Goldfarb RJ, Groves DI, 2015. Orogenic gold: Common or evolving fluid and metal sources through time. Lithos 233, 2-26.

Grimshaw MR, 2018. Gold Mineralisation in the Lone Star area of the Klondike Gold District, Yukon, Canada. PhD Thesis, University of Leeds, School of Earth and Environment. 354 p.

MacWilliam KRG, 2018. The geology and genesis of the Coffee gold deposit in west-central Yukon, Canada: Implications for the structural, magmatic, and metallogenic evolution of the Dawson Range, and gold exploration models. PhD Thesis, the University of British Columbia. 497 p.

Micklethwaite S, Sheldon HA, and Baker T, 2010. Active fault and shear processes and their implications for mineral deposit formation and discovery. Journal of Structural Geology 32, 151-165.

Sibson RH, Robert F, Poulsen KH, 1988. High-angle reverse faults, fluid pressure cycling, and mesothermal gold-quartz deposits. Geology 13, 551-555.

Wilkinson JJ, Johnston JD, 1996. Pressure fluctuations, phase separation, and gold precipitation during seismic fracture propagation. Geology 24, 395-398.

Wilkinson JJ, Boyce AJ, Earls G, Fallick AE, 1999. Gold remobilization by low-temperature brines: evidence from the Curraghinalt gold deposit, Northern Ireland. Economic Geology 94, 289-296.

Yardley BWD, Cleverley JS, 2015. The role of metamorphic fluids in the formation of ore deposits. In: Jenkin GRT, Lusty PAJ, McDonald I, Smith MP, Boyce AJ, Wilkinson JJ, (eds.). Ore Deposits in an Evolving Earth. Geological Society of London Special Publication 393, 117–134.