Making wealth: Using detailed field analysis, novel experiments and high end microscopy to elucidate how gold is "made"

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This project provides you with the opportunity to produce some seminal work on an area that is surprisingly under-researched. All previous studies on metallic gold have focussed on metal generated through a smelting process. We now know that the textures and compositional variations in gold precipitated from hydrothermal solutions are completely different. This is the first study which seeks to use field observations to inform the design of experiments which will grow gold-bearing veins from synthetic solutions. You will undertake a detailed geological, mineralogical and metallogenic study of an auriferous area in Co Mayo, Ireland, to provide a platform for these studies. You will then use classical petrographic skills together with an array of instrumental techniques to characterise auriferous veins, and develop new experimental procedures to generate synthetic gold veins for study in our state-of-the-art electron optics suite and other high end analytical methods. This new understanding of the controls on gold growth, size and alloy heterogeneity will both illuminate fundamental questions on 'how gold veins get there' and underpin increasingly sophisticated approaches to the use of detrital gold as an indicator mineral in exploration.

Project background

There is a considerable body of work which addresses the properties of gold alloys as they find wide ranging use in the jewellery, dental and electronic industries. These studies focus entirely on smelted metal, i.e., an alloy which has solidified from a molten state where the composition is determined by additions to the smelted charge. There has been a tendency to assume that the compositional characteristics of natural gold are similar to these synthetic metals, however, work undertaken at Leeds over the last 20 years has shown that alloy within natural gold particles may be chemically highly heterogeneous, but we have a very limited understanding of the causes and implications of this heterogeneity.

Most natural gold is formed by precipitation from hydrothermal solutions in a wide range of geological environments. Generic 'styles' of gold mineralization are defined according to specific geological environments, that are characterized by variable pressure (P), temperature (T) and compositional (X) conditions. Both gold mineralogy (i.e. the incorporation of other metals such as Ag, Cu, Hg, Pd within the alloy) and particle size are controlled by the permissible range of P-T-X. Thus, different styles of gold record their mineralization history through different ore mineralogy and the compositional range of the gold itself.

At Leeds (UoL) we have been studying natural gold for over 20 years, building up an outstanding compositional database describing over 30,000 gold grains. This work was initially undertaken in close collaboration with the British Geological Survey (BGS; e.g. Chapman et al. 2000) but grew into an international network of collaborators studying Cordilleran (e.g. Chapman et al. 2010, 2016, 2017). We have unparalleled experience in characterizing compositional variations in natural gold both within and between different styles of gold mineralization. We have used state-of-the-art techniques such as scanning electron microscopy (SEM) based analyses, electron microprobe (EMP) and laser-ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS) to reveal generic compositional signatures related to specific styles of mineralization and to characterise compositional heterogeneity within individual gold particles (e.g. Fig. 1A). In addition, recent exploratory work has shown that the gold alloy may be highly heterogeneous with respect to trace element content (Fig. 1B), but the underlying controls on such textures are currently unclear.

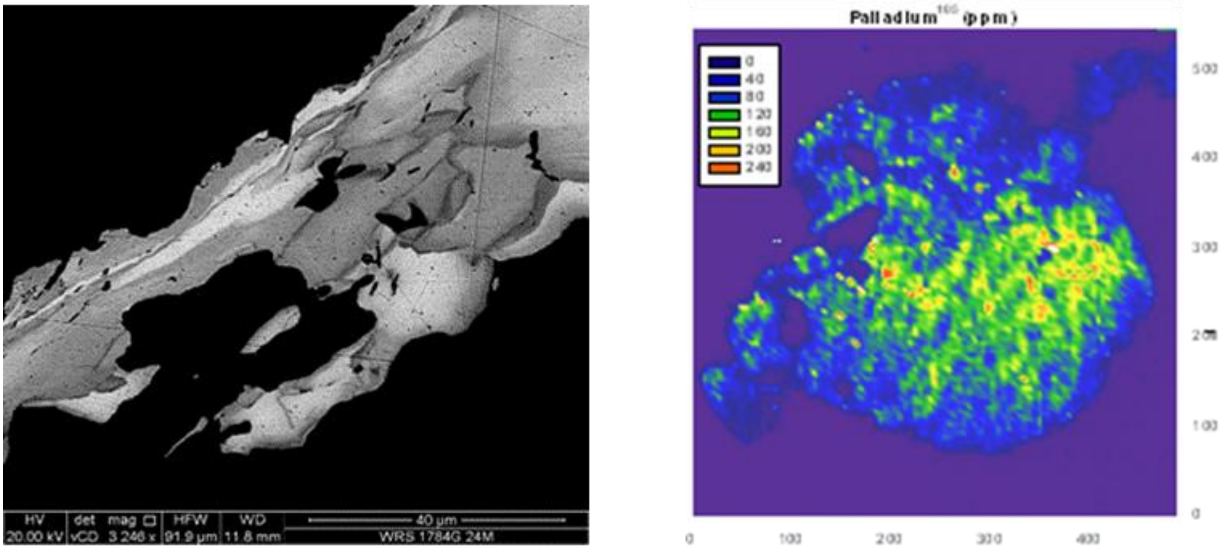

Figure 1: Examples of compositional heterogeneity in particles of natural gold revealed in SEM backscattered electron images. A: Complex grain paragenesis: placer grain Similkameen River, British Columbia. B: Time of flight LA-ICP-MS trace element map showing heterogeneity of Pd at trace level in detrital gold grain from Cariboo Gold District, British Columbia

The quartz – gold association is common, (e.g. Fig. 2) but there is a wide range of textures within this category. Individual veins may contain multiple generations of quartz, identified by cathodoluminescence (CL) not all of which contain gold (e.g. Grimshaw, 2018). The particle size of gold may vary from submicroscopic to nuggets weighing several ounces. The factors which influence gold presence/absence and/or particle size are not understood. In addition, the significance of natural gold heterogeneity at the trace element level is a new area of research which has the potential to greatly enhance our understanding of processes of gold deposition.

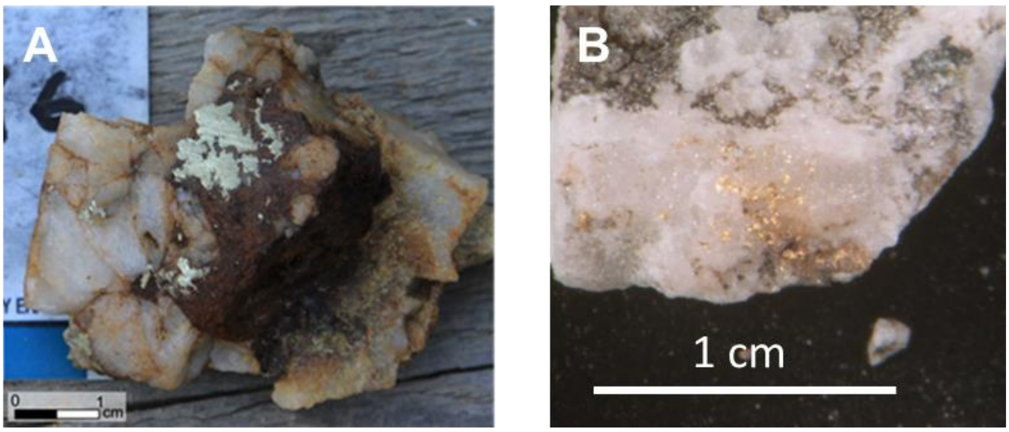

Figure 2: Examples of Different particle size of gold in auriferous quartz veins: A: Nuggety gold from Klondike District, Yukon, Canada, B: sub mm gold flecks in quartz vein: Co Mayo, Ireland

Aim of the project

In this project we aim to illuminate the controlling factors for gold precipitation and nucleation and link these to chemical and mineralogical signatures observed in natural gold. This will be achieved through novel, well-constrained experiments, where the parameters are informed by detailed field studies of in-situ vein occurrences (described below; Fig. 3). We seek to generate gold alloy and associated minerals such as quartz, calcite and pyrite from synthetic hydrothermal solutions under various P-T-X regimes. By systematically varying the experimental P-T-X-t conditions it will be possible to identify the controlling parameters, quantify the rates of gold precipitation and to compare the resulting textures and compositional variations to the various features that we have already observed in natural gold. Characterization of synthetic natural gold both chemically and texturally will permit interpretation of textures observed in natural gold globally, which will be of great benefit in developing an indicator mineral methodology based on detrital gold.

Figure 3: Auriferous quartz veins in the Cregganbaun Shear Zone

Approach

Characterization of auriferous and associated non- auriferous quartz veins will provide basis upon which to design initial experiments to generate synthetic auriferous quartz. Initially the work will focus on characterization of the geological setting and paragenesis of auriferous quartz from the Cregganbaun Shear Zone, Co Mayo, Ireland, (Fig. 3). Previous work undertaken during exploration (unpublished, K Harrington, pers comm) identified three generations of quartz veins at different orientations, viz. i. barren; ii containing high grades of finely divided gold; and iii. containing low grades of coarse (<3mm) gold. Characterization of individual veins will include: i. interpretation of the vein quartz textures and wall-rock alteration; and ii. fluid inclusion studies on the individual quartz generations identified by CL. The laboratory methods have already been established and used to investigate other silicate and carbonate systems and we expect the experimental program to evolve with increasing experience of these auriferous systems. We aim to illuminate factors controlling gold particle size, and the destiny of other metals present in the fluid. Synthetic samples so produced will be characterized by the same array of techniques previously applied to natural gold.

Specific scientific questions to be addressed

1. Can we identify fundamental differences between gold- bearing and adjacent barren veins on either a field scale and/or micron scale?
2. Are the changes in Ag-contents of alloys formed from synthetic hydrothermal solutions under different P-T-X conditions faithful to those predicted by theoretical consideration of equilibrium relations (e.g. Gammons and Williams-Jones, 1995).
3. Do changes in P-T-X applied during gold grain growth generate textures which correspond to those observed in natural gold, and what are the implications for our interpreting the paragenesis of gold bearing mineralization based on gold alloy textures?
4. Does synthetically produced gold exhibit heterogeneity at the trace element level comparable to that observed in samples of natural gold?
5. What parameters control the rate and resulting particle size of gold co-precipitated with quartz, calcite and pyrite? How important is the rate of T, P and chemical changes?

Project elements

1. Field work to characterize the geology of the vein systems and environs and to collect materials as required by the project.
2. Characterization of selected samples of natural auriferous material (vein material, placer gold particles) using SEM, EMP, fluid inclusion studies and LA-ICP-MS.
3. Laboratory- based synthesis of gold – quartz precipitation using rapid-quench cold seal apparatus and state-of-the-art flow through cells (Fig. 4).
4. Characterization of fluids and synthetic gold and quartz using SEM, EMP and ICP-MS
5. Interpretation of results in terms of defining P-T-X conditions and timescales for hydrothermal gold deposits.

The project has the capacity to evolve in a variety of directions according to the interests and expertise of the candidate, (and the supervisory team may vary accordingly) : these might include one or more of the following:
1) Correlation of conditions of formation of synthetic gold with detailed microstructural studies using EBSD and TDK analysis down to the nanoscale (e.g. Piazolo et al. 2016a, 2016b)
2) Detailed investigations of the effect of different trace elements within the system, and the resulting mineralogy of the synthetic gold.
3) Modelling of the theoretical conditions present in the system and their relationship to the characteristics of synthetic gold.
4). Investigations of other suitable field areas to provide comparative data.

Figure 4: Cold seal apparatus with the option to perform rapid quenching to simulate abrupt changes in natural hydrothermal systems

Potential for high impact outcome

This project is the first to simulate gold–quartz precipitation mimicking natural settings under controlled, experimental conditions. Its value lies not only in this novelty but also the high potential of data exploration as UoL is uniquely placed to interpret the results of the study on account of the existing library of natural gold samples. Thus, the project will make a powerful contribution to our ability to define mineralizing conditions at many localities worldwide where characteristics of detrital gold particles provide the only route to establishing the nature of their undiscovered source. This knowledge comprises a powerful driver for the widespread use of detrital gold as an indicator mineral.

The ability to extract the gold from an ore is of paramount importance to mining companies. Refractory ores, containing sub- micron sized gold require extensive pulverization in the processing operation which is both expensive and inefficient in terms of final gold recovery. Consequently, even rich deposits where the gold is finely divided constitute unattractive targets. However, such mineralization is clearly gold-rich, and changes in P-T-X could lead to changes in gold particle size and the presence of economically viable mineralization at other points in the hydrothermal system. This project will seek to establish vectors which may be applied in specific geological settings to aid the exploration process.

Analysis of natural gold by EMP and LA-ICP-MS routinely involves measurements taken on a small amount of material exposed in polished section, on the assumption that the gold alloy is homogenous. This project will evaluate that premise and thereby inform fundamental approaches to gold analysis in general whilst also undertaking a pioneering study into the compositional micro textures in natural gold alloy.

Consequently, we expect high ranking outputs in both academic facing and applied facing journals.

Training

The student will work under the supervision of Dr Rob Chapman (Institute of Applied Geosciences) and Dr Thomas Müller (Institute of Geophysics and Tectonics), with a major contribution from Dr David Banks (Institute of Geophysics and Tectonics), plus contributions from other members of staff according to the evolution of the project (Prof Sandra Piazolo, Dr Taija Torvela and Dr Dan Morgan) who provide a raft of specialist expertise.

The project will involve field work for sample collection, in auriferous areas where mineralization corresponds to the classification provided above. The student will gain experience of detailed local mapping and detailed vein scale mapping in a structurally complex environment.

The student will be trained in planning and carrying out experimental series to work independently in the experimental petrology laboratory of UoL. The training will include sample preparation before and after the experiment as well as extensive use of cutting edge analytical tools (e.g. Cohen labs, electron optics, etc.) and experimental equipment available on UoL campus.

In addition, the student will have access to a broad spectrum of training workshops offered in house e.g. image analysis, presentation skills, through to 'managing your degree' and 'preparing for your viva' (http://www.emeskillstraining.leeds.ac.uk/).

Student profile

The successful student will have strong background in either applied or physical sciences demonstrated by high marks in relevant undergraduate and/or postgraduate modules or final dissertation project. The ability to clearly communicate results visually and in writing is also essential. Experience in gold mineralization, laboratory techniques, microanalytical techniques, and a publication record is desirable but not essential.

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