SUSTAINABLE MINERAL RESOURCES SUPPLY

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ABSTRACT BOOK
Sponsors
Rare metal concentration and regional metallogenetic zonation of granitic pegmatites and quartz veins in the Musha-Ntunga area, Rwanda

Jolan Acke1,2,*, Anouk Borst1,2, Alastair Goodship3, Daniel Kwizera3, Stijn Dewaele4

1Department of Earth and Environmental Sciences, KU Leuven, Leuven-Heverlee, Belgium
2Geodynamics and mineral resources, Royal Museum for Central Africa, Tervuren, Belgium
3PIRAN Rwanda Ltd, St Peters Port, Guernsey, UK
4Mineralogy & Petrology Research Group, University of Ghent, Belgium

*Corresponding author: jolan.acke@kuleuven.be

Granitic pegmatites are complex coarse-grained igneous rocks that typically form out of the last bits of highly fractioned melt in a granitic system. Fractional crystallization and melt-fluid immiscibility processes within pegmatitic melts may lead to the concentration of rare metals, such as tantalum (Ta), niobium (Nb), tin (Sn) and lithium (Li). Granite-related rare metal mineralization occurs widespread across the Mesoproterozoic Karagwe Ankole Belt in the Great Lakes region (Central Africa) with a peak of mineralization formed around 1000 Ma.

At Musha-Ntunga, Eastern Rwanda, shallow mining activities for Ta-Nb-Sn rich kaolinized pegmatites and Sn-rich quartz veins are currently (re-)developed and prospected for upscaled activity. The mineralized pegmatites and quartz veins are genetically associated with the Lake Muhazi granitic pluton and hosted within the metasedimentary Musha Formation. Additional to underground mining activities (up to 50m deep), recent core drillings expose fresh pegmatites. Spodumene-rich pegmatites can be found from depths up to 400m. Samples from mineralized kaolinized pegmatites and quartz veins in outcrops and shallow mine shafts, together with core samples, now provide a rare opportunity to study the regional zonation and alteration patterns of a granitic pegmatite and quartz vein system relative to its inferred granitic source. Preliminary findings show a vertical zonation from deep unweathered Li-rich pegmatites to shallow kaolinized Ta-Nb-Sn rich pegmatites and Sn-rich quartz veins.

Detailed petrographic studies, combined with bulk rock and trace element geochemistry and fluid-melt inclusion analyses are carried out to (I) study the unique regional zonation of granitic pegmatites, (II) to determine the role of immiscible melts-fluids, as well as the input of (III) metamorphic fluids in concentrating and precipitating the ore minerals and to (IV) constrain the origin and evolution of Li-bearing minerals in pegmatites. In addition, the importance of exploring and mining LCT-pegmatites in order to facilitate the clean energy transition is assessed.
Superimposed porphyry Cu and epithermal Au-Ag systems at Kirazlı District, Biga Peninsula, Turkey

Ali Aluç1,2,*, Robert Moritz2, Ilkay Kuşcu3, Alexey Ulianov4, Dave Selby5, Roelant van der Lelij6, Clémentine Antoine2, Richard Spikings2, Mehtap Karcı7

1Muğla Sıtkı Koçman Üniversitesi, Menteşe, 48000 Muğla, Türkiye
2University of Geneva, Mineral Resources and Geofluids, 1205 Genève, Switzerland
3SSR Mining Inc. / Anagold Madencilik San. ve Tic. A.Ş. Ankara Türkiye
4University of Lausanne, Geopolis UNIL-Mouline 1015 Lausanne, Switzerland
5Durham University, Department of Earth Sciences, DH1 3LE, Durham, United Kingdom
6The Geological Survey of Norway (NGU), 7040 Trondheim, Norway
7Doğu Biga Madencilik subsidiary of Alamos Gold INC., Etili, Çan, 17400 Çanakkale, Türkiye

*Corresponding author: alialuc@mu.edu.tr; ali.aluc@etu.unige.ch

Kirazlı district at the center of the Biga Peninsula, Turkey, hosts a superimposed porphyry Cu prospect and high sulfidation epithermal Au-Ag deposit with a north-south trending enigmatic genetic model. New radiometric ages of alteration, mineralization, and host rocks obtained by U-Pb, Ar-Ar, K-Ar, and Re-Os dating methods alongside whole-rock geochemistry revealed three distinct high-K calc-alkaline magmatic suites including intermediate intrusions (41.7 – 40.3 Ma), plagioclase-phyric andesite (37.6 – 38.7 Ma), and basaltic andesite and pyroclastic rocks (31.4 – 33.0 Ma) accompanied by at least four generations of hydrothermal events overlapped at the Kirazlı district. Hydrothermal history of the Kirazlı started with Porphyry Cu event at 36.6 Ma (Muscovite, Ar-Ar) and was overprinted by late Qtz-molybdenite event at 33.3 Ma (Molybdenite, Re-Os). A high sulfidation type epithermal system developed at 30.5 Ma (WR-alunite, Ar-Ar) followed by the re-heating of the system at around 26 Ma (illite, K-Ar) and formed overprinting argillic alteration to the entire district.

The five target zones are determined in the district: Kirazlı Main, Çatakaya, Kale, Rock Pile, and Iri. An NNW-SSE trending epithermal orebody lies beneath the Kirazlı main, where the porphyry Cu style mineralization intersected by drilling at Kale zones in the south. The HS epithermal Au-Ag mineralization hosted by a volcanic-volcaniclastic sequence consisting of a basaltic andesite lava flow and lithic/crystal tuff occurs as disseminations, small veins, and veinlets within argillaceous and silicified (mainly vuggy and massive) bodies and hydrothermal breccia. The host intrusive rock of the porphyry Cu mineralization is highly deformed by conjugate fault systems and undifferentiated due to overprinting of pervasive hydrothermal alterations, which affects the entire district in different degrees of intensity. The porphyry Cu mineralization occurs as dissemination and porphyry-type veins in potassic alteration in the Kale zone.
Application of ASTER spectral data algorithms for detection of hydrothermal alterations and ore deposits in north Siroua massif (Central Anti-Atlas, Morocco)

Abdelhay Ben-Tami¹*, Said Belkacim¹,², Adnane Labbaci³, Mohamed Bouabdellah⁴, Bouchra Baidada⁵, Mohammed Assalmi⁶

¹Faculty of Sciences, Ibn Zohr University, B.P. 8106, Agadir, Morocco
²Research Institute in Mines and Environment, University of Quebec in Abitibi-Témiscamingue, 341 Main Street North, Amos J9T 2L8, Canada
³GGEL, Faculty of Sciences, Ibn Zohr University, Agadir, Morocco
⁴Laboratory of Mineral deposits and Hydrogeology, Faculty of Sciences, Mohammed First University, 60000, Oujda, Morocco
⁵Higher school of Technology, Fkih Ben Salah, Morocco
⁶Zgounder Millennium Silver Mining (ZMSM), Aya Gold and Silver Group, L'epargne street, Racine district, Casablanca, Morocco

*Corresponding author: abdelhaybentami@gmail.com

Located in north Siroua massif, the area subjected to this study is covered by the 1/50 000 sheets of Assarrag and Tachoukacht, with mostly magmatic and sedimentary rocks ranging from Neoproterozoic to recent in age. Presently, more than one hundred twenty mineral occurrences have been recorded in the area, including Au, Ag, Cu, Pb, Mo, Zn, Hg, Mn, U and Ba which seems to be mostly associated to Neoproterozoic rocks. In an analysis of this region, we applied the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data for identifying alteration zones associated with the Au-Ag-Cu-Mo-Pb-Zn mineralization. The goal was to assess the implications for mineral exploration targeting and to better differentiate geological structural features linked with various elements in the area. Field investigations and sampling were concentrated for the most part at the Zgounder Ag-Hg deposit and the Imourkhsen porphyry environment.

The image transformation techniques like the specialized band rationing and Principal Component Analysis (PCA) were used to delineate lithological units and alteration minerals. For the supervised classification techniques, Spectral Angle Mapper (SAM) was applied to detect subtle differences between indicator alteration minerals associated with ground-truth minerals locations in the area. The directional filtering technique was applied to help in tracing along the strike of the different linear structures associated with ore formation in the Zgounder mining area. Results demonstrate that the integration of image transformation techniques and supervised classification of ASTER data with fieldwork and laboratory studies has a great efficiency in targeting new prospects of mineralization in the study area. The approach adopted provides a fast, cost-efficient means to start a comprehensive geological and geochemical exploration programs in areas with a similar geological setting to those of the present study.
Trace elements in sulfides from several orogenic Pb-Zn-Ag ores of the Western Alps (France)

Maxime Bertauts¹,* Marie-Christine Boiron², Emilie Janots¹, Magali Rossi³, Isabelle Duhamel-Achin⁴, Chantal Peiffert²

¹ISTerre, Université Grenoble Alpes, CNRS, Grenoble, France
²Université de Lorraine, CNRS, GeoRessources, F-54000 Nancy, France
³EDYTEM, Université Savoie Mont-Blanc, CNRS, Chambéry, France
⁴Bureau de Recherches Géologiques et Minières (BRGM) – Orléans, France

*Corresponding author: maxime.bertauts@univ-grenoble-alpes.fr

In the French Alps, more than 250 polymetallic occurrences are hosted in various lithostructural domains inherited from the complex and polyphased orogenic history. This study presents mineralogical data from six hydrothermal Pb-Zn-Ag deposits, along an East-West transect across the western Alps.

In the Internal Alps, mineralizations occur within Triassic quartzite foliation at Peisey-Nancroix (PN) and Macôt-la-Plagne (MP). In the External Alps, the Sapey (SAP) and Bois-Feuillette (BF) orebodies form vertical lodes cross-cutting the crystalline basement and the Mesozoic sedimentary cover, whereas Le-Gros-Villan (LGV) and Penay (PEN) occurrences are hosted in shear zones within the crystalline basement. Based on a detailed petrographic and microstructural study, the ore-minerals’ paragenetic sequence has been newly established at a micron-scale. In situ trace elements were determined in sulfides with special interest for Ag, Sb, Bi in galena and Ga, Ge, In for sphalerite. Galena from MP shows the most important dispersion in Ag (480-1570 ppm) and Sb (580-2080 ppm) with the highest concentrations found in the massive texture. In contrast, PN galena displays the lowest Ag (<370 ppm) and Sb+Bi (<430 ppm) contents from the entire dataset, attributed to abundant tetrahedrite. Galena Bi concentrations are low in all samples (<60 ppm), except for BF (up to 2260 ppm) with significant intragranular variations (240-1060 ppm). Sphalerite is rare in MP-PN. The Ga concentration in sphalerite is highly variable in BF-SAP (8-685 ppm) and remains rather low in LGV-PEN (<11 ppm). Sphalerite Ge and In concentrations are low (<1-10 ppm), with the highest Ge concentration measured in sector zoning of BF grains (40 ppm). Sphalerite thermometry was combined to complementary geochronological data for better constraining the metallogenic model. Alpine ore mineralizations (PN-MP, LGV-PEN) form during episodic deformation stages (35-40 Ma and 19 Ma) at around 300-350°C. Mesozoic ore mineralizations (SAP-BF) form at 200°C during Tethysian extension.
Hod Maden Deposit, Eastern Pontides, NE Turkey: A Cretaceous Au-rich VMS System - Geochemical and Isotopic Characterization of Hydrothermal Alteration and Mineralization

Mustafa Erde Bilir1,2,*, İlkay Kuşcu2, Robert Moritz1, Alexey Ulianov3, Torsten Vennemann3, Benita Putlitz3, Jorge Spangenberg3, Ebamüşläüm Topal4

1Department of Earth Sciences, University of Geneva, Geneva, Switzerland
2Muğla Sıtkı Koçman University, 48000, Kötekli, Muğla, Turkey
3Institute of Earth Sciences, University of Lausanne, 1015 Lausanne, Switzerland
4Artmin Madencilik, Beştepe Mahallesi, Yaşam Caddesi, Ak Plaza No: 7 / 7 Kat: 1 Yenimahalle, Ankara, Turkey

*Corresponding author: mustafa.bilir@etu.unige.ch

Hod Maden deposit is located in eastern Pontides, NE Turkey, and represents one of the highest-grade gold-copper (~ 4 Moz @11.1 g/t AuEq) discoveries made globally in recent years. It is hosted by Late Cretaceous volcanic sequences of Çatak and Kızılkaya formations which host several Kuroko-type VMS and epithermal deposits throughout the eastern Pontides. Hod Maden differs from them with significantly elevated gold grades and mineralization/alteration styles.

Petrographic studies indicate a submarine environment for host volcanics and hydrothermal alteration mineralogy is mainly controlled by the host rock composition (chloritic alteration with andesitic host or sericitic-clay alteration with dacitic host). High grade Au mineralization is associated with the hydrothermal alteration sequence starting with an early stage pervasive fine-grained quartz and chlorite/sericite-clay alteration cut by fine-grained quartz veinlets followed by comb coarse-quartz veins bearing pyrite and chalcopyrite and with the late stage anhydrite, epidote and carbonate phase as overprint or open space filling.

New zircon U-Pb dating clarifies that columnar dacites were (evaluated as the same volcanic phase with the host dacite breccias at the South Zone) formed at 84.78 ± 0.20 Ma while the rhyodacitic unit of Old Workings Zone has been dated at 84.11 ± 0.15 Ma. In addition, the volcanic clasts of a red conglomerate unit, a marker horizon in the region, yielded the age of 163.50 ± 0.35 Ma.

The majority of $\delta^{34}$S values of sulfide minerals record minor deviations between -0.81 and +3.33 ‰ and represents a magmatic source (magmatic water and/or seawater interaction with pre-existing host volcanic rocks). The $\delta^{34}$S values of anhydrites display variations between 17.06 and 19.93 ‰ and overlap with the sulfur isotopic composition of Late Cretaceous seawater sulfate. Hydrothermal fluids in equilibrium with chlorite and sericite have $\delta^{18}$Owater between +1.7 to +7.0 ‰ and $\delta D_{\text{water}}$‰ values between -8 to -24 that define a trend between evolved seawater and a magmatic fluid as a result of fluid-rock interactions and a possible magmatic water input.
Submarine Volcanic Rock Textures, Hydrothermal Alteration Assemblages and Mineralization of Hod Maden Au-Cu Deposit, Eastern Pontides, NE Turkey

Mustafa Erde Bilir\textsuperscript{1,2,*}, İlkay Kuşcu\textsuperscript{2}, Robert Moritz\textsuperscript{1}, Ebamüslüm Topal\textsuperscript{3}

\textsuperscript{1}Department of Earth Sciences, University of Geneva, Geneva, Switzerland
\textsuperscript{2}Muğla Sıtkı Koçman University, 48000, Kötekli, Muğla, Turkey
\textsuperscript{3}Artmin Madencilik, Beştepe Mahallesi, Yaşam Caddesi, Ak Plaza No: 7 / 7 Kat: 1 Yenimahalle, Ankara, Turkey

*Corresponding author: mustafa.bilir@etu.unige.ch

Hod Maden deposit, located in the eastern part of eastern Pontides, contains ~4 Moz of gold. It consists of various mineralization styles including massive sulfide to semi-massive sulfide lenses and stockwork quartz-sulfide veins. The ore zones form three distinct ore bodies that are from north to south, Main Zone, South Zone and Old Workings Zone.

Main Zone consists gold and copper sulfide-quartz veins and zones of disseminated to semimassive sulfides. The ore zone is spatially associated with jasper-bearing, chlorite and zeolite altered amygdaloidal andesite breccia with occasional hyaloclastite and sericite – and clay (Mg-illite, kaolinite-dickite) altered spherulitic/amygdaloidal dacite breccia units. A late, intense anhydrite phase overprints the pre-existing volcanic and hydrothermal alteration textures. South Zone consists of auriferous semimassive veins, zones of sulfide stringers and disseminated sulfides that are hosted in spherulitic/amygdaloidal, monomictic dacite breccia and mass flow deposits. Quartz-pyrite-chalcopyrite-sphalerite veins and clasts replaced by sulfides form the mineralized bodies. The alteration consists of an assemblage of sericite (fine-grained muscovite, K- illite), clay (dickite, kaolinite, halloysite, montmorillonite) and late calcite, dolomite and anhydrite overprint. Old workings zone consists of copper and zinc sulfide (chalcopyrite-pyrite-sphalerite)-quartz veins. The ore zone is hosted in amygdaloidal andesite breccia and rhyodacitic dome with banded lava flow and pyroclastic products (pumice-bearing crystal tuff). Quartz-sulfide veins are accompanied by pervasive chlorite, sericite and occasional dolomite, epidote, rhodochrosite alteration.

The volcanic textures of the host rocks including (i) spherulitic texture, replacements of radiating fibers of crystals by later sericite, chlorite and sulfides; (ii) hyaloclastites or false vitriclastic textures (hydric fragmentation of quenched lava flows); (iii) amygdaloidal texture, infilling of vugs and replacement of lithic clasts by chlorite, quartz, carbonates and zeolites; (iv) subaqueous mass flow deposits with dacitic lithic clasts and sulfide clasts; (v) presence of “tetsusekiei” (or jasper-hematite); and hydrothermal alteration features such as (i) spatial zonation of Fe-rich chlorites and zeolites; and (ii) the late anhydrite phase overprinting gold-copper mineralization provide a better understanding toward the formation of seafloor/subseafloor hydrothermal alteration and mineralization.
The Eureka mine: an approach to its formation model

Judit Blasco Neira\textsuperscript{1,*}

\textsuperscript{1}Departament de Mineralogia, Petrologia i Geologia Aplicada, Universitat de Barcelona, c/Marti i Franquès s/n, 08028 Barcelona, Spain

*Corresponding author: judit.b.neira@gmail.com

My bachelor’s thesis aim is to understand the formation mechanism of the Eureka Cu-U-V stratified deposit, embedded in sandstones in Bundsastein facies in the Pyrenees (Castell-Estaó, Catalonia, Spain). Specifically, the goals are to know the source of the S of the sulphides, determine the conditions of pressure and temperature during the alpine deformation and metamorphism, as well as to determinate the possible source of the reducing agent with data of $\delta^{13}$C and $\delta^{18}$O.

This deposit is in an area affected by Alpine-age overlaps involving the Palaeozoic series (including black slates with Silurian pyrite and Upper Palaeozoic coal levels) and Triassic series with Bundsastein facies sandstones, Muschelkalk limestones, and gypsum with diabase, from Keuper. The deposit consists of spreads as local cement of sulphides and uraninite in reduced trams of the red series of the Bundsastein, associated with coal and vets of organic material; there are also small syntectonic streaks of carbonates.

The methodology, therefore, includes fieldwork, transmitted and reflected light optical microscopy, SEM-BSE-EDS, EMPA, XRD, stable isotope analysis (C, O, S) and Raman.

Preliminary results show DRX analysis of the diabase the local presence of pumpellyite, prehnite and epidote, which would indicate a very low degree of metamorphism in the study area. In addition, chalcopyrite, bornite, chalcocite and pyrite have also been found in the spreads with thin section in late vein mineralization. The SEM results corroborate the presence of these minerals, as well as chlorites, muscovite, and uranium minerals, mainly uraninite, associated with organic matter veins. Isotopic values of $\delta^{34}$S are indicative that S comes from sulphate reduction.
Combining deep electrical resistivity, drone surveying and geochemical tracing to decipher the architecture of the Calamita distal Fe-skarn deposit, Elba Island (Italy)

Damian Braize1,*, Julien Sfalcin1,*, Matteo Lupi1, Kalin Kouzmanov1, Andrea Dini2

1Department of Earth Sciences, University of Geneva, Rue des Maraîchers 13, CH-1205, Genève
2Istituto di Geoscienze e Georisorse, CNR, 56124 Pisa, Italy

*Corresponding author: Damian.Braize@etu.unige.ch

The deposit of Calamita, on the south-eastern coast of Elba Island, Italy, is a distal Fe-skarn containing massive magnetite-hematite ore bodies hosted in marbles and micaschists from the Tuscan Units. Skarn and ore formation at Calamita matches with the waning stage of the Miocene magmatism on Elba and share peculiarities with several other Fe-skarn deposits on the island, formed during the post-collisional extension of the Apennine orogenic belt. To date, no genetic or spatial link between the Calamita deposit and a potential causative intrusion has been established.

In this project, a DERT (Deep Electrical Resistivity Tomography) 2D survey has been carried out to study the subsurface geology of the deposit based on a resistivity and IP modelling to a depth of 200 meters. Geophysical data will be integrated into a high-resolution 3D topographic model acquired by standard and thermal drone imagery. Surface mapping and characterization of the alteration and mineralization styles using SWIR, XRF and LA-ICP-MS techniques as well as Ar/Ar dating of adularia from a late epithermal event will contribute to determine the architecture of the Calamita deposit and the chronology of the skarn and ore formation.

This multidisciplinary project will define the possibilities and limits of the DERT in estimating ore bodies volumes for future research and exploration and will contribute to the understanding of the deep structure of distal skarn deposits.
The development of new magmatic oxybarometers to assist with regional-scale exploration for magmatic-hydrothermal ore deposits

Enzo-Enrico Cacciatore¹,*, Alexandra Tsay¹, Zoltán Zajacz¹

¹Department of Earth Sciences, Mineral Resources and Geofluids, University of Geneva, Geneva CH-1205, Switzerland

*Corresponding author: Enzo-Enrico.Cacciatore@unige.ch

Oxygen fugacity ($f_{O_2}$) plays an important role in determining magmatic ore fertility by affecting ore metal transport and precipitation. Therefore, the understanding of magmatic-hydrothermal ore formation relies on reconstructing the redox-path along which the parental magmatic systems develop.

For example, this will determine whether or not magmas saturate a magmatic sulfide phase during transport and differentiation (e.g. oxidizing conditions favor enrichment in sulphur and chalcophile metals in basalts). Such magmatic sulfides could sequester the chalcophile ore metal budget of the magma leading to infertility, or potential spatial pre-enrichment of these metals for later remobilization, thus promoting an alternative way of ore genesis. The degassing efficiency of sulfur and its speciation in magmatic fluids are also strongly $f_{O_2}$-dependent impacting both transport and precipitation of ore-forming elements. The question remains, whether the redox-evolution of a magmatic system determines the degree of ore fertility, and the distribution and dimensions of associated ore deposits.

This study, will provide a robust and versatile tool to help answering these questions. New oxybarometers will be established based on experiments using a new type of rapid-quench Molybdenum-Hafnium-Carbide pressure vessel apparatus. It is coupled with a semi-permeable hydrogen membrane facilitating $f_{O_2}$-control in hydrous experiments with an accuracy of 0.1 log unit. This approach enables the calibration of mineral-melt exchange coefficients of redox-sensitive trace elements simulating a shallow crustal magmatic environment of calc-alkaline nature. These oxybarometers can in turn be applied to volcanic rocks with suitable pairs of silicate melt inclusions and their host phenocryst to reconstruct their redox history.

For instance, two exploratory experiments at $P = 200$ MPa ($T_1 = 1020^\circ$C and $T_2 = 1000^\circ$C) showed V/Sc exchanges coefficients of:

$$\log_{10} K_{D \text{V/Sc}}^{\text{ol/melt}} = -1.45 \mp 0.14 \left(\Delta FMQ_1 = 1.5\right) \text{ and } -1.08 \mp 0.14 \left(\Delta FMQ_2 = 0\right)$$

These values are consistent with the expected degree of the variation in V/Sc partitioning as a function of $f_{O_2}$ based on previous experiments.
High-grade copper and gold deposited during post-potassic chlorite-white mica-albite stage in the Far Southeast porphyry deposit, Philippines

Michael F. Calder¹,*; Zhaoshan Chang²; Antonio Arribas³; Kalin Kouzmanov⁴; Jeffrey W. Hedenquist⁵

¹Economic Geology Research Centre (EGRU), James Cook University, Townsville, Queensland 4811, Australia
²Department of Geology and Geological Engineering, Colorado School of Mines, Golden, Colorado 80401, USA
³Department of Earth, Environmental and Resource Sciences, The University of Texas at El Paso, Texas 79968 USA
⁴Department of Earth Sciences, University of Geneva, CH-1205 Geneva, Switzerland
⁵Department of Earth and Environmental Science, University of Ottawa, ON K1N6N5 Canada

*Corresponding author: michael.f.calder@gmail.com

Ninety-eight underground diamond holes (~102 km) drilled by Far Southeast Gold Resources Inc. at the Far Southeast porphyry Cu-Au deposit, Philippines, from 2011 to mid-2013, provide a three-dimensional exposure of the deposit between 700 and −750 m elevation, with surface at ~1400 m elevation. Far Southeast contains an inferred resource of 891.7 Mt averaging 0.7 g/t Au and 0.5 wt.% Cu, equivalent to 19.8 Moz Au and 4.5 Mt Cu. This contribution reports the spatial and temporal distribution of alteration and mineralization at Far Southeast, notably a white mica-chlorite-albite assemblage that formed after early secondary biotite and before late quartz-white mica-pyrite alteration and that is associated with the highest copper and gold grades.

Alteration assemblages were determined by drill core logging, short-wavelength infrared (SWIR) spectral analysis, petrographic examination, and a quantitative evaluation of materials by scanning electron microscopy (QEMSCAN) study. The paragenetic sequence includes stage 1 granular gray to white quartz-rich (± anhydrite ± magnetite ± biotite) veins with biotite-magnetite alteration. These were cut by stage 2 lavender-colored euhedral quartz-rich (± anhydrite ± sulfides) veins, with halos of greenish white mica-chlorite-albite alteration. The white mica is largely illite, with an average 2203 nm Al-OH wavelength position. The quartz veins of this stage are associated with the bulk of copper deposited as chalcopyrite and bornite, as well as gold. Thin Cu-sulfide (chalcopyrite, minor bornite) veins with minor quartz and/or anhydrite (paint veins), with or without a white mica halo, also occur. These veins were followed by stage 3 anhydrite-rich pyrite-quartz veins with white mica (avg. 2197 nm, illite)-pyrite alteration halos. The ore shells have a typical bell shape centered on a dioritic intrusive complex.
Fluid evolution in the San Rafael Sn-Cu deposit, Peru: constraints from fluid inclusion analyses and chlorite geochemistry

Malena Cazorla Martínez1,*  Kalin Kouzmanov1

1Department of Earth sciences, University of Geneva, Geneva, Switzerland

*Corresponding author: malena.cazorla@etu.unige.ch

The San Rafael Sn-Cu deposit in southern Peru is the third most important Sn producer worldwide (>2% Sn). The Sn-Cu-Zn-Pb-Ag mineralization is genetically related to Miocene magmatic bodies emplaced in Ordovician shales. The four mineralization stages are: early barren quartz-tourmaline stage I, main Sn ore stage II, sulfide-dominant stage III, and late barren quartz-carbonate stage IV.

Despite being thoroughly studied due to its exceptional Sn grades, detailed fluid inclusion study on the San Rafael deposit has never been conducted. Thus, the present study addresses the questions about the fluid evolution and ore precipitation mechanisms, by means of a detailed fluid inclusion study (petrography, microthermometry, Raman micro-spectroscopy and LA-ICP-MS analyses), complemented by chlorite geochemistry.

Average homogenization temperatures and salinities for stages I, II, III and IV are 403°C and 44.7 wt.% NaCl eq., 290°C and 7.5 wt.% wt.% NaCl eq., 280°C and 5.1 wt.% NaCl eq., and 212°C, and 0.8 wt.% NaCl eq., respectively.

CH4 has been detected by Raman micro-spectroscopy in 52 fluid inclusions (FIs), and N2 and CO2 in 6 FIs. Water is the main solute identified and B(OH)3 has been detected in 12 FIs. These results stand for reduced and B-rich mineralizing fluids at San Rafael.

Preliminary LA-ICP-MS analyses of stage-II FIs exhibit average B, Cu, Zn and Pb concentrations of 1552 ppm, 3.8 ppm, 47.5 ppm and 10.8 ppm, respectively; average Na/K ratios of 34.7 account for magmatic signature of the fluids, Na/Li ratios ranging from 3.2 up to 39.0 show that both Li-rich (≤5) and non-Li-rich fluids are involved, and constant Cs/Na ratios (~10-3) point towards a common magmatic source. Further LA-ICP-MS analyses will be performed to obtain a better understanding of the geochemical evolution of the hydrothermal system.
Magmatic and hydrothermal processes in the carbonatite-related REE mineralization system: insight from the Maoniuping Deposit, Southwestern China

Zhe Chi\(^1,2,*\), Pei Ni\(^1\), Junyi Pan\(^1\), Zengqian Hou\(^3\), Cyril Chelle-Michou\(^2\)

\(^1\)State Key Laboratory for Mineral Deposits Research, Institute of Geo-Fluids, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China
\(^2\)Department of Earth Sciences, ETH Zürich, Clausiusstrasse 25, 8092 Zürich, Switzerland
\(^3\)Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

*Corresponding author: zhe.chi@erdw.ethz.ch

Carbonatites host most of the REE resources in the world. However, the magmatic and hydrothermal processes in carbonatitic systems that concentrate REE elements to economic levels (wt.%) are still poorly constrained. The Cenozoic Maoniuping deposit has clear mineralization zonation, a well-established intrusion sequence, and limited supergene alteration, providing an outstanding case study to decipher the magmatic and hydrothermal processes. Multistage magmatism has been recognized in the mining district: the earliest nordmarkite stock, followed by the intrusion of lamprophyre dykes, carbonatite dykes, and a late granite porphyry. The REE mineralization is hosted in carbonatite or forms veins crosscutting the nordmarkite stock and lamprophyre, but the ore veins are truncated by the barren granite porphyry. We use the pre-ore nordmarkite and post-ore granite porphyry to bracket the lifespan of REE mineralization. Our new in-situ zircon dates combining the previous geochronological results show million-year zircon age spreads (22.4-28.5 Ma) for nordmarkite, indicating its long magmatic history, and suggest a weighted age of ca. 23.7 Ma for granite porphyry. However, the ages of the youngest zircon grains in pre-ore and post-ore intrusions overlap within a much shorter time interval, allowing a short time window for the REE mineralization. Ongoing high-precision dating will provide a more accurate lifespan of the mineralization. Two ore types can be classified based on predominant mineral assemblages: aegirine-augite barite veins and carbonatitic veins. These two type veins show similar mineral paragenesis sequence: aegirine-augite/feldspar—arfvedsonite—bastnaesite—quartz/fluorite—barite. The fluid inclusions hosted in bastnaesite and associated minerals (quartz and fluorite) are polycrystalline inclusions, with sulfate and minor carbonate as daughter minerals. LA-ICPMS analyses of these fluid inclusions reveal high REE concentrations up to 6000 ppm for the ore-forming fluids. The giant Maoniuping deposit may be generated from super-enriched fluids within a relatively short period.
Geological setting and mineralization of Gicik low-sulfidation epithermal Au-Ag±Te deposit (Ankara, North-Central Anatolia)

Akın Çil¹*, Ali İmer¹

¹Department of Geological Engineering, Middle East Technical University, Ankara 06800, Turkey

*Corresponding author: akincil@metu.edu.tr

Gicik Au-Ag±Te deposit, situated at north central Anatolia, is a part of post-subduction magmatism of Eocene age which is highly prospective in terms magmatic-hydrothermal mineralization (particularly Biga Peninsula, and eastern Pontides Mineralized veins have been emplaced within dacitic lavas overlying basement of Sakarya Zone. Lithogeochemical analyses revealed that host rocks (medium-K, calc-alkaline, relatively depleted in HFSE and enriched in LILE and REE) indicate subduction-related magma sources.

Reverse faults exerted strong structural control on emplacement of sub-vertical siliceous veins which were episodically reactivated during vein formation, possibly enhancing fluid focusing. Second set of faults offset mineralized veins, and also facilitate emplacement of late dikes throughout Gicik.

Immediate wall-rocks surrounding veins have been completely silicified (chalcedony/fine- to medium-grained quartz). Silicification pass outwards into argillic (quartz-illite-kaolinite), and later into district-scale propylitic alteration (chlorite-epidote-carbonate-quartz-pyrite).

Siliceous veins display characteristic epithermal textures (colloform banding, hydrothermal brecciation, lattice-bladed). Vein samples collected from surface exposures have been extensively oxidized into hematite and goethite. Relatively fresh exposures, however, contain hypogene sulfide phases mainly including pyrite and arsenopyrite. Observed textures, alteration and ore minerals suggest that Gicik is a typical low-sulfidation epithermal system. Paragenetically late veins with abundant Ag-tetrahedrite, as well as native gold, electrum, Au-Ag tellurides, with lesser sphalerite, and chalcopyrite locally overprinted the early veins, and these were likely formed from hydrothermal fluids of intermediate sulfidation states.

K-Ar and Ar/Ar dating of igneous and hydrothermal minerals suggest that volcanic activity and hydrothermal alteration occurred contemporaneously at ~44 Ma. This period of volcanism is considered to have been triggered either by collisional processes or by breakoff. Overall deposit characteristics are analogous with similarly aged gold deposits of the collisional belt located in in Biga Peninsula and eastern Pontides. Thus, we propose that middle Eocene tectonomagmatic conditions along central Sakarya Zone were also favorable for generation of low-sulfidation epithermal mineralization.
Tracking ore metamorphism to unravel critical metal distribution

Alexandre Cugerone\textsuperscript{1,2,\ast}, Bénédicte Cenki\textsuperscript{2}, Kalin Kouzmanov\textsuperscript{1}, Denis Fougerouse\textsuperscript{3}, Kai Luo\textsuperscript{4}

\textsuperscript{1}University of Geneva, Switzerland
\textsuperscript{2}Géosciences Montpellier, Université de Montpellier, France
\textsuperscript{3}School of Earth and Planetary Sciences, and Geoscience Atom Probe Facility, John de Laeter Centre, Curtin University, Australia
\textsuperscript{4}School of Earth Sciences, Yunnan University, China

\ast Corresponding author: alexandre.cugerone@unige.ch

Critical metal market is growing associated to various key high-tech applications such as permanent magnets (REE), optical fibers (Ge), solar panels (Ga) or electronic devices (In). Most of these resources frequently occur as trace components (ppm levels) in various base metals and magmatic rocks. However, these critical metals can form specific mineral assemblages as well (wt.% levels). The mechanisms of their natural concentration/remobilization are still poorly explored but the roles of deformation and dynamic recrystallization as well as particular fluid conditions seem to be key elements in their redistribution and remobilization.

Presently, base metal reserves are mainly located in orogenic settings and may have endured deformation/metamorphic events, such as Australian VHMS deposits or deformed carbonate-hosted Pb-Zn deposits in China. Critical metal redistribution/remobilization may have occurred in these deposits, but innovative methods need to be applied to assess their critical metal concentrations and their relationships with sulfide mineralization.

A particularly well studied example of deformed Pb-Zn ore is documented in the Pyrenees (France-Spain). Sphalerite from two distinct types of vein mineralization (Late-Variscan and Mesozoic in age) contain Ge-minerals with Ge content up to ~70 wt.%. Sphalerite appears with partly recrystallized texture, detected with electron back-scattered diffraction (EBSD). At microscale, Ge-minerals are mostly observed along grain boundaries of Ge-poor recrystallized sphalerite or in twin-boundaries of Ge-rich parental sphalerite. Nonetheless, in the Late-Variscan and Mesozoic vein-type mineralization, progressive lateral diffusion in sphalerite cleavage or patchy-oscillatory zoning of Ge and Ga appear, respectively, and were mapped with laser-induced breakdown spectroscopy (LIBS). Indeed, dynamic recrystallization of sphalerite enhanced ore porosity and was favorable to the circulation of low-temperature fluid (< 250 °C) which induced redistribution of Ge and Ga contents, probably associated with intragranular diffusion and fluid-rock reaction processes.
Chemistry of ore minerals at the W-Mo porphyry deposit Ochtiná-Rochovce, Slovakia

Diego Delgado Yáñez¹*, Peter Koděra¹

¹Comenius University in Bratislava, Faculty of Natural Sciences, Department of Mineralogy, Petrology and Economic Geology, Ilkovičova 6, Mlynská dolina 842 15 Bratislava

*Corresponding author: yanez1@uniba.sk

W-Mo porphyry deposits are a rare type of magmatic-hydrothermal deposits. The deposit at Ochtiná-Rochovce is a unique occurrence of this type in the Western Carpathians, related to a Cretaceous porphyry biotite granite intrusion with estimated resources of 5.0 Mt at 0.22 wt. % W and 2.4 Mt at 0.216 wt. % Mo. This mineralization is divided in a lower Mo and an upper W zone, mainly occurring in micaschist and metamafic rocks and it is accompanied by potassic alteration and chloritization.

The main ore minerals are molybdenite, wolframite and scheelite which are hosted in quartz veinlets that also include variable amounts of pyrite and chalcopyrite. Wolframite is partially replaced by scheelite, and its composition ranges from ferberite to huanzalaite (a rare Mg-rich endmember with up to 0.55 apfu Mg). The Fe²⁺ content of wolframite is 0.37-0.54 apfu and Nb₂O₅ content 0.15-0.35 wt. %. Scheelite exhibits a standard composition, with Nb as the only distinctive trace element up to 0.10 wt. % Nb₂O₅. It is common to find W in molybdenite related to quartz-wolframite-scheelite-pyrite veinlets, reaching up to 0.4 wt. % W; while Co in pyrite and Bi in chalcopyrite are found more rarely as trace elements, with concentrations up to 0.27 wt. % Co and 0.28 wt. % Bi, respectively.

The presence of Mg-rich wolframite and associated chloritization could be related to extra Mg input from fluids that was leached from amphiboles of the metamafic rock during hydrothermal alteration. Replacement by scheelite could be related to an extra Ca input derived from a potassic alteration when fluids were enriched in Ca due to replacement of plagioclase and calcic amphiboles by K-feldspar in the host rocks.
The Journey of REE from the Tethys Ophiolites to Corinth Gulf, Greece

Efthimios Douros¹, Nikolaos Sofis¹, Margarita Iatrou¹,², Stavros Kalaitzidis¹,*

¹Department of Geology, University of Patras, Rio-Patras Greece
²Institute of Oceanography Hellenic Centre for Marine Research (HCMR).

*Corresponding author: skalait@upatras.gr

Parnassos-Ghiona Unit, located in Central Greece hosts significant bauxite resources and proven reserves, of karstic type. Three main horizons occur, namely b1, b2, b3 that were deposited between Middle Jurassic and Upper Cretaceous times. Nowadays mainly b3 horizon is exploited, b2 has been the subject of mining in the past, whereas b1 was never extracted as it occurs sporadically, with limited quantities and low grade. Diaspore, boehmite and gibbsite are the main Al-minerals of interest, whereas the mineralogical composition frequent includes also hematite, goethite, kaolinite, chlorite, anatase and pyrite.

Although bauxite mining in Greece takes place for almost a century, nowadays the focus shifts towards the REEs that occur either within the bauxite or the bauxite residues (red mud) after metallurgical processes.

In this presentation the features of the various lithologies being involved in bauxite formation and exploitation, i.e. ultramafic and mafic lithologies of the adjacent ophiolites as possible parent formations, and bauxites occurring in the broader area, as well as red mud, the latter being deposited within the Corinth Gulf are presented. Considering the bauxite residues approximately 700-800 tons are produced each year by the local mining companies, and until recent 25 Mt have been deposited in the Corinth Gulf, covering 12% of its total surface area.

The red mud lying on the bottom of the sea is a fine-grained sediment, mainly comprised by silt, with calcite, hematite, quartz, chlorite, kaolinite, mixed-clay layers and REE minerals like monazite comprising the main mineralogical composition.

The main outcome of this ongoing study is to map the distribution of REE in the whole natural (lateritization-BAuxitization) and anthropogenic (metallurgical processes) route.
3D facies mapping, metal zonation and mineralogical variation and alteration at the Rosh Pinah Zn-Pb deposit, Namibia

Halleluya Naantu Ekandjo1,*, John F Güven1, Koen Torremans1, Murray Hitzman1

1SFI Centre of Research in Applied Geoscience (iCRAG), School of Earth Sciences, University College Dublin, Ireland

*Corresponding author: halleluya.ekandjo@icrag-centre.org

The Rosh Pinah Zn-Pb-Ag (Ba) deposit located in southern Namibia is hosted by Neoproterozoic volcano-sedimentary units of the Rosh Pinah Formation (Hilda Subgroup of the Port Nolloth Group), and forms part of the Gariep Terrane. The mine has been in production for over 52 years, yet its metallogenesis remains unclear. Significant volcanic rocks are present in the Rosh Pinah basin near and around the deposit, however, their relationship to mineralisation is not well known. Hydrothermal alteration of the host rocks has been previously recognized at the deposit, however, it has been poorly described and has not been well differentiated from changes in mineralogy that may have occurred due to the low greenschist facies metamorphism that affected the area.

This study will present the paragenetic sequence of mineralisation, alteration and the 3D distribution of these aspects of the deposit. It combines whole-mine scale 3D subsurface data and modelling with detailed petrography, whole-rock geochemical and laser ablation ICP-MS data. The ore occurs as massive, disseminated, fracture and vein filling and as stringers layer-parallel. The footwall to mineralisation is often intensely silicified and brecciated with disseminated and stringer sulfides filling fractures. Strongly folded occasionally overturned sequences and mega-sheath folds, mostly SE trending and facies controls on mineralisation are evident. Careful petrography work suggest the original protoliths for the ore equivalent horizon consisted of carbonates and siltstones and shales now altered, organised in distinct mappable facies bands. The OEH represents a period of relative depositional quiescence between two active arkosic depositional events. This research combines different geological datasets to add to the existing understanding of the genetic model for the deposit useful for continued exploration on the mine and the region.
Mineralogical study of Co-Ni-Fe arsenides and sulfo-arsenides from the F53W deposit related to the southern contact of the Ait Ahmane serpentinite massif (Bou-Azzer El Graara inlier, Central Anti-Atlas, Morocco)

Mohamed Ez-zghoudy1,*, Moha Ikenne1, Mustapha Souhassou2, Ilya R prokopyev3, Said Ilmen4, Lhou Maacha5, Mohamed Zouhair5.

1Lagage, Faculty of Sciences, Ibn Zohr University, BP. 8106, Cité Dakhla Agadir, Morocco.
2Egerne, Polydisciplinary Faculty of Taroudant, Ibn Zohr University, Agadir, Morocco.
3Sobolev Institute of Geology and Mineralogy, Novosibirsk, Russia.
4Ibn Zohr University, Ouarzazate, Morocco
5Managem Group, Twin Center, Casablanca, Morocco.

*Corresponding author: mohamed.ez-zghoudy@edu.uiz.ac.ma

The F53W deposit at Aït Ahmane, located east of the Bou-Azzer district, shows two morphological types of mineralization with notable mineralogical variations depending on the type of mineralization. The chemical composition of the ore minerals determined by electron microprobe (EMPA) at Novosibirsk State University, Russia.

The results of analysis show that massive contact mineralization hosted in quartz-calcite lenses with chlorite located in the N120 contact between serpentinized ultrabasic rocks and quartz diorites or gabbros is characterized by the presence of Ni and Co mono-arsenides (nickeline, langisite, modderite) di-arsenides of Co-Fe Ni (safflorite, löllingite and rammelsbergite) with a dominance of löllingite, tri-arsenides of Co (skutterudite, ferroskutterudite) with abundant skutterudite and Ni-Co-Fe sulfo-arsenides marked by a dominance of gersdorffite and arsenopyrite with low values of cobaltite, alloclasite, westerveldite and glaucodot. Sulphides of Cu, Pb, Zn and Mo (chalcopyrite, bornite, galena, sphalerite and molybdenite) and bismuth are later than the Co-Ni-Fe arsenides.

The banded-texture vein-type mineralization hosted in chlorite-quartz-carbonate veins oriented N00 to N40 intersects the quartz diorite and gabbros, and is characterized by the presence of Co mono-arsenides (modderite) Co-Fe di-arsenides (safflorite and löllingite) marked by a dominance of safflorite, Co tri-arsenides (skutterudite and ferroskutterudite) with an abundance of ferroskutterudite and Co and Fe sulpho-arsenides marked by a dominance of cobaltite with low values of alloclasite and westerveldite. Late Cu, Pb, Zn sulfides (chalcocite, galena and sphalerite) are less abundant in this case.

From the analytical results, we concluded that in the F53W vein mineralization deposit of Aït Ahmane, the Ni and Fe arsenide minerals (nickeline, rammelsbergite, gersdorffite and arsenopyrite) and native elements (Bismuth) are absent probably due to Ni mobilization as well as skutterudite and safflorite varieties of vein mineralization, poor in Fe and Ni indicating low Fe and Ni contents in this type of mineralization.
Magmatic diversity and metallogenic implications in the Southeastern part of Kedougou-Kenieba Inlier, Senegal

Cheikh Ibrahima Faye¹,²,*, Ndiaye Abdoul Aziz¹, Dia Ibrahima³, Diene Mahamadane¹, Gueye Mamadou¹, Grosjean Marion², Ulianov Alexey⁴, Chiaradia Massimo³, Moritz Robert²

¹Institut des Sciences de la Terre, Université Cheikh Anta Diop, BP 5396, Dakar-Fann, Senegal
²Department of Earth Sciences, University of Geneva, rue des Maraîchers 13, CH-1205 Geneva, Switzerland
³Ecole Supérieure des Mines, de la Géologie et de l'Environnement, Université Amadou Mahtar Mbow, BP 45 927 Dakar Nafâ YDN Dakar-Senegal
⁴Institute of Geological Sciences, Lausanne, Switzerland

*Corresponding author: cheikhibrahima3.faye@ucad.edu.sn

The Dialé-Daléma and Falémé Series have been intruded during the Paleoproterozoic by two main intrusions:

i) the Boboti Suite which intrudes the calc-alkaline andesitic and sedimentary rocks of the Falémé Series between 2120 and 2080 Ma and (ii) the Saraya Suite which intrudes the Dialé-Daléma Series between 2080 and 1975 Ma.

These two magmatic Suites display different geochemical characteristics as e.g., the Saraya Suite show depletion of HREE and negative Eu anomalies (Eu/Eu*= 0.52 – 0.82), high (La/Yb) N (32.56 – 34.61), high Rb/Sr ratio and (Dy/Yb) N values ranging from 2.37 to 1.53, high SiO₂ contents (average 72.03%); depletion in MgO (0.35% on average) and enrichment of Ba, Sr. On the other hand, the Boboti Suite and its andesitic host rocks are characterized by moderate (La/Yb) N values (7.26 - 21.43) and low (Dy/Yb) N ratio ranging from 1 to 1.5, with almost no negative Eu anomaly, an average SiO₂ content of 61.54%, an enrichment in MgO (average 3.80%) and in elements such as Y, Ni, Cr and Nb, which reflects a deep source probably with contribution of mantle materials which is reflected by the high Ni content (up to 211 ppm) noted on these rocks.

Furthermore, the depletion of Nb, Ta and Ti anomalies as well as the enrichment of LILE elements such as K, Rb, Ba for both the Boboti and Saraya Suites are typical of subduction zones. The fusion of subducted juvenile oceanic wedge having interacted with the mantle, yield rocks of adakitic type in the Falémé Series enriched in Au, Fe, Ni, Nb-Ta. The Saraya Suite would be derived from a more evolved magma at around 2075 Ma with contamination of crustal materials and fractional crystallization giving local concentrations of lithophile elements such as U, Sn, W, Li associated with greisen, pegmatite and fracture zones.
Gold mineralization associated with the granitic complex of Boboti (West African Craton)

Cheikh Ibrahima Faye$^{1,2,*}$, Gueye Mamadou$^1$, Moritz Robert$^2$

$^1$Earth Sciences Institut, University C.A.D of Dakar, Senegal
$^2$Dep. Earth and Environmental Sciences, University of Geneva, Switzerland

*Corresponding author: cheikhibrahima3.faye@ucad.edu.sn

We demonstrate that, the western part of the Senegal Mali Shear Zone (SMSZ), which corresponds to the FVPB, is characterized by a succession of dome and basin structures. The domal structures consist of fertile granitoids (diorite, granodiorite) with a brittle-ductile deformation regime.

The gold ore bodies are controlled by shear zones with opposing senses of shear (sinistral and dextral kinematics) which resulted in local zones of extension and brecciation favorable for hydrothermal mineral deposition within and around magmatic intrusions.

By contrast, in the adjacent Kofi series of the eastern part of the SMSZ, the gold ore bodies are mainly controlled by the main SMSZ and its secondary structures, where sedimentary rocks (turbidite sequences and sandstone) mostly host the gold ores.

Thus, the geophysical, geological, geochemical, and structural studies show that the Falémé volcano-plutonic belt is a very prospective area.

For future work it would be appropriate to study in detail the petrographic nature of the different units of the intrusion complex and the host rocks through detailed isotopic and geochronological analyzes and also fluid inclusions studies, in order to determine the exact nature of the mineralized fluid and its formation conditions.
Sericite $^{40}\text{Ar}/^{39}\text{Ar}$ ages constraints on lode gold and porphyry-hosted gold mineralization of the Yixingzhai gold deposit in Taihangshan District, North China Craton

Wen-Sheng Gao$^{1,2,3,\ast}$, Xiao-Dong Deng$^1$, Cyril Chelle-Michou$^3$, Li-Zhong Zhang$^{1,2,4}$, Jian-Wei Li$^{1,2}$

$^1$State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan 430074, China.
$^2$School of Earth Resources, China University of Geosciences, Wuhan 430074, China.
$^3$Department of Earth Sciences, Eidgenössische Technische Hochschule (ETH) Zurich, Zürich 8092, Switzerland.
$^4$Zijin Mining Group Co Mineral Exploration Institute, Xiamen 361006, China.

*Corresponding author: wensheng.gao@erdw.ethz.ch

The Yixingzhai deposit is one of the largest gold deposits in the Taihangshan district, North China Craton. This deposit consists of four types of gold mineralization: skarn breccia-hosted gold, porphyry molybdenum, lode gold (36 t @ 6.71 g/t Au), and porphyry-hosted gold mineralization (54.7 t @ 2.12 g/t Au). However, the ages of the lode gold and porphyry-hosted gold mineralization which are the dominant components of the Yixingzhai deposit, are unknown, limiting our understanding of the ore genesis. Sericitic alteration is widely developed in lode gold and porphyry-hosted gold mineralization of the Yixingzhai deposit. Petrographic and mineralogical observations show that sericite is closely intergrown with native gold, pyrite, and quartz, indicating sericite is related to lode gold and porphyry-hosted gold mineralization. In this study, two sericite samples collected from the lode gold and porphyry-hosted gold ores have been used for $^{40}\text{Ar}/^{39}\text{Ar}$ analysis, and yielded $^{40}\text{Ar}/^{39}\text{Ar}$ plateau dates of $138.9 \pm 1.4$ Ma (2σ) and $139.2 \pm 1.4$ Ma (2σ), respectively. These $^{40}\text{Ar}/^{39}\text{Ar}$ dates can be interpreted as the timing of lode gold and porphyry-hosted gold mineralization, which are consistent with the previous garnet U-Pb date ($140 \pm 2$ Ma) of the breccia-hosted gold mineralization and the molybdenite Re-Os date ($141 \pm 4$ Ma) of the porphyry molybdenum mineralization. In addition, these dates are consistent with the published zircon U-Pb dates of quartz porphyry and granite porphyry intrusions (c.a. 140 Ma) in the Yixingzhai deposit. Consequently, field relationships and geochronological results demonstrate a close temporal and genetic relationship between gold mineralization and magmatism of the Yixingzhai deposit, highlighting the magmatic-hydrothermal origin of the gold deposits in the Taihangshan district. Further, high-precision geochronology will clarify the time span in between these two main gold-mineralization events at Yixingzhai.
Cation exchange and ore-forming potential in Cl-bearing upper-crustal magmatic-hydrothermal systems

Ivano Gennaro¹*, Alexandra Tsay¹, Zoltan Zajacz¹

¹Département de Sciences de la Terre, Université de Genève, Rue des Maraîchers 13, 1205 Genève

*Corresponding Author: ivano.gennaro@unige.ch

Magmatic-hydrothermal fluids play a major role in transporting metals and metal-carrying ligands from metal source to sink – they are crucial to the formation of porphyry and other magmatic-hydrothermal ore deposits. These fluids carry a wide range of chlorine species, predominantly NaCl, KCl, FeCl₂, and HCl, along with chlorine complexes of various ore metals such as Cu, Ag, and Au. With Cl being such an important metal-carrying ligand, understanding the speciation and fluid-melt exchange of elements in chlorine-rich systems is paramount to creating accurate models of magmatic-hydrothermal ore genesis. Despite this importance, fluid-melt exchange, especially with respect to major elements, remains an understudied field. To this end, a series of high-pressure–high-temperature experiments were performed to constrain the relative ratios of major element cations in a fluid equilibrated with a rhyolitic melt at upper crustal conditions and various chlorine concentrations. The experiments also focused on the fluid-melt partitioning of common ore metals in porphyry systems, namely Cu, Mo, Ag, and Au. Preliminary results reveal increasing K and Fe in the fluid phase, relative to Na, with increasing silicate melt peraluminosity; Ca does not follow this trend. Results also show increasing HCl concentrations in the fluid with increasing ASI (aluminum saturation index), a trend which has been noted in the past but can now be better quantified. There are no discernible trends relating chlorinity to major element fluid-melt exchange, however further experiments are underway to test a wider range of Cl concentrations. As for ore metal partitioning, all metals studied show increased partitioning into the fluid phase as a function of Cl concentration, yet negligible or decreasing trends with increasing melt ASI. Copper shows the strongest trend in both cases. Further experiments are underway to continue probing the effects of ASI and Cl-content on major element and ore metal fluid-melt partitioning.
Petrological investigations of Panjal Dykes from Northern Indian Plate North-west Pakistan

Abdul Ghaffar¹,*

¹Jagiellonian university Krakow, Poland.

*Corresponding author: abdul.ghaffar@doctoral.uj.edu.pl

The late Lower to Middle Permian Panjal Traps (NW Himalaya, India-Pakistan) represent the greatest magmatic province erupted on the northern Indian platform during the Neotethys opening. The geochemical and isotopic analyses will be performed on basaltic dykes from the Kashmir-Mansehra-Khyber areas of North-west Pakistan in order to characterize this volcanism, to discuss its compositional variations in comparison to Panjal counterparts and its relationships with the opening of Neotethys.
Metal mobilizing processes in the actively forming seafloor massive sulfide in the Kolumbo volcano: basement leaching or magmatic input?

Simon Hector¹*, C. G. C. Patten¹, Stephanos. P. Kilias², Paraskevi. Nomikou², Jochen Kolb¹

¹Institute for Applied Geosciences, Geochemistry and Economic Geology, KIT, Karlsruhe, Germany
²National and Kapodistrian University of Athens, Athens, Greece

*Corresponding author: simon.hector@kit.edu

Kolumbo is a shallow, submarine arc-volcano, located in the Aegean volcanic arc in Greece. It hosts an active hydrothermal system currently forming polymetallic massive sulfides on the seafloor (SMS) with anomalously high As, Ag, Au, Hg, Sb and Tl contents. It is one of the few known SMS deposit associated with continental margin volcanism.

The Kolumbo hydrothermal system represents an active analogue of hybrid epithermal-VMS mineralization. The particular geological setting of the Kolumbo volcano in the Anydros basin makes it an excellent natural laboratory to investigate the metal flux and potential source rocks as the underlying units crop out on the neighboring islands of Santorini, Ios and Anafi.

The sources of metals and processes mobilizing them into the hydrothermal system are yet not clearly identified. The basement rocks can bring metals into the system, either by leaching by magmatic-hydrothermal fluids or by contamination of the melt by assimilation. The magma can release metals during magmatic degassing.

Whole rock geochemistry of the basement and volcanic rocks allows to identify the potential metal reservoirs in the system. Constraining the metal reservoirs involved in magmatic-hydrothermal systems is crucial for understanding the formation of SMS and variability in the metal endowment between the deposits.

In this case, it appears that the basement and volcanic units are fertile for base metals and As, Pb and Tl and can provide these metals via leaching while Au, Ag and Sb are likely provided by magmatic fluids.
Three-dimensional modelling of the copper-silver ore deposit in the Legnica- Głogów Copper District

Maciej Jeż\textsuperscript{1,*}

\textsuperscript{1}Institute of Geological Sciences, Polish Academy of Sciences, Cracow, Poland

*Corresponding author: ndjez@cyfronet.pl

Stratoid copper deposits of the Fore-Sudetic Homocline in SW Poland are related to the post-Variscan tectonic evolution of the Permian-Mesozoic Basin. Based on borehole and subsurface mining data, a structural 3-D model was created using Datamine Studio RM software to mitigate water and gas hazards in the Cu-Ag deposit. Measurements of faults and flexures jointly with the analysis of thickness pattern allowed for identification of the migration paths for hydrogen sulphide and hydrocarbons, and recognising a source of gas emanations. Besides distribution of structural and stratigraphic conduits, the circulation of fluids and gases are influenced by the overlying rock salt with a sealing effect.
Garnet group minerals from selected localities of granitic pegmatites in the Moldanubicum unit, Bohemian Massif, Czech republic

Jan Kamenský¹,*

¹Institute of Geochemistry, Mineralogy and Mineral Resources, Charles University, Czech republic

*Corresponding author: jan.kamensky@natur.cuni.cz

This thesis deals with the issue of garnets from selected localities of granitic pegmatites in the Moldanubian unit, Czech republic. The aim of this thesis was to use analytical methods and field observations to document the occurrence of garnets in two geographically and geologically different localities.

The first studied garnets are from pegmatite near the village of Strážek (region Vysočina, district Žďár nad Sázavou, Czech republic) and the second is from pegmatite near Přibyslavice (Central Bohemian Region, district Kutná Hora, Czech republic).

Pegmatite near Strážek forms a zonal body enclosed in the pararules of the Strážek Moldanubian (Kupská 2015). The chemistry of garnets is around the boundary almandine47-67-spessartine29-53. The results were compared with the diploma thesis of H. Kupská. One of the garnet grains also contains inclusions of barite, oxides and hydroxides of Fe and Mn.

The studied garnets from the Přibyslavice locality come from the contact of aplite and pegmatite. The measured garnet grain shows a predominance of the almandine component and corresponds to the chemical composition of almandine64-78-spessartine14-34. These results from an electron microscope were compared with a representative analysis by R. Nováček.

The inclusions inside the grain of the Strážek garnet prove that the local pegmatite was affected during development by the action of hydrothermal solutions and supergene processes. A number of pegmatite garnets near Přibyslavice were also affected by metasomatosis, in which the original garnets were replaced by quartz, K-feldspar and muscovite.

Even though garnets occur in pegmatites mostly as accessory minerals, they provide extremely valuable information about the nature of the pegmatite melt and the processes that take place during pegmatite development.
New scheelite occurrence in the Ore Mountains, Czech Republic

Jiří Klepp¹,*

¹Institute of Geochemistry, Mineralogy and Mineral Resources, Charles University, Prague, Czech Republic

*Corresponding author: kleppj@natur.cuni.cz

This study aims to the newly discovered occurrence of scheelite (CaWO₄), near the city of Volyně in the central part of the Ore Mountains (Czech Republic). Recently, the scheelite mineralization was detected in heavy mineral concentrates from local streams sediments but has never been found in situ. During fieldwork in 2018 focused on the old mining areas, scheelite-bearing vein has been founded. The vein is developed in the metamorphic rocks of Přísečnice’s group which consist dominantly of double mica paragneiss with positions of quartzite gneisses, mica-schist's paragneiss and orthogneiss.

Based on the field observations and measurements, it has been estimated that the vein is approximately 20 – 50 cm thick and 230 m long. The beginning of the vein is located about 50 meters north-east of the asphalt road on a hillside with a slope 20°, then the hillside continues, and slope is 40°. The vein is located on the left side of the road that leads to the largest former quarry of limestone (the distance between the quarry and the vein is ca. 230 m).

The vein is mainly formed by quartz in association with fluorite and both idiomorphic scheelite grains and microcrystalline aggregates. Nevertheless, according to our preliminary findings, the surface zone of the vein is highly altered, which might be documented by fluorite (CaF₂) decomposition and the formation of secondary Fe-(oxohydr)oxides.

The local scheelite's crystals are in the tetragonal crystal system, appearing as dipyramidal pseudo-octahedra. Scheelite fluoresces under shortwave ultraviolet light, the mineral glows a bright sky-blue. The size of the crystals ranges from 1 to 3 mm.

Currently the locality is becoming popular site for amateur mineral collectors that are unfortunately causing the irretrievable damage to this historical site. Therefore, further investigation is certainly needed in order to be able to decipher the conditions of this mineralization formation.
Exploring the use of titanite as a porphyry indicator mineral: discrimination of primary igneous and replacement titanite in a giant porphyry Cu district

Thomas J. Matthews\textsuperscript{1,2,*}, Jamie J. Wilkinson\textsuperscript{1,2}, Matthew A. Loader\textsuperscript{2}, Tim Ireland\textsuperscript{3}, Yannick Buret\textsuperscript{2}, Will Brownscombe\textsuperscript{2}, John Spratt\textsuperscript{2}, Juan Burlando\textsuperscript{3}

\textsuperscript{1}Imperial College London  
\textsuperscript{2}Natural History Museum  
\textsuperscript{3}First Quantum Minerals

*Corresponding author: t.matthews18@imperial.ac.uk

Porphyry copper deposits provide a substantial contribution to the global supply of metals, sourcing much of the planet’s copper, as well as gold and molybdenum. Despite projected rises in copper demand associated with the green energy transition, new deposits are becoming increasingly difficult to locate. As a result, new exploration technologies, such as mineral chemical indicators, are being increasingly employed. Of particular use to exploration are mineral indicators that can be used to assess magma fertility (e.g. were magmas suitably wet, oxidised, volatile-rich etc.) or identify porphyry-associated alteration. Application of titanite, however, is relatively uncommon; despite its variable trace element composition and occurrence in both fresh igneous and hydrothermally altered parts of the porphyry system.

This study utilises samples from the giant Cobre Panama porphyry Cu-Mo-(Au) district, where mineralisation is associated with a series early-Oligocene stocks and dykes of dioritic to granodioritic composition. Detailed petrographic study identified two major types of titanite: primary igneous and replacement (propylitic). Textural data were subsequently combined with titanite major and trace element, as well as whole-rock chemistry, to discriminate between igneous and replacement titanite. We show that igneous titanite is characterized by high Fe/Al ratios, REE, Zr and Mn concentrations, whereas F and Sc are enriched in replacement titanite. These distinctions can be explained by differences in mineral-melt partitioning, mobility in hydrothermal fluids, or by inheritance from precursor igneous minerals. Furthermore, REE signatures of igneous titanite reflect the ‘fertile’ whole-rock signature, with discrepancies in MREEs possibly indicating that significant fractionation of amphibole has occurred prior to titanite saturation. Our study highlights the potential utility of titanite, a resistate mineral that is commonly found in stream sediments, in detecting fertile magmas and hydrothermal alteration.
Environmental and societal impacts of mining in Cameroon: case of far north and east region

Bidjo Mbonomo Mike Vianney¹,*

¹National Advanced School of Mine and Petroleum Industries, University of Maroua, Kaele, Cameroon.

*Corresponding author: mikebidjo@gmail.com

The desire for many countries like Cameroon to move from predominantly artisanal mining to modern mining with positive impact is constrained by the implementation of decentralization policies. The studies carried out during the academic field trips to the former Mobono aggregate quarry and Kambele artisanal gold mining have demonstrated the gap between mining policies in terms of local content and the consequences observed on the populations and their environment. A paradigm shift and better use of resources are needed to reduce the negative impact and maximize local content in the mining industry and with the implementation of decentralization policies to develop the local mining environment, the far north and east region. To this end, the acceleration of the procedures and transfer of competences to the local territorial collectivities as for their powers of sanction and control in order to reduce the pollutions on the environment. The aim is to decarbonize mining operations and accelerate local development by using decentralization policies adapted to each municipality in order to facilitate the process of creating local businesses, defending local interests and post-mining operation. However, the positive impact of mining in these areas is hampered by the corruption of leaders, the limited means of law enforcement generally far from being as close as possible to the real situation, the ignorance of populations about their rights and the tools for developing resources close to them and complaint procedures. The development of the environmental mining sector requires the existence of a political and regulatory framework specific to each region facilitating the deployment of state institutions and management bodies promotion of local interests.
Late Ediacaran Cu–Ag epithermal deposits of the Tizi n’Oussatour district, Eastern Anti-Atlas, Morocco: mineralogy and lithostratigraphy

Ousbib Mehdi¹*, Charroud Mohammed², Essalhi Mourad³, Qalbi Abderrahim⁴

¹ Ibn Zohr University, Faculty of Sciences, Agadir, Morocco
² Sidi Mohamed Ben Abdellah University, Faculty of Science and Technology, Fez, Morocco
³ Moulay Ismail University, Faculty of Sciences and Techniques, Errachidia, Morocco
⁴ ONHYM, Rabat, Morocco

*Corresponding author: Ousbib.mehdi@gmail.com

The Tizi n’Oussatour ore deposit represents a high-grade strata-bound, vein-type silver accumulation, located in the Moroccan eastern Anti-Atlas Mountains. It is hosted by the Upper Proterozoic defined by ash-flow caldera emplacements, thick and widespread ignimbrites, lavas, and volcanioclastic sedimentary rocks. The ore mineralogy consists principally of Bornite, covellite, stephanite, native copper, cuivre natif, arsenopyrite, pyrite, sphalerite, and galena. Gangue constituents are dominated by calcite, dolomite, quartz. Ore-related hydrothermal alteration includes, in order of decreasing abundance, carbonatization, silicification, sericitization, and chloritization. Field relationships indicate that the economic mineral concentrations are epigenetic, and that the deposit is polygenetic.

Three periods of magmatic activity have been recognized. The andesitic flows represent the first recognized volcanic period in this area. The second period comprises dacitic to rhyodacitic flows, intercalated with epiclastic deposits, indicating a temporary volcanic activity cessation. The third volcanic event consists of felsic emissions marked by the establishment of rhyolitic lavas, a thick succession of welded ignimbrites and dykes of both felsic and mafic compositions. These volcanic edifices consist of two generations of volcano-tectonic faults oriented N90 and N180. They have probably guided volcanism as evidenced by the spatial relationship between these faults, the volcanic edifices, and the mineralization. The volcano-tectonic activity seems to be related to a Late Neoproterozoic regional crustal extension. These tectonic faults were most probably reworked later during the Hercynian events. Hydrothermal transformation is particularly restricted in the crossings of N–S and E–W faults. The local thermal hydrothermalism probably resulted from the Bou Gafer granitic intrusion at the north.
Emplacement of the Yerington batholith and associated porphyry dikes, Nevada, USA: a conciliation challenge between field observations and high precision zircon petrochronology

Maria Paula Castellanos Melendez$^{1,*}$, John Dilles$^2$, Cyril Chelle-Michou$^1$

$^1$Institute of Geochemistry and Petrology, Department of Earth Sciences, ETH Zurich, Clausiusstrasse 25, CH-8092, Zurich, Switzerland
$^2$College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, USA

In porphyry copper deposits, where ore grades are low, the volume of the ore body is key to determine its economic potential. Yet, the factors that control the deposit size are still an open question, crucial for finding large porphyry copper deposits (PCDs). One of the highly debated size-modulating factors, time, could control whether a magmatic system forms a small or large PCD. While the generally limited access to the plutonic roots of PCDs hinders our ability to study the systems as a whole, Cenozoic tilting of the Yerington district (Nevada, USA) enabled us to study the Yerington batholith and associated volcanic sequences, porphyritic dikes and Cu mineralized centers. The ideally exposed complex upper-crustal batholith is comprised of three consecutive plutons that with time increase in silica content, granulometry and depth of emplacement while decreasing in volume. Field observations show sharp intrusive contacts between the three plutons, interpreted as periods of magmatic quiescence between the three intrusions, overall accounting for about 1 Ma of magmatic activity. Our new high-precision zircon U-Pb ID-TIMS ages, in contrast, demonstrate that the Yerington batholith crystallized over a period of more than 2 Ma. The data show a continuum in zircon crystallization ages from the McLeod quartz monzodiorite and coeval Artesia Lake Volcanics to the Luhr Hill granite and porphyritic dikes without any hiatus. Zircon trace element composition further indicate a continuous geochemical evolution with time that follows normal fractional crystallization trends. These data argue for a sustained crystallization of a single or series of magmas to produce the three main plutonic bodies. Our new lifetime of the magmatic system changes the previously defined thermal models for the Yerington district, affects how we assess its mineralizing potential and challenges the current understanding and application of zircon petrochronology in porphyry copper systems.
Pegmatites from the Pb-Zn deposits in South Bulgaria as potential source for strategic elements

Georgi Milenkov¹*, Yana Georgieva², Rossitsa Vassileva¹, Sylvina Georgieva¹

¹Geological Institute, Bulgarian Academy of Sciences, Bulgaria
²Sofia University “St. Kl. Ohridsky”, Faculty of Geography and Geology, Bulgaria

*Corresponding author: joro.milenkov@abv.bg

Pegmatite bodies with various thickness and position are emplaced in the high grade metamorphic rocks of the Rhodopean massif in south Bulgaria. They are major constituent of the wall rocks in the vein and metasomatic Pb-Zn deposits in the central Rhodopes. Samples from deposits in Madan (Petrovitsa and Kroushev Dol) and Laki districts (Djourkovo and Govedarnika) are studied. Different analytical procedures are used in attempt to determine pegmatite’s mineral and chemical composition and estimate their potential as a source for strategic elements.

The pegmatites have NYF- or mixed type geochemical characteristics. An intensive hydrothermal alteration affected the primary mineral composition (K-feldspars, plagioclases and quartz) generally along the lithological contacts, resulting in formation of secondary epidotes, chlorites, sericite, adularia, carbonates and clays. Part of the primary titanite crystals are transformed to leucoxene. Formation of hydrothermal titanite is widespread. Variety of accessory minerals, known as concentrators of important elements are an integral part of the studied pegmatites. Allanite, titanite, zircon and apatite are presented in almost all studied samples, while monazite, rutile and thorite are sporadic. Large amounts of REE, Ti, V, Nb, Ga, Th, U, Cr, P, Hf, Zr and other critical elements are important constituents of the pegmatite minerals. Significant incorporation of Ce and La is characteristic for allanite, together with high concentration of other REE, Th, Cr, Y, Ga, Ge, V. Magmatic titanites are enriched in REE, Th, V, Zr, Ga, compared to hydrothermal ones, where Y, Nb and Cr are typical. Apatite reveals increased values of LREE, Y and Sr. The latter is abundant in the feldspars as well. Despite the insignificant quantity in the rock volume, the accessory minerals in the studied pegmatites suggest promising perspectives, based on their large REE concentrations.
Remote sensing results of Gudjareti-Khachkovi Ore Field. Adjara-Trialeti Folded Zone, Lesser Caucasus (Georgia)

Giorgi Mindiashvili

This project consists of interpretations of more than 40 data obtained by remote sensing analyses and techniques in order to detect geological features and potential of probable Gudjareti-Khachkovi ore fields in the area located in South-East Georgia (Adjara-Trialeti folded zone, Lesser Caucasus) using Terra ASTER Multispectral satellite data.

The area is quite intensive in terms of vegetation, snow, glacier and cloudiness. Therefore, the best satellite data among all ASTER images have been ordered that could represent the area the best way and which has the least snow and cloud cover. The acquisition date of the satellite data is 24.08.2012. It is noticeable that although the time of acquisition is autumn season, excess snow covers still remain on mountain tops. During these analyses VNIR, SWIR and TIR spectral bands have been used. Wavelength intervals of these bands are especially useful in the determination of alteration minerals. ASTER SWIR bands have been used during mapping of acidic alteration minerals such as: alunite, kaolinite, Phyllis, alteration minerals such as: sericite and muscovite. ASTER SWIR bands have been studied to determine alteration zones of minerals by applying the band rationing technique and potential areas where ore metallic minerals appear.

It should be noted that the study was conducted for the first time in the study area by remote sensing method. Obviously, hydrothermal alterations and mineralization types cannot fully reflect the current geological processes of the study area, but as conducted works show, ore mineralization processes are genetically related to the magmatic activities of the region. Using the remote sensing method, hydrothermally altered zones were distinguished and the areas of geochemical anomalies were contoured. The data obtained by this method literally repeat the contours of the existing ore manifestations. It is important that several new substantial ore manifestations were revealed by this method.
Development of new methods to track magma degassing and fluid fluxing in complex magmatic systems: The study of heavy halogens

Mara Miranda¹*, Zoltan Zajacz¹

¹University of Geneva – Department of Earth Sciences

*Corresponding author: mara.miranda@unige.ch

Magma degassing and fluid fluxing within trans-crustal magma reservoirs play an important role in the transport of volatiles and ore metals. Tracking the migration of magmatic fluids within this system is challenging, and important for the understanding of magmatic-hydrothermal ore genesis.

We aim to develop new tools to trace fluid migration between various parts of the trans-crustal magma reservoir system in arc magmatic settings, to assess the extent of degassing in intermediate and evolved magmas. To develop this new method, we are studying the fluid/melt partition coefficient \( D_{f/m} \) of heavy halogens such as bromine and iodine as a function of melt composition, pressure, and fluid salinity.

Few studies have shown the increase of the \( D_{f/m} \) with increasing radius of the halogenide ion, indicating the potential usefulness of halogen ratios for our purpose. The new partition coefficient data could be applied together with halogen concentrations measured in silicate melt inclusions in natural systems to allow researchers to track magma degassing and fluid fluxing.

The experiments realized were conducted at 785°C and 150 to 800 MPa. We used a peralkaline, metaluminous, and peraluminous haplogranitic starting glass and starting fluids with 7 different salinities. The experiments were performed in externally heated René 41 and Molybdenum-Hafnium Carbide (MHC) pressure vessels between 150 and 300 MPa. An end-loaded piston-cylinder apparatus was used for higher-pressure experiments.

Halogen concentrations in the run product glasses were determined by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the University of Geneva. The \( D_{f/m}^{\text{halogens}} \) increases with fluid salinity and with increasing ionic radius. Halogens partition less strongly into the fluid from peralkaline melts than from metaluminous and peraluminous melts. Moreover, \( D_{f/m}^{\text{halogens}} \) shows a clear relation between fluid salinity and pressure. For high salinity fluids, \( D_{f/m}^{\text{halogens}} \) decreases with increasing pressure, whereas \( D_{f/m}^{\text{halogens}} \) increases with increasing pressure for low salinity fluids.
How efficient are mineral trace-element signatures to target ore deposits and unravel their parageneses?

Loïs Monnier1*, Stefano Salvi1

1GET, CNRS/IRD/UPS Toulouse University, 14 avenue Edouard Belin, 31400 Toulouse, France

*Corresponding author: loismonnier@yahoo.fr

In this contribution, we re-evaluate the interest of characterizing the chemical signature of different gangue minerals in order to pinpoint tomorrow's deposits. Based on our own work and review of recent literature, we focus our discussion on magmatic-hydrothermal settings, using the LA-ICP-MS method. We also show how implementation of multivariate statistical analysis can help distil the greatest amount of information. The final objective is to provide indications on the most promising minerals according to the type of deposit and metal(s) targeted. A few examples include:

• Barren quartz veins are probably the most distal potential indicator of mineralization. Anomalous concentrations of Sb, and, though less well constrained, Li and Rb in quartz have been used as successful vectors to mineralizations.

• Minerals such as micas, pyrite, zircon, amphibole etc. can incorporate a wide variety of elements to important concentrations, providing a direct marker of mineralization. Conversely, during dissolution, these minerals may release important stocks of metals, which can be incorporated by fluids to form distal deposits.

• Recently, tourmaline chemistry has received a lot of attention. These data are widely used to provide insights on geological processes, but turned out to only have limited applications for exploration at best.

Of course, combining several of these indicators could strongly improve our capacity to target and constrain a mineralization process (e.g., quartz and micas from greisen deposit; quartz and pyrite for porphyry/epithermal systems; tourmaline, mica and rutile for stockwork). As a practical guide, here is a non-exhaustive list linking what we consider the best candidates as vectors to specific metals: Pyrite for Cu-Au; quartz for Sb; micas and tourmaline for Sn; micas for W and Nb-Ta; rutile and goethite for W; zircon, amphibole and pyroxene for REE (silicate melts); apatite and calcite for REE (carbonatites).
Zircon and pyrochlore record opposite light and heavy REE behaviors during the magmatic-hydrothermal evolution of the Evisa peralkaline pluton, Corsica, France.

Loïs Monnier1,*, Stefano Salvi1, Cyrielle Bernard1, Guillaume Estrade1, Camille Dusséaux2, Laurent Truche2, Mathieu Leisen1, Philippe de Parseval1, Oscar Laurent1

1 GET, CNRS/IRD/UPS Toulouse University, 14 avenue Edouard Belin, 31400 Toulouse, France
2 ISTerre, CNRS, Grenoble Alpes university, 1381 rue de la Piscine, 38610 Gières, France

*Contact author: loismonnier@yahoo.fr

The Evisa peralkaline pluton is characterized by a REE enrichment of several orders of magnitude higher than chondrite. Such concentrations result from a combined process involving magmatic fractionation and hydrothermal remobilization. Zircon and pyrochlore can be important hosts of REE in peralkaline granites and alkaline systems in general. At Evisa, these minerals crystallized throughout the entire evolution of the pluton, i.e., from the early magmatic stage to the late hydrothermal alteration. Interestingly, both minerals form several generations which display drastic changes in texture and chemistry through these stages, providing a unique opportunity to monitor REE evolution during cooling of the granite.

Magmatic zircon commonly contains several wt% oxide of Y, HREE, U and Th. During alteration, the zircon crystals are partially reset, which results in leaching and remobilization of most of these elements. Hydrothermal zircon, in general, contains much lower amounts of all these elements, although some crystals may still host significant Y and HREE. Contrarily to magmatic zircon, coeval igneous pyrochlore incorporates only LREE, at concentrations of ~ 10 wt% oxide, while HREE are below detection levels. As with the zircon generations, igneous pyrochlore undergoes important dissolution or replacement by hydrothermal pyrochlore. Surprisingly, in this generation the REE display an opposite trend compared to the magmatic ones, i.e., HREE strongly fractionate in the pyrochlore, to levels of ~ 10 wt% oxide, while LREE are missing.

In light of the above features, we suggest a mechanism during which LREE and HREE are exchanged among various minerals during the magmatic/hydrothermal transition: HREE from magmatic zircon are incorporated in hydrothermal pyrochlore, while the LREE removed from igneous pyrochlore go to form late-crystallizing LREE-rich phases such as monazite and bastnaesite.
Apatite evidence for a fluid-saturated crystal mush beneath porphyry copper deposits

Chetan Nathwani1,2,*, Simon Large1, Jamie Wilkinson1,2, Yannick Buret1, John Spratt1, EIMF3

1London Centre for Ore Deposits and Exploration (LODE), Department of Earth Sciences, Natural History Museum, Cromwell Road, South Kensington, London SW7 5BD, UK
2Department of Earth Science and Engineering, Imperial College London, Exhibition Road, South Kensington Campus, London SW7 2AZ, UK
3Edinburgh Ion Micro-Probe Facility, Grant Institute, School of GeoSciences, University of Edinburgh, James Hutton Road, Edinburgh EH9 3FE, UK

*Corresponding author: chetan.nathwani14@imperial.ac.uk

Porphyry Cu deposits are the product of the efficient degassing of Cu-charged fluids from upper crustal magma reservoirs. It has been widely shown that the critical ingredients to form a porphyry Cu deposits (e.g. Cu, Cl and S) are all sourced from the underlying magmatic system. Due to the pervasive hydrothermal alteration in porphyry Cu rocks, the magmatic record of volatile evolution is rarely preserved. Therefore, the transfer and style of volatile transfer between magmas and fluids in porphyry Cu systems remains poorly constrained.

Here, we present electron microprobe and secondary ion mass spectrometry analysis of apatite inclusions in zircon from the Quellaveco porphyry copper district, Southern Peru. We show that apatite inclusions in zircon capture the magmatic volatile record of the underlying magmatic system, as opposed to groundmass apatites which are hydrothermally altered. The apatite inclusions from the porphyry copper deposit exhibit inherently low Cl/OH and low F/Cl relative to the pre-mineralisation batholith.

We use a thermodynamic approach to apatite/melt F-Cl-OH partitioning in tandem with numerical modelling of magma degassing to show that the magma reservoir was fluid saturated for the entirety of Cu mineralisation at Quellaveco. Our modelling suggests the magma reservoir was crystal-rich and felsic which favoured the efficient extraction of Cl and Cu from the magma which could rapidly accumulate and outgas to form a porphyry copper deposit. Our contribution highlights the importance of long-lived crystal-rich magma reservoirs in forming world-class porphyry copper deposits.
Shear hosted gold mineralization in Central Anatolian Metamorphic Massifs

Kaan Onat\textsuperscript{1,}\textsuperscript{*}, Nuretdin Kaymakç\textsuperscript{1}, Ilkay Kuşcu\textsuperscript{2}

\textsuperscript{1}Middle East Technical University, Department of Geological Engineering, 06800, Ankara, Turkey
\textsuperscript{2}Muğla Sıtkı Koçman University, Department of Geological Engineering, 48000, Muğla, Turkey

\textsuperscript{*}Corresponding author: konat@metu.edu.tr

Niğde Massif (South-central Turkey) is a metamorphic core complex consisting of a migmatite-paragneiss basement, overlain by schist-marble-amphibolite alternation and a thick marble sequence. The massif experienced peak pressure-temperature conditions of $>725\,^\circ\text{C}$ and $\sim 16-20\,\text{km}$ at the age of $\sim 91\,\text{Ma}$, which led to the partial melting of continental crust and generation of a subsequent intrusion of the crustal-derived Üçkapılı Granite and dike/sill arrays into the massif.

The field studies led to three distinct mineralization sites: (i) breccias along the low-angle faults at schist-marble contacts, (ii) high-angle cataclastic shear zones in schist layers, and (iii) in between the foliation planes of schists.

A common association of intrusive bodies with mineralized shear zones implies that intrusion played a role in transporting or remobilizing the ore via a hydrothermal fluid. Discrete shear zones and associated foliation planes are used as fluid pathways and hosts.

Structural relationships between brittle and ductile structures and the Au-Hg-As-Sb-Pb paragenesis indicate that these deposits can be classified as orogenic gold deposits. However, considering that these deposits are accumulated during the extensional exhumation of the metamorphic units, the absence of mezo/macro scale mineralized quartz veins/veinlets contradicts the classical models proposed for the development of the Precambrian orogenic gold deposits.
Complex zoning patterns of sphalerite in the Jingchong Cu-Co-Pb-Zn deposit, South China

Erke Peng\textsuperscript{1,2,3,*}, Jochen Kolb\textsuperscript{2,3}, Benjamin F. Walter\textsuperscript{2,3}, Max Frenzel\textsuperscript{4}, Yufei Wang\textsuperscript{1}, Zhiling Wang\textsuperscript{1}

\textsuperscript{1}Key Laboratory of Metallogenic Prediction of Nonferrous Metals and Geological Environment Monitoring, Ministry of Education, School of Geosciences and Info-Physics, Central South University, Changsha 410083, China.
\textsuperscript{2}Karlsruhe Institute of Technology (KIT), Chair of Economic Geology and Geochemistry, Adenauerring 20b, 76131 Karlsruhe, Germany.
\textsuperscript{3}Laboratory for environmental and Raw Materials Analyses (LERA), Adenauerring 20b, 76131 Karlsruhe, Germany.
\textsuperscript{4}Helmholtz-Zentrum Dresden-Rossendorf, Institute Freiberg for Resource Technology, Chemnitzer Str. 40, 09599 Freiberg, Germany.

*Corresponding author: erkepeng@gmail.com

The hydrothermal Jingchong Cu–Co–Pb–Zn-vein-type deposit is located in the northeastern Hunan Province, South China. Sphalerite, the most significant ore mineral in Pb-Zn mineralization, is divided into three generations based on texture and composition. Euhedral SphI is characterized by oscillatory zoning of brown alternating with dark zones that have minor amounts of chalcopyrite inclusion and crosscut by healed fractures. Anhedral SphII and SphIII have more chalcopyrite inclusions than SphI, and SphII is further divided into two subtypes based on color, structure, and texture. SphII-1 fills fractures in SphI and replaces it, SphII-2 overgrows SphII-1, and SphIII crosscuts other early formed sphalerites. Geochemical data show that SphI has higher Fe, Mn, and Cd contents but lower Cu, In, and Ag contents than SphII and SphIII. LA-ICP-MS mapping reveals two element groups, Fe+Mn+Cd and Cu+Ag+In, which define the different oscillatory zoning patterns in SphI. Copper and Ag also show similar distribution trends in SphII and SphIII. Elemental correlation is reproduced by PCA. Based on this, the element substitution mechanisms are interpreted as follows: \( \text{Zn}^{2+} (\text{Fe}^{2+}) \leftrightarrow \text{Fe}^{2+} (\text{Mn}^{2+}, \text{Cd}^{2+}, \text{Co}^{2+}); \) \( 2\text{Zn}^{2+} \leftrightarrow (\text{Cu}, \text{Ag})^+ + \text{In}^{3+} \) Estimated temperature and \( \text{log}(f\text{S}_2) \) data change from 293 ± 58°C and -11 (SphI), 312 ± 55°C and -9.6 (SphII-1), 258 ± 57°C and -11.4 (SphII-2), to 304±60°C and -10.1 (SphIII), indicating fluctuations of temperature and \( f\text{S}_2 \) in the ore-forming system. It is proposed that replacement and diffusion in sphalerite are caused by fluid influx after cataclasis, leading to the transformation of Fe-rich SphI into Fe-poor SphII and SphIII and simultaneously formed abundant chalcopyrite inclusions. Silver and In are remobilized via coupled substitution in this process.
The role of fluid chemistry in carbonatite-hosted HFSE-REE deposits

Mohsin Raza\textsuperscript{1,2,3}, R. Johannes Giebel\textsuperscript{4,5}, Jochen Kolb\textsuperscript{1,2}, Benjamin F. Walter\textsuperscript{1,2,*}

\textsuperscript{1}Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences, Chair of Economic Geology and Geochemistry, Adenauerring 20b, 76131 Karlsruhe, Germany
\textsuperscript{2}Laboratory of Environmental and Raw Materials Analysis (LERA), Adenauerring 20b, 76131 Karlsruhe
\textsuperscript{3}Department of Geology, Bacha Khan University Charsadda, Pakistan
\textsuperscript{4}Technische Universität Berlin, Ernst-Reuter-Platz 1, 10587 Berlin, Germany
\textsuperscript{5}University of the Free State, 250 Nelson-Mandela-Drive, Bloemfontein 9300, South Africa

*Corresponding authors: b.walter@kit.edu

Carbonatites are defined as igneous rocks that contain more than 50% carbonate minerals. Due to their high Nb, P, Fe, F, etc., but in particular high field strength elements (HFSE)-light rare earth element (LREE) content, size of the deposit, and partly extraction-friendly mineralogy, carbonatites are ideal host rocks and important exploration targets. In the last years, significant progress has been made in understanding the role of fluids for HFSE-REE mineralization during various evolutionary carbonatite stages. This includes the fractionation at the early magmatic stage, brine-melt stage (magmatic-hydrothermal transition), hydrothermal late- and postmagmatic stage, and weathering.

Fluids are crucial for the mobility and enrichment of HFSE-REE in carbonatites. Therefore, understanding the nature, chemistry, and evolution of these ore-forming fluids is critical. However, fertilized carbonatites have been studied in more depth than unfertilized carbonatites. We anticipate that the simultaneous study of both mineralized and unmineralized carbonatites will unravel the complex system.

The current study uses petrographic, microthermometric, and geochemical analysis to reveal paragenetically well-constrained assemblages of early and late-stage fluids, which will provide insight into their role in the transport of HFSE and the deposition of rare earth minerals. Furthermore, a comprehensive investigation of distinct daughter minerals found in fluid inclusions will aid in improving the genetic model of carbonatite evolution. In previous studies, the trend is already emerging that mineralized deposits have a higher diversity of solid phases in fluid inclusions than barren deposits.
Lithium sorption characteristics of zeolite 13X sorbents

Rebekka Reich1,*, Rosa Micaela Danisi2, Elisabeth Eiche1, Jochen Kolb1

1Chair of Geochemistry and Economic Geology, Institute of Applied Geosciences, Karlsruhe Institute of Technology, Karlsruhe, Germany;
2Chair of Technical Petrophysics, Institute of Applied Geosciences, Karlsruhe Institute of Technology, Karlsruhe, Germany.

*Corresponding author: rebekka.reich@kit.edu

Progressing energy transition increases the global demand of raw materials that are critical regarding their use in energy and technology applications, such as Li. Since conventional Li mining is limited regarding supply and resilience, exploration for new, environmentally friendly and mineable Li resources will become more important in the future. Technological development of new methods for the direct Li extraction from these resources is indispensable. Geothermal water, containing up to 240 mg/L Li, is regarded to representing a promising alternative Li resource, potentially mineable by sorption on inorganic sorbents.

We study Li sorption to synthetic zeolite 13X powder and spheres of 1.6 – 2.5 mm in diameter in batch sorption experiments using pure LiCl solution. The impact of variable stirring time, pH and temperature on the sorption properties are investigated. The major ion exchange process in zeolites is the substitution of Li+ with Na+ or H+. Therefore, aqueous solutions with different concentrations of NaCl, HCl, CH3COOH and C2H3NaO2 have been tested for Li desorption.

Using zeolite 13X powder, a maximum Li sorption capacity of ~20 mg/g is reached, whereas only ~10 mg/g Li is sorbed to zeolite 13X spheres. Equilibrium is reached after two hours using the zeolite spheres. Lithium sorption kinetics are much faster for the powdery zeolite, reaching equilibrium in less than one minute, favoring a potential industrial application. Desorption was successful for all studied solutions, i.e., 94 – 100% Li has been recovered from the previously loaded sorbent. However, dissolution of zeolite has been observed by acid treatment, disqualifying any acid solution for desorption since long sorbent lifetime and cyclability is required for a feasible and technical application of zeolite-type sorbents. Aiming at a direct Li extraction technique from geothermal brines in the future, we show that zeolite 13X powder is a promising sorbent.
Sulphide trace element redistribution during the metamorphism of the Rävliden North VMS deposit, northern Sweden

Jonathan Rincon1,*, Nils Jansson1, Helen Thomas2, Majka Kaiser2, Mac Persson2, Filip Simán1, Christina Wanhainen1

1Department of Civil and Environmental Engineering, Luleå University of Technology, Luleå, Sweden.
2Exploration department, Boliden Mineral AB, Boliden, Sweden.

*Corresponding author: jonathan.rincon@ltu.se

Sulphide trace element compositions were used to better constrain the metamorphism and deformation of the Rävliden North Zn-Pb-Cu-Ag VMS deposit during the 1.88–1.86 Ga D1-D2 events of the Svecokarelian orogeny. The ore lenses were flattened and translocated into inverted synvolcanic normal faults, stretched out sub-parallel to F2 fold hinges. The bulk metal zonation consists of Zn- and Pb-rich ore lenses situated structurally and stratigraphically above Cu-rich lenses, characteristic of VMS deposits. Remobilisation via dislocation flow transposed sulphides sub-parallel to S1, S2, and S2L foliations, and into brittle-ductile and brittle structures.

Laser ablation-ICP-MS spot analysis of sphalerite grains hosted in Cu-rich mineralisation contain higher concentration of In, Co, Fe, and Cu relative to the Zn-rich mineralisation, consistent with high-temperature, pre-metamorphic crystallisation and later trace element redistribution during metamorphism. Sphalerite hosted in late brittle structures in the hanging wall, associated with Pb-Ag-Sb-As-S minerals, contains relatively higher Cd, Ge, Ga and Sb contents, forming oscillatory zoning in growth twins, indicating low crystallisation temperature. Meanwhile, comparisons between LA-ICP-MS maps of pyrite porphyroblasts sampled from proximal positions between Zn-rich mineralisation and stratigraphic hanging wall, show Co, As, and Ni zonation defining anhedral cores and euhedral recrystallised halos. Recrystallised pyrite is commonly less enriched in trace elements, indicating chemical partitioning with other sulphides during metamorphism. Antimony, Pb, and Ag are hosted in galena and Ag-sulphosalts micro-inclusions, likely remobilised from the main ore lenses.

The compositions of sphalerite and pyrite from Rävliden North show internal redistribution of trace elements during the deformation phases of the Svecokarelian orogen in the Skellefte district, with limited local occurrences due to external remobilisation. The latter likely occurred during an unrelated, overprinting mineralization event which remobilised Ag and Sb from the Rävliden North deposit.
Newly discovered uranium mineralization at Giftkies mine a new site within Jáchymov ore district, Czech Republic

Michal Roll1,3,*, Viktor Goliáš1, Jiří Zachariáš1, Jakub Plášil2, Lukáš Falteisek4

1Institute of Geochemistry, Mineralogy and Mineral Resources, Faculty of Science, Charles University in Prague, Albertov 6, CZ–128 43, Prague 2, Czech Republic
2Institute of Physics of the Czech Academy of Sciences, Na Slovance 1999/2, 182 21 Prague 8, Czech Republic
3Institute of Geology of the Czech Academy of Sciences, Rozvojová 269, Prague 6, 165 00, Czech Republic,
4Department of Ecology, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic

*Corresponding authors: roll@gli.cas.cz

Two uranium mineralization were found at former arsenic mine Giftkies, located on the edge of Jáchymov ore district. First mineralization was found at first adit consists of multi generation zeunerite. Second mineralization was found at second level of the mine and it’s represented by uranyl monokarbonate rutherfordine and uranyl tricarbonates liebigite and scarce agricolaite.

The second mineralization with the following simplified succession: hydrothermal quartz → older siderite → younger siderite → pyrite → iron oxides/hydroxides → rutherfordine was studied closely with emphasis on rutherfordine formation. The tiny vein was formed in a shallow part of Giftkies mine with a dynamic hydrogeological regime which is lasting till present. Textural and structural evidence such as strong corrosion of siderite, admixtures of U, Cu, Zn, As or pseudomorphs of iron oxides/hydroxides after pyrite, conclude that vein must underwent several oxidic-redox cycles. Stable isotope data were used to distinguish an origin of mineral phases and determine formation temperatures. Calculation suggest width span of formation temperatures from 200°C where hydrothermal quartz formed to present-day ambient temperatures (7-10°C) where supergene phases (liebigite, agricolaite, calcite and aragonite) occurred. The radiometric age of rutherfordine was determined using 230Th/234U isotopic pair, which provided late Holocene ages and suggesting at least two episodes of rutherfordine formation, 4600-2600 and 1350-300 years old, respectively. The ages fit well with supergene origin of the rutherfordine indicated by stable isotopes and other mineralogical evidences.

According to data, we assume that supergene processes which formed studied vein and ultimately lead to rutherfordine crystallization started at the beginning of the Subboreal period (or at least not significantly earlier) and lasting till nowadays.
Geology, alteration and mineralization in the Kahyaz low-sulfidation epithermal gold deposit, Esfahan province, Central Iran

Mahin Rostami¹*, Mohammad Maanijou¹, Robert Moritz², Ali Sholeh³

¹Department of Geology, Faculty of Science, Bu-Ali Sina University, Hamedan, Iran
²Department of Earth Science, Geneva University, Switzerland
³Department of Geology, Faculty of Basic Sciences, Tarbiat Modares University, Tehran, Iran

*Corresponding author: Rostami.m99@gmail.com

During the Alpine-Himalayan orogeny, convergence between the Eurasian and African-Arabian plateaus in the Cretaceous and Tertiary has led to the Zagros orogeny (Stocklin., 1974). The Zagros orogeny consists of three parallel belts, including the Urmia-Dokhtar magmatic belt (Schröder., 1944; Förster., 1978; Berberian and Berberian., 1981), Sanandaj-Sirjan zone (Mohajjel and Ferguson, 2000; Mohajjel et al., 2003; Agard et al., 2005), and the folded Zagros belt (Stöcklin., 1968; Mohajjel et al., 2003). Kahyaz Au deposit is located in the middle part of UDMA, NE Esfahan.

On the basis of field observations and petrographic studies, Eocene andesite-trachyandesite and latite-quartz latite are most abundant rock units in this area. Sub-volcanics rocks consist of dacite-rhyodacite and microdiorite and younger pyroxene andesitic dikes that intruded into the andesite rocks.

Hydrothermal alteration in the study area includes silicification, propylitic, argillic, carbonatization, sericitization and sulfidation. Propylitic alteration has resulted in gray and green colors in pyroclastic and volcanic rocks. Important minerals of this alteration include chlorite, epidote and calcite. The minerals of argillic alteration include montmorillonite, jarosite, illite and albite, which have affected the dacite-rhyodacite rocks. Silicic alteration has occurred in the form of vein-veinlet, as well as silicification of host rocks.

Quartz-calcite vein, with an approximate length of 2 km and a width of 2 m and with east-west trend, is hosted in the andesitic rocks. In addition, several sub-veins are exposed around the main vein. Based on the study of drilling cores, several boiling stages have occurred, which are characterized by the presence of adularia and bladed calcite. Boiling zones often conform to high gold grades. The Kahyaz deposit has alteration assemblages and ore minerals of low sulfidation epithermal deposits.
Multi-stage Au-(Cu-Co) mineralization in orogenic gold deposits from the Pohjanmaa Belt, Finland

Andressa Silva¹*, Clifford Patten¹, Simon Hector¹, Benjamin Walter¹, Jochen Kolb¹

¹Laboratory for Environmental and Raw Materials Analysis, Department of Geochemistry and Economic Geology, Institute of Applied Geosciences, Karlsruhe Institute of Technology

*Corresponding author: andressa.silva@kit.edu

The Pohjanmaa Belt (PoB) consists of Paleoproterozoic volcano-sedimentary rocks localized in the Svecofennian Domain, Western Finland, and hosts orogenic gold deposits. In addition to gold, some deposits are showing enrichment in atypical metals, such as Cu and Co. The processes controlling the variation in metal content between the deposits are not well known. This study aims to characterize the different ore stages and alteration zones from typical and atypical orogenic gold deposits in order to better understand their genesis. A detailed petrographic study has been carried out on two typical orogenic gold deposits: Laivakangas and Huhta, and two orogenic gold deposits with the atypical metal association: Jouhineva (Au-Cu-Co) and Kurula (Au-Co). Our results show that all deposits contain at least two main ore stages. A primary stage, defined by Au-Co-Ni, is dominated by Ni-Co-Au arsenides, arsenopyrite, pyrite, pyrrhotite, and native gold. These minerals are hosted in (hornblende-actinolite-biotite)-plagioclase-quartz-veins. The host rocks close to the mineralized veins show 1mm to 5 cm bleaching zones with quartz-plagioclase enrichment, mafic minerals depletion, and disseminated ilmenite haloed by titanite and sulfides. A second ore stage, defined by Cu, intersects the first ore stage and consists of chalcopyrite, pyrite, and sphalerite, associated with sericite-chlorite-actinolite veinlets. We conclude that the orogenic gold deposits were formed during two distinct ore stages with a different metal endowment, the varying intensity of the expression of the ore stages is controlling the metal association in the deposits.
Detachment fault specularite mineralization in Agios Elissaios, SE Peloponnese, Greece

Nikolaos Sofis,1 Ioannis Iliopoulos1, Matthew Leybourne2, Stavros Kalaitzidis1*

1Department of Geology, University of Patras, Rio-Patras Greece
2Queen’s University, Kingston, ON, Canada

*Corresponding author: skalait@upatras.gr

This presentation deals with iron-ore mineralization occurring in the Agios Elissaios area, in southeast Peloponnese, Greece. The Fe-ore was extensively mined between the late 19th until the mid-20th century, whereas today some relicts of these historic mining activities are still visible. The aim of the study is to elucidate the ore-forming conditions and provide a genetic model of the mineralization. For this purpose, petrographical, mineralogical, geochemical, and isotopic studies were conducted.

The Fe-mineralization occurs within the detachment fault that delimits the Triassic Carbonates of the Tripoli Unit in the hanging wall from the Permian-Triassic Phyllite-Quartzite Unit in the footwall. The mineralization displays a lensoid structure along the fault, in parts disseminated but also massive, being hosted exclusively within the base of the carbonates, and revealing a replacement texture. The mineralogical assemblage of the ore is quite uniform and consists almost entirely of hematite and goethite, with subordinately ankerite and calcite. A quite distinctive feature is the dominance of the specular hematite, indicating syntectonic formation. Apart from Fe, and Ca, the ore is quite lean in other elements, and with values of the rest of the major oxides below 1 wt.%. In terms of trace elements only As, Co, Cr, Sr, V, and Zn fluctuate between 10 and 100 mg/kg, while V occasionally reaches 400 mg/kg; the rest elements display values below 1 mg/kg in most samples.

Preliminary isotopic data on the host carbonates reveal a marine depositional setting, whereas O-isotopes of the iron oxides indicate a low-thermal forming process, involving circulation of meteoric water.
Age and composition of magmatic rocks, and hydrothermal alteration characteristics of the Yanıklı Prospect, Eastern Pontides, Turkey

Şafak Utku Sönmez1,*, Robert Moritz1, François Turlin1, Alexey Ulianov2, Roelant Van Der Lelij3, Ümit Aydın4, Serdar Keskin4

1Department of Earth Sciences, University of Geneva, Rue des Maraîchers 13, 1205 Geneva, Switzerland
2Institute of Earth Sciences, University of Lausanne, 1015 Lausanne, Switzerland
3Geological Survey of Norway, Leiv Eirikssons Vei 39, 7040 Trondheim, Norway
4General Directorate of Mineral Research and Exploration of Turkey, Department of Mineral Research and Exploration, Ankara 06520, Turkey

*Corresponding author: safak.soenmez@unige.ch

The Yanıklı Prospect is interpreted as an epithermal type of mineral occurrence that is hosted by Late Cretaceous volcanic and volcaniclastic suites in the Artvin District within the Eastern Pontides, NE of Turkey.

This study aims at constraining the absolute age of magmatic and alteration events, the lithogeochemical composition of the magmatic host rocks, and the 3-dimensional distribution of the hydrothermal alteration zones in Yanıklı.

The volcanic and volcaniclastic rocks have a predominantly rhyolitic to dacitic, with subsidiary intermediate to mafic compositions. Two dominant dike generations are observed in the prospect. The first dike generation is NE-oriented and has an intermediate composition, whereas the second generation is NW-oriented and has mafic to intermediate compositions. Uranium-lead dating indicates that the felsic and intermediate-mafic magmatic rocks have been emplaced between 81.3-82.5Ma. Early Oligocene NW-oriented dikes dated at 29.6-32.3Ma crosscut the volcanic sequences in the prospect.

The predominant alteration minerals include chlorite-epidote, sericite (K-illite-muscovite±paragonite) and kaolinite group minerals (kaolinite-halloysite-nacrite-dickite). These alteration minerals are accompanied by carbonates (chalcite-dolomite-ankerite). Anhydrite is observed in late stage veins.

Two mineralization stages have been identified in the prospect. The first metal phase consists of a Cu-rich metal zone hosted by a predominantly chlorite-epidote alteration zone, which also includes a Pb and Zn mineralization. In contrast, the second phase is enriched in Zn and Pb related to the sericitic alteration zone. Gold mineralization is mainly associated with the second mineralization phase, which also contains weak, subsidiary Cu assemblages.

Potassium-argon geochronology of K-illite yielded ages ranging between 68.6-72.4Ma. This K-Ar age is younger by about 9-13 m.y. with respect to the U-Pb ages of the Late Cretaceous magmatic host rocks. Therefore, it remains open to question if the K-illite K-Ar ages records the hydrothermal alteration or has been partly reset during a thermal-tectonic overprint during the Eocene or Oligocene events.
Taking the pulse of MVT systems: in-situ U-Pb dating of hydrothermal dolomite from the San Vicente deposit, Central Peru

Lorenzo Tavazzani¹,*, Marcel Guillong¹, Lena M. Bastian¹, Lluís Fontboté², Cyril Chelle-Michou¹

¹ETH Zürich, Department of Earth Sciences, Zürich, Switzerland
²University of Geneva, Department of Earth Sciences, Geneva, Switzerland

*Corresponding author: lorenzo.tavazzani@erdw.ethz.ch

Mississippi Valley-type (MVT) deposits source about 24% of the global lead and zinc resources. Despite their economic importance, difficulties in obtaining absolute age determinations on MVT systems contributes to the lack of consensus on the genesis of these deposits. In-situ, U-Pb dating of pre-, syn- or post-ore hydrothermal carbonates through laser ablation-inductively coupled-mass spectrometry (LA-ICP-MS) provide a new, powerful tool to constraint age of formation and duration of mineralizing events in MVTs.

The Upper Cretaceous stratabound San Vicente Zn-Pb MVT deposit, Central Peru, is one of the largest MVT deposit in the world. It is hosted by massive dolomite units of the Upper Triassic–Lower Jurassic Pucarà formation. Carbonate U-Pb data were acquired by LA-ICP-MS on thirteen petrographically characterized carbonate-bearing samples from the San Vicente mine (n=7), and two satellite ore bodies (Uncush and Chilpes, n=6) to the South of the main mineralized center.

In total, nineteen measurements sites gave robust radiometric dates. Ore-related, hydrothermal dolomite associated with the San Vicente ore crystallized in a ~25 Myr interval, between 104.4 ± 6.3 Ma and 81.2 ± 3.9 Ma. In the two southern satellite bodies (Uncush and Chilpes), systematically younger dolomite crystallization ages span an unresolvable shorter interval, between 87.4 ± 7.2 Ma and 75.4 ± 10.1 Ma. Overall, these ages define a prolonged mineralization episode (~30 Myr) characteristic of the San Vicente MVT, spanning between the Mochica and Peruvian Andean orogenic stages. A longer crystallization interval for the main Pb-Zn ore compared to minor satellite bodies, suggests a scaling of the duration of the mineralization with size of the deposit. Moreover, a shift in absolute age of deposition moving from North to South indicate that spatial focusing of mineralizing fluids might play a crucial role in formation of economically viable Zn-Pb deposit.
Reconstructing the fluid evolution of a basalt-hosted, epithermal Au occurrence in SW-Iceland

Thierry Solms¹*, Thomas Driesner¹

¹ETH Zurich, Switzerland

*Corresponding author: thierry.solms@erdw.ethz.ch

Low-sulfidation epithermal Au deposits are commonly hosted in bimodal volcanic suites attributed to continental and island-arc rifts. Iceland, although hosted on a combined MOR and hot spot setting hosts few Au anomalies with epithermal characteristics the genesis of which is still poorly constrained.

At Mógilsá on Esja peninsula (SW-Iceland), a NNE-SSW-oriented, sub-economic Au anomaly is apparently linked to the activity of several nearby central volcanoes. Based on field evidence and analytical measurements (calcite δ¹⁸O, δ¹³C, and Δ⁴⁷, fluid inclusion microthermometry, LA-ICP-MS analysis of pyrite and calcite, host rock δ¹⁸O and element composition), we propose that hydrothermal activity can be distinguished into three stages:

1) Percolation of presumably relatively high-temperature (~200-300 °C) meteoric fluids following the emplacement of a shallow (~2 km) mafic intrusion, which led to pervasive host rock alteration (chl, ep, qtz, py, the latter hosting sparse po and hm).

2) Precipitation of calcite of varying morphologies and minor py and qtz temporally coincides with hydrothermal brecciation, which suggests fluctuating pressure conditions during this stage. Pyrite among late calcite generations shows elevated Au, As and Se concentrations compared to earlier pyrite generations, and was deposited along with native Au and Au-rich cpy. During the calcite-dominant stage, fluid temperatures remained relatively constant (200-240 °C), but fluid δ¹⁸O became more positive with time (-7.2‰ to -2.5‰ (VSMOW)), probably as a result of chemical interaction between the meteoric fluids and the mafic host rock.

3) More negative fluid δ¹⁸O (-6.8‰ to -10.3‰ (VSMOW)) and precipitation temperatures below 120 °C attributed to late calcite veins indicate the cessation of the heat supply to the hydrothermal system.

We suggest that the combination of the regional tectonic stress regime (favoring repetitive faulting), a nearby heat supply (shallow intrusion), and possibly pre-existing fluid pathways (regional faulting) were responsible for the “untypical” epithermal Au enrichment in this geologic setting.
Element fluxes during alteration in high-sulfidation epithermal systems

Ethan R. Tonks¹, ²*, Jamie J. Wilkinson¹, ², Robin N. Armstrong¹, Andrew T. Wurst³

¹LODE, Department of Earth Sciences, Natural History Museum, London, UK
²Department of Earth Science and Engineering, Imperial College London, UK
³Barrick Gold Corporation, Toronto, Canada

*Corresponding author: e.tonks@nhm.ac.uk

The processes involved in the alteration of rocks associated with high-sulfidation epithermal ore deposits, which host significant quantities of gold and silver, cause a large-scale and complex migration of chemical elements. Elements can either be added into the system by magmatic-hydrothermal fluids or mobilized from one alteration facies to another due to the hydrothermal dissolution of minerals in the precursor rock and subsequent re-precipitation as new minerals elsewhere.

In this study, we present an elemental mass transfer analysis of alteration associated with the Pueblo Viejo Au-Ag(-Cu) high-sulfidation deposit, Dominican Republic. The whole-rock chemistry of precursor and variably altered andesite was used to determine the behavior of 64 elements during quartz-alunite, quartz-pyrophyllite, and chlorite-carbonate-kaolinite facies alteration. For high-sulfidation systems, relatively few mass transfer analyses have previously been successfully undertaken due to the difficulty in accurately identifying elements that remain immobile during alteration. This is necessary to remove the effects of significant bulk mass change on whole-rock element concentrations. Elements typically considered to be immobile in other settings where hydrothermal alteration occurs are unsuitable in the high-sulfidation environment, due to the highly acidic fluids responsible for alteration. We show that LREEs are immobile during high-sulfidation-related alteration because of the low stability of LREE complexes in the fluids (lower ionic potential) relative to HREE complexes, and the resultant formation of alteration minerals, such as woodhouseite, which preferentially retain LREEs on a local scale.

The calculated changes in elements during alteration were integrated with changes in mineralogy and mineral chemistry, determined using electron microprobe and laser ablation ICP-MS, to identify the minerals in which elements are hosted in both precursor and altered andesite. Understanding chemical and mineralogical changes that occur during alteration and mineralization provides an insight into the nature of ore-forming fluids and the changes in their physicochemical properties during intense fluid-rock interaction.
Mineralogy of contaminant-bearing particles from polluted grass in mining areas of sub-Saharan Africa

Marek Tuhý1,*, Vojtěch Ettler1, Juraj Majzlan2, Stefan Kiefer2

1Institute of Geochemistry, Mineralogy and Mineral Resources, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic
2Institute of Geosciences, Friedrich-Schiller University, Burgweg 11, D-07749 Jena, Germany

*Corresponding author: marek.tuhy@natur.cuni.cz

For this investigation, biomass and soil samples from several smelter areas in sub-Saharan Africa were used. Grass samples and topsoils were collected in the Tsumeb area in northern Namibia (Cu-smelter, former mine), Selebi-Phikwe in Botswana (Ni-Cu mine and smelter), Luanshya in the Zambian Copperbelt (Cu mine and smelter), and Kabwe in central Zambia (Pb-Zn mine and smelter). Metal(loid)s concentration in soils and grass were generally in the order of hundreds to thousands mg/kg.

The surfaces of all the grass biomass samples contained a variety of geogenic (quartz, carbonates, clay minerals, feldspars) and anthropogenic (usually metal-bearing) particles directly attached to the biomass tissues. These smelter-derived particles are predominantly slag fragments enriched in various contaminants, droplets of metals/sulfides, and, in the case of the biomass from Kabwe, newly formed aggregates of submicrometric anglesite (PbSO₄) crystals. Heavy mineral fractions were obtained from all biomass samples to better understand the solid-phase speciation of contaminants. In Tsumeb, the key metal-hosting minerals/phases on biomass were Cu-Fe sulfides, arsenolite (As₂O₃) and metal-bearing slag glass. In Selebi Phikwe pyrrhotite (Fe₁₋ₓS), pyrite (FeS₂), pentlandite [(Fe,Ni)₉S₈] and chalcopyrite (CuFeS₂) were predominant. Samples from Kabwe were composed of galena (PbS), pyrite (FeS₂), sphalerite (ZnS), chalcopyrite (CuFeS₂) and anglesite (PbSO₄) and in Luanshya, the particulates were mainly formed by phases from the Cu-Fe-S ternary system. The mineralogy of particulates collected in the grass samples was similar to that in the corresponding topsoil samples. The knowledge of solid-phase speciation is of key importance for determining the fate of contamination in such environments.
Rare-metal potential of Variscan granites from the Eastern Pontides, NE Turkey

François Turlin¹*, Robert Moritz¹, Serdar Keskin², Şafak Utku Sönmez¹, Alexey Ulianov³, Massimo Chiaradia¹

¹Department of Earth Sciences, University of Geneva, Rue des Maraîchers 13, 1205 Geneva, Switzerland
²General Directorate of Mineral Research and Exploration of Turkey, Department of Mineral Research and Exploration, Ankara 06520, Turkey
³Institute of Earth Sciences, University of Lausanne, 1015 Lausanne, Switzerland

*Corresponding author: francois.turlin@unige.ch

Variscan granitoids from Western to Eastern Europe host numerous rare-metal (Sn-W/U/Nb-Ta) deposits. However, their lateral equivalents in other Variscan segments have been poorly or not investigated with respect to their rare-metal potential. This is particularly the case of the Variscan granitoids that form the basement of the Eastern Pontides, which is a Tethyan segment in NE Turkey.

The Eastern Pontides consist in a Gondwana-derived terrane accreted to the Eurasian margin and subsequently reworked during successive orogenic events associated with the closure of Paleotethys and Neotethys oceans. The basement of this belt is composed of post-Panafrican granitoids, the most abundant and best-preserved ones being of Variscan age. They form a concordant “boutonnière” striking parallel to the belt.

In this study, we compare the Variscan granitoids from the Eastern Pontides with the rare-metal-bearing ones of Europe. We use published whole-rock, geochronological and isotopic data, coupled to our newly obtained whole-rock, U-Pb-Hf isotope and trace element data of zircons from plutons of the Eastern Pontides’ basement. Based on these data, our aim is to compare signature, age, source and fertility indicators (e.g. whole-rock Nb/Ta ratios) of granitoids from both areas. These results will allow us to evaluate the rare-metal fertility of the Turkish Variscan granitoids and to reappraise the metallogenic potential of the Eastern Pontides in terms of Sn-W/U/Nb-Ta deposits.
Protracted thermal histories and multiple porphyry intrusions in the Chuquicamata porphyry copper district resolved by zircon petrochronology

Adrianna Luiza Virmond¹,*, Jörn-Frederik Wotzlaw¹, Cyril Chelle-Michou¹

¹Department of Earth Sciences, ETH Zürich, Clausiustrasse 25, 8092 Zürich

*Corresponding author: adrianna.virmond@erdw.ethz.ch

The Eocene Chuquicamata district is one of the world’s largest porphyry copper systems and hosts more than 130 Mt of Cu. The Chuquicamata Intrusive Complex (CIC) comprises the Radomiro Tomic (RT) and Chuquicamata mines and occurs as a subvertical megadyke located east of a N-S-oriented regional structure, the West Fissure Fault. Seven kilometers to the south of the Chuquicamata mine and to the west of the fault, lies the Ministro Hales mine (MMH), whose relationship to the CIC has been debated.

We investigate the thermal and magmatic evolution of the district by collecting high precision zircon petrochronological data (U-Pb CA-ID-TIMS geochronology in tandem with LA-ICPMS trace element).

The CIC shows a protracted period of zircon crystallization, spanning at least 1.5 Ma. Radomiro Tomic, in the north, yields older ages and zircon dates get younger towards the southern part of the Chuquicamata mine. A second episode of porphyry emplacement, at least 0.5 Ma younger, is resolved and its age is closer to the reported Re-Os molybdenite ages in literature, suggesting this minor intrusion could be the one related to the mineralization. At MMH, the obtained U-Pb dates are older than those obtained for Chuquicamata, suggesting that the deposits might not be coeval, as previously proposed.

Despite the age difference, zircon trace element compositions and Ti-in-zircon temperatures are identical for all three mines, pointing to a similar source and protracted thermal history of the magmatic system. Within CIC, varying emplacement ages across the complex, under similar temperature evolution, suggest the complex was assembled slowly, by multiple intrusions. Mass balance calculations suggest that magma volumes compatible with super eruptions were necessary source the Cu in CIC. A protracted multimillion-year thermal history could be key to allow emplacement of large volumes of magma, sustain the hydrothermal activity and ultimately form behemothian porphyry districts.
Jurassic crustal structure in southern Tibet controls the development of porphyry Cu deposits

Xuhui Wang$^{1,2,*}$, Xinghai Lang$^1$, Robert Moritz$^2$

$^1$College of Earth Science, Chengdu University of Technology, Chengdu 610059, China
$^2$Department of Earth Sciences, University of Geneva, Geneva 1205, Switzerland

*Corresponding author: wangxuhui618@126.com

In the Jurassic magmatic belt (JMB) of southern Tibet, Jurassic subduction-related porphyry copper deposit (PCDs) and Miocene post-collision PCDs are, respectively, distributed in southern and northern belts of the JMB. Jurassic magmatic rocks of the southern JMB have higher zircon Eu/Eu* and whole-rock Sr/Y ratios, and higher Cu concentrations compared to the northern belt. Crustal thickness Sr/Y proxy indicates that the crust in the southern belt is thicker (~42 km) than in the northern belt (~26 km), which reflects the Jurassic arc-back-arc architecture. Auto-oxidation of Jurassic magmas, controlled by lower crustal garnet fractionation, was favored by the thicker southern belt, and explains increasing magma oxygen fugacity ($f_{O2}$) and higher sulfur solubility. Thus, Cu was more effectively released into magma during partial melting. Because of the absence of such an oxidation control, the Jurassic magmas of the thinner northern belt had a lower $f_{O2}$. As a consequence, Cu has been efficiently removed from the melt, leading to the formation of Cu-bearing cumulates in the lower crust of the northern belt. This explains the redox and Cu concentration variations across the JMB and Jurassic PCDs occurrences. Since Miocene PCDs occur only in the northern belt, we conclude that pre-collision fertilization was a fundamental process for the formation of post-collision PCDs, and they preferentially developed in a thinner crust, such as the paleo-back-arc setting of the northern belt. Our findings reveal that the Jurassic arc-back-arc geodynamic evolution resulted in differences in crustal thicknesses across the JMB, and it controlled the PCDs distribution in southern Tibet.
Mapping paragenetic sequences in hydrothermal veins: challenges and opportunities

Shane Webb¹*, Taija Torvela², Rob Chapman³

¹Ores and Mineralisation Group, School of Earth and Environment, University of Leeds, UK

*Corresponding author: eespdw@leeds.ac.uk

When studying hydrothermal veins, geologists routinely establish the temporal relationship between mineral phases. This is known as developing a paragenetic sequence, and it is fundamental in constraining the number of fluid flow events involved in vein formation. Such information is essential in correlating ore-bodies and trace metals for mineral exploration, and in academic studies, it provides a context for the occurrence of dateable minerals and their radiometric ages to be interpreted within. Paragenetic information can also inform commercial operations – post-mineralisation fluid flow events could be associated with the dissolution and downgrading of a prospect. Attempts at characterising vein paragenesis began in the 1800s with the advent of optical microscopy, and today, they are undertaken with reflected light microscopes or SEMs. Here, we demonstrate the role of constraining paragenesis in understanding the metallogeny of some poorly studied mineral deposits from Loch Tay, Scotland, whilst outlining the theoretical considerations and common pitfalls that researchers may encounter.

The law of cross-cutting relationships is the most powerful tool for establishing paragenesis. Signs of replacement processes are important because these provide unambiguous evidence of one preceding phase being replaced by another. However, many of the criteria historically used to constrain vein paragenesis may be misleading, and care is needed during interpretation. The law of included fragments, which stipulates that inclusions are younger, is problematic because metallic inclusions commonly form as a result of coprecipitation. Certain inclusion textures, such as chalcopyrite disease, occur as a result of dissolution and replacement of a prior phase.

In the process of characterising the paragenesis of the Loch Tay veins, apatite crystals have been identified in association with the first generation of quartz. This confirms the viability of later geochronological studies, and means that any radiometric ages will apply to the earliest episode of fluid flow involved in vein formation.
Metallogenesis of Cobalt deposits in Eastern Kunlun Orogenic Belt, North Tibetan Plateau, NW China

Dongqian Wu¹*, Fengyue Sun¹*, Robert Moritz², Lu Yu¹

¹College of Earth Sciences, Jilin University, Changchun 130061, China
²Department of Earth Sciences, University of Geneva, Genève 1205, Switzerland

*Corresponding author: wudq19@outlook.com

As one of the world's critical minerals, Co resources have special significance in economic and social development. Along with the extensive application of electronic products and new energy vehicles, the increasing demand for Co resources is attracting more and more attention. The Eastern Kunlun Orogenic Belt (EKOB) is located in the western part of the central orogenic belt in mainland China, which is bordered by the Qaidam block to the north and the BayanHar-Songanganzi Terrane to the south. It experienced a multi-stage tectono-magmatic evolution and has great metallogenic potential of Co deposits.

The cobalt deposits in EKOB occur in a wide variety of types, and they exhibit diversity in the source of ore-forming fluids and materials. The metallogenesis is characterized by multiple periods and superimposition. In this study, five different types of Co (bearing) deposits which located in different tectonic units of the EKOB were chosen for further discussion. In hydrothermal and exhalative hydrothermal-sedimentary deposits, cobalt occurs primarily in cobaltite, erythrite, heterogenite or cobaltiferous pyrite. In magmatic deposits, sulfarsenides such as cobaltite or cobaltiferous gersdorffite can be observed under the microscope.

In Precambrian, under the influence of the mantle plume, the forming of Wanbaogou oceanic basalt plateau laid an important material foundation for the metallogenesis in later period (Longshigeng). In Caledonian, the trench-arc-basin system was formed in south Qaidam, and then the exhalative hydrothermal-sedimentary types of cobalt mineralization occurred in both the south (Tuolugou) and north Kunlun belt. Along with the Proto-Tethyan Ocean slab broke off, magmatic nickel-cobalt mineralization occurred in the central Kunlun belt (Akechuksai, Xiarihamu). After the closure of the Palaeo-Tethyan Ocean in Indosinian, strong regional magmatism and crust mantle interaction created conditions for hydrothermal cobalt mineralization (Dulenggou).
Key geology features of high-grade hypogene porphyry Cu deposits

Chao Yang$^{1,*}$

$^1$London Centre for Ore Deposits and Exploration (LODE), Department of Earth Sciences, Natural History Museum, Cromwell Road, South Kensington, London SW7 5BD, UK

*Corresponding author: chao.yang@nhm.ac.uk

Porphyry Cu deposits provided the majority (70%) of global Cu resources, and high-grade hypogene porphyry (HGHP) Cu deposits are of particular interest to industry in a low-carbon energy transition generation. Compilation of twenty typical HGHP worldwide suggests that two transitional alteration stages: potassic to sericite, and sericite to advanced argillic stages, are frequently associated with high-grade mineralization. The corresponding sulfides are mainly bornite-rich and high-sulfidation state assemblage. Deposit scale self-induced high density of quartz veins, breccia, and other types of open space are the dominant host of high-grade Cu concentrations. There are several favorable host rocks for generating high-grade hypogene ores, such as mafic rocks, carbonate, and sandstones, due to their impermeable cap effects and buffer ability. Compressive tectonic settings facilitate protracted deep magma fractionation and hydrothermal exsolution, generating large amounts of fertile hydrothermal fluids to be concentrated in giant HGHP deposits without diluting them in several low-grade deposits or releasing them into the air with volcanic eruptions.

A surprisingly large proportion (75%) of HGHP deposits have high-grade Cu mineralization associated with acidic (sericite to advanced argillic) hydrothermal alteration with late and shallow features. Three major reasons may explain: 1) Intensive open spaces tend to form at late stages during a rapid syn-mineralization exhumation and deem magma doming stages, which correspond to hydrolytic and acidic alteration. 2) Meanwhile, it causes telescoping of the porphyry system and overprinting of later hydrothermal fluids that remobilize early-stage Cu sulfides and results in hypogene enrichment by oxidizing, decreasing pH, and additional Cu. 3) Rock ductile-brittle transition, silica solubility retrograding, $\text{SO}_2$ disproportionation, and rapid Cu solubility decrease jointly happen at a relatively low temperature of around 400-350 °C, which corresponds to sericite alteration. However, many deposits still have sericite alteration depleted Cu, and controls of Cu hypogene enrichment and depletion remain unknown.