D7

Fluid Inclusions and Origin of Carlin-style Mineralization at the Cove Deposit, Nevada

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Carlin-style gold deposition provides up to 5% of the global gold budget and is the leading gold source in the Unites States. Despite its significance, there is not a consensus on the source of gold or fluid for these deposits. The fine-grained nature of ore assemblages as well as lack of associated quartz veins and suitable/workable fluid inclusions (FI) makes it difficult to ascertain the conditions of mineralization, including the temperature, pressure, salinity, and source of the hydrothermal fluids. The Cove deposit, located in north-central Nevada, grades from deep base metal vein type mineralization (BMVT) to Carlin-style mineralization. Both types formed during the Eocene between 39.2 and 34.3 Ma. Past research provides a geologic framework, including identifying magmatic signatures for sulfur isotopes of BMVT mineralization. The association of BMVT with Carlin-style mineralization affords a unique opportunity to investigate fluid sources of Carlin-style mineralization. Additionally, oxygen isotopes in carbonates have been proposed as a vector for Carlin-style deposits to evaluate the extent of fluid-rock interactions. Current work tests this vector at Cove.

This study combines petrography, microthermometry, and Raman spectrometry analysis of FIs to characterize BMVT mineralization fluids. Petrographic study identified three categories of FIs. Group (I) are rounded, lobate, two-phase FIs with 20-40 volume % vapor bubbles. Preliminary microthermometry for group (I) indicates moderate homogenization temperatures (236°-362°C, avg = 330°C) and low salinities (1.7-4.9 wt % NaCl eqiv, avg = 3.7 wt % NaCl eqiv). These conditions are consistent for “E-veins”- an emerging classification of base metal veining distal to or late in porphyry systems, when coupled with previously obtained $\delta^{34}S$ values at Cove. Group (II) crosscuts (group I) and shows reequilibration textures, prohibiting further work. Group (III) consists of rounded, lobate to irregularly shaped FIs. Multi (5-7)-phase hypersaline brine FIs locally coexist in the same fracture planes with vapor FIs in low proportions, indicating that they may be trapped during phase separation, while other FI planes trap only brines. The presence of multiple fluids at similar modern depths at the Cove deposit may indicate overprinting of the deposit during its formation or multiple pulses of fluid emerging from depth. Next steps will evaluate the potential for BMVT fluids to evolve to Carlin-style mineralization by quantifying the metal content of individual FIs by LA-ICP-MS to search for specific geochemical signatures such as Au, As, Hg, and Tl enrichments.

A challenge in locating Carlin-style mineralized systems is the scarcity of exploration vectors. Oxygen isotope analysis in carbonates has been invoked as a possible method of measuring the extent of fluid-rock interactions, with depleted $\delta^{18}O$ values correlating to higher degrees of fluid-rock interaction and elevated gold grades. Preliminary results show depleted $\delta^{18}O$ values in Au-bearing samples relative to barren ones, supporting that $\delta^{18}O$ values in carbonates are a potentially effective vector into Carlin’s cryptic alteration halos. The knowledge gained from characterization of fluids, geochemistry, and $\delta^{18}O$ values of carbonates could result in more advanced metallogenic models for distal-disseminated and Carlin-style gold deposits in the McCoy district, Nevada, and elsewhere in the world.

D8

The Vergenoeg Strato-Volcano – IOCG-like Mineralization Associated with Felsic Magmatism in the Bushveld Magmatic Province, South Africa

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The Vergenoeg Igneous Complex (VIC) defines a strato-volcano that erupted as the terminal phase of the bimodal Rooiberg Group (RG), the latter representing the extrusive component of the 2057-2054 Ma Bushveld Magmatic Province. The RG was extruded immediately prior to emplacement of both the mafic (Rustenburg Layered Suite - RLS) and felsic (Lebowa Granite Suite - LGS) intrusive phases of the Complex. The lowermost portion of the RG comprises the basaltic-to-andesitic Dullstroom Formation, much of which occurs beneath the RLS and therefore predates the main layered mafic intrusion. The upper portions of the RG, including the VIC, comprise the dacitic-to-rhyolitic, Damwal, Kwaggasnek, and Schrikkloof Formations, which are closer in composition to the highly fractionated A-type granites of the LGS. The VIC hosts world-class fluorite mines associated with a Fe-F-(Cu-REE) mineralization style that has marked IOCG affinities.

Numerous polymetallic, magmatic-hydrothermal mineral deposits occur throughout the various felsic phases of the Bushveld Magmatic Province, and these are typically represented by a three-stage paragenetic sequence: early magmatic Sn-W-Mo-F ores (600° > T > 400°C), followed by a Cu-Pb-Zn-As-Ag-Au paragenesis (400° > T > 200°C) and then late-stage Fe-F-U mineralisation (<200°C). Borehole core from mineralized intervals of the VIC reveals a sharp, erosional contact (~35°) between the uppermost RG volcanics (i.e., the Schrikkloof Formation) and pyroclastic rocks of the VIC, suggesting that the latter postdates the RG and may be synchronous with subjacent LGS emplacement. A well-defined vent occurs in the centre of the complex and is also the site of the world-class F-Fe-REE deposit of the Vergeneog Mine. The vent preserves a coarse volcaniclastic breccia comprising mainly hematite (goethite/siderite)-fluorite-magnetite-fayalite—minor minerals include apatite, cassiterite, monazite, titanite, and REE-carbonate phases. It is zoned vertically and records a complex interplay between volcanic eruptive processes, magmatic-hydrothermal remobilization of ore constituents, and later supergene overprinting. Prominent sulphide mineralization occurs in the form of pyrite and chalcopyrite with lesser arsenopyrite and sphalerite. Away from the vent, subaerially-deposited volcaniclastic material defines a strato-volcano (ca. 10 x 5 km in extent) comprising two distinct units, becoming finer grained with increasing distance from the vent. The lower portion of the VIC is built of siliceous ignimbrite with a minor rhyolitic component. This is overlain by volcanic hematite-fluorite breccia intercalated with laminated, locally reworked, fan-delta sediments, all deposited in a maar-like structure. The recently developed Nokeng fluorite mine is hosted in these bedded VIC volcaniclastic sediments, distal to the vent.

Genesis of the polymetallic mineralization in the VIC, and other felsic phases of the Bushveld Complex, remains poorly understood. The association between intrusive and extrusive pulses of felsic magmatism, together with evidence for widespread magmatic-hydrothermal Fe-F-(Cu-REE) mineralization processes, define a Bushveld metallotect that has similarities to other iron-oxide-copper-gold (IOCG) provinces in, for example, Brazil and Sweden. An IOCG footprint in the felsic phases of the Bushveld event would render them more prospective than previously thought.

D9

Tungsten Mineralization in the Eastern Alps – Tracking Ore-Forming Processes Using Scheelite Trace Element Chemistry and Micro-textures

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The increasing demand for raw materials used in high-technology applications, and their economic importance, is reflected in efforts by the European Union to achieve strategic autonomy on key raw materials. Tungsten is one of the prominent raw materials highlighted by EU criticality assessments. Discovery of the world-class Felbertal W-deposit (Austria) in 1967, which is still Europe's largest producing tungsten mine, triggered substantial greenfield exploration during the 1980s. Many tungsten occurrences were discovered in the Eastern Alps and are currently being investigated with the aim to define differences in mineralization processes. The goal is to establish assessment criteria ("fingerprint") to identify regions with high potential for significant tungsten endowment that can be used in mineral exploration.

Scheelite ($CaWO_4$) is the most common tungsten mineral in the Eastern Alps, occurring in different geological settings and mineralization styles, including stratabound mineralization in metabasites, meta-carbonate and calc-silicate rocks, skarns, orogenic Au-W veins, and scheelite-bearing metamorphic veins etc. Scheelite from these different settings is studied using a combination of cathodoluminescence (CL), electron probe micro-analyzer (EPMA), SEM-based automated mineralogy (MLA), and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) techniques.

In the metamorphosed Felbertal vein-stockwork deposit, several stages of scheelite (re)crystallization are recorded. In addition to magmatic-hydrothermal scheelite, there is metamorphic scheelite, which formed during polyphase regional metamorphic overprint. CL-documented micro-textures and in situ trace element data allow us to define individual scheelite generations and track changing conditions during ore formation. Based on the Felbertal trace element signature of scheelite, a comparison with scheelite from other ore-forming environments will be carried out.

The results of this study show that Na, Mg, Sr, Y, Nb, Mo, Ba, REE, Hf, Pb, and U are sensitive to specific mineralization processes and, hence, useful to discriminate scheelite formed in different environments. In combination with CL imaging, in situ trace element analysis of scheelite distinguishes metamorphic scheelites from those of other provenance. Metamorphic scheelite exhibits homogeneous micro-textures, whereas magmatic-hydrothermal scheelite commonly shows primary and oscillatory zoning. Secondary zoning and replacement textures develop in scheelite affected by subsequent metamorphism, resulting in formation of several generations of scheelite with different trace element signatures. Molybdenum, Sr, and, particularly, REEs experience significant redistribution between these generations. Total REE concentrations and REE patterns may vary considerably; e.g., LREE enrichment or depletion and negative or positive Eu-anomalies. Furthermore, fractionation of REE between scheelite and coprecipitating minerals (e.g., apatite, allanite-Ce, epidote, titanite, etc.) is also important.

D10
Characterization of Polymetallic Vein-Type Occurrences in the Meguma Terrane: A Lesser-Known Gold Deposit Type for Nova Scotia?

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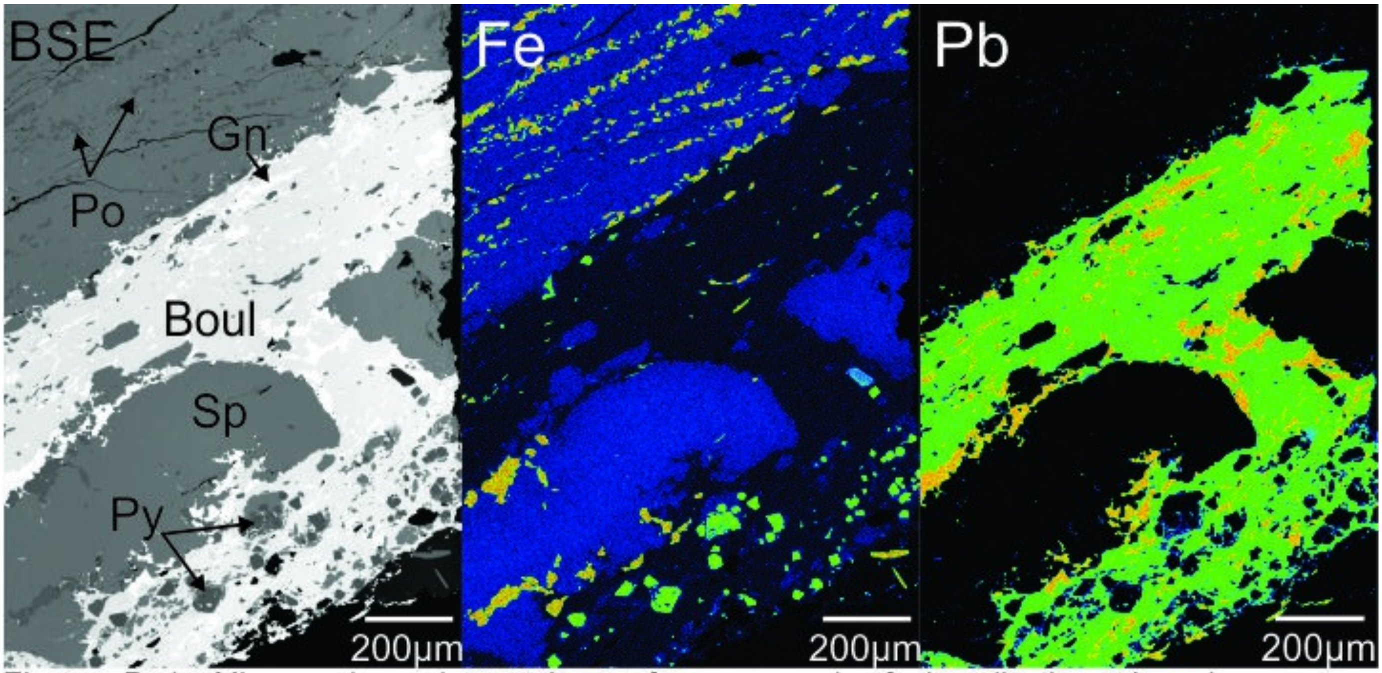
This study focuses on three Au-bearing, polymetallic (Sb-Pb-Zn-Co-Ni-Cu-Bi-Ag-Au) vein occurrences in the western Meguma Terrane with a suspected, but unproven, genetic link. The aim is to understand how the occurrences formed, including their timing, sources of metals, and relationships to other Meguma Au deposits and metasedimentary-hosted polymetallic vein deposits globally (e.g., Sb-Au deposits of the Bohemian Massif, Variscan Orogen, Europe).

At the Lansdowne and Cape Saint Mary's (CSM) occurrences in Digby County, Bear River Formation, metapelites are intruded by gabbro (~440 Ma; apatite U-Pb) and crosscut by quartz ± carbonate veins, some of which host multi-stage, sulfide-sulfosalt mineralization. At Lansdowne, mineralization crosscuts the early quartz veins and consists of an early Fe-As stage (pyrite-arsenopyrite-pyrrhotite), a Zn-Cu stage [(Cd-rich) sphalerite-chalcopyrite], and a later Pb-Sb stage (boulangerite-jamesonite-galena) with multiple generations of quartz-calcite-chlorite gangue. Arsenopyrite thermometry indicates temperatures of 425°-450°C, while chlorite of the Zn-Cu stage provides a lower temperature of 350°-390°C. The latest chlorite provides a temperature of 120°-160°C. Isocon diagrams generated using least- and most-altered samples from the mafic intrusions and metapelites indicate variable depletion in the above metals (except Sb, which was gained), potentially indicating these rocks as metal sources.

At the CSM Stibnite Occurrence, siderite infilled-breccia hosts mineralization and crosscuts earlier, brittle-ductile deformed quartz veins in Bear River Formation metapelites. Mineralization consists of an early As ± Co-Ni stage [arsenopyrite-(Co-rich) gersdorffite], followed by a Cu-Sb-Ag stage [tetrahedrite-(Ag-rich) freibergite], a Cu-Sb-Bi stage (chalcopyrite, Bi-Sb alloy), and late REE-P alteration (florencite-pyrite). At the Mavillette Beach Occurrence, Pb-Sb mineralization (boulangerite-jamesonite-galena) is observed in quartz-pyrite veins.

At the Nictaux Falls Dam Occurrence (NFDO), variably mineralized quartz veins and quartz-infilled breccia cut Kentville Formation metapelites near their contact with the South Mountain Batholith (370 Ma), diabase dykes, and a gabbro intrusion (~380 Ma; apatite U-Pb). Mineralization consists of early pyrite, a zoned Fe-Co-Ni-As stage (arsenopyrite-cobaltite-gersdorffite) with chlorite (~280°C) and rutile, and late-stage electrum.

The mineralogy, paragenesis, metal associations, and ore textures are distinct from typical Meguma Au deposits. The occurrence of mineralization in breccias and mineral thermometry suggest their formation in relatively shallow crustal environments at moderate to high temperature. Striking similarities between Lansdowne and CSM with the West Gore Sb-Au deposit (Hants Country, N.S.) in terms of mineralogy and paragenesis are noted. Future work includes Re-Os dating of arsenopyrite and trace element work on ore minerals to compare with similar deposit types.



Electron Probe Micro-analyzer elemental maps for core sample of mineralization at Lansdowne (sample LAN2-2). BSE image with labelled minerals: sphalerite (Sp), pyrite (Py), pyrrhotite (Po), boulangerite (Boul), and galena (Gn). Fe map differentiates pyrite (green) and pyrrhotite (orange). Pb map differentiates boulangerite (green) and galena (orange).

D11
Remote Sensing-based Mapping of Zn-Pb-Carbonate Hosted Ore Deposits Using Sentinel-2 and PRISMA Satellite Imagery: The Jabali Test Site (Western Yemen)

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In this study, we have developed an integrated methodology, based on hyperspectral and multispectral imagery, for mapping the spatial distribution of the hydrothermal and supergene alteration associated with the Zn-Pb(-Ag) Jabali deposit (Yemen). The Jabali deposit is located in a desert area northeast to the capital of Yemen, Sana'a, along the western NW-SE-trending margin of the Sab'atayn basin. The Zn-Pb mineralization consists mainly of nonsulfides of supergene origin, mainly represented by smithsonite, minor hydrozincite, and hemimorphite (+ acanthite and greenockite in small amounts). The nonsulfide ore is hosted by a partly hydrothermally dolomitized Jurassic limestone. The supergene ore derived from oxidation of the primary sulfide mineralization (sphalerite, pyrite, and galena) that has been interpreted as a Mississippi Valley Type deposit emplaced via fluid migrations in extensional tectonic regime. Satellite data enabled the identification of the hydrothermal dolomitization, as well as the outlining of the gossans and secondary mineralized products, which extensively outcrop in the test area. The area was analysed by means of Sentinel-2 multispectral (European Space Agency) and PRISMA* hyperspectral (Italian Space Agency) imagery. These two missions provide to the scientific community and to other users free-of-charge data and were chosen for sensing the different materials' spectral responses in the visible near infrared (VNIR) and the shortwave infrared (SWIR) regions, respectively. PRISMA provides images at a spectral resolution of 12 nm in a continuum of 240 bands in the VNIR to SWIR wavelength region of the electromagnetic spectrum (400-2,505 nm). This satellite imagery allows the clear distinction between dolomite and limestone in the SWIR region by enhancing the spectral differences between these two carbonate phases in bands 148 and 150 (2,320 and 2,335 nm, respectively). The distribution of gossans and alteration products, instead, was tested on 10-m resampled Sentinel-2 products, which offer a full set of 12 bands, with several bands in the VNIR region (B2, B4, B6, B7, and B8A) covering the Fe-bearing minerals spectral features. Spectral signatures of representative host-rock samples and Fe- and Zn-bearing mineralized alteration products were collected and validated via XRD analyses in order to build up a spectral library needed for image classification, which has been produced with the support of band combinations, spectral indices, and statistical analyses. Despite the great number of bands provided by PRISMA, a prompt visualization of the known Fe and alteration minerals outcrops with the 30-m spatial resolution was not achieved yet. However, the availability of multiple bands in the SWIR region and the hyperspectral resolution make PRISMA a suitable tool for mapping the dolomitization footprint, while the use of multispectral, Sentinel-2 "easy-to-handle" products suits best for the identification of the gossan outcrops associated with the Jabali ore type.

This work proves that an integrated satellite-ground-based mapping approach using multiple sources of spectral data with different spectral resolution is a promising exploration strategy for the Jabali ore type at regional scale in the Sab'atayn basin of Yemen, transferable to other sedimentary basins worldwide.

*Project carried out using PRISMA Products, © of the Italian Space Agency (ASI)

D12
Petro-Geochemical Characterization Of Supergene Copper Mineralization In Atacama Desert (Northern Chile): U-Pb Chronometric Potential And Formation Conditions

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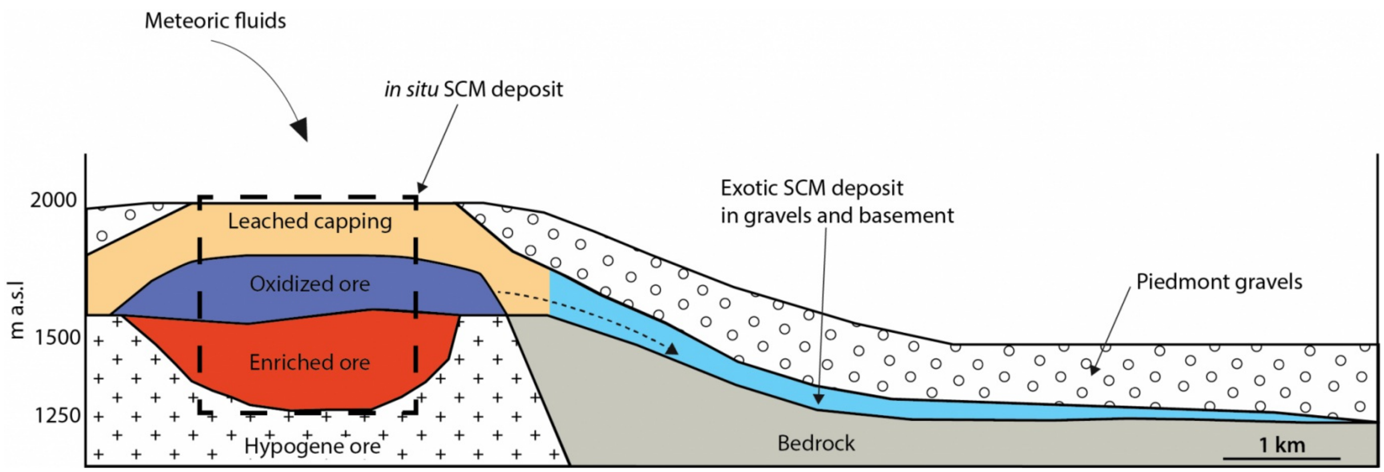
Supergene copper mineralizations (SCM) are nowadays the economic viability of many porphyry copper deposits worldwide. These mineralizations are derived from supergene processes, defined as sulfide oxidation and leaching of ore deposits in the weathering environment, and any attendant secondary sulfide enrichment. For supergene copper mineralization to form, favorable tectonics, climate, and geomorphologic conditions are required. Tectonics control the uplift needed to induce groundwater lowering and leaching of sulphides from a porphyry copper deposit. Climate controls copper leaching in the supergene environment and groundwater circulation toward the locus where supergene copper-bearing minerals precipitate. In the Atacama Desert of northern Chile, SCM seem to take place during specific Tertiary climatic periods and relief formation. But many uncertainties remain regarding the genesis and the exact timing for SCM formation.

We present mineralogical and chemical data on supergene copper-bearing minerals sampled from in situ and exotic SCM from the Atacama Desert of northern Chile. Although northern and southern areas of the Atacama Desert have experienced different geological evolution, they both underwent similar geological and climatic controls to form and preserve SCM.

Chrysocolla and pseudomalachite are the most common copper-bearing minerals found in SCM from the Atacama Desert of northern Chile. This led us to test the potential of both minerals as dating materials to place the SCM formation in a geochronological context. However, variation of U content from one mineral to another, common Pb contribution, and the absence of matrix-matched-standard for both minerals made U-Pb LA-ICP-MS dating of chrysocolla and pseudomalachite challenging. A mixed approach combining texturally-controlled in situ LA-ICP-MS U-Pb dating and multi-elements mapping, together with SIMS oxygen isotope analyses, was applied to the Mina Sur, Damiana, and El Cobre exotic copper deposits from the Atacama Desert.
Regardless of location, the results obtained demonstrate the important role played by the local geological parameters on the control of the U-Pb chronometer in supergene copper minerals. Initial high U content of the porphyry source can promote U-rich supergene copper minerals as is the case at Mina Sur. Additionally, a long-term supergene alteration will favor long-term water circulation in the depositional environment, which can leach U from the porphyry source and allow the formation of U-low supergene copper minerals during recent times.

The promising results obtained represent a new tool to understand the physicochemical, climatic, and geological conditions that prevailed during the formation of supergene copper deposits, as well as a proxy for their prospection around the world.



Meteoric fluids
in situ SCM deposit
Exotic SCM deposit
in gravels and basement
Piedmont gravels
2000
1500
1250
m a.s.l
Leached capping
Oxidized ore
Enriched ore
Hypogene ore
Bedrock
1 km