# June 27 - July 4 - 2025 Turin Italy

# ECROF O TORINO 2025

## EUROPEAN CURRENT RESEARCH ON FLUID AND MELT INCLUSIONS

Dedicated to Gacques Touret

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## VENUE INFORMATION



#### **Pre-Conference Workshop Venue**

Located in the historic building of the Galileo Ferraris National Electrotechnical Institute in Via Valperga Caluso 33 in Turin, the Aula Pognante is the ideal setting for our pre-congress workshops.

The classroom, equipped for Petrography teaching, is equipped with 36 microscopes in the student station and 1 microscope in the teacher station, with projector, monitor and the services necessary for in-person, on-line and mixed teaching.

Via Valperga Caluso 35 Turin



#### **Main Conference Venue**

The Great Hall, seat of the ECROFI 2025 Congress, is located at the former -Baroque Convent of the Lateranenses Canonesses, renovated between 1982 and 2004. In the Aula Magna, originally the old chapter house or refectory, you can admire a series of frescoes attributed to the pictorial and chromatic technique of the Guidobono. A family of artists, active between the end of the seventeenth century and the beginning of the eighteenth century, who during their stay in Turin, have left testimonies also at the Royal Palace.

Via Accademia Albertina 13 Turin



Post-Conference Field Trip Venue The post-conference field trip will take participants to the stunning Val Sesia, ca. 100 km NNE of Turin, renowned for its significant geological features.

Within the Sesia Val Grande Geopark, this region provides an exceptional outdoor laboratory to explore the continental lithosphere, offering insights into geological processes that have shaped the Earth between the end of the Variscan cycle and the beginning of the Alpine one.

Varallo Sesia (Vercelli Province)



## **SOCIAL PROGRAM**



## Ice Breaker Party

#### June 29

05.00 pm Registration desk open 06.30 p.m. Ice breaker party

(Participation included in Registration Fee)

Turin University DBIOS Via Accademia Albertina 12 Turin



#### **Conference dinner**

July 1st

07.00 p.m. Private Guided Tour 08.30 p.m. Conference Dinner

(Participation NOT included in Registration Fee)

**Egyptian Museum Turin** Via Accademia delle Scienze 6 Turin



	WORKSHOP AT A GLANCE			
	<b>Friday</b> June 27	<b>Saturday</b> June 28	<b>Sunday</b> June 29	
8:30 a.m9:00 a.m.	Registration		Raman Spectroscopy Maria Luce Frezzotti	
9:30 a.m9:30 a.m.		Thematic - Melt inclusions		
9:30 a.m10:00 a.m.	Introduction	Silvio Ferrero		
10:00 a.m10:30 a.m.	Presentation of Participants			
10:30 a.m11:00 a.m.		COFFEE BREAK	COFFEE BREAK	
11:00 a.m11:30 a.m.	Fluid Inclusion	Introduction to	Thermodynamic	
11:30 a.m12:00 a.m.	Alfons van den Kerkhof	thermodynamics of fluid systems Maria Luce Frezzotti	modelling of COH fluids Jan Marten Huizenga	
12:00 a.m12:30 a.m.				
12:30 a.m1:00 p.m.				
1:00 p.m1:30 p.m.		Lunch	Lunch	
1:30 p.m2:00 p.m.	Lunch			
2:00 p.m2:30 p.m.				
2:30 p.m3:00 p.m.	Petrographic Studies of fluid Inclusions Maria Luce Frezzotti	Isochores calculation Jan Marten Huizenga	Thematic - Fluids in the lower crust and upper mantle Maria Luce Frezzotti	
3:00 p.m3:30 p.m.				
3:30 p.m4:00 p.m.		Thematic – Significance of fluid and melt inclusions to		
4:00 p.m4:30 p.m.	COFFEE BREAK	understand igneous processes Eniko Bali	Microscopy class demonstration All	
4:30 p.m5:00 p.m.	Microthermometry Alfons van den Kerkhof	COFFEE BREAK		
5:00 p.m5:30 p.m.		Thematic – Fluid	Final discussion	
5:30 p.m6:00 p.m.		Pilar Lecumberri - Sanchez		

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A Street

5:00 p.m.

**Sunday** June 29

6:00 p.m.

Ice - breaker party

## MAIN CONFERENCE AT A GLANCE

	<b>Monday</b> June 30	<b>Tuesday</b> July 1	Wednesday July 2	
8:30 a.m9:00 a.m.	Registration desk	Peristration desk	Penistration desk	
9:00 a.m9:15 a.m.	Opening	Keyisiiulioli uesk		
9:15 a.m9:30 a.m.	Commemoration of Touret	Kevnote - Sanchez-Valle C.	Keynote - Mikhail S.	
9:30 a.m9:45 a.m.	Kevnote - Barnes J.			
9:45 a.m10:00 a.m.	.,	Session 5	Session 4	
	Session 1 - Sedimentary	Geothermal energy	Ore deposits	
9:45 a.m10:00 a.m.	environment - Oil & gas	Dallara E.	Estrella Mosquera M.P.	
10:00 a.m10:15 a.m.	Capriolo M.	Aden A.	Koufogiannis I.	
10:15 a.m10:30 a.m.	Gasparrini M.	Satriani J.	Xu X.	
10:30 a.m10:45 a.m.	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	
10:45 a.m11:00 a.m.				
	Session 2 Magmatism	Session 4 Ore deposits	Session 7 Metamorphism & Mantle processes	
11:00 a.m11:15 a.m.	Lo Forte F.M.	Ortega L.	Maffeis A.	
11:15 a.m11:30 a.m.	Belousov I.	McFall K.	Myovela J.L.	
11:30 a.m11:45 a.m.	Merrill H.	Soltanmohammadi A.	Zachariáš J.	
11:45 a.m12:00 a.m.	Cannatelli C.	Fusswinkel T.	Spránitz T.	
12:00 a.m12:20 a.m.				
12:20 a.m12:40 a.m.	Lunch	Lunch	Lunch	
12:40 a.m1:00 p.m.				
1:00 p.m1:20 p.m.				
1:20 p.m1:40 p.m.	Poster session	Poster session	Poster session	
1:40 p.m2:00 p.m.				
	Sess New frontiers - The	Session 3 New frontiers - Theory - Experiments		
2:00 p.m2:15 p.m.		Schmidt C.	Noronha F.	
2:15 p.m2:30 p.m.	Invited - Bodnar R.J.	Lange T.P.	Bozkaya G.	
2:30 p.m2:45 p.m.	Bakker R.	Caumon MC.	Ortega L.	
2:45 p.m3:00 p.m.	Xu X.	Ferrero S.	Banks D.	
3:00 p.m3:15 p.m.	González-Acebrón L.	Créon L.	Soltanmohammadi A.	
3:15 p.m3:30 p.m.	Ferrando S.	Barbini P. (Horiba)	Courba S.	
3:30 p.m3:45 p.m.	COFFEE BDEAK			
3:45 p.m4:00 p.m.				
	Session 4 Ore deposits	Session 6 Climate change	General discussion and Closing	
4:00 p.m4:15 p.m.	He Q.	Capriolo M.		
4:15 p.m4:30 p.m.	Costa e Silva S.	Sendula E.	General discussion	
4:30 p.m4:45 p.m.	Tarantola A.	Guillerm E.	and Closing	
4:45 p.m5:30 p.m.	Postor cossion	Poster session	·	
5:30 p.m6:00 p.m.	FUSIEI 56551011	TOURinSTONE		
6:00 p.m7:00 p.m.			Post-conference	
7:00 p.m.		Egyptian Museum - Private Guide Tour & Conference Dinner	field trip departure	

## POST - CONFERENCE FIELD TRIP AT A GLANCE

	Wednesday July 2	<b>Thursday</b> July 3	Friday July 4
MORNING		Field trip	Field trip
LUNCH	Main conference	On the field (lunch bag)	On the field (lunch bag)
AFTEROON	At the end of the conference, departure for Varallo Sesia	Field trip	Departure for Torino
DINNER	Dinner in a Restaurant-Pizzeria in Varallo	"Gala" dinner at the Albergo Italia	
OVERNIGHT	ALBERGO ITALIA CASA PER FERIE VILLA SANTA MARIA	ALBERGO ITALIA CASA PER FERIE VILLA SANTA MARIA	



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## **Keynotes**

## Talk

The role of sub-continental lithospheric mantle and continental crust in the global halogen cycle. <u>Barnes J.D.</u><sup>1\*</sup> <sup>1</sup>University of Texas at Austin, Austin, United States

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\*jdbarnes@jsg.utexas.edu Keywords: metasomatism, mantle, ore deposits

Halogens (CI, F, Br, I) play a fundamental role in modifying the properties of fluid, magma, and minerals on Earth (e.g., halogen-rich fluids increase the transport of metals leading to the development of ore deposits), yet we still lack a complete understanding of halogen budgets of potentially major reservoirs. Additionally, mass balance calculations show that more halogens are subducted than are returned to the surface via volcanism suggesting sequestration of halogens in additional reservoirs. I will present recent work aimed to better quantify the halogen composition of the continental crust and sub-continental lithospheric mantle, and their roles in the global halogen cycle. For example, bulk halogen concentrations of peridotite xenoliths from the Navajo Volcanic Field (Colorado Plateau, USA) show CI, Br, and I enrichments relative to the depleted mantle, consistent with fluid contributions from the subducting Farallon plate resulting in sequestration of halogens in the North American sub-continental lithospheric mantle (Segee-Wright et al., 2023). On-going work on intermediate -to-felsic igneous rocks from the Sierra Nevada range (California, USA) shows that halogens do not preferentially enrich plutonic or volcanic sections of a continental arc system, and that mafic mineral phases may be the predominant halogen reservoirs in intermediate to felsic igneous rocks. Future work is needed to include halogens trapped in fluid inclusions to these Earth reservoir budgets.



## **Keynotes**

## Talk

The power of fluid metasomatism preserved by the geochemistry of silicates trapped in mantle diamonds.

## Mikhail S.1\*, Rinaldi M.2, Sverjensky D.A.3

<sup>1</sup> School of Earth and Environmental Sciences, University of St. Andrews, St Andrews, United Kingdom, <sup>2</sup> Department of Geology, Trinity College Dublin, Dublin, Ireland, <sup>3</sup> Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, United States

#### \*sm342@st-andrews.ac.uk

Keywords: metasomatism, thermodynamic calculations, fluid-phase equilibria

Mineral and fluid inclusions trapped within diamonds from Earth's interior provide essential information concerning the history of Earth's otherwise inaccessible interior and the nature of the deep carbon cycle over the past 3.5 billion years. The geo-chemical and petrological diversity of diamond inclusions either reflects [i] mantle heterogeneity and/or [ii] the processes(s) of diamond-formation. These options are not mutually exclusive, but misinterpreting the origin of these mineral inclusions in diamond will generate inaccurate geodynamic models. I will present recently published work alongside exciting ongoing and projects which suggest that geodynamic models derived via the (mis)interpretation of diamond inclusion record require a significant re-evaluation. For example, the abundance of carbon in the fluids controls the behaviour of the bivalent ions through the formation of aqueous Mg-Ca-Fe-C complexes which directly govern the composition of garnets and clinopyroxenes precipitated by fluid-rock metasomatism. Moreover, we find that the role of the fluid metasomatism appears to be more important than the one played by host rock mineralogy. Therefore, the paragenetic groups used to classify diamonds should not be considered a genetic classification – which means some conceptual geodynamic models may need to be re-thought or re-drawn.

#### Reference

Mikhail et al. (2021), Geochem. Perspectives Letters, 17, 33-38. Rinaldi et al. (2023), Geochim. Cosmochim. Acta, 356, 105-115.



Caption: Garnet compositions from nature (blue points) and two modelled trends (purple and orange) from Mikhail et al., (2021) and Rinaldi et al., (2023).



## **Keynotes**

## Talk

#### Fluids in ore-forming processes as seen from in situ studies in a hydrothermal autoclave.

Sanchez-Valle C. 1\*, Louvel M.2, Diagileva D.1, Springklee C.1, Testemale D.3, Hazemann J-L.3

1 Institute of Mineralogy, University of Münster, Münster, Germany, 2 Institut des Sciences de la Terre d'Orléans, Univ. Orléans, Orleans, France,

**3** Institut Néel, CNRS, Université Grenoble Alpes, Grenoble, France

\*sanchezm@uni-muenster.de

Keywords: experiments, ore deposits, hydrothermalism

Aqueous fluids are important player in transcrustal magma processes, including those leading to the genesis of world-class magmatic-hydrothermal ore deposits. Fluids are subject to significant variations in pressure and temperature, which modify their physical-chemical properties and thus affect their circulation in magmas and host rocks, and their ability to mobilize and transport other elements, including volatiles and metals, between deep and surficial reservoirs.

A robust quantitative understanding of these processes relies on predictive models for complex fluids supplied by experimental databases. Yet, experiments involving fluids remain challenging and call for in situ probes due to their unquenchable nature.

Here progress in monitoring in situ the chemical composition, the molecular structure and thermodynamic quantities of magmatic-hydrothermal fluids in the crust will be discussed in the light of synchrotron-based spectroscopic studies in a hydrothermal autoclave. In particular, we will present the results of original approaches to constrain: 1) the density and phase relations of fluids in the H<sub>2</sub>O-CO<sub>2</sub>-NaCl system, which are good proxies for crustal fluids; 2) the solubility of ore minerals under controlled redox conditions; and 3) the partition and transport of metals by magmatic volatiles as magmas degas and crystallize. The implications for extraction, transport and deposition of metals in the crust will be discussed.





# **Session 1**

# Sedimentary Environment - Oil & Gas



## Talk

## Volcanic and thermogenic emissions from a mafic complex intersecting a petroleum system in the Oslo Rift (Norway). <u>Capriolo M. 1\*</u>, Callegaro S.2, Aradi L.3, Ackerson M.4, Karlsen D.5, Svensen H.5

<sup>1</sup> University of Birmingham, Birmingham, United Kingdom, <sup>2</sup> University of Bologna, Bologna, Italy, <sup>3</sup> Lithosphere Fluid Research Lab, Eötvös Loránd University, Budapest, Hungary, <sup>4</sup> National Museum of Natural History, Smithsonian Institution, Washington D. C., United States, <sup>5</sup> University of Oslo, Oslo, Norway

\*m.capriolo@bham.ac.uk

Keywords: fluid inclusion, melt inclusion, oil&gas

Reference

Interaction between magmas and organic matter from host sedimentary rocks may lead to ore mineralization (Hoggard et al., 2020), hydrocarbon cracking (Senger et al., 2017) and thermogenic gas emissions (Svensen et al., 2004).

Bile Island is a tiny island in the Oslo Fjord (Norway), where Upper Silurian sandstones are crosscut by a pyrobitumenbearing sill and several dykes, which date back to the Oslo Rift activity, the northernmost branch of the 300 Myr-old Skagerrak -centred Large Igneous Province (Torsvik et al., 2008).

These intrusions represent the magma plumbing system of an adjacent basaltic volcano from the earliest phase of the Oslo Rift, and the sedimentary succession in this area contains oil and bitumen mainly sourced from Cambrian–Ordovician organic-rich shales.

Combining field observations and geochemical analyses, we reconstructed the nature of interaction processes involving basaltic melts, bitumen- and oil-bearing sandstones.

Our multi-technique approach characterized the transformation of bitumen and oil into pyrobitumen (Fig. 1) along with abundant methane ( $CH_4$ ) and ethane ( $C_2H_6$ ) emissions.

Our geochemical dataset described element exchange and mass transfer between melts, fluids and host rocks, from magmatic to hydrothermal stages, depicting a scenario with magmatic intrusions of a large mafic complex intersecting a pre-existing petroleum system.

Bile Island yields an extraordinary record, where magmatic and sedimentary carbon is synchronously released via the same volcanic vent(s).

#### Reference

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Caption: Figure 1- Chilled facies of porphyritic basalt around pyrobitumen-bearing xenoliths within the studied, dolerite sill at Bile Island (Norway).

## Talk

Carbonate diagenesis contribution to the prediction of Thermochemical Sulphate Reduction from the Western Canada Sedimentary Basin.

## Gasparrini M.<sup>1\*</sup>, Mangenot X.<sup>2</sup>, Elias Bahnan A.<sup>3</sup>

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The aim of this study is to constrain the occurrence of the Thermochemical Sulphate Reduction (TSR) reaction during the burial history of carbonate reservoirs. We focused on the Devonian reefal carbonate reservoirs of the Nisku and Leduc formations from the Western Canada Sedimentary Basin, where some hydrocarbon fields have experienced TSR and contain up to 30% of  $H_2S$ .

Seven cores were chosen from areas of the basin having experienced different thermal histories and characterized by contrasting  $H_2S$  production. Thin section petrography identified the main diagenetic events, established their spatial and temporal occurrence (paragenesis) and focused on TSR-related phases such as deep burial blocky calcite and saddle dolomite phases.

Carbon, oxygen isotope analysis on these carbonate phases togehter with fluid inclusion microthermometry and Raman spectroscopy on specific calcite and saddle dolomite samples revealed the possible crystallization temperatures, the total salinity of the parent fluids involved and their gas content. Main results indicate that saddle dolomite pre-date blocky calcite. Homogenization temperatures of fluid inclusions in dolomites vary (depending on the core of provenance) between 80 and 160 °C, with mode values always above 110 °C. Salinities of the same fluids are rather consistent and vary between 19 and 24 wt. % NaCl eq. The dolomites have positive  $\delta^{13}$ CV-PDB, possibly inherited from Devonian host carbonates, and do not contain gaseous fluid inclusions, this overall suggesting that they crystallized before H<sub>2</sub>S generation.

Homogenization temperatures of fluid inclusions in calcites vary (depending on the core of provenance) between 80 and 180 °C, with mode values always above 130 °C. Fluid salinity vary largely between 12 and 24 wt. % NaCl eq. The calcites have fairly negative  $\delta^{13}$ CV-PDB down to -23‰ and consistently contain gaseous (H<sub>2</sub>S-rich) fluid inclusions displaying clathrate dissociation at temperatures up to 13 °C, this suggesting that they formed after H<sub>2</sub>S generation. These calcites are possibly a byproduct of the TSR reaction and represent the best candidates to gather further constraints on the TSR process in this basin.

The thermal information obtained from fluid inclusions was combined with the burial-thermal history modelled for Devonian rocks. This allowed to infer possible timing for the occurrence of TSR reaction at basin scale. Further constraints will provided by U-Pb carbonate geochronology.



## Poster

Fluid inclusion constraints on overpressure evolution in Wufeng-Longmaxi shales, southeastern Sichuan Basin. <u>He Q.</u>1;2\*, Dong T.2, Steele-MacInnis M.1, Lecumberri-Sanchez P.1 <sup>1</sup> University of Alberta, Edmonton, Canada, <sup>2</sup> China University of Geosciences (Wuhan), Wuhan, China

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Fluid overpressure is a key aspect of natural gas generation, migration, and accumulation. This study investigates overpressure dynamics in the Wufeng-Longmaxi shales, southeastern Sichuan Basin, where adjacent wells show contrasting present-day pressures: either hydrostatic, or significantly overpressured (>70% lithostatic). We assess whether normal (~hydrostatic) pressured shales never developed overpressure, or rather lost prior overpressure over geologic time. Key findings reveal that both sets of wells experienced intense early overpressure (120-106 Ma) from gas generation during deep burial. Divergence between their subsequent pressure regimes occurred during tectonic uplift: currently normal-pressured zones underwent rapid uplift during the late Yanshanian orogeny (Late Cretaceous), which reduced their gas retention capacity and allowed pressure to dissipate. In contrast, overpressure was preserved in areas that experienced gradual uplift, maintaining seal integrity. Analysis of fluid inclusions hosted in shale fracture veins directly tracks these contrasting pressure trajectories. This work establishes that pressure differences reflect differential tectonic histories rather than distinct source properties.



#### Poster

## Molecular fractionation of ancient organic compounds in deeply buried halite crystals.

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Keywords: fluid inclusion, oil&gas, sedimentary basins

The molecular fractionation of organic compounds through adsorption in minerals has wide implications, including tracing the origins of life, carbon sequestration, and climate change.

Here we present the first in situ examination of molecular fractionation within individual crystals via optical-photothermal infrared (O-PTIR) spectroscopy. Our study focuses on a unique inclusion trail within deeply buried halite crystals, characterized by a distinctive orange-to-blue fluorescence gradient, providing primary evidence of molecular variation in ancient carbon-based fluids within the inclusion trail (Fig. 1).

The findings reveal a trend in the CH<sub>2</sub>/C=O and CH<sub>3</sub>/C=O ratios, conforming with a consistent decrease from the blue fluorescence region to the orange fluorescence region. The chemically influenced fluorescent behavior of these ancient liquid carbon-based compounds is attributed to the fractionation of fluids in the inclusions as a result of microfractures within the crystal acting as chromatography capillaries. These capillaries facilitated interactions between specific organic compounds, serving as adsorbates, and the halite mineral, representing the adsorbent.

Our study provides insights into the fluid–solid physicoche mical interactions within extreme environments and extends our understanding of molecular processes in such settings (Liu et al., 2024).



Caption: Figure 1- UV light image of fluorescing inclusions varying from orange (left) to blue (right) along the trail, with O-PTIR point measurements of (CH<sub>2</sub>+CH<sub>3</sub>) /C=0.



#### **Poster**

## Ore-forming conditions of the Piani Resinelli Zn-Pb deposit (Lombardy, Italy): insights from fluid inclusions. Summino L.<sup>1\*</sup>, Giorno M.<sup>2</sup>, Barale L.<sup>3</sup>, Bertok C.<sup>1</sup>, Frenzel M.<sup>2</sup>, Gasparrini M.<sup>4</sup>, Martire L.<sup>1</sup>

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Keywords: hydrothermalism, diagenesis, ore deposits

The Piani Resinelli deposit is a stratabound, carbonate-hosted Pb-Zn Alpine-type deposit (a subclass of the well-known Mississippi Valley-type deposits, MVT). The orebodies are hosted by the lower Carnian stratigraphic succession of the Lombardian Basin, which experienced a complex diagenetic evolution resulting in variable styles of host-rock modification rocks (brecciation, dissolution) and ore mineral precipitation. U-Pb radiometric dating on ore-associated carbonates reveals a late Carnian-early Norian age for the sulfide mineralization, and an early Jurassic age for the latest calcite cements.

Fluid inclusion (Fl) analyses were performed both on ore-related minerals like (in order of precipitation) dolomite (Dol), sphalerite (Sp, Fig.1), and fluorite (Fl), and on post-ore calcite (Cal). For the purposes of this study, only the primary Fls were considered. The syn-ore fluids are characterized by homogenization temperatures (Th) increasing from 51—90°C (Sp) to 78—163 °C (Fl), eutectic temperatures (Te) between -43 to -51 °C (suggesting a CaCl<sub>2</sub>-NaCl-H<sub>2</sub>O system), and salinity values decreasing from 22.5—18.2 (Sp) to 18.9—9.1 (Fl) eq. wt% of NaCl+CaCl<sub>2</sub>. Fls from late calcite reveal Th between 98—132 °C, Te between -21 to -19 °C (suggesting a NaCl-H<sub>2</sub>O system), and salinities between 5.1 and 9.1 eq. wt% of NaCl.

The resulting data demonstrate the involvement of moderately hot, high-salinity brines during ore precipitation. Ore-precipitation occurred at a relatively shallow burial depth during the late Triassic revealing the hydrothermal nature of the ore-forming fluid. Ore precipitation has been interpreted as the result of a mixing between a hot metal-bearing fluid and a low-temperature connate seawater rich in reduced sulfur (which is typically suggested as mechanism for ore precipitation in MVT deposits). The lower Th measured on Sp has been interpreted as the dominance of the cooler seawater rich in reduced sulfur during sulfide precipitation, whereas the higher Th measured in Fl has been interpreted as the dominance of the deep metal-bearing fluid during Fl precipitation. Finally, post-ore Cal precipitation represents the later cementation of the remaining voids during the circulation of hydrothermal fluids linked to the early Jurassic rifting phase.



Caption: Figure 1- Microphotograph in transmitted light of fluid inclusions in sphalerite.





# **Session 2**

# Magmatism



## Session 2: Magmatism

## Talk

Melt inclusions and embayments in olivine – determination of magma ascent rates and tracing mafic replenishment processes. <u>Belousov I.</u>1\*, Danyushevsky L.2, Oalmann J.1

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The rate at which magma ascends to the surface is a critical parameter governing the style and intensity of volcanic eruptions. Melt embayments are re-equilibrating with the melt surrounding crystal through diffusion processes. The surrounding melt changes its composition on the way from magma chamber to the surface. Therefore, diffusion profiles of volatile elements from the center of embayment towards an outside melt can be used to determine rates of magma ascent and paths of its evolution. Melt embayments could be also used to trace magma mixing processes.

We have studied melt inclusions as well as melt embayments in olivine using a combination of EPMA, LA-ICP-MS and LA-ToF mapping from two volcanoes from Kamchatka: Karymsky (1996 eruption) and Tolbachik (2013 eruption). Both magmas erupted were basaltic in compositions, however during 1996 Karymsky eruption basaltic magma erupted into a shallow lake near the volcano, but also replenished the andesitic magma chamber. Eruption of basaltic magma into the lake resulted in efficient quenching of melt in inclusions and embayments. Additionally, resorbed olivine phenocrysts were also found in the andesitic magma which was erupting from main vent of andesitic Karymsky volcano for several months following the basaltic recharge. This study provides new constraints on magma ascent rates and mafic recharge mechanism and assesses usability of trace element profiles and mapping of melt embayments in olivine for such purposes.



Caption: Examples of quenched melt embayments in olivine from Karymsky and Tolbachik volcanoes.



## Session 2: Magmatism

## Talk

## Spatio-temporal reconstruction of the magma plumbing system of Santiago and Santo Antão islands, Cape Verde archipelago. Lo Forte F.M., 1\*, Rizzo A.L.2, Aiuppa A.1, Frezzotti M.L.2, Maffeis A.2, Zanon V. 3

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Keywords: fluid inclusion, magmatism, volcanism

The Cape Verde archipelago represents a key volcanic setting in Eastern Atlantic for investigating the dynamics of OIB magmatism. Despite its long-lived and spatially distributed volcanic activity, the architecture and evolution of magma plumbing systems beneath the less active islands remain poorly constrained. Understanding the depth, structure, and temporal variability of these systems is crucial for deciphering mantle melting processes, crustal magma storage, and volatile transfer from source to surface. In this context, the role of deep CO<sub>2</sub>-rich fluids and their entrapment in fluid inclusions provides valuable insights into the volatile budget and magmatic evolution beneath Cape Verde.

We present novel microthermometric analyses of pure CO<sub>2</sub> fluid inclusions hosted in olivine (Fig. 1) and pyroxene phenocrysts from mafic tephra samples to reconstruct the evolution of trans-crustal magma plumbing systems beneath Santiago and Santo Antão islands in the Cape Verde archipelago. Our results reveal that the magmatic systems beneath both islands exhibit a vertically extensive and complex architecture, comprising: (i) a deep magma reservoir (~31–33 km, Santiago; ~38–40 km, Santo Antão); (ii) a main storage zone (~23–25 km, Santiago; ~20–30 km, Santo Antão); (iii) a stagnation zone near the mantle–crust boundary (~18–20 km, Santiago; ~10–14 km, Santo Antão).

Compared to previous barometric estimations from Fogo volcano (Cape Verde) and other similar intraplate volcanic islands, these systems are characterized by multiple magma storage levels populated by small magma batches and separated by non-eruptive, crystal mush zones. This architecture reflects dynamic processes of magma storage, stagnation, and transport across the crust-mantle transition.

Our findings will be integrated with ongoing analyses of pre-eruptive volatile contents in melt inclusions to address two key objectives:

(i) tracking spatio-temporal variations in CO<sub>2</sub> concentrations across the Cape Verde archipelago and within individual eruptive episodes;

(ii) constraining the carbon content of the mantle source.



Caption: Figure 1- Photomicrograph of fluid inclusions in olivine phenocryst form Santiago Island. L-liquid phase, V- vapour phase.



## Session 2: Magmatism

## Talk

## Melt inclusion composition of the 2021-2023 Fagradalsfjall eruptions, Iceland.

## Merrill H.1\*, Bali E.1, Caracciolo A.2, Matthews S.1, Halldórsson S.1, Kunz B.3, Jenner F.3

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Keywords: melt inclusion, mantle, volcanism

The whole-rock compositions of Iceland's Fagradalsfjall 2021-2023 lavas (Halldórsson et al., 2022; Caracciolo et al., under review) record temporal changes indicative of parental melt variability (Fig. 1). Homogenization of melts during storage, mixing and transport to surface can obscure the true magnitude and cause (e.g., mantle source heterogeneity and melting dynamics) of the parental melt variability. Hence, we undertook major (EPMA; n=835) and trace element (LA-ICP-MS; n=191) analyses of melt inclusions (MI) that were trapped during different stages of the genesis of the carrier lavas.

Our analyses of MIs hosted in olivine, plagioclase and clinopyroxene show a range in compositions that significantly exceeds those of their carrier melts each year (Fig. 1). These systematics demonstrate accumulation of melts from varying melting conditions and significant mixing of heterogenous melts prior to eruption. The range in Dy/Yb vs. La/Yb reveal a substantial contribution from shallow-sourced (low Dy/Yb) depleted melts that are mixed with enriched melts (high La/Yb) sourced from deeper in the mantle. The enriched deep-sourced melts became increasingly prevalent from 2021 to 2023.

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Caption: Figure 1- Dy/Yb vs. La/Yb of the Fagradalsfjall MIs, whole-rock (WR) and Reykjanes Peninsula (RP) historical lavas (Peate et al. 2009).





# **Session 3**

# **New frontiers - Theory - Experiments**



Talk

Hydrogen in fluid inclusions. Bakker R. J. 1\* 1 Resource Mineralogy, Montanuniversity Leoben, Leoben, Austria

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The interest in hydrogen is recently inflated due to its economic value for sustainable energy supply and mobility. Natural hydrogen is part of this interest. Although hydrogen is the most abundant element in the universe, it is relatively scarce on Earth. Hydrogen can be produced through industrial chemical processes, which, however, diminish the perceived cleanness of this energy source. The origin of  $H_2$  in the aerth crust and mantle is twofold: either primordial or produced by geological processes, and part of this hydrogen is preserved in fluid inclusions. Processes that produce hydrogen include serpentinization, radiolysis, and fluid-rock interactions under highly reduced conditions. There are only a few accessible scientific studies that document the presence of  $H_2$  in fluid inclusions, directly related to these processes. Mafic/ultramatic rocks in ophiolites are often affected by serpentinization, which is locally accompanied with rodingitization processes. The mineralogy of fine-grained serpentinites does not favour the trapping and preservation of fluid inclusions. As a result, H<sub>2</sub>-rich fluids will primarily remain free in pore spaces, allowing them to escape the rock system through seeps. However, coeval rodingites (Ca-rich metasomatic alteration of mafic rock) may trap these fluids in coarse-grained diopside and garnet crystals, providing information about serpentinization and rodingitization. A preliminary study of rodingites from the ophiolitic complex of Troodos (Cyprus) reveals the presence of abundant hydrogen in fluid inclusions (Fig. 1). In addition,  $H_2$  is detected in fluid inclusions in podiform chromitites (Fig. 1), indicating that hydrogen was already present in the primary processes of ultramafic magma evolution. In a new project financed by the Austrian Science Fund (FWF, PAT5274524) the locality of hydrogen-rich fluid inclusions will be identified in a geological context to understand processes of hydrogen formation and trapping in natural rock. This study will be complemented with an experimental study about efficiency of hydrogen diffusion, that may cause post-entrapment modifications of fluid inclusions.



Caption: hydrogen-rich flui inclusions in chromite an diopside.



#### **Poster**

Software package FLUIDS: a review. <u>Bakker R. J.</u> 1\* <sup>1</sup> Resource Mineralogy, Montanuniversity Leoben, Leoben, Austria

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The software package FLUIDS has been in existence for 25 years and includes a large variety of programs designed to model fluid properties in geological environments. It incorporates the most accurate and highly complex thermodynamic models, which have been adapted specifically for fluid inclusion research. The benefits of using these models include a more accurate reproduction of experimental data and improved extrapolation capabilities. While there is widespread satisfaction in the literature with the use of oversimplified models, a similar approach to continuous improvements seen in analytical techniques could be applied to modelling fluid inclusions properties, effectively pushing the limits'. The limitations of oversimplified models include greater uncertainties, which can lead to incorrect values. The first generation of the FLUIDS package featured a simple input-output interface (SIOUX) for fluid mixtures that may include  $H_2O-CO_2-CH_4-N_2-C_2H_6-H_2S-NH_3-H_2-O_2-CO$  and NaCl-KCl-CaCl<sub>2</sub>-MgCl<sub>2</sub>-FeCl<sub>2</sub>. Both challenging thermodynamic models and simple, purely empirical models of limited systems can be handled with this software. Fluid property calculations are based on the input of homogenization temperatures, dissolution temperatures, and volume fraction estimates. Gas compositions can be defined by additional Raman spectroscopic analyses. The occurrence of gas hydrates in inclusions is handled with other software: the package CLATHRATES (Bakker, 1997). Subsequent programs have been equipped with flexible Graphical User Interfaces (GUIs). Additional gas mixtures of noble gases, alkanes, and isotopic variations are included. The programs are designed to model a comprehensive range of properties calculable using equations of state, including homogenization conditions, liquid-vapour equilibria, corrected isochores, activities, fugacities, spinodal curves, critical points, thermodynamic properties (e.g., Helmholtz energy, Gibbs energy, Enthalpy, Entropy), viscosity, re-equilibrated properties, and diffusion profiles. Fluid modelling is not restricted to fluid inclusion research, and can also be applied to other research fields that involve a fluid phases The software package can be freely downloaded using the QR codes provided in Figure 1 and is continuously updated and expanded with new programs.



Caption: Scan the QR code to visit our website and download the software.



Talk HORIBA Solution for Earth Sciences: Techniques and Applications. <u>Barbini P.</u>1\* 1 Horiba, Roma, Italy

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A complete microscopic characterization of certain geological samples is very complex, particularly on studies related to their spatial distribution of the mineral phases and inclusions composition. Indeed, structural, elemental and chemical variations on the micro- or nano-scale are hard to observe by a single instrument, like a simple optical microscope, or even a scanning electron microscope (SEM). A comprehensive evaluation by multiple techniques is key for a good understanding of the material properties. However, multi-technique studies generally lead the user to physically move the sample among different instruments. This approach can become even more difficult if the user is interested in evaluating a specific area or pattern.

HORIBA is proposing several different techniques to analyze Earth Sciences samples (rocks, mineral, meteorites, gems, jewels, etc) like Raman Spectroscopy, X-Ray Microfluorescence, Particles Characterization, Ellipsometry, etc.



#### Talk

Stable isotopic (H, O) analysis of individual fluid inclusions by cryo-Time of Flight Secondary Ion Mass Spectrometry. (cryo TOF-SIMS)

## Bodnar R.J.<sup>1\*</sup>, Dolocan A.<sup>2</sup>, Zolensky M.<sup>3</sup>, Gearba-Dolocan I.R.<sup>2</sup>, Prouty J.<sup>1</sup>

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Keywords: fluid inclusion, new frontiers, planetary science

One of the most widely used tools to determine source(s) of H2O associated with various geological and planetary processes is the D/H and 180 isotopic composition of the H<sub>2</sub>O. Traditionally, the H & O isotopic composition of water associated with various processes that occur in the deep earth has been through bulk analysis of waters released from fluid inclusions (FI) during crushing or heating to decrepitate FI, or by calculating the water composition based on analysis of the isotopic composition of the host mineral combined with an assumption of the trapping temperature and partitioning behavior. The former method is limited by the presence of fluids of many different generations, and having different isotopic compositions in most samples, whereas the latter is limited by potential reequilibration between fluid and host during cooling. Here, we describe preliminary results of an ongoing study to measure the H & O stable isotopic composition of individual FI using cryo-Time of Flight Secondary Ion Mass Spectrometry (cryo-TOF-SIMS). With this technique, the sample containing Fl is cooled to approximately -150°C under ultra-high vacuum, and the sample is ablated with a Cs± ion beam. The sample is monitored continuously to determine when the FI beneath the sample surface has been intersected. A single analysis can take up to 24 hours, depending on the depth of the FI beneath the surface and the size of the FI.

Results obtained from analyses of mineral standards with known isotopic composition were promising, and thus we have begun to analyze fluid inclusions with known isotopic compositions. Analysis of a synthetic fluid inclusion in halite with a known D/H of 0.0005 but unknown 180/160 showed that reliable results are obtained when hydrogen isotopes are measured by setting the analysis gun in "Spectrometry Mode, producing a constant mass ratio as a function of ablation time (Figure 1).

Preliminary results suggest that the H & O stable isotopic composition of individual fluid inclusions can be measured with sufficient precision and accuracy to distinguish various extraterrestrial water sources, including bulk solar system, cometary water, and ordinary and carbonaceous chondrite waters. Current efforts are focused on improving the analytical precision to distinguish different terrestrial water signals.



Caption: Figure 1- Hydrogen isotopic ratio of a synthetic FI in halite obtained by cryo-TOF-SIMS.



## Talk

Identification of LiCI hydrates by Raman spectroscopy. <u>Caumon M.-C.</u> 1\*, Tarantola A. 1, Hussard C. 1, Chauvel G. 1, Segui M. 1 1 Université de Lorraine, CNRS, GeoRessources, Nancy, France

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Li can reach high concentrations in natural fluids and thus be traced in fluid inclusions (Dubois et al., 2010). The ionic composition of aqueous fluid inclusions can be determined by Raman Spectroscopy (RS) as an alternative to microthermometry for complex compositions. However, the salinity measured by RS depends on chlorinity, this technique being enable to detect monoatomic ions. The only way to identify the cation is to generate hydrates by coupling it with the microthermometry technique. Hydrates are identified by the signals of the OH vibration modes. However, the signals can be complex to interpret, due to the presence of several modes of vibration and crystal sites of H<sub>2</sub>O, vibrational couplings, or harmonics.

Some Raman spectra of salt hydrates are available in literature (e.g. Baumgartner & Bakker, 2010; Chu et al., 2016; Dubessy et al., 1982; Uriarte et al., 2015). While the spectra of hydrohalite and antarcticite appear to be consensual, there are slight to severe differences regarding other salt hydrates. These variations are most likely related to how challenging it is to determine which hydrate has been analyzed: complexity of the phase diagram, metastability of these hydrates, difficulty in controlling the chemical composition of the sample during the multiple preparation stages and differences in analysis temperature.

To the best of our knowledge, there is no Raman spectrum of identified LiCl hydrates in literature. Here a database of Raman spectra of LiCl hydrates at different temperatures is built (Fig. 1) using silica microcapillary as synthetic fluid inclusions (Caumon et al., 2013). Generating hydrates in LiCl media is challenging because of strong metastable behavior. Nonetheless, LiCl·2H<sub>2</sub>O and LiCl·3H<sub>2</sub>O are identified based on the observation of the peritectic temperatures, their Raman spectra as a function of temperature, and their signature in 5% D<sub>2</sub>O solutions.

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Caption: Raman spectra of LiCI-2H2O and LiCI-3H2O.

## Talk

## Natural H<sub>2</sub> produced during slab exhumation: a fluid inclusion record from the Western Alps.

## Ferrando S.<sup>1-3\*</sup>, Frezzotti M.L.2

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Keywords: new frontiers, metasomatism, fluid inclusion

Natural H<sub>2</sub> is considered the cheapest energy source and the one with the lowest carbon footprint among the H<sub>2</sub> sources considered in the green economy. However, natural H<sub>2</sub> is often mixed with other gases (in particular, CH<sub>4</sub>) and is rarely present in high molar ratios.

Natural  $H_2$  trapped in fluid inclusions allows us to understand the geological processes responsible for  $H_2$  production, preservation (storage) or mobilization.

In HP rodingite from the Piemonte ophiolite Zone (W Alps), primary fluid inclusions (Fig. 1) occur in vesuvianite veins that formed at P=0.2 GPa and T=375°C. During slab exhumation, at ca. 500-375°C and P=2.0-0.2 GPa, retrograde serpentinization of olivine in presence of water produces reducing fluids containing H<sub>2</sub> and, in presence of carbonates, CH<sub>4</sub> (i.e., Fo + H<sub>2</sub>O = Atg + Brc and the linked reactions: Fa + H<sub>2</sub>O = Fe-Atg + Mag + H<sub>2</sub> and Atg + CaCO<sub>3</sub> + H<sub>2</sub> = Di + Brc + CH<sub>4</sub> + H<sub>2</sub>O).

Microthermometry and micro-Raman spectroscopy on the primary fluid inclusions reveal that the fluid is a brine (6 wt% CaCl<sub>2</sub> + 6 wt% NaCl) with H<sub>2</sub> + CH<sub>4</sub>  $\leq$  1 mol% and H<sub>2</sub>/(H<sub>2</sub>+CH<sub>4</sub>) = 0.40-0.92.

The amount of  $H_2$  produced depends on the amount of available water and olivine. Its fate after production is still enigmatic due to its low viscosity and high diffusivity. However, the presence of a high molar ratio of  $H_2$  in most of the analyzed FI raises intriguing questions about its diffusivity in some minerals.



## Talk

Pfaffenbergite & "Phase 430", new minerals crystallizing in melt inclusions.

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The systematic use of micro-Raman spectroscopy has revealed the presence of two novel crystalline phases in crystallized melt inclusions.

The first is a feldspar polymorph, pfaffenbergite  $KNa_3(Al_4Si_{12})O_{32}$ , which has the composition of an unmixed binary K-Na feldspar. Its micro-Raman spectrum displays a very strong vibrational mode at 412 cm<sup>-1</sup> (hence its informal name of "phase 412"), two secondary peaks at 105 cm<sup>-1</sup> and 832 cm<sup>-1</sup> and two weaker peaks at 130 cm<sup>-1</sup> and 470 cm<sup>-1</sup>. Pfaffenbergite is a hexagonal mineral, crystallizing in space group P6/mcc. This mineral is a sheet silicate isostructural with kokchetavite (KAlSi<sub>3</sub>O<sub>8</sub>) and wodegongjieite [KCa<sub>3</sub>(Al<sub>7</sub>Si<sub>9</sub>)O<sub>32</sub>]. The latter is a mineral recently found as crystallization product of melt in inclusions found in the corundum from chromitite from the Luobusa ophiolite (Tibet, China), and subsequently with pfaffenbergite in garnet from the Saxony Granulite Complex.

The second novel mineral is provisionally called "phase 430" from its main micro-Raman vibrational mode. Three secondary peaks are present at 186 cm<sup>-1</sup>, 264 cm<sup>-1</sup> and 292 cm<sup>-1</sup>, along with two weaker peaks at 485 cm<sup>-1</sup> and 823 cm<sup>-1</sup>. Our results show that this phase has the ideal formula KK<sub>2</sub>Na<sub>3</sub>(Al<sub>6</sub>Si<sub>36</sub>)O<sub>84</sub> and crystallizes in the P6/mcc space group with a topology not yet reported as far as we know. We interpret pfaffenbergite, wodegongjieite and "phase 430" as metastable phases crystallizing rapidly in a small pore under non-equilibrium conditions.



## Talk

## Freezing experiments on intrasediment gypsum crystals of the Duero sedimentary Basin (Spain).

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Keywords: experiments, sedimentary basins, diagenesis

Cenozoic lacustrine gypsum crystals from the Cuestas Fm in the Duero Basin (Portillo, Valladolid, Spain) were studied to measure the salinity of the paleofluids. Millimetrical-size crystals were obtained by cleaving gypsum along the (010) with a razor blade. These fragments were petrographically studied, and two types of fluid inclusions (FI) were recognized (Fig. A): 1. Primary FI, which follow the growth zones marked with solid inclusions of marl. They present irregular shapes and sizes between 2-50 µm. 2. Secondary FI present negative crystal shapes and sizes up to 150 µm. Both types of FI are mostly all-liquid at room temperature (Fig. A, B, D). Primary FI are interpreted as formed in a phreatic environment and secondary FI as related to cleavage planes. Different freezing cycles were tried in order to nucleate bubbles to measure final melting of ice temperature (T<sub>m</sub>ice). We followed the protocol of Bigi et al. (2022) (from -100°C to +120°C) and a shorter one (from -100°C to +20°C, Fig. C, E) with similar results: around 10-50% of the FI nucleate a bubble during the first four runs. Around 57% of the measured FI provided a positive (irreal) T<sub>m</sub>ice, 15% lost the bubble during freezing runs (and do not recover after a week) and at least 9% of the bubbles increase in size after 1-2 days. In the FI that provided negative T<sub>m</sub>ice (19%), contrary to Bigi et al.(2022), we did not usually obtain replicable T<sub>m</sub>ice results in individual FI.

Contribution to PID2022-140713NB-I00

#### Reference

Bigi et al. (2022), Geology, 50, 454-459



Caption: A. Primary and secondary FI in gypsum. B & C. Black inset (mainly secondary FI). B: Before freezing: FI are all-liquid with only one exception (blue arrow). C. After freezing (-100 to +20°C), many FI have nucleated a bubble (black arrows). D & E. White inset (mainly primary FI). Before (D) and after freezing (E). D is slighly tilted. All photographs are with parallel nichols and at room T.



### Talk

The role of hydrous monolayers in amphibole formation and growth in the lithosphere.

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Keywords: fluid inclusion, new frontiers, mantle

Volatile diffusion along grain boundaries in the lithospheric mantle is an important mechanism that can result in volatile accumulation and the formation of volatile-rich minerals. Enrichment of high-polarity fluid complexes can occur at solid-fluid interfaces, generating hydrous monolayers in which, for example, H<sub>2</sub>O and OH-fluid complexes are enriched compared to the bulk free fluid (Schoch et al., 2005). The geochemical difference between the bulk fluid and the fluid at the solid-fluid interface suggests that the two fluids have different physical-chemical properties. The accumulation of the fluid at the interface can promote hydrous mineral formation.

In mantle environment, amphibole nucleation and growth are critical processes for mantle  $H_2O$  consumption. Because  $H_2O$  dissolves silicate components such as Na, Al, and Si, the consumption of  $H_2O$  into the solid phase will influence the molecular behaviour of the residual fluid.

To understand the molecular evolution of mantle fluids, we studied a clinopyroxene-amphibole-fluid inclusion system within an upper mantle xenolith, from the Carpathian-Pannonian region. The entrapped fluid is CO<sub>2</sub>-rich (>95 mol%), associated with H<sub>2</sub>O and silicate-derived components (Na, Al, Si) (Lange et al., 2023). Along the clinopyroxene-fluid interface a hydrous monolayer formed as a result of the polarity difference between CO<sub>2</sub> and H<sub>2</sub>O. This monolayer is enriched in H<sub>2</sub>O and dissolved silicate components (Si, Al, Na) and supports amphibole formation. The model provides a possibility to better understand amphibole formation in the upper mantle at the nanoscale.

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#### **Poster**

## Relative Raman cross-sections of powdered minerals: implications for 3D Raman mapping of fluid and melt inclusions. <u>Myovela J.L.</u>1;2;3\*, Aradi L.E.4;5, Spránitz T.3;4, Németh T.1;6, Miklósy A.1, Kovács J.1;7, Berkesi M.3;4

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Keywords: fluid inclusion, melt inclusion, new frontiers

Variable Raman scattering properties of phases in inclusions may cause over- or underrepresentation of the phases in their 3D Raman models, hindering the determination of their volume ratios, which may affect geological interpretation (Aradi et al, 2023; Myovela et al, 2025). Improving these models requires understanding the Raman cross-sections of trapped phases. We aim to determine relative Raman

cross-sections (RRCS) or intensity ratios of minerals in both crystal and powder forms and assess their effect on 3D Raman models of inclusions. Mineral samples, commonly in garnet-hosted fluid inclusions of HT-HP metamorphic rocks (Aradi et al., 2023; Spránitz et al., 2022),, were ground into powders (< 10 μm) to reduce crystal orientation effects during Raman analysis. X-ray diffraction analysis, conducted at Szentágothai Research Centre of the University of Pécs (Pécs), was used to confirm the purity of the powdered minerals. Raman analyses were performed using three Raman instruments at the Research and Industrial Relations Center of the Faculty of Science (Eötvös Loránd University, Budapest), the Archaeometry Laboratory of the National Institute of Archaeology (Budapest), and the Institute of Biophysics (University of Pécs, Pécs). Raman intensity ratios of single euhedral crystals (neon lamp as a standard) were measured based on their orientation. Orientation-controlled Raman analyses were performed on euhedral crystals, besides the powders. A 15:85 garnet (standard):mineral volume ratio was used to obtain Raman intensity ratios from three different Raman instruments on powdered minerals. Preliminary results show that hexagonal single crystals show the lowest RRCS along the c-axis when compared to the crystals from other crystal systems. Powdered carbonates and gypsum show high RRCS values of 9.3-24.7 and 11.8, respectively (Fig. 1). In comparison, the RRCS values of pyrophyllite (2.3), enstatite (0.9), corundum (0.6), and chlorite (0.3) are significantly lower, which may pose challenges in accurately determining their volume ratios in inclusions during 3D Raman mapping. We revealed that the RRCS of the powdered minerals do not significantly change across different instruments and garnet compositions. Our study shows that dolomite, calcite, siderite, ankerite, and gypsum are the best Raman scatterers; quartz is a good Raman scatterer; and pyrophyllite, enstatite, chlorite, and corundum are the worst Raman scatterers.

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Caption: Figure 1- Average relative Raman cross-sections of powdered minerals at their strongest Raman peaks (1/cm), obtained from different Raman instruments.

### Poster

Carbon contents in subduction-related primary melts: High-P&T experiments on melt inclusions. <u>Nikogosian IK.</u>1\*, Westrenen W.1, Koornneef J.M.1, De Hoog J.C.M.2 <sup>1</sup> Vrije Universiteit, Amstredam, Netherlands, <sup>2</sup> The University of Edinburgh, Edinburgh, United Kingdom

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Different components of subducted crust are the main agents responsible for carbon enrichment in the mantle. Carbon dioxide  $(CO_2)$  concentrations in primary magmas play an important role in the characterization of such subducted components. Melt inclusions (MI) trapped in high-Fo olivines are expected to yield the most realistic estimates for  $CO_2$  concentrations in primary melts. However post-entrapment modification of MI during transport to the surface lowers the pressure inside, resulting in changes of  $CO_2$  solubility and exsolving  $CO_2$  from melts to shrinkage bubbles. "Traditional" partial homogenisation experiments of MI at 1 atmosphere indicate that up to 90% of all  $CO_2$  in a MI can be transferred to a shrinkage bubble, and that empirical  $CO_2$  back-calculation procedures introduce > 50% uncertainties.

In this study we present pioneer results of high pressure and high temperature (8-20 kbar – 1350-1450°C) experiments in which we achieved complete homogenization of MI in olivines from subduction-related lavas, re-establishing the initial CO<sub>2</sub>. We show results for different types of magma and geodynamic settings, e.g. classical Island ARC (Marina ARC), and postcollisional lavas from Italy (Vulsini and Aeolian islands), representing mantle modification by two different subducting slabs (Adriatic and Ionian). The diversity of carbon-rich inputs to the subduction-modified mantle, as well as comparison between empirical and experimental results will be discussed.




#### Talk

The system Na<sub>2</sub>O + CO<sub>2</sub> + H<sub>2</sub>O ± SiO<sub>2</sub>: Experimental study on phase relations and the solubility of pyrochlore. Schmidt C.<sup>1\*</sup>, Horn I.<sup>2</sup>, Nikolenko A.<sup>1</sup>, Veksler I.V <sup>1</sup>

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Keywords: fluid-phase equilibria, experiments, ore deposits

Evidence from inclusions indicates that the system  $Na_2O+CO_2+H_2O$  can be used as a relatively simple model for fenitising fluids and natrocarbonatites. Very little is known about the phase diagrams at high pressures and temperatures (mostly from differential thermal analysis), and on the solubility of pyrochlore, the predominant Nb ore mineral in carbonatites, in alkali carbonate and silicate fluids. Here, we used a hydrothermal diamond-anvil cell to gain information on phase relations for the bulk compositions  $H_{20}CO_{13}Na_2$  (Fig. 1),  $H_{20}CO_{13}Na_2$ +quartz,  $H_2CO_4Na_2$ , and  $HCO_3Na$  by visual observation and in situ Raman spectroscopy.

Decompression at high temperatures resulted in unmixing of two aqueous fluids, a dilute solution and the other rich in silica species (Q<sup>0</sup>, Q<sup>2</sup>, Q<sup>3</sup>) and carbonate. For H<sub>2</sub>CO<sub>4</sub>Na<sub>2</sub>, the natrite liquidus was observed at 794 °C, ~460 MPa in the presence of aqueous fluid, and showed a positive dP/dT slope. For HCO<sub>3</sub>Na, it was located at 787 °C, ~100 MPa, in the presence of two aqueous fluids. In contrast to HCO<sub>3</sub>Na, heating of H<sub>20</sub>CO<sub>13</sub>Na<sub>2</sub> did not generate detectable CO<sub>2</sub><sup>0</sup>.

Dissolution of pyrochlore resulted in a Raman band at ~870 cm<sup>-1</sup> assigned to Nb–O stretching vibrations. Based on integrated intensities of Nb–O, Si–O, and C–O stretching bands, the Nb concentration released from pyrochlore at 600 °C was much higher if quartz was added. In a SiO<sub>2</sub>-free run at 600 °C, 623 MPa, the aqueous sodium carbonate liquid reacted with pyrochlore contained about 60 µg/g Nb. At 600 °C, 1456 MPa, it contained about 1 mass% Nb if quartz and pyrochlore were present. The experiments and studies of natural inclusions indicate that several types of fenitising fluids occur, with different potential to carry Nb, REE, and other elements.

#### References

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Caption: Figure 1- P-T diagram, bulk composition  $H_{20}CO_{13}Na_2$ . Nat-natrite  $Na_2CO_3$ , Aq-aqueous fluid, V-vapor, c.p.-critical point, diamonds-this study, squares-Koster van Groos (1990), triangle-Ravich (1974).

#### **Poster**

ICP-Base: a new data reduction software for LA-ICP-MS inclusion analysis. Stumpf S.1\*, Pettke T.1, Gies NB.1, Guillong M.2 <sup>1</sup> University of Bern, Bern, Switzerland, <sup>2</sup> ETH Zürich, Zürich, Switzerland

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Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has become a powerful and well-established technique for analyzing the composition of entire single- and polyphase fluid and melt inclusions. While analysis methods have been improved continuously, data reduction procedures and tools notably for transient LA-ICP-MS inclusion signals have remained largely unchanged. The few available software solutions often lack flexibility in data processing and visualization, and limited accessibility of the software code impedes development of data reduction procedures.

We therefore developed ICP-Base, a free and open-source software solution. It features an easy to use Graphical User Interface (GUI) designed to enhance control and efficiency during data reduction and evaluation of LA-ICP-MS inclusion analyses. ICP-Base streamlines data processing through a linear workflow using multiple modules and stores all information in an easily accessible centralized data structure.

Integration intervals can be defined using highly customizable visualizations and ratio plots, while host-inclusion mixed signal deconvolution is performed via linear regression using a refined host-only tracer or baseline-correction method. Data quantification with multiple external standards increases quality of results and includes robust limit of detection filtering.



Caption: Figure 1- Example of host-inclusion unmixing via baseline-correction of a LA-ICP-MS transient signal.



EUROPEAN CURRENT RESEARCH ON FLUID AND MELT INCLUSIONS

#### Talk

Fluid inclusions as an independent thermometer to evaluate the effect of fluid-assisted dynamic recrystallization on Ti-in-quartz thermometry in porphyry-epithermal deposits: Insights from Pagoni Rachi (NE Greece).

#### Tarantola A.<sup>1\*</sup>, Abiven B.<sup>1</sup>, Richard A.<sup>1</sup>, Keith M.<sup>2</sup>, Melfos V.<sup>3</sup>, Voudouris P.<sup>4</sup>

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Reconstruction of temperature of magmatic-hydrothermal systems is key to unraveling ore-forming processes. Ti-in-quartz thermometry is widely used to estimate temperatures of hydrothermal quartz veins, yet its reliability may be affected by several parameters. Here, with the example of the Cu-Mo-(Re-Au) Pagoni Rachi deposit (NE Greece), we use fluid inclusions (FIs) as an independent thermometer to evaluate the effect of Ti diffúsion associated with fluid-assisted recrystallization.

Typical A-type (ductile, 460–510 °C), B-type (ductile/brittle, 420-440 °C) and E-type (brittle, 220–330 °C) veins developed in a continuum of deformation, forming from boiling fluids followed by cooling and dilution by surface waters. In A-type veins, fluid-assisted dynamic recrystallization leads to variable Ti concentrations (10–60 ppm), yielding Ti-in-quartz temperatures (330–500 °C) lower than FI trapping temperatures, likely due to Ti loss. In later B-type veins, out-of-equilibrium rapid growth results in Ti-in-quartz temperatures (440–750 °C) higher than FI trapping temperatures. However, late brittle E-type veins show better agreement between Ti-in-quartz (160–360 °C) and FI trapping temperatures.

We show that out-of-equilibrium crystallization and fluid-assisted dynamic recrystallization processes can significantly shift Ti concentration. Thus, careful examination of quartz veins microtexture and FI is crucial for reliable use of Ti concentration in hydrothermal quartz.



Caption: Heterogenous assemblage of VL and LVH fluid inclusions in A-type veins of the Pagoni Rachi Cu-Mo-(Re-Au) porphyry-epithermal deposit



EUROPEAN CURRENT RESEARCH ON FLUID AND MELT INCLUSIONS

#### Talk

Single fluid inclusion analysis: in-situ elemental and isotopic compositions with cryogenic SIMS. <u>Thomen A.</u><sup>1\*</sup>, Créon L.<sup>1</sup>, Defouilloy C.<sup>1</sup>, Debliqui M.<sup>1</sup>, Gelencser O.<sup>2</sup>, Szabo C.<sup>2</sup>, Aléon J.<sup>3</sup>

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Elemental and isotopic composition analysis of fluid inclusions has traditionally relied on bulk techniques, limiting the resolution of chemical heterogeneities between primary and secondary inclusions crucial for reconstructing fluid histories. Conventional in-line mass spectrometry averages signals from multiple inclusions, obscuring compositional differences.

We present a novel approach using the NanoSIMS-HR, a high-resolution secondary ion mass spectrometer equipped with a cryogenic stage for in-situ analysis of frozen fluid inclusions. Combining 30 nm lateral resolution with mass resolving power and high sensitivity, it enables simultaneous elemental and isotopic measurements on individual fluid inclusions <2  $\mu$ m diameter. Analyses are performed directly on the thick section prepared for petrographic studies, requiring no additional sample preparation.

This method was applied to samples from two contrasting geological settings. In halite (provided by the Lithosphere Fluid Research Lab), fluid inclusions were visualized via their oxygen content (Fig 1), and associated µm-scale Si -and C-rich phases (identified by Raman spectroscopy) were interpreted as quartz and organic matter. In chert (provided by the MNHN),  $\delta^{18}O$  and  $\delta D$  values obtained by imaging are within uncertainties of  $\pm 5\%$  and  $\pm 16\%$  resp. below terrestrial variability for robust interpretation of geological mechanisms. The NanoSIMS-HR for the first time enables complete characterization of single fluid inclusions.



Caption: C and O images from fluid inclusion in halite with the NanoSIMS-HR. Red ROI surrounds the Fluid Inclusion.



## Talk

Carbonate melts responsible for crustal metasomatism: evidence from melt inclusions in flame perthite Xu X. 1\*, Steele-MacInnis M. 1 <sup>1</sup> University of Alberta, Edmonton, Canada

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Metasomatism is originally regarded as a primarily hydrothermal process, where in mineral replacement reactions involve coupled dissolution and precipitation from an aqueous fluid phase. However, in the liquid state, fluids are not limited to aqueous fluids, certain melts can also be highly permeable and serve as potential metasomatic agents in the lithosphere. Albitization is one of the striking examples of crust metasomatism, whereas flame perthite is a distinct morphology of coarse perthite K-feldspar and albite. The albite flame is usually interpreted as hydrothermal metasomatic products from alkali exchange between aqueous fluid and alkali feldspar.

Here, we present a exceptional example from the Lyon Mountain Granite (LMG) in the northeastern Adirondack Mountains of New York State, where carbonate-rich melt acted as the metasomatic agent, driving the replacement of alkali feldspar. Polymineralic, crystallized melt inclusions are hosted only within albite flame lamellae and are absent from the surrounding K-feldspar. Petrography and Raman spectroscopy show that these inclusions are composed of calc-silicate and carbonate minerals that re-melt during laboratory heating, and thus represent aliquots of silicate-carbonate melts. Such liquids are known to have high interconnectivity, low density, and low viscosity relative to silicate melts, and as such can be capable of infiltrating and replacing alkali feldspar in a way analogous to a reactive hydrothermal fluid.





# **Session 4**

## **Ore Deposits**



## Talk

## Ag-Isotope Ratios in Fluid inclusions from Au-bearing Hydrothermal Fluids. Banks D. A. 1\*, Bozkaya G.2

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The transport of high concentrations of Au-Ag in the form of nanoparticles has been shown to occur in diverse types of mineralization. Fluid inclusions in the Arapucandere epithermal sulphide-precious metal deposit contains Au-Ag nanoparticles trapped during several fluid pulses. During late-stage growth of large quartz crystals numerous episodes of hydrothermal fluids were trapped and indicate boiling or trapping of low salinity vapor/fluid with nanoparticles. These have been visually identified and have been observed in SEM-BSE images. These fluid inclusions have been analysed by LA-ICP (ToF) MS giving a complete compositional analysis of the fluids. This provides isotopic data on all the elements that are present. In this instance, the analyses of Ag<sup>107</sup>, Ag<sup>109</sup> and Au<sup>197</sup> of the nanoparticles are sufficiently robust to record differences in the fluid during crystal growth. In areas where fluid inclusions show evidence of boiling Ag<sup>107</sup> is significantly greater than Ag<sup>109</sup>, but where boiling is not observed the isotopes are approximately equal, also Ag/Au is much lower in the former fluid inclusions. These observations are consistent with experimental data on Ag-isotope fractionation. Ag<sup>107</sup> and Au are enhanced in the vapor phase while Ag<sup>109</sup> is enhanced in the liquid. The link between the composition of nanoparticles and fluid processes may provide a partial explanation for Au-Ag variation in gold deposits.



## Talk

Polymetallic melt droplets coexist with a H<sub>2</sub>O-CO<sub>2</sub>-(CH<sub>4</sub>) hydrothermal fluid in a gold-bearing tin deposit Bermejo D.1<sup>\*</sup>, <u>Ortega L.</u><sup>1</sup>, Barrios S.<sup>2</sup>, Crespo E.<sup>1</sup>, Castiñeiras P.<sup>1</sup>, Dos Santos K.<sup>2</sup> <sup>1</sup> Universidad Complutense de Madrid, Madrid, Spain, <sup>2</sup> Universidad de Salamanca, Salamanca, Spain

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Bismuth associated with gold in polymetallic inclusions has been often reported in hydrothermal ore deposits. Their textural features and the Bi melting temperature at 271°C suggest that they crystallized from a metallic melt. According to the liquid bismuth collection model (Tooth et al., 2008), bismuth may precipitate as a liquid and scavenge gold from the coexisting hydrothermal fluids.

Here, we present data from the Martinamor Sn-W district, in Spain. The polymetallic melt droplets studied appear as polycrystalline inclusions in arsenopyrite and quartz coexisting with fluid inclusions, thus allowing to characterize the ore fluids from which polymetallic melt droplets formed.

Poikilitic arsenopyrite hosts abundant inclusions consisting in native Bi, Bi-Te-Se sulfosalts, electrum, and galena, which occur infilling cracks and voids between arsenopyrite grains. Linear and arcuate trails of native Bi or polymetallic droplets occur in healed microfractures in quartz, along with H<sub>2</sub>O-CO<sub>2</sub>-(CH<sub>4</sub>)-bearing fluid inclusions (<3.7 wt% NaCl<sub>eq</sub>,Th=250-285 °C). In some cases, polymetallic melt drops were mechanically trapped within fluid inclusions.

Temperatures obtained from FI are consistent with the occurrence of molten droplets as the addition of Au $\pm$ Te $\pm$ Se to Bi decreases the melting point of the mixture well below 271°C. In turn, these conditions would have placed the fluid within the gap of immiscibility in the H<sub>2</sub>O-CO<sub>2</sub>-(CH<sub>4</sub>) system.

Reference

Tooth et al. (2008), Geology, 36, 815-818.



## Talk

Evidence of gold-transporting magmatic fluids: A Case study from the Oligocene porphyry copper-gold deposits in Biga Peninsula, NW Türkiye.

## Bozkaya G.1\*, Banks D.A.2, Ramazan S.3, Hakan E.3, S.Batuhan M.3, Bozkaya Ö.1

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Keywords: fluid inclusion, hydrothermalism, ore deposits

Porphyry copper-gold deposits in the Biga Peninsula are associated with Paleozoic metamorphic rocks and Eocene to Oligocene calc-alkaline post-collisional magmatism. The mineralization is contained within stockwork veinlets and disseminations hosted in stocks and dikes ranging in composition from granodiorite to diorite porphyry and monzodiorite, and is associated with the potassic and phyllic alteration. The alteration assemblages, from periphery to core are: propylitic, with chlorite, epidote, actinolite, and smectite; argillic, including kaolinite, illite, and montmorillonite; advanced argillic, with dickite, alunite-pyrophyllite; and phyllic, with muscovite-phengite and paragonite. In the innermost zone, potassic alteration rich in potassium feldspar and secondary biotite is present. The main ore minerals, in order of abundance, are pyrite, chalcopyrite, chalcocite-covellite, bornite, sphalerite and molybdenite.

The systematic increase concentrations of Cu, Mo and Sn and decrease of As, Sb and Pb in epidote near mineralization have been utilized to evaluate the fertility of porphyry system and determine the center of the mineralization. Epidote and chlorite rich zones with Ti/Sr  $\geq$  50 are correlated with Cu, Mo and Au anomalies. As, Sb, Pb and Zn are the distal pathfinder elements forming crucial anomalies in the outer zones.

Fluid inclusion assemblages hosted in quartz can be classified as: 1) single-phase (Type I): liquid (L) or vapor (V); 2) two-phase (Type II): liquid-rich (L+V) or vapor-rich (V+L) and 3) multi-phase (Type III): solid phase (mostly salt crystal and opaque mineral) assemblages (Figure 1). The high homogenization temperatures and salinity (Th > 600 °C, %NaCl > 55 wt.% NaCl) and the presence of coexisting halite bearing and vapor-rich inclusions, with opaque minerals, such as hematite and chalcopyrite, identify the pluton region. The co-existence of vapor-rich and liquid-rich fluid inclusions indicates boiling. From the petrographic and micro-thermometric studies, inclusions with lower homogenization temperatures and salinities were also determined. The fluid inclusions indicate an evolving hydrothermal system from the magmatic fluids to a epithermal system overlying the porphyry.

Acknowledgement: This work was supported by the Türkiye Maden Industry and Trade Inc. (Ankara).



Caption: Figure 1- Different type of inclusions in quartz. (a) low-density vapor-rich inclusions (b) multiphase inclusions containing hematite.

## Poster

Characterization of mineralizing fluids from Kumarlar (NW Turkiye) low suphidation deposit: New insight from isotope geochemistry, microtermometry and LA-ICP-MS analysis of fluid inclusions. <u>Bozkaya G.</u>1\*, Bozkaya O.<sup>1</sup>, Abaka M.<sup>1</sup>, Çelik Ş.<sup>2</sup> 1 Pamukkale University, Denizli, Turkey, <sup>2</sup> Dedeman Mining Ltd., Ankara, Turkey

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The Kumarlar (Canakkale) deposit is a typical example of lead-zinc mineralization associated with Tertiary volcanic rocks exposed in the Biga Peninsula. Ore veins along fault zones within the tuffs are primarily composed of galena and sphalerite, with minor amounts of pyrife, chalcopyrite, fahlerz (tedrahedrite), marcasite, covellite, bornite, tenorite, adularia and quartz. Fluid inclusion and stable isotope (O, S) studies were conducted on sulfur- and quartz-bearing minerals to determine the origin of the hydrothermal fluids. Microthermometric data indicate the presence of CaCl<sub>2</sub>- and MgCl<sub>2</sub>-type salts in the mineralizing fluids and the salinity of these fluids was 15.8 wt.% NaCl equivalent during sphalerite crystallization in the early stage of mineralization, and 18.5 wt.% NaCl equivalent during quartz crystallization in the later stage. Homogenization temperatures from sphalerite and quartz ranging from respectively 238.6 to 263.5 °C and 247.2 to 281.4 °C. The  $\delta^{18}$ O values of water in equilibrium with quartz range from -6.14 to 8.36 % SMOW, suggesting that the ore-forming fluids were derived from both meteoric and magmatic sources. Relatively higher temperature values are associated with quartz of likely magmatic origin, sampled from deeper parts of the veins, whereas lower temperatures are associated with quartz of meteoric origin, sampled from shallower levels. In other words,  $\delta^{18}$ O values increase with temperature. The  $\delta^{34}$ S values of galena (ranging from –10.41 to –6.28 ‰, with a mean of –7.6 ‰) suggest that the sulfur was reduced from sulfate (SO<sub>4</sub><sup>2-</sup>) derived from seawater or sulfate-bearing sedimentary rocks through bacterial or inorganic processes. Based on sulfur isotope fractionation during sulfate reduction in closed systems, and comparison with isotopic age curves of marine sulfates, it is inferred that the sulfur may have been leached from the Triassic sedimentary basement rocks.



#### Poster

An investigation into the genesis of the specularite iron deposit related to the miocene volcanic event, (case of study: ZACCAR deposit, ALGERIA).

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meteoric waters.

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The Zaccar metasomatic-type iron deposit in northwestern Algeria is hosted in Jurassic carbonate sequences proximal to Neogene volcanic rocks. The deposit consists of iron carbonates and oxides. Country Jurassic limestone is partly replaced by the original epigenetic metasomatic ore of ankerite and siderite. The emplacement of the Miocene volcanic formation is followed by another type of iron mineralization, namely specularite, which crosscuts the former mineralization of iron and polymetallic ore. The microthermometry study of primary fluid inclusions trapped in quartz associated with specularite shows the existence of cavities with a dominance of the aqueous phase, a gas bubble, and a cube of halite; visually estimated vapor-to-liquid ratios in all samples range from 5 to 10 vol.% without large variation. Most of the fluid inclusions homogenize into the liquid phase at a temperature ranging from 270° to 290°C before the dissolution of halite. The dissolution temperature of halite ranges from 300° to 320°C. Thus, the "300° to 320°C + ca. 10°C" was applied to calculate salinity from the dissolution temperatures of halite crystals according to Sterner and Bodnar (1988). In this case, salinities of mineralizing fluids range from 38 to 40 wt% NaCl eq. The plotting of measurements into the "Magmatic-Meteoric Mixing" fields (Beane 1983) indicates that specularite was formed by hydrothermal activity related to Neogene volcanism, evolved from the mixing of magmatic and

EUROPEAN CURRENT RESEARCH ON FUID AND MELT INCLUSIONS

## Poster

P-T-X conditions of deposition of scheelite in the W(Sn) deposit of Murçós, Northern Portugal. <u>Costa e Silva S.</u>1\*, Noronha F.<sup>1</sup>, Guedes A.<sup>1</sup>

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The W(Sn) deposit of Murçós is located in the Laza-Rebordelo-Murçós shear zone, in the eastern of the Galicia-Trás-os-Montes Zone (GTMZ). Along this structure, several tin (Sn) and tungsten (W) mineralized quartz veins occur, distributed in the axial zone of the Chaves-Miranda do Douro antiform, hosted by the Silurian metasediments of the Parautochtonous Domain and spatially associated to a great variety of variscan granitic rocks. This study is focused in the Murçós deposit, an old scheelite productive mine. Petrographic studies revealed the presence of biphasic primary and secondary fluid inclusions (FI) on scheelite. Microthermometric analysis of these FI showed temperatures of ice melting comprised between -2,4 - -4,4 °C, of CO<sub>2</sub> melting between -59,6 - -63,4 °C, of CO<sub>2</sub> clathrate melting between 6,1 to 11 °C, CO<sub>2</sub> homogenization between 3,1 to 10,1 °C and global homogenization temperatures in the range of 333 to 345 °C in liquid (L). The trapped fluids in scheelite from Murçós are rich in water (76,2 - 86,5 mol%) with a volatile phase basically composed of CO<sub>2</sub> (42,2 - 79,7 mol%) with important quantities of N<sub>2</sub> (13 - 50,4 mol%) and lesser amounts of CH<sub>4</sub> (1,4 - 14,9 mol%). These fluids are of low density (0,8475 - 1,0028 g/cm<sup>3</sup>) and low salinity (1,08 - 2,16 eq.NaCl , corresponding to Lw-c type, representative of H<sub>2</sub>O-CO<sub>2</sub>-CH<sub>4</sub>-N<sub>2</sub>-NaCl, trapped at minimum conditions of 345 °C and 280 MPa.



## Talk

## P-T-X conditions of scheelite deposition in panasqueira wolframite rich deposit.

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The Panasqueira Mine locates in the Central Iberian Zone (CIZ) of the Iberian Massif, corresponding to the most important wolframite deposit in the Iberian Peninsula. Previous studies have shown that wolframite((Fe,Mn)WO<sub>4</sub>)) deposition is related to modified aqueous-carbonic fluids resulting from the interaction of primary magmatic fluids with the surrounding shales, producing modified fluids enriched in Fe and Mn, crucial for wolframite deposition. Very recently, scheelite (CaWO<sub>4</sub>), was identified in a mineralized vein, that cuts through a basic rock dyke, intrusive in the schists. Scheelite is later than wolframite and occurs associated with ferromagnesian chlorites and carbonates. Microthermometric and Raman microspectrometry analysis of fluid inclusions in scheelite revealed that the trapped fluids are water-dominated (82.8-97.38 mol%) and a volatile phase rich in CO<sub>2</sub> (58.9-85.3 mol%) and variable amounts of N<sub>2</sub> (10.5-23.3 mol%) and CH<sub>4</sub> (2.5-19.2 mol%). These fluids are characterized by low density (0.9786 – 1.0301 g/cm<sup>3</sup>) and salinity (2.2–2.7 g/cm<sup>3</sup>). Thermometric analyzes revealed minimum trapping temperatures between 212,8°C and 221,3°C. We consider lithological control on the deposition of scheelite, as the Ca necessary resulted from the interaction of the mineralizing fluids with the pre-existing basic rock dyke intersected by the mineralized vein.



#### Talk

Paragenesis and supergene evolution of the Cu-Ba±Pb-Amethyst mineralization from Baba Joua Ali, Eastern Anti-Atlas, Morocco: Exploration Application.

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Keywords: fluid inclusion, geodynamics, gemmology

The Baba Joua Ali (BJA) ore mineralization is situated in the Maider basin at the Eastern Anti-Atlas. In this area, the mineralization is hosted within the Ktaoua group and the Second Bani Formation of the Upper Ordovician. The upper Ordovician terrane display ductile deformation, characterized by a succession of synclinal and anticlinal structures. From north to south, the Ordovician formations show a WNW-ESE trend syncline at Jbel El Machhot. The veins ore mineralization is controlled by N-S to NE-SW trending faults. These faults are linked to the Variscan orogeny and kinematic indicators suggesting left-lateral and right-lateral motions, respectively. Based on the metallographic relationship between minerals from outcrop to microscopic observation, two major mineralizing stages are proposed for the precipitation of ore mineralization. The first is a hypogene stage with a banded texture, it comprises colorless quartz with sulfides, amethyst with iron oxide, and finally barite and sulfides. Microthermometric analysis of fluid inclusions was carried out on colorless quartz and amethyst. Primary fluid inclusions trapped in colorless quartz indicate temperatures from 120 to 140°C and salinity between 14.46 and 19.84 wt.% NaCl<sub>eq</sub>.This fluid is characterized by Te ranging from -32 to -22°C, interpreted as a NaCl-H<sub>2</sub>O system. The fluid inclusion from amethyst indicates a temperature from 100 °C to 110 °C and salinity between 13 and 14 wt.% NaCleg. The banded texture of the primary mineralization (border to center: colorless quartz, amethyst, and barite) reflects the extension context and may correspond to fluid percolation in the Variscan orogeny fault during the Triassic extension (CAMP). The second major stage is characterized by the formation of covellite, chalcocite, malachite, hematite, chrysocolla, cuprite and native copper. This assemblage is linked to the supergene process, the percolation of meteoric acidic water is favored by the intense fracturing in upper Ordovician quartzite, cavities, and fractures crosscutting quartz, amethyst, and barite. The copper and iron oxide with copper carbonate observed at BJA correspond to oxidized zone.





#### Poster

Fluid Inclusion Studies in Oolitic Iron Ore Deposits of Djebel Had, Algeria: Insights into Ore Formation Processes and Paleofluid Evolution. <u>Diab H.</u><sup>1\*</sup> 1 SOMIFER, Tebessa, Algeria

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The oolitic iron ore deposits of Djebel Had in Eastern Algeria represent a significant mineral resource, formed under complex geological conditions. This study investigates the fluid inclusions within these deposits to unravel the physicochemical conditions of ore formation and the evolution of paleofluids.

Detailed petrographic analysis identified primary and secondary fluid inclusions hosted in iron oxides and associated gangue minerals. Microthermometric measurements indicate a wide range of homogenization temperatures ( $100-250^{\circ}C$ ) and salinities (5-15 wt% NaCl equivalent), suggesting a multi-stage fluid evolution. Laser Raman spectroscopy further reveals the presence of CO<sub>2</sub> and CH4 in some inclusions, indicative of mixing between hydrothermal and meteoric fluids during ore genesis.

Stable isotope analyses ( $\delta^{18}$ O and  $\delta$ D) on fluid inclusions point to interactions with basin-derived fluids influenced by tectonic activity during the Mesozoic. These findings highlight the role of regional faulting in fluid migration and ore precipitation, providing critical insights into the paleohydrological and geodynamic setting of Djebel Had. This study enhances our understanding of the genesis of oolitic

This study enhances our understanding of the genesis of oolitic iron ore deposits in Algeria, with implications for regional mineral exploration and broader models of iron ore formation in sedimentary basins.



#### **Poster**

Hydrothermal evolution and fluid mixing for the deposition of Punta Corna five-element deposit, Western Alps (Italy). Domeniahini G.<sup>1</sup>, Walter B.<sup>2</sup>, Markl G.<sup>2</sup>, Ferrando S.<sup>1-4</sup>, Steele-MacInnis M.<sup>3</sup>, <u>Santoro L.<sup>1\*</sup></u>

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The process driving the deposition of five-element mineralization involves the fast reduction of Ni-Co-Fe-As-bearing fluids, caused by variable reducing agents.

The Fe-Co-Ni-Ag-Bi-As deposit of Punta Corna (Italian Western Alps) occurs in veins formed during Alpine exhumation in an extensional-transtensive regime. Various textures indicate a complex hydrothermal circulation with multiple pulses. This study provides updates on mineral assemblage and new fluid inclusion (FI) data obtained through CL, microthermometry, µRaman and crush leach analysis.

Hydrothermal activity started with silicification and sericitization of the host rock, followed by precipitation of carbonates (Sd, Ank, and Cal), Qz, and Brt. The Sulfide Stage I corresponds to deposition of base metal sulfides (Py, Ccp, Gn). The subsequent Arsenide Stage is characterized by deposition of nickeline (overgrown by safflorite), followed by euhedral skutterudite and by final rammelsbergite in Sd and in Qz gangue. The last Sulfide Stage II comprises tetrahedrite, Ccp, Sp, Gn, Py, and bournonite. At the very end, this stage also consists of Bi-Sb sulfosalts in Sd, Qz, Ank, and Brt.

Four FI types were identified in different Qz generations associated with Sulfide Stage I (fluid types A and B) and Arsenide Stage (fluid types C and D). Fluid type A is a solution of H<sub>2</sub>O, NaCl, CaCl<sub>2</sub>, and SO<sub>4</sub><sup>2-</sup> with average T<sub>h</sub>=140°C and high total salinity. This fluid coexists with a volatile-bearing aqueous fluid type B, characterized by the presence of CH<sub>4</sub>, N<sub>2</sub>, and CO<sub>2</sub>, and with average T<sub>h</sub>=163°C and average salinity =18.8 wt.% NaCl+Ca-Cl<sub>2</sub>. During the Arsenides Stage, mixing between fluid C (high salinity, average 18.7 wt.% NaCl+CaCl<sub>2</sub>, average T<sub>h</sub>=156°C) and fluid D (low salinity, average 13 wt.% NaCl+CaCl<sub>2</sub>, average T<sub>h</sub>=230°C) occurs. The only volatile species in types C and D is N<sub>2</sub>. Fluid A is a surface-derived brine. Fluids B and C share similar characteristics, except for the lack of CH<sub>4</sub> and CO<sub>2</sub> in Fluid C. This is interpreted as evidence that methane was consumed in the reaction precipitating the five-element mineralization. Fluid D is interpreted as a deep-sourced, metal-rich fluid responsible for leaching metals from the underlying ophiolites. In the context of a tectonically active regime, the upwelling of fluid D and its mixing with reducing, volatile-bearing fluid B/C, facilitated by fault opening and fluid migration (i.e., "natural fracking"), triggered the deposition of arsenide mineralization at Punta Corna.

## Talk

Constraining magma evolution associated with alkalic porphyry mineralization in British Columbia, Canada: a melt inclusion study. <u>Estrella M.P.</u><sup>1\*</sup>, Lecumberri-Sanchez P.<sup>1</sup>, Xu X.<sup>1</sup>, Rees C.<sup>2</sup>

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Alkalic porphyries are Cu-Au high-grade deposits mainly localized in two metallogenic provinces worldwide: British Columbia (BC) in Canada and New South Wales, Australia. Alkalic deposits share some similarities with their calc-alkalic counterparts but differentiate primarily in their alteration mineralogy and hydrothermal footprint.

Mount Polley and Galore Creek are two large Late Triassic – Early Jurassic alkalic porphyries in BC, in which copper sulfide mineralization is associated with hydrothermal-breccia bodies and coeval intrusive and volcanic rocks. Unaltered clinopyroxene crystals in the alkalic intrusive and volcanic units of Galore Creek and Mount Polley host crystallized melt inclusions consisting of sulfate, carbonate and silicate phases identified by Raman Spectroscopy. FIB/SEM-EDS analyses also revealed single point chlorine enrichment in one of the inclusions at Mount Polley, potentially indicating halide saturation of the melts.

Electron Probe Microanalyses (EPMA) data obtained from these inclusions will be further used to identify local geochemical changes throughout magma evolution to discuss sources of alkalinity in magmas from British Columbia during the Late Triassic – Early Jurassic period and the implications of different magmatic processes shaping metal enrichment in alkalic porphyries.



### Talk

#### Halogen signatures of salt melt inclusions in Kiruna-type magnetite-apatite deposits. Fusswinkel T. 1\*, Xu X.2, Steele-MacInnis M.2, Koděra P.3, Tornos F.4, Hanchar JM.5, Bain W.6

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The origin of Kiruna-type magnetite-apatite (MtAp) deposits remains controversial, with genetic models ranging from orthomagmatic to hydrothermal. Central to this debate are iron-rich melt inclusions composed of chlorides, sulfates, and carbonates. These inclusions are ubiquitous in MtAp deposits and have been controversially interpreted as magmatichydrothermal hydrosaline liquids, residual melts from melt-melt immiscibility triggered by assimilation of evaporitic rocks, or anatectic melts resulting from melt intrusions into evaporitebearing carbonate rocks.

Here, we present LA-ICP-MS triple-halogen (CI-Br-I) data from MtAp deposits at El Laco, Laco-Salar (Chile), and Hormuz Island (Iran), alongside Fe-K-Na salt melt inclusions from the Biely Vrch porphyry-Au deposit (Slovakia). The latter formed via magmatic hypersaline brine exsolution at shallow depth, followed by water loss to vapor during ascent, generating an Fe-K-rich salt melt, thus providing a comparative framework for evaluating MtAp formation models. MtAp inclusions exhibit very low Br/Cl and I/ Cl signatures closely resembling evaporitic halite, whereas Biely Vrch salt melts show elevated ratios typical of porphyry and other arc-related magmatic systems.

We show that fluid-fluid mixing, magmatic fractionation, or fluid-rock interaction cannot reconcile the observed MtAp halogen signatures with a magmatic-hydrothermal origin, instead pointing toward a critical role of evaporites in the formation of MtAp deposits.



Caption: Salt melt inclusions in apatite containing rinneite (K<sub>3</sub>NaFe<sub>2</sub>+Cl6) and hibbingite (Fe<sub>2</sub>+2(OH)<sub>3</sub>Cl), from the Laco-Salar MtAp deposit, Chile.



#### Poster

## Fluid inclusion study in Celestine of Koudiat Djebassa locality (Bibans area, Algeria).

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The studied celestine deposits occur in the Triassic evaporitic formations of the Koudiat Djebassa sector in the Bibans area, located within the Southern Tellian Atlas in Northern Algeria. This study focused on celestite crystals, which mainly exhibited primary one-phase or two-phase inclusions (liquid + vapor). The primary fluid inclusions (Fls) found in celestines were classified in three types: (i) pure-liquid single-phase (PL-type), (ii) liquid-rich two-phase (L-type), and (iii) vapor-rich two-phase (V-type). They are abundant and typically occur in groups of four to five inclusions at most. Their sizes range from 10 to 300 µm and their shapes vary widely. The microthermometric results obtained from the primary fluid inclusions in celestite crystals show that the homogenization temperatures ( $T_e$ ) range from  $-48^{\circ}$ C to  $-25^{\circ}$ C and the ice melting temperatures ( $T_m$  ice) range from  $-5^{\circ}$ C to  $+5^{\circ}$ C. Low salinity is determined, ranging from 1.92% to 8.76% eq. NaCl. The high homogenization temperatures from the primary fluid inclusions indicate that the fluids responsible for celestite crystallization are of deep origin, likely drained through diapir/cover contacts during halokinesis. The null and slightly positive ice melting temperatures, combined with the low salinity values, suggest a fluid rich in pure water, probably originating from a deep groundwater table, which may have been contaminated by Triassic salts.



Caption: Photomicrographs of primary liquid-rich two-phase fluid inclusions in the celestine of Koudiat Djebassa in Bibans area (Algeria).Scale bar is 30µm.



### Talk

#### Source, properties and evolution of ore-forming fluid in five-element (Ag-Co-Ni-As-Bi) deposits. He Q.1;2\*, Graham C.1, Falck H.3, Reynolds M.4, Canam R.4, Lecumberri-Sanchez P.1

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Five element vein deposits are a mineralogically complex deposit type historically mined for silver (e.g., Bou-Azzer) but also rich in critical metals such as cobalt. Several systems in the Slave craton have mineralogy and paragenetic sequences typical of five element vein deposits, but regional differences with respect to other five element vein deposits such that the mineralization processes might be distinct. This study focuses on five-element veins in the Camsell River area of the Great Bear magmatic zone, Northwest Canada. Through petrographic observations and electron probe microanalysis, the minerals and paragenetic sequences have been identified. The mineralogy includes native elements (e.g., Bi and Ag), arsenides (e.g., nickeline), sulfoarsenides (e.g., gersdorffite), and sulfides (e.g., pyrite) in five main stages characteristic of five element vein deposits. Paleofluids associated with mineralization at Camsell River are represented by liquid- and vapor-rich inclusions. Liquid-rich inclusions contain small amounts of methane. In the context of five element vein deposits models, these inclusions may represent the reduced end member in a mixing between an oxidized and a reduced fluid that triggers mineralization. This presentation will discuss the paleofluid record at Camsell river, how it relates with specific mineralization stages and its implication for metal regional distribution of this ore deposit type.



#### Talk

Can Messinian brines impact the evolution of a Fe-Skarn? The case of Serifos (Cyclades, Hellas). Koufogiannis I. <sup>1\*</sup>, Fusswinkel T. <sup>1</sup>, Wagner T. <sup>1</sup>

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Fluid inclusions in the synkinematic Fe-skarn of Serifos island (Cyclades, Hellas) track the evolution of the hydrothermal system and the provenance of the involved fluids. Proximal quartz exhibits complex cathodoluminescence patterns with oscillatory zoning and overgrowths, and hosts boiling assemblages of coexisting Na–Ca–K–Fe-Cl brine and vapour inclusions. Salinities reach up to 40% NaCleq and homogenisation temperatures range from 370 to 170 °C. Baryte and iron oxide precipitate in quartz's outer growth zones and coexist with brines of reduced salinity (~22% NaCleq) and low-salinity fluid inclusions, enriched in vapour-partitioning elements (Li, B, S, As, Sb, I). We interpret the latter as contracted vapours. Depressurisation, cooling, mixing with oxidised external fluids and ore deposition are observed down to the growth zone level (Fig. 1).

Despite dilution, proximal mineralisation retains a magmatic signature, as evidenced by LA-ICP-MS fluid inclusion analysis. Halogen ratios (CI-Br-I) reveal a transition from magmatic to residual brine signatures from the proximal to the detachment-bound distal parts of the system. Uniform fluid  $\delta D$  of -14 to -30%, yet strongly variable  $\delta^{18}O$  values between proximal and distal mineralisation suggest progressive fluid mixing.

Considering thermochronological constraints, hydrothermal activity persisted during the Messinian Salinity Crisis. Our data demonstrate that Messinian evaporitic brines infiltrated the system via the West Cycladic Detachment System and played a substantial role in its evolution.



Caption: Tip of a quartz crystal from a vein within proximal garnetite (Serifos, Cyclades, Hellas), with its fluid inclusion record.

#### Poster

Geochemical characteristics of the Tietonggou Pluton, Luxi area and metallogenic indicators of sulphide inclusions. Liu J.<sup>1\*</sup>, Ning Z.<sup>2</sup>

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Keywords: melt inclusion, metasomatism, ore deposits

On the basis of field geological investigation and indoor petrographic observation, the major and trace element compositions of Tietonggou pluton (hornblende gabbro) and its hornblende xenoliths in western Shandong province were analyzed by means of optical microscope, SEM, EMPA and LA-ICP-MS. The structural characteristics and chemical composition of sulfide inclusions in pyroxene and hornblende wereanalyzed. The genesis and evolution of hornblende gabbro and hornblende pyroxene inclusions, and implication of primary sulfide inclusions in minerals to mineralization is discussed.

Clinopyroxene formation depth 10.88~12.92 km in hornblende gabbro. The formation depths of clinopyroxene and leek amphibolite in hornblende pyroxenite are 57.8~61.2 km and 8~12.7 km. The formation depth of magnesia hornblende is 2.1~3.8 km. The formation depth of hornblende in hornb lende pyroxenite is similar to that of clinopyroxene in hornblende gabbro, indicating that there may be a magmatic mixing process in shallow magmatic chamber.

Sulfides in Tietonggou pluton can be divided into two types: pyrite and chalcopyrite. One is round in clinopyroxene and the other is irregular in hornblende. The contents of Ag and Pb of pyrite are higher in clinopyroxene, the contents of Co, Ni, Cu, Zn, As, Sb, Te, Au, Bi and Mn of pyrite in hornblende are higher, and the contents of Cu, Zn and Mn of chalcopyrite in hornblende are obviously higher, while the content of Au is lower. The distribution coefficient of chalcophile elements in sulphide solid solution phase is low, and magma can still retain a large number of chalcophile elements after saturation differentiation, which leads to the enrichment of fluid phase in the late hydrothermal process of magma.

To sum up, the magmatic evolution of the Tietonggou pluton can be divided into two stages: the early gabbro magma captures hornblende pyroxene and rises rapidly to the shallow magma chamber far from the surface 8~12 km, resulting in crystallization differentiation and equilibrium with hornblende pyroxene; in this process, the early sulfide is rounded and captured by deep stacking clinopyroxene. The late sulfides show that they are captured by shallow hornblende, and a large number of cronophile elements enter into the late sulfides. In the later stage, the magma rose to about 3 km from the surface and suffered fluid metasomatism with low degree of evolution, and magnesia hornblende was formed at the edge of leek amphibolite.



Caption: Petrological pictures of sulfide melt inclusions in clinopyroxene and hornblende from Tietougou xenolithos.

## Talk

## Hydrous salt melts and their importance to metal transport in magmatic and magmatic-hydrothermal mineral deposits. <u>McFall K.A.</u><sup>1\*</sup>, McDonald I.<sup>2</sup>, Hanley J.J.<sup>3</sup>, Kerr M.<sup>3</sup>, Yudovskaya M.A.<sup>4</sup>, Kinnaird J.<sup>4</sup>, Tattitch B.<sup>5</sup>

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Keywords: fluid inclusion, ore deposits, new frontiers

The Northern Limb of the Bushveld Complex, South Africa is one of the most important magmatic sulphide Ni-Cu-PGE provinces in the world. A systematic fluid inclusion survey of all ore deposits in the Northern Limb observed inclusions present as trails within cumulate magmatic silicate minerals, terminating at crystal boundaries. These inclusions contain multiple daughter minerals, 10-15 vol.% H<sub>2</sub>O-CH<sub>4</sub> vapour and 5-15% liquid H<sub>2</sub>O. Detailed confocal raman spectroscopy has shown that the majority of the daughter minerals are multiple types of carbonates, including ankerite, natrite, magnesite, siderite and calcite. These inclusions homogenise >820°C, above solidus temperatures, and are thus interpreted to represent a hydrous carbonate salt melt.

Hydrous carbonate-rich salt melt inclusions are present in all magmatic-sulphide Ni-Cu-PGE deposits surveyed in the Northern Limb, throughout stratigraphy and along strike. Evidence of salt melt-sulphide melt interaction was also observed in all deposits, implying this was a common factor during their development. Similar salt melt inclusions have been identified in other magmatic-hydrothermal ore deposit types such as IOA, IOCG, and carbonatites (e.g. Walter et al. 2021, Xu et al. 2024). Hydrous salt melts may therefore play an important role in metal transport in high temperature magmatic-hydrothermal systems.

References

Walter et al. (2021), Earth Science Reviews, 215, 103-509

Xu et al. (2024), Geology, 52, 417-422



Caption: Figure 1- Salt melt inclusions in magmatic sulphide deposits in the Northern Limb of the Bushveld Complex: a.) Trail of salt melt

inclusions cross-cutting an olivine crystal, terminating against orthopyroxene peritectic reaction rim. b.) Trail of salt melt



#### **Poster**

Exploration for stratabound Cu–(Ag) "manto-type" in Chile. Moncada D. 1\*

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Fluid inclusions in hydrothermal ore deposits showed a systematic variation in volumetric properties that could be used to predict locations in the overall system and can be used in exploration to provide "vectors" to the ore.

Economic "manto type" deposits have been controversial regarding the origin of the mineralized fluid. Some are restricted to one layer of mineralization; others show at different layers of host rock (sedimentary and/or volcanic) on intervals of mineralization.

More than 100 samples were observed under a petrographic microscope to describe mineral textures and characterize the different types of fluid inclusions present at room temperature. The features associated with those events show evidence of fluid inclusion assemblage (FIA) classified at room temperature. Nineteen FIAs indicate the presence of boiling, including secondary FIAs consisting of coexisting liquid-rich and vapor-rich fluid inclusions (FI) hosted in quartz that show temperatures from 500 °C to 100 °C as they go away from the dikes or intrusive. Vapor-rich (flashing) FIAs were observed in 41 samples. FIAs halite bearing fluid inclusions and solid inclusions are 15 samples. Finally, FIAs in liquid-rich fluid containing sylvite crystals and solid inclusions are 6 samples.

Also, FIAs are liquid-rich with different electrolytes (halite and sylvite) and solids that could be related to salts such as; Thenardite (Na<sub>2</sub>SO<sub>4</sub>), Nahcolite (NaHCO<sub>3</sub>), Pyrosmalite-(Fe) [Fe<sub>2</sub>+8Si<sub>6</sub>O<sub>15</sub>(OH,Cl)<sub>10</sub>] (Fig 1). Those have implications for element enrichment in oxidation-related fluid systems where porphyry Cu-Mo, Au, As, and Zn are found; REE-metal OMS-Be, Mo, F, and Zn; Cu-Ni, OMS-Cu, Ni, Co, Fe. The spatial distribution and targets for exploring these could be recognized in the field. The evidence of boiling, flashing, halite, and sylvite-rich fluids for characterization

of potential zones for exploration of "manto type" Cu-rich systems.



Caption: Figure 1- L=liquid-rich fluid inclusion, H=halite, K=sylvite, S=solids.



#### Poster

## Exploration of Au-Ag systems from central-southern Chile. Mora J. 1\*, Moncada D. 1

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The demand for metals is increasing, and discoveries are insufficient for the demand. The new discovery is increasingly deeper, lower-grade, hidden, and more isolated regarding infrastructure. Chile is the main copper producer worldwide, with outstanding porphyry deposits (e.g., Escondida, Chuquicamata, Andacollo, Pelambres). Gold and silver production are mainly by-products of copper mining. Most precious metal deposits are located in the north of Chile.

The Coastal Range in central-southern Chile hosts few major mines. Several areas with significant precious metal mineralized occurrences that are less understood and therefore less explored, such as the Chépica Mine District. Chépica is an active operation with a milling capacity of up to 10,000 tons/month of Au, Cu, and Pb-Zn (Ag). The geology hosting the mesothermal (?) veins with low to intermediate sulfidation epithermal pulses of the Chépica District are of Jurassic age, belonging to the Altos de Hualmapu Formation.

This unit consists of tuffs, volcanic breccias, andesitic lavas, subvolcanic intrusives, and minor intercalations of marine sediments at the base. The structures of Chépica are of vein form type (brecciate-vein structures), constituted by white to gray quartz, massive to colloform and brecciated, with the presence of pyrite and chalcopyrite as main minerals, as well as in smaller quantities, bornite, galena, hematite, covellite, and sphalerite. The structures are 1 to 15 m thick with preferential NW-SE to NNW-SSE orientation, 75° NE to sub-vertical dip, and have exposed runs of up to 1,000 m. Of the Chépica vein system, 4 are the best known and mined structures: Santa Elena, Chépica I, Chépica II, and Colin. The known and mined mineralization does not go deeper than 200m. More than 200 rock chip samples have been collected and analyzed (around Chépica, obtaining Au values up to 7 ppm, 98 ppm Ag, 7% Cu, 1.5% Pb, and 12% Zn.

Our work proposes applying fluid inclusion petrography, characterizing gangue mineral textures, and understanding the paragenesis of mineralization. The results we will obtain could be used to predict mineralization grades, evaluate and understand the hydrothermal fluid's age, project other structures in the district, and evaluate, recognize, and economic potential of Au-Cu mineralization in the Chépica District.

### Talk

The ptx conditions of the w mineralization in hydrothermal quartz vein deposits (Portugal). <u>Noronha F.</u> 1\*, Guedes A. 1, Costa e Silva S. 1 1 ICT-Porto Pole – Faculdade de Ciências Universidade do Porto, Porto, Portugal

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Most of the tungsten deposits in NW of Iberian Massif locates in Galicia-Trás-os-Montes zone (GTMZ) and in the Central-Iberian zone (CIZ), corresponding to hydrothermal quartz veins and skarns, related with Variscan granites.

The mineral assemblage in the veins reveals the existence of distinct deposition stages: "oxide silicate stage" (OSS); "main sulfide stage" (MSS); pyrrhotite alteration stage (PAS); a later period marked by the occurrence of quartz, adularia and chlorite and carbonates "late carbonate stage" (LCS).

The deposition conditions of the W mineralization in hydrothermal quartz veins have been carried out in Portuguese W deposits. We choose three examples where fluid inclusions (FI) studies were carried out on scheelite: from Murçós and Borralha (in GTMZ) and Panasqueira (in CIZ).

In the three cases, scheelite, with a powellite component lesser than 2 mol%, is later than wolframite but prior to MSS. The FI are biphasic, and fluid composition associated with scheelite deposition are aquo-carbonic (Lw-c). Additionally, to  $CO_2$ , the presence of  $CH_4$  and  $N_2$  in the volatile phase is common. In all cases a progressive dilution and enrichment of the volatile phase in  $N_2$  and  $CH_4$  can be recorded. In Panasqueira, we find the lowest T and P conditions, between 240 and 278°C and <100 MPa. In Borralha the mineralization formed, at higher temperatures between 266 to 300 C and pressures (ca 110 MPa). In Murçós, the minimum trapping conditions are between 245 to 302°C and 280 MPa.

		Panasqueira	Murcós	Borralha
	Host mineral	Scheelite	Scheelite	Scheelite
	FI Type	Biphasic	Biphasic	Biphasic
Criometry	Tmice (°C)	-5.6 -4.8	-4.4 -2.4	-8.9 -2.2
	TmCl (°C)	+10.4 +12.2	+6.1 +11.0	+0.2 +11.5
	TmCO2 (°C)	-62.0 -60.2	-63.4 -59.6	-63.0 -59.4
Thermometry	TH (°C)	240 - 278	245 - 302	210-300
Bulk Composition (In mol%)	H2O	82.4 - 87.4	76.2 - 86.5	76.5 - 87.7
	CO2	7.4 - 12.3	6.4 -18.3	7.17 - 17.5
	CH4	0.2 - 2.0	0.2 - 3.2	0.03-0.6
	N2	1.0-2.4	2.0-6.0	0.7 - 3.8
	NaCl	2.2 - 2.7	1.1 - 2.2	2.3-3.7
	Density (g/cm3)	0.98 - 1.03	0.84 - 1.10	0.97 - 1.03
Volatile phase composition (In mol%)	CO2	58.9 - 85.3	42.2 - 79.7	74.3 - 95.4
	CH4	2.5 - 19.2	1.4 - 14.9	0.2-4.3
	N2	10.5 - 23.3	13.0 - 50.4	3.8-47.8
	Fluid type	Lw-c	Lw-c	Lw-c
	Fluid system	H2O-CO2-CH4-N2- NaCl	H2O-CO2-CH4-N2-NaCl	H2O-CO2-N2-CH4- NaCl
	Minimum trapping pressure (MPa)	<100	280	≈110

Caption: Compilation of FI data



#### Talk

Primary vs. secondary inclusions in hydrothermal ore deposits: choosing the right FIAs for a successful research. <u>Ortega L.</u><sup>1\*</sup>

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Fluid inclusion studies have widely contributed to the understanding of ore-forming processes in hydrothermal deposits. Thus, their study should be a basic tool achievable for any economic geologist. The key point is identifying which set of fluid inclusions may answer the problem we want to solve. Selecting primary or secondary inclusions will depend on the geologic problem being studied and noteworthy, where it could have been recorded. Here, two case studies illustrate this assessment:

1) An orogenic Sb-Au deposit, where massive stibnite is coeval with comb textured quartz. Primary inclusions record the coexistence of liquid-rich and vapor-rich inclusions, endmembers of an unmixing process responsible for ore deposition at 300 °C and 1 kb.

2) A fluid-deposited highly crystalline graphite hosted by volcanic rocks. Graphite occurs in the hydrothermally altered matrix of a breccia pipe, which also carries uprooted fragments of quartz. This quartz recorded the graphite mineralizing fluid as secondary inclusions which represent the quartz brecciation and transport upwards within the pipes. Estimated initial PT of graphite precipitation were 500 °C and 2 kb.

This contribution highlights the importance of combining a good geological understanding of the hydrothermal system under inspection, with a detailed petrography of fluid inclusions. This approach will allow to find and select the right fluid inclusion assemblages and to design a successful fluid inclusion research.



#### Poster

## REEs mineralized fluids: Montecristo IOCG district, Antofagasta, Chile.

## Paredes A.<sup>1</sup>, <u>Moncada D.</u><sup>2\*</sup>, Diaz A.<sup>3</sup>, Arredondo C.<sup>4</sup>, Ortega R.<sup>3</sup>

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The Montecristo mining district is approximately 22.5 km from Paposo City, Antofagasta, Chile. Situated in the western zone of the ferritic coastal mountain range belonging to the middle-late Jurassic, there are deposits of copper porphyry, mineralized veins, and copper stratobounds type deposits. The district is hosted by the Matancilla Intrusive Complex and is associated with the Paposo segment of the Atacama Fault System. There are at least twelve NNE-SSW oriented veins with early IOA type mineralization and a later event of IOCG type mineralization. The primary mineralization consists of chalcopyrite, pyrite, bornite, and molybdenite, which are associated with magnetite and hematite. Secondary sulfides relate to chalcocite and covellite, while the oxidized zone is characterized by malachite, chrysocolla, atacamite, and antlerite. (Alvarez et al., 2016) IOCG and IOA type mineralization in the Montecristo district has been a discussion about their potential genetic relationship. Not many deposits worldwide exhibit both types of mineralization and Rare earth elements (REEs). The presence of REEs (La, Er, and Ho) in apatite crystals was discovered in the early phases of paragenesis by SEM and Ramana spectroscopy (Cabello Cabello, 2024). These observations generate new questions about the source of the fluid present. Preliminary detail petrography shows across mineralized samples. The fluid inclusions assemblages (FIA) in apatite contain liquid-rich inclusions with a red-to-brown mineral in the inclusions. Secondary halite-bearing fluid inclusions with opaque minerals in apatite. Secondary liquid-rich fluid inclusions in quartz. Secondary FIAs consisting of coexisting liquid-rich and vapor-rich inclusions in epidote. Primary and secondary liquid-rich FIAs in rhombic calcite. Preliminary results in the decrepitation of chalcopyrite in a heating experiment show the presence of V, Br analyzed by SEM. In-situ analyses on individual fluid inclusions and minerals will be performed using micro-analytical techniques such as infrared (IR) petrography for opaque minerals, SEM/EDS/EBSD and spectroscopy Raman.

#### Reference

Alvarez (2016), Cartas Punta Posallaves y Sierra Vicuña Mackenna, Región de Antofagasta.

Estudio y distribución de tierras raras en depósitos de tipo IOA/ IOCG de la provincia metalogénica de la cordillera de la costa en la región de Antofagasta. Universidad de Chile.

### Talk

# Petrogenesis of the lower crustal sulfides in the Bay of Islands Ophiolite Complex, Canada. <u>Soltanmohammadi A.</u>1\*, Bédard J.<sup>1</sup>, Hinchey A.<sup>2</sup>, Stern R.<sup>3</sup>

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The Bay of Islands Ophiolite Complex in western Newfoundland exposes mafic-ultramafic rocks, including lower crustal sections of the North Arm Massif (NAM), where sulfide concentrations have an unclear origin. To assess base metal (Cu, Ni, Fe)mobility, we analyzed siderophile elements in whole-rock and minerals. At NAM, boninitic peridotitic and pyroxenitic intrusions assimilated altered gabbros of the overlying tholeiitic crust. These gabbros had undergone greenschist-grade hydrothermal alteration, forming subordinate pyrite. Field and mineralogical data show feldspathic peridotites are hybrids with gabbroic and pyroxenitic xenoliths. Sulfide lenses (cm-scale) are present in reaction zones, with up to 58,000 ppm S and 538 ppb  $\Sigma$ PGE. Elevated siderophile element contents are found in sulfide-rich feldspathic peridotites and pyroxenites. Textures like sulfide inclusions in chromite, pyroxene, and olivine, as well as immiscible sulfide blebs, suggest high-temperature magmatic processes. Laser ablation analyses confirm magmatic S/Se values (~2000–6000). Boninitic melts are S-poor and typically trigger sulfide immiscibility late, but assimilation of S-rich gabbros may induce early immiscibility. S/Se ranges from <2000 to 23,000, with high ratios in gabbronorite lenses and low (mantle-like) ratios in feldspathic wehrlites, suggesting both magmatic and hydrothermal sulfur contributed to sulfide saturation at the crustal base.



### Talk

Origin of alkaline magmatism: a perspective on its link to the distribution of Critical Mineral Deposits. <u>Soltanmohammadi A. 1\*</u>, Rabinowicz M.2, Fontaine F.3

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The term "alkaline rock" is used to describe rocks that contain high concentrations of alkali metals (like k and Na) and rare earth elements. The metal endowment of these rocks, particularly the rare earth elements and alkali metals, is subject to specific thermal conditions and the chemical composition of their mantle sources. Our primary synthesis shows that, although alkaline rocks in the middle part of the Alpine-Himalayan belt and the Grenville Province in Canada were emplaced during different geological periods (Cenozoic vs. Mesoproterozoic), they share similarities in the mantle components involved in their formation, reflecting contributions from both lithospheric and asthenospheric mantle sources in these distinct settings. Recently, an integrated approach combining results from petrology, geophysics, and geodynamic modeling has led to the proposal of a new model, "compaction pockets", explaining the origin of alkaline melts in the Tethyan orogenic belts. The application of this model suggests that the distribution of alkaline melts in the Grenville Province may also be explained by similar mechanisms. Our synthesis indicatés that these novel models can be applied to investigate metallogenic domains hosting alkaline rocks in eastern Canada. This insight offers a new approach to tracking the trajectories of fertile melts, enabling a more systematic investigation of regions with potential for critical mineral exploration.

Reference

Soltanmohammadi et al. (2018), J. Petrol., 59, 2273-2310.



#### Poster

#### Fluids in Volcanic Massive Sulphides: Bahía Blanca - Caleta Benavente, Magallanes, Chile.

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The Volcanogenic Massive Sulfide (VMS) deposit at Bahía Blanca-Caleta, located at the southernmost tip of Chilean Patagonia. Consisting mainly of pyrite, chalcopyrite, sphalerite, pyrrhotite, galena, argentite, arsenopyrite, cobaltite?, vaesite, stannite, glaucodot, and relics of marcasite–melnikovite they are concordant in massive quartz-bearing quartz. VMS deposits are stratiform or stratabound Cu–Pb–Zn deposits formed by sulfide accumulations at or near the seafloor. The regional geology consists of volcanic, sedimentary, and metamorphic sequences subjected to multiple tectonic events during the Mesozoic and Cenozoic.

More than 100 samples were collected during a campaign in 2022 and 2023 from SERNAGEOMIN. The samples were collected in outcrops, analyzed by 56 elements, including major, trace, and REEs, into three major areas:Domain 1(south), Domain 2(central) and Domain 3(north).

A Scanning Electron Microscope (SEM) analysis of mineralized samples from the three metallogenic domains revealed distinct mineral associations and elemental enrichments. In Domain 1, galena and chalcopyrite show Se and Co, with Fe sulfides containing As and Co. Ni, Co, As, Sb, Zn, Bi, and U are noted in pyrite and pyrrhotite. Titanite and zircon are associated with high REEs, Ti, Th, and U. In Domain 2, pyrites show As, Co, Sb, Pb, Zn, and Sn. Chalcopyrite, sphalerite, and pyrite contain galena inclusions with As and Co. In Domain 3, altered pyrrhotite zones have high Al, P, Si, and Rh. In metalutites, elevated Na, Cd, and Mn are seen in sphalerites, while Fe sulfides contain Co, Ni, Ca and Si, with oxidized zones showing Ni, Mg and Ca. Pyrite with framboids textures contain Mn, Co and Pb. Sulfides in the lower stratigraphic sequence show Co and occasional Zn in chalcopyrite, with oxidized chalcopyrite-pyrrhotite-pyrite zones exhibiting high Zn, Rh and Cl. High Ba is linked to barite in chalcopyrite.

Preliminary works show a detailed petrography of 14 samples in the three zones, looking for fluid inclusions. The Domain 1 shows secondary liquid-rich fluid inclusions assemblages (FIA) in quartz veins related to pyrite and chalcopyrite. Domain 2 samples show secondary FIAs in quartz veins and stockwork consisting of coexisting liquid-rich and vapor-rich FIAs (boiling) in equilibrium with pyrite, arsenopyrite, and other sulfides. Primary liquid-rich FIAs in calcite. Finally, Domain 3 shows secondary liquid-rich FIAs.

## Talk

Crustal carbon reduction triggers iron oxidation: Insights from minerals, fluid and melt inclusions. Xu X. 1\*, Steele-MacInnis M. 1 1 University of Alberta, Edmonton, Canada

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Carbon plays a crucial role in magmatic, metamorphic, and metallogenic processes. While the contribution of sedimentary elemental and organic carbon to reductive mineralization is well established, the role of carbon in oxidized ore formation remains unclear.

We investigate the Sybille monzosyenite and associated nelsonite from the Laramie Anorthosite Complex (LAC), Wyoming. Mineral assemblages and melt-fluid inclusions reveal a close association of carbonate,  $CO_2$ , graphite, and magnetite. The widespread carbonaceous fluids are largely anhydrous, multi-stage, and dominated by carbonates, chlorides,  $CO_2$ , and minor  $CH_4$ . Inclusions along the same fluid trail show variable compositions depending on the host mineral, reflecting strong fluid-host interaction. For instance, inclusions in ferrosilite lack  $CO_2$  but are rich in polycrystalline crystals including carbonate, diopside, magnetite, graphite, apatite, and awaruite.

These observations suggest that dry carbonaceous fluids play a key role in redox processes, promoting iron oxidation and generating graphite as a reduction byproduct. These fluids with high mass-transfer facilitate the build-up of Fe<sup>3+</sup> and P, produce Nelsonite by cumulative metasomatism, and obscures their traces later via decarbonation and degassing. We propose that oxidized carbon reduction is critical for ore formation under specific geological conditions and oxidized carbon may act as a fundamental oxidant in diverse crustal settings.



#### Poster

Fluid inclusions in scheelites from Tabuaço and Freixo de Numão deposits (Douro Scheelite Belt area, Portugal). <u>Yakovenko A.</u>1\*, Guedes A.<sup>1</sup>, Nogueira P.<sup>2</sup>, Noronha F.<sup>1</sup>

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Keywords: fluid inclusion, ore deposits, hydrothermalism

Petrographic, microthermometric and Raman microspectrometry analyses were performed on scheelites from Freixo de Numão (FN) and Tabuaço (TAB) deposits in the Douro Scheelite Belt, Portugal. The mineralized structures hosting scheelite consist of quartz veins, with gold mineralization, cutting calcsilicate levels in FN and skarns in TAB. In FN, scheelite is present as coarse grains in quartz veins and fine-grained in calcsilicate levels, while in TAB both fine and coarse-grained scheelite occur in skarns.

Primary fluid inclusions (FI) in scheelite from both deposits show high H<sub>2</sub>O content and the presence of minor volatile components, such as CH<sub>4</sub> and N<sub>2</sub>. FI in scheelites from quartz veins and their calcsilicate host rocks in FN exhibit 91.1 to 96.5 mol% H<sub>2</sub>O, CH<sub>4</sub> (21–100 mol%), N<sub>2</sub> (0–26 mol%) and rarely CO<sub>2</sub> (0–77 mol%). Scheelites from skarns in TAB exhibit FI with 95.5 to 97.4 mol% H<sub>2</sub>O and volatile phase containing CH<sub>4</sub> (59–100 mol%) and N<sub>2</sub> (0–41 mol%). Although salinity range is similar in FI from scheelites of both deposits (3.7–5.4 wt% NaCl eq.), lower salinity was found in FI from scheelite hosted in calcsilicate rocks (3.7–4.9 wt% NaCl eq.). These FI also show the highest homogenization temperatures (TH between 300–357 °C) (Fig. 1).

The deposition of scheelite is assisted by aqueous, slightly saline fluids, with a volatile phase enriched in  $CH_4$  and  $N_2$ , probably due to interaction with the host metamorphic rocks under reducing conditions, at different temperatures.



Caption: Figure 1- Salinity vs. homogenization temperature (TH) plot for fluid inclusion data at studied deposits.



#### Poster

 Fluid- and melt inclusions from apatite in the Per Geijer Iron-Oxide-Apatite-REE deposit, Sweden.

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The Per Geijer (PG) Iron Oxide-Apatite (IOA)-REE deposit has substantial content of apatite-hosted REEs. However, the formation mechanism of apatite, and indeed the entire IOA system, remains contentious.

We present detailed information on apatite-hosted fluid and melt inclusions that cover different apatite types observed in the PG deposit. Petrography and laser Raman spectroscopy reveal at least eight different inclusion types (all around 5 µm), mostly comprising primary one-phase ( $\approx$ 60%) and multi-phase ( $\approx$ 20%) inclusions. Secondary inclusions ( $\approx$ 20%) are common but very small, <5 µm. Most abundant inclusion types are primary (one-phase) tabular shaped monazite and apatite inclusions concentrated within the centre of the host apatite and oriented along the c-axis (Figure 1).

Extensive polycrystalline (salt) melt inclusion assemblages as reported in Xu et al. (2024) are uncommon in the studied samples. This suggests that the involvement of molten salts in the formation of the PG deposit is unlikely to have been ubiquitous in every apatite generation.

#### Reference

Xu. et al. (2024). Magnetite-apatite ores record widespread involvement of molten salts. Geology, 52, 417-422.



Caption: Figure 1 - Salinity vs. homogenization temperature (TH) plot for fluid inclusion data at studied deposits.





# **Session 5**

# **Geothermal Energy**



## Session 5: Geothermal energy

## Talk

Chemical and thermal evolution of the hydrothermal fluids in the Gale-Le-Koma and the Asal-Fiale geothermal fields, Republic of Djibouti.

### Ahmed Aden A.<sup>1</sup>;<sup>2</sup>;<sup>3\*</sup>, Bali E.<sup>3</sup>, Galeczka I.M.<sup>3</sup>

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Keywords: fluid inclusion, hydrothermalism, geothermal energy

The Asal-Ghoubbet rift has undergone geothermal exploration since 1970s. This study focuses on the Gale-Le-Koma and Asal-Fiale fields. Four wells were drilled from 2016 to 2019—GLC-1 (538 mMD) in Gale-Le-Koma and F1 (2743 mMD), F2 (2705 mMD), and F3 (2660 mMD) in Asal-Fiale—to assess geothermal reservoir potential.

The objective is to present the chemical composition and thermal evolution of geothermal fluids using fluid inclusion microthermometry, Raman spectroscopy, and LA-ICP-MS.

Liquid-rich (L-rich) and Vapor-rich (V-rich) fluid inclusions, with occasional solid phase, were observed in secondary quartz from rock cuttings. To constrain the characteristics of the fluids, we analyzed the primary and secondary L-rich fluid inclusions.

In GLC-1, homogenization temperatures (Th) (150-178°C) exceed current temperatures (130°C) but are lower than estimates from alteration minerals (220°C) at 500-508 mMD. In contrast, the shallow reservoir (520-850 mMD) in Asal-Fiale shows thermal equilibrium between Th, alteration mineralogy, and current temperatures ( $\geq$ 200°C), before cooling due to seawater inflow. Below 1900 mMD, Th and alteration minerals showed high temperatures ( $\geq$ 280°C), and current heating near boiling conditions (362°C at 2625 mMD in F3), see Fig. 1. Salinities were 10-18 wt% NaCleq in GLC-1, and 4-15 wt% NaCleq in F1, F2, and F3. High salinity might indicate seawater/ basalt interaction and/or trapping from boiling seawater.

LA-ICP-MS will provide new fluid chemistry data in both geothermal fields.



Caption: Figure 1- Correlation of formation, alteration minerals and fluid inclusions temperatures (°C) in well F3. Error bars refer to 1 standard deviation (1 $\sigma$ ).


#### Talk

#### The role of fluids in subduction zones: implications for volcanism and geothermal activity.

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Keywords: melt inclusion, magmatism, geothermal energy

Water supply and budget are essential aspects of a subduction system as they affect the productivity of arc magmas, the cycling of volatiles in the mantle, and the rheology of the mantle beneath subduction zones. Volatiles (H<sub>2</sub>O, CO<sub>2</sub>, S, F, Cl, Br, Li) play an important role in the evolution of magmatic processes and the physics of volcanic eruptions. However, volatiles are also necessary for the development of magmatic-derived hydrothermal systems. We will present some recent findings on immiscible volatile phases exsolving from melts from the Southern Volcanic Zone (SVZ) in Chile and their role in crystallization and heat and mass transfer to geothermal systems. We will present pre-eruptive magma compositions obtained from bubble-bearing olivine-hosted melt inclusions in phenocrysts from several eruptive centers, from stratovolcanoes and monogenetic volcanic centers. Our data shows that in the SVZ, magmatic processes and geothermal activity are affected by the location of volcanic centers with respect to the Liquiñe – Ofqui transpressional fault system and that volatile migration and magma/fluid distribution are strongly intertwined with the regional stress field and well-defined vertical structures through the lithosphere.



#### Talk

The chemical composition of hydrothermal fluids from the deeper reservoir of the Larderello geothermal system (Italy) as deduced from LA-ICP-MS study of quartz-hosted fluid inclusions.

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Keywords: fluid inclusion, geothermal energy, hydrothermalism

The Larderello geothermal field (Italy) is a well-known vapor-dominated geothermal system. Its two reservoirs, (carbonic-evaporitic units above and metamorphic rocks below) have long been studied through many methodologies. Fluid inclusion (FI) studies have determined the P-T conditions and chemical composition of major salts and gases (Boiron et al., 2007; Catelineau et al., 1994; Ruggieri et al., 1999). However, very few direct measurements of the chemical composition of Larderello FIs have been completed (Blundy et al., 2021), and none covering a wide range of elements, fluid compositions, or P-T variations.

We selected two proximal wells from the NE area of Larderello, and sampled quartz-hosted FIs from three cores at different depths in the deeper reservoir. Our study, for the first time, directly quantifies the trace chemistry of the vapor-rich and salt-rich fluids that likely represent the present-day pore fluids of the deeper/hotter (>350°C) portions of Larderello geothermal field.

First, microthermometry on 800 FIs constrained P-T conditions and salinity of the fluids and are a good match to present-day temperature estimates. To directly quantify the trace chemical composition, LA-ICP-MS analyses were conducted on 236 individual FIs for 25 major and trace elements at ETH Zürich (Fig.1).

Our data show clear differences in fluid composition as a function of depth. Indeed, we observed a major influence of infiltrating meteoric water on the shallow fluids, while deeper samples appear to retain some magmatic fluid contribution to their composition.

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Caption: Figure 1- LA-ICP-MS signal of one fluid inclusion, with a selected subset of elements (Si, Na, K, Li, Pb).

#### Poster

Preliminary microthermometric fluid inclusion data on Mofete 3 and 5 geothermal wells (Campi Flegrei, Italy). <u>Masi M.</u><sup>1\*</sup>, Fulignati P.<sup>1</sup>, Marianelli P.<sup>1</sup>, Pistolesi M.<sup>1</sup> <sup>1</sup> University of Pisa, I-56126 Pisa (Italy), Pisa, Italy

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The Campi Flegrei caldera is a densely populated area which has undergone intense volcanic activity in the last 39 ka. The area is undergoing bradyseism showing early signs of increasing activity. To improve our understanding of the current state of the active hydrothermal system hosted within the Campi Flegrei caldera, we investigated fluid inclusions (FI) from 3 core samples from 2 geothermal wells (from 1324 m at Mofete-3, 2604 m and 2698 m at Mofete-5).

All samples are hydrothermally altered. Mofete-3 sample is a hydrothermally altered tuff containing quartz, calcite, adularia, albite and chlorite. Both samples from Mofete-5 are found in the thermometamorphic zone (De Vivo et al., 1989). At 2062 m of depth, hydrothermal alteration is made of quartz, adularia, albite, diopside, scapolite, calcite, titanite and pyrite, while at 2698 m an association of quartz, scapolite, anhydrite, diopside, calcite, titanite and pyrite occurs.

FIs are of primary or pseudo-secondary origin and are hosted within quartz. We found three different types of FIs:Type-1 (two phases liquid + vapor), Type-2 (two phases vapor + liquid) and Type-3 (three-phase liquid + vapor bubble + one or more daughter minerals of round or cubic shape, sometimes tabular) (Fig.1).

Only Type-1 Fls were only found in Mofete-3 well sample, while Type-2 and Type-3 Fls occur in both samples of Mofete-5 well. Type-1 Fls have ellipsoidal shape and are found in quartz.

Type-2 FIs are the most common type of inclusions in both samples of Mofete-5 well. They have a rounded shape and are rarely ellipsoidal. Type-3 FIs seem to be rarer and have rounded, ellipsoidal or rarely irregular shape.

Type-2 and Type-3 FIs were found often associated. Microthermometric experiments on Type-1 FIs indicate homogenization temperatures (Th) with a mode around 250° C and salinity with modal value around 3.5 wt.% NaCleq (Mofete 3 well – 1324 m of depth). Preliminary data on Type-3 FIs indicate a wide Th range between 317° C and 647 °C and salinities between 46 and 77 wt.% NaCleq The small size of Type-2 FIs precludes at present the collection of microthermometric data.

#### References

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Caption: Figure 1- Micropicture showing Type-3 fluid inclusions hosted within a quartz crystal from Mofete-5 (2698 m of depth).

#### Poster

Fluid inclusion analyses in granite intrusion cuttings from boreholes at Hoffell/Miðfell area in Geitafell Central volcano. <u>Pilicita B.</u>1\*, Bali E.<sup>1</sup>

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Keywords: fluid inclusion, geothermal energy, hydrothermalism

Exploration boreholes in Geitafell, a fossil central volcano in southeastern Iceland, penetrated a granitoid intrusion between 1000 and 1590 m depth. This study explores the fluid processes related to this intrusion.

The granite cuttings contain plagioclase, K-feldspars, quartz and disseminated magnetite as primary minerals. At least four (4) fluid inclusion assemblages (FIAs) were identified. Early inclusions are primarily located at the centre and crystal growth zones of quartz and include brine inclusions (A, Fig 1) with multiple solid phases, decrepitated melt inclusions (B) alongside vapor-rich (C) inclusions. Late inclusions, occur mainly in crystal fractures, consist of a range of brine (D), liquid-rich (E, F, G) and liquid-only (H) inclusions.

Microthermometry and Raman spectrometry uncovered two main homogenization temperature (Th) and salinity ranges: one exceeding 580°C and 71 wt% NaCleq for the A inclusions (associated with inclusions B and C) and another between 220 to 300°C with salinity of 0-4wt% NaCleq mainly for the E, F and G inclusions.

We distinguish two fluid types in the system: one with high temperatures and salinity of magmatic origin, represented by the early inclusions and a second with lower temperatures and salinities, possibly linked to meteoric water sources. Evidence of mixing and re-equilibration is indicated by some Late FIAs showing necking down texture and intermediate Th values and salinities.



Caption: Figure 1- Photomicrograph of multiple phase (S: solid, V: vapor, L: Liquid) brine inclusions (A) containing in Quartz.



#### Talk

Fluid inclusion analysis of silica scale and cutting samples from Sikidang Area, Dieng Geothermal Field, Indonesia.

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Keywords: fluid inclusion, geothermal energy, geothermal energy

This study aims to characterize the subsurface lithology, hydrothermal alteration, and geothermal fluids in Sikidang area of Dieng geothermal field, Indonesia. Fluid inclusions in silica scale, quartz, and calcite cuttings from three wells were analyzed by measuring homogenization temperature (Th). Salinity was calculated as NaClequiv from melting temperature (Tm) (Bodnar & Vityk, 1994) and from Raman spectra (Caumon et al. 2015).

Fluid inclusions in silica scale at 1087 m in well JS-5 showed a median Th of 179.9 ± 14 (1 $\sigma$  stddev)°C, matching the downhole temperature at 1100 m (180.9°C). Salinity ranged 1.6-7.3 wt% NaClequiv with median of 2 wt% NaClequiv.

In well JS-2, measured temperature at 650 m is 221.9°C, matching the median Th of fluid inclusions at 638 m (234 ± 40 (1 $\sigma$  stddev)°C), with median salinity of 0.7 wt% NaClequiv. At 659 m, median Th was lower at 178 ± 32 (1 $\sigma$  stddev)°C with median salinity of 2.2 wt%. Variations in Th and salinity along with casing corrosion and scale deposition at 647-700 m suggest boiling which leads to higher salinity, mineral supersaturation, and possibly condensation of corrosive gases in this interval.

A wide range of Th values (145.0-269.9°C) with median of 234.6  $\pm$  29 (1 $\sigma$  stddev)°C was observed in well JS-1 at 1050 m. This is attributed to re-equilibration by necking down processes (Fig. 1).

Fluid inclusion data will be interpreted together with wellhead fluid composition, and mineral saturation indices calculated by WATCH and PHREEQC.

References

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Caption: Figure 1- Photomicrograph of necking down fluid inclusions with 10x magnification (a) and 50x magnification (b) in quartz (Qz) from well JS-1 at 1050 m.





# **Session 6**

# **Climate Change**



#### Talk

## Greenhouse gas emissions from the North Atlantic Igneous Province at the time of Paleocene–Eocene Thermal Maximum Capriolo M.<sup>1\*</sup>, Jones S.<sup>1</sup>, Theurer T.<sup>2</sup>, Muirhead D.<sup>2</sup>, Mortensen H.<sup>3</sup>, Tegner C.<sup>3</sup>

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Keywords: fluid inclusion, melt inclusion, climate change

The North Atlantic Igneous Province (NAIP) coincided in time with the Paleocene–Eocene Thermal Maximum (PETM), which is the most recent natural analogue for anthropogenic greenhouse gas emissions (Jones et al., 2019).

The temporal association between Large Igneous Provinces and climate perturbations throughout the Phanerozoic points to a potential causality via magmatic and thermogenic emissions.

In order to constrain greenhouse gas emissions from the NAIP, we studied melt and fluid inclusions within intrusive and effusive rock samples from East Greenland and Faroe Islands (Fig. 1), which represent the locations closest to the original centre of the mantle plume on Western and Eastern margins, respectively (Larsen & Tegner, 2006; Jolley et al., 2022).

Our Raman microspectroscopy data on melt and fluid inclusions in rock samples from Skaergaard and its overlying Plateau Basalt unveiled the occurrence of different carbon species.

In the effusive rock samples, olivine and clinopyroxene phenocrysts host primary melt inclusions containing  $\rm CO_2$  or elemental C within gas bubbles.

In the intrusive rock samples, olivine crystals sometimes host  $CH_4$ -bearing fluid inclusions, and quartz crystals usually host abundant multiphase fluid inclusions, containing  $CH_4$  and sometimes  $CO_2$  along with  $H_2O$ .

These tiny amounts of carbon species preserved by melt and fluid inclusions represent the direct evidence of magmatic and thermogenic emissions from the NAIP, whose characterization and quantification are fundamental to reconstruct the Earth system response at the time of PETM.

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Caption: Figure 1- Columnar jointed basalt of a lava flow in Suðuroy (Faroe Islands).

#### Talk

Far away from the isochore: a physical model for paleotemperature reconstruction from fluid inclusions in halite. <u>Guillerm E.</u><sup>1\*</sup>, Lowenstein T.<sup>2</sup>, Gardien V.<sup>3</sup>, Brauer A.<sup>1</sup>, Krüger Y.<sup>4</sup>, Arnuk W.<sup>5</sup>, Caupin F.<sup>3</sup>

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Keywords: sedimentary basins, thermodynamic calculations, climate change

Fluid inclusions (FI) in halite from sedimentary basins are archives of past waterbodies and are thus key to understanding past climates and environments. However, due to some extreme properties of the halite FI system, the relevance of using the observed liquid-vapor homogenization temperature (Th,obs) as a paleothermometer of ancient water has been debated. Indeed, contrary to most other minerals in which FI can be assumed isochoric (i.e. of constant volume), in halite the solubility, thermal expansion, elasticity and plasticity of the FI walls cannot be overlooked. Moreover, surface tension at the liquid-vapor interface and pressure-temperature-composition paths are heavily influenced by the high salinity and complex chemical composition of the brine. Here we present a halite FI model that accounts for the complex physical properties of fluid and host. A user interface of the model allows calculating FI pressure, yield stress and entrapment temperature as a function of Th,obs, temperature, FI size, chemical composition, water height during entrapment and burial conditions. We find that the thermal expansion, elasticity and plasticity of halite may affect considerably Th,obs, by several Celsius, and that these effects are highly dependent on FI size and chemical composition. Solubility, on the other hand, has a more moderate effect. This work opens the door to robust halite FI paleothermometry. It also has implications for the study of FI in other soft, soluble minerals.



#### **Poster**

An attempt to synthesize fluid inclusions under cave-analogue conditions. <u>Krüger Y.</u> 1\*, Day C.C.2, Pasqualetto L.1, Meckler A.N.1 1 University of Bergen, Bergen, Norway, 2 University of Oxford, Oxford, United Kingdom

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Surface tension corrected homogenisation temperatures  $T_{h\infty}$  (Marti et al., 2012) of petrographically coeval fluid inclusions in stalagmites display a systematic scatter of 4-6 °C with Gaussian-like distributions, corresponding to standard deviations (1SD) of about 1 °C (Løland et al., 2022; Krüger et al., 2025). For comparison, the analytical precision of the individual  $T_{h\infty}$  values is in the range of  $\pm 0.2\text{-}0.3$  °C (2SD) and hence cannot explain the observed scatter of the  $T_{h\infty}$  data. The reason(s) for this scatter is not yet clear and we currently speculate about potential non-thermal factors altering the volume properties of the inclusions, e.g. relaxation of stresses in the crystal fabric or water diffusion along (sub-)crystal boundaries.

Against this background we are trying to synthesize fluid inclusions in calcite under controlled cave-analogue conditions 1. to test whether we can reproduce the scatter of  $T_{h\infty}$  in the experiment and 2. to compare the mean of the  $T_{h\infty}$  distribution with the actual formation temperature of the inclusions. To do so, we "drill" an array of holes of ca. 170 µm depth and 20 µm diameter in a calcite substrate by means of laser ablation using an amplified femtosecond laser. The sample is then placed in a temperature-controlled vessel (a redesign of the so-called "Oxford Cave"; Day & Henderson, 2011) to seal the water-filled holes by a calcite overgrowth precipitating from a supersaturated solution continuously dripping on the surface. Although the experiments were run for several months to form a ca. 1 mm thick calcite overgrowth, we did not yet succeed in tightly sealing the holes and after preparation of 300 µm thick sections we found them all empty. SEM analysis of exposed holes, however, show that calcite precipitated at the walls of the holes, indicating that they must have been water-filled during the experiment. Further tests are needed to improve and optimise the experimental protocol and we are confident that we will eventually manage to synthesize fluid inclusions under cave-analogue conditions.

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#### Poster

FluidMICSolver: a new software tool for nucleation-assisted microthermometry in speleothems. <u>Pasqualetto L.</u><sup>1\*</sup>, Krüger Y.<sup>1</sup>, Meckler N.<sup>1</sup> <sup>1</sup> University of Bergen, Bergen, Norway

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Nucleation-assisted microthermometry has paved the way for homogenisation temperature (Th) measurements of single-phase liquid fluid inclusions by employing ultrashort laser pulses to induce bubble nucleation (Krüger et al., 2007). This technique has been successfully applied in speleothem science as a temperature proxy for paleoclimate reconstructions, enabling high-resolution temperature records with standard errors of the mean (2SEM) <0.5 °C (e.g., Løland et al., 2022). This method also includes bubble size measurements to correct the T<sub>h</sub> for surface tension effects at the liquid-gas interface of vapour bubble.

Here we present FluidMICSolver, an open-source standalone software solution developed in MATLAB that standardizes the data processing and improves the analytical workflow efficiency. The tool consists of four graphical user interface modules: (i) Bubble measures opens, categorises and edits microscope images of nucleated bubbles for measuring and storing their radii; (ii) Calculator runs an updated version of the thermodynamic pure water model by Marti et al. (2012) to compute the surface tension correction for measured Th; (iii) Plot performs statistical analysis on the corrected temperatures and plots the results in predefined diagrams for evaluating temperature distributions and their relationships with the fluid inclusion volumes; (iv) Multiplot allows for simultaneous processing of multiple samples, ensuring consistent analysis across all datasets and facilitating the visualisation of the temperature records.

This first version includes updated thermal expansion models for several host minerals, (e.g., calcite, quartz, gypsum), improving the prediction of the non-isochoric behaviour of low temperature inclusions. It also offers robust statistical tools for identifying outliers and assessing potential bi-/multi- modality of  $T_h$  distributions. Finally, a Monte Carlo simulation based on the model proposed by Spadin et al. (2015) may fit the intensity profiles of the bubble images and determine bubble size at different focal planes. All these tools and models will be presented and discussed.

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#### Poster

Methane-rich fluid inclusions in hydrothermally altered granulite. <u>Pengg A.</u>1\*, Bakker R.1, Misch D.1 <sup>1</sup> Technical University of Leoben, Leoben, Austria

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As natural hydrogen harbors great potential to contribute to a future climate-friendly energy system, it recently moved into the focus of research in geosciences. This contribution presents the results of a fluid inclusion study that was carried out to investigate hydrogen-generative processes in serpentinized ultramafic rocks and granulitic crystalline rocks from the Bohemian Massif (Austria) in order to assess their natural hydrogen potential. The samples were taken from outcrops in an active quarry where the investigated lithologies occur separated by a tectonic contact that is characterized by strong mylonitic deformation and significant hydrothermal alteration. The applied methods were Raman Spectroscopy and microthermometry.

While fluid inclusions in the serpentinized ultramatic rocks and the unaltered granulitic rocks were rarely observed and contained mainly water, the altered granulite showed a large amount of fluid inclusions in which  $CH_4$  ( $\pm$  H<sub>2</sub>O) was the main component. Besides  $CH_4$ , H<sub>2</sub>, N<sub>2</sub>, and H<sub>2</sub>S occurred in trace amounts. As reduced gas species are uncommon in granulitic rocks, the question of their origin arises. The adjacent serpentinite would be a potential source for both  $CH_4$  and H<sub>2</sub>, which would impose a later hydrothermal origin of the fluid inclusions. Alternatively, H<sub>2</sub> could be mantle-derived. Further investigations will clarify the origin of  $CH_4$  and H<sub>2</sub>.



#### Talk

#### Trace element proxies in evaporite fluid inclusions: unlocking a new archive for paleoceanographic reconstruction.

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Keywords: fluid inclusion, climate change, new frontiers

Fluid inclusions entrapped within marine evaporites offer a unique and direct archive of paleoseawater chemistry, providing invaluable insights into past ocean redox conditions, ancient climates, atmospheric CO<sub>2</sub> levels, and fundamental Earth system processes such as supercontinent cycles, chemical weathering, and seafloor spreading. However, our knowledge of secular variations in major/minor/trace element compositions of ancient seawater remains limited. Despite the considerable potential of halite fluid inclusion archives, significant uncertainties persist in accurate and precise analysis and interpretation of their geochemical signatures. These uncertainties largely stem from challenges associated with single fluid inclusion analyses and limited understanding of the fractionation behavior of trace elements during progressive evaporation of seawater, crystallization of evaporite minerals, and potential local bioge ochemical interactions.

To address these critical knowledge gaps, here we present elemental compositions of modern and ancient halite samples, including from laboratory seawater evaporation experiments, from single fluid inclusions analyses using a state-of-the-art LA-ICP-MS setup. This integrated approach allows us to trace the behavior of a suite of major, minor, and redox-sensitive trace elements – including but not limited to B, Fe, Mn, Mo, U, V – during seawater evaporation and mineral crystallization, and across the Phanerozoic record.





# **Session 7**

# **Metamorphism and Mantle Processes**



#### Poster

Deep CO<sub>2</sub>-rich fluid migrations in the lower crust of the Pannonian Basin: fluid inclusion systematics from metapelitic granulite xenoliths.

Keresztes T.<sup>1</sup>, Spránitz T.<sup>2\*</sup>, Fehér K.<sup>3</sup>, Aradi L.<sup>1</sup>;<sup>4</sup>, Kovács D.<sup>1</sup>, Szabó Á.<sup>5</sup>, Török K.<sup>6</sup>, Hencz M.<sup>2</sup>, Gilio M.<sup>7</sup>, Alvaro M.<sup>7</sup>, Berkesi M.<sup>2</sup>

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Keywords: fluid inclusion, metamorphism, fluid-phase equilibria

In the lithospheric upper mantle, carbon is mainly present as a CO<sub>2</sub>-rich fluid, while upon further upward transport, fluid-involved metamorphic reactions can be expected in the lower crust, as shown on mafic granulites (Török et al., 2005). Our study focuses on graphite-rich metapelitic granulites hosting abundant primary and secondary fluid inclusion assemblages. The rocks were found as xenoliths from the Bakony-Balaton Highland Volcanic Field representing the metasedimentary portion of the lower crust in the Pannonian Basin.

Metapelitic xenoliths are made up mostly by garnet and sillimanite together with plagioclase, quartz, graphite, rutile and zircon in minor quantitites. Granulite facies metamorphism occurred at  $\sim$  1 GPa and  $\sim$  860 °C, followed by partial melting under UHT conditions at 1.0-1.2 GPa and 910-940 °C. Garnet hosts abundant primary graphite and fluid inclusions within its core (Fig. 1), which were commonly co-entrapped with quartz, rutile and zircon. Primary negative crystal-shaped fluid inclusions dominantly contain high-density CO<sub>2</sub>. Subordinate CO<sub>2</sub>, N<sub>2</sub> and CO were detected in graphite inclusions, whereas small graphite flakes occur within the coexisting fluid inclusions. Besides the dominant CO<sub>2</sub>, primary and also secondary fluid inclusions contain varying amounts of CO, N<sub>2</sub>, H<sub>2</sub>S, CH<sub>4</sub> and H<sub>2</sub>.A negative correlation is observed in the proportion of CO<sub>2</sub> and CO, thus fluid inclusions preserve the record of graphite involved redox reactions took place at lower crustal depths.

#### References

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Caption: Figure 1- Photomicrograph showing typical fluid and solid inclusion texture in garnet in metapelitic granulite xenoliths from the Bakony-Balaton Highlan



#### Talk

Metastable CO<sub>2</sub> - CO fluids in the lithospheric mantle: an intermediate in the reduction of CO<sub>2</sub> to graphite. <u>Maffeis A.</u>1\*, Frezzotti M.L<sup>1</sup> <sup>1</sup> Università degli Studi di Milano - Bicocca, Milano, Italy

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Carbonic fluids in Earth's lithosphere can be generated from mantle metasomatism through degassing of CO<sub>2</sub>-rich, SiO<sub>2</sub>-undersaturated melts (e.g., carbonatites). Carbon monoxide, however, with concentrations exceeding 1–2 mol%, has been rarely detected within CO<sub>2</sub>-rich fluid inclusions in mantle rocks (e.g., Bergman & Dubessy, 1984; Cannatelli, 2012).

In peridotite xenoliths from Sal Island (Cape Verde), carbonic inclusions in porphyroclastic olivine and orthopyroxene contain up to 17 mol% CO. Besides  $CO_2$  and CO, these inclusions may also contain minor  $N_2$ , silicate glass, clinopyroxene, sulfides, phosphates, Cr-spinel, Mg-calcite, dolomite, graphite, and nanocrystalline disordered carbon. Notably, graphite is absent in these rocks.

Peridotite xenoliths from Sal Island provide evidence of metasomatism and redox processes occurring at approximately 3.3 GPa and 1200°C. Fluid inclusions occur in trails that extend from microveins and reaction coronae surrounding ortho-pyroxene, suggesting the heterogeneous entrapment of a reacting and degassing silicate-carbonate melt along with the associated fluid.

CO(H) thermodynamic modelling indicates that CO<sub>2</sub>-CO fluids are C-supersaturated (aC>>1). Therefore, CO is metastable, while graphite should be present. Only open-system modelling, in which CO<sub>2</sub> infiltrates reduced peridotites, results in high CO concentrations due to redox disequilibrium. Through this process, the rock's fO<sub>2</sub> increases beyond the CCO buffer, indicating a heightened oxidative capacity for CO<sub>2</sub>. This scenario suggests that fluid expulsion occurred before fluid-rock equilibrium could be reached. As a result, CO remains a metastable intermediate during ongoing metasomatic redox reactions that will be consumed by the Boudouard reaction,  $CO \rightarrow C+CO_2$ , upon reaching equilibrium. This metastability preserved in fluid inclusions provides valuable insights into the mechanistic understanding of carbon-driven mantle oxidation. It also helps to understand how CO<sub>2</sub>-rich fluids precipitate reduced carbon phases, such as graphite or diamond.

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#### Poster

Raman spectroscopy in fluid inclusions reveals CO intermediates during carbon precipitation from CO<sub>2</sub>-rich fluids. <u>Maffeis A.</u><sup>1\*</sup>, Frezzotti M.L.<sup>1</sup>, Esposito R.<sup>1</sup>

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Epigenetic graphite, which exhibits a highly variable degree of order, has been observed precipitating from CO<sub>2</sub> fluids in various crustal rocks, particularly in granulites (e.g., Huizenga and Touret, 2012). Notably, metastable carbon-saturated COH fluids have also been reported, revealed by graphite - initially absent inside a fluid inclusion - appearing during Raman analysis when fluid inclusions are heated under laser light.

In this study, we report on graphite precipitation observed during Raman analyses of metastable  $CO_2$ -CO fluids (CO = 1-17 mol%) trapped in the deep mantle lithosphere of Cape Verde (Sal Island). Inclusions are found in harzburgitic xenoliths experiencing silicate-carbonatic metasomatism at ~1200°C and ~3.3 GPa, in the aragonite stability field. Metastable  $CO_2$ -CO fluids, trapped inside secondary inclusions in olivine and orthopyroxene, are produced by disequilibrium redox processes during metasomatism by the reduction of  $CO_2$ released by degassing of reacting carbonatitic melt component without the formation of graphite.

A general trend observed in many inclusions is that after Raman analysis, the CO content decreases significantly, and graphite is detected within the inclusions, both optically (as dark particles inside the inclusions) and in repeated Raman analyses. The Raman spectra of sp<sup>2</sup> carbon exhibit two prominent bands of equivalent sizes at ~1350 and ~1580 cm<sup>-1</sup>, and the absence of second-order vibrations indicates a very low degree of crystallinity, identifying it as nanocrystalline amorphous carbon. Additionally, in inclusions where amorphous carbon precipitates, extra bands are consistently observed at 2050 cm<sup>-1</sup> and 2130 cm<sup>-1</sup>, corresponding to adsorbed CO (CO<sup>ads</sup>) and activated \*CO intermediates onto a metal site (likely Fe) in the host mineral surface inside the inclusion. Carbon precipitation from CO occurs through the reaction pathway:

 $2 \text{ CO}^{\text{Fluid}} \leftrightarrow 2 \text{ CO}^{\text{ads}} \leftrightarrow 2 \text{ }^{\text{cOa}} \rightarrow \text{C} + \text{CO}_2^{\text{Fluid}}$ 

Operando Raman spectroscopy indicates that the reduction of  $CO_2$  to graphite encompasses the formation of adsorbed CO molecules on the surface of the host mineral. The subsequent formation of activated \*CO intermediates is essential for catalysing Boudouard-type reaction on the way to thermodynamic equilibrium.

References

Huizenga & Touret (2012), Gondwana Res., 22,799-809

#### Poster

#### Fluids in the formation of the Western Series, Bahía Mansa metamorphic basement, Chile.

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Keywords: fluid inclusion, metamorphism, surface

The Bahía Mansa metamorphic complex (CMBM) is located at 39 and 42°S in the Coastal Range of the Los Lagos Region, Chile. It presents Devonian to Permian ages, being part of the western series of the metamorphic basement of the southern central Andes whose genesis of its rocks is associated with a Late Carboniferous and Triassic basal accretionary prism system.

Therefore, the metamorphic complex has been exposed to two phases of deformation and metamorphism where D1 was exposed to high pressures and temperatures in the blue shale facies and D2 was exposed to high pressure and low temperature deformation in the green shale facies with Carboniferous and Permo-Triassic ages.

As mentioned, Touret (1977) "The study of fluid inclusions starts with their observation under the microscope, which, done carefully, may yield a surprising amount of information. Millions of fluid inclusions may occur in a single thin section of hydrothermal quartz in a high grade metamorphic rock, but their size rarely exceeds a few tens of microns in segregation and a few microns in massive rocks".

A detailed petrographic observation shows secondary fluid inclusions assemblages (FIA) in quartz consisting of coexisting liquid-rich and vapor-rich (effervescence). Secondary liquid-rich FIA in quartz. These fluids hosted in the CMBM were trapped in rocks with small fluid inclusions with  $CO_2$  and  $CH_4$  detected by Raman spectroscopy. These fluids come from the accretion of crustal fragments to the southwestern margin of Gondwana.

A preliminary study shows evidence of  $CH_4$  in the fluid inclusions (sample CM2-09-8, Fig. 1). This sample shows that the texture of the grains is nearly equal in size. The mineralogy found in this sample shows epidote, actinolite, quartz, albite, and chlorite, described as Actinolithic greenschist. The location of the samples belongs to Estaquilla unit.

#### References

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Caption: Figure 1- Raman spectroscopy of sample CM2-09-8, showing CH4 fluid.



#### Talk

## Application of 3D Raman mapping on complex inclusions: a case study of the Styrian Basin mantle xenoliths (W-Carpathian Pannonian Region)

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Keywords: fluid inclusion, melt inclusion, thermodynamic calculations

Fluid and melt inclusions trapped in mantle xenoliths provide direct insights into the metasomatic agent in the lithospheric mantle, including its volatile content. We conducted 3D Raman mapping on fluid and melt inclusions in modally metasomatized mantle xenoliths from the Styrian Basin (W-Carpathian Pannonian Region) to explore how this method can be utilized to study the role of fluids and melts in the upper mantle. 3D Raman mapping revealed complex phase assemblages of coexisting mapping revealed complex phase assemblages of coexisting fluid and solid phases in the inclusions (Fig. 1). Fluid phases are  $CO_2$  (49.2–98.4 mol%, 19.1–61.0 vol%) and  $H_2O$  (1.5–50.8 mol%, 8.6–35.3 vol%). The  $H_2O$  mol% is much higher than in most mantle fluids (~10–15 mol%). Solid phases are silicates, carbonates, sulfides, and sulfates, showing varying vol%. 3D Raman mapping shows that liquid  $H_2O$  wets other phases in the mapped fluid inclusions and may be preferentially lost compared mapped fluid inclusions and may be preferentially lost compared to the CO2-rich phase during inclusion decrepitation. The accuracy of  $CO_2$ -H<sub>2</sub>O mol ratios from Raman 3D mapping in fluid inclusions can be affected by varying Raman cross-sections of trapped phases. Thus, thermodynamic modeling is suggested to validate measured fluid mol ratios. Thermodynamic models suggest that the fluid compositions in the fluid inclusions reflect non-equilibrium entrapment, whereas those in the melt inclusions reflect equilibrium entrapment in the mantle portion. The discovered C-O-H fluids provide new insights into fluid-rock reactions in the upper mantle.



Caption: Figure 1- 3D Raman mapping workflow of the studied inclusions.



#### Talk

#### Fingerprinting mantle degassing in the Carpathian-Pannonian region: evolution of CO2 emission in time and space.

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Keywords: fluid inclusion, mantle, geodynamics

Isotope composition of subsurface fluids, like CO<sub>2</sub>-rich fluid inclusions in mantle xenoliths or dissolved gases in groundwater, is a powerful tool to trace lithospheric-scale fluid processes, such as mantle degassing, and to explore their impact on carbon cycle. Here, we present a basin-scale connection of deep and shallow fluids, combined with thermo-kinematic simulations to understand the history of CO<sub>2</sub> emissions in the Carpathian-Pannonian region (CPR, Central Europe).

He-Ne isotope ratios were determined from fluid inclusion-rich mantle xenoliths from three monogenetic volcanic fields. These deep fluids originate from a portion of upper mantle that has been newly accreted to the lithosphere during post-rift thermal relaxation in the CPR since the Late Miocene. He isotopic ratios of xenoliths completed with  $\delta^{13}$ C on CO<sub>2</sub> in groundwater clearly indicate significant contributions from mantle sources.

Our results can be extrapolated to recent times owing to the same geodynamic setting as during xenolith upbrought. The history of  $CO_2$  emissions based on our models show considerable flux of non-magmatic  $CO_2$  during the post-rift phase until present time, due to new lithospheric mantle accretion from the asthenosphere along with addition of  $CO_2$ -rich fluids that can flow throughout the lithosphere reaching the shallow groundwater level (Fig. 1). Such basin-scale mechanism can explain mantle/ tectonic degassing and  $CO_2$  emissions in similar geodynamic settings without active volcanism.



Caption: Figure 1- Schematic cross-section of the crust-lithospheric mantle-asthenosphere beneath the Carpathian-Pannonian region (Central Europe).



#### Poster

Heterogeneous entrapment and CO<sub>2</sub>-rich fluids in nephelinite-hosted mantle xenoliths, eastern China. <u>Wang L.</u>1;2\*, Han Y.2, Steele-MacInnis M.1 <sup>1</sup> University of Alberta, Edmonton, Canada, <sup>2</sup> China University of Geosciences (Wuhan), Wuhan, China

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Cenozoic basaltic volcanism in eastern China is manifested by numerous small-scale flood basalt fields and sporadic monogenetic volcanic fields. Among these, nephelinites, a highly alkaline volcanic rock type, exhibit oceanic island basalt (OIB)-like trace element signatures and are recognized as typical asthenosphere-derived intraplate basalts in continental settings. This study presents a petrological and Raman spectroscopic investigati on of mantle xenoliths hosted in 6 Ma nephelinites from this region.

Our findings reveal complex fluid and melt inclusion assemblages within olivine, dominated by carbon dioxide with subordinate graphite, rutile, ilmenite, magnesite, and trace methane. Some inclusions exhibit coexisting liquid and vapor phase  $CO_2$  within individual bubbles, with high volume fractions of carbonic liquid implying high fluid densities and trapping pressures. Coexistence of  $CO_2$ /carbonate minerals, graphite and  $CH_4$  suggest localized redox gradients and/or fluctuating oxygen fugacity conditions during nephelinite magma ascent. Common and abundant Ti-bearing phases (rutile, ilmenite) suggest anomalously high Ti contents of the trapped melts.

#### Talk

Metamorphic overprint of the VMS Besshi-type Tisová Cu deposit, Czech Republic. Zachariáš J. 1\*

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The Tisová deposit, situated in the southwestern part of the Erzgebirge Mts., exemplifies a metamorphosed Besshi-type VMS deposit. It is hosted by a Cambro-Ordovician metasedimentary complex, which was intruded by metabasaltic sills and dikes. Ore is dominated by pyrrhotite. The deposit underwent regional metamorphism at 480-550 °C and 10-13 kbar during Variscan subduction of the Saxothuringian Unit beneath the Teplá-Barrandian Unit.

Fluid inclusions were studied in quartz grains enclosed in pyrrhotite. Carbonic (C-type) and aqueous-carbonic (AC-type) inclusions were identified. C-type contains almost pure  $CO_2$ (Tm $CO_2 = -56.6$  to -56.9 °C) and shows wide range of homogenization temperatures of  $CO_2$  (from -8 °C to +31 °C; to L). The lower-density (0.63 g/ccm) C-type inclusions are by far more abundant than the higher density ones (0.97 g/ccm). The AC-type inclusions show low salinity (3.0-1.4 wt.% eq. NaCl; TmClath = +8.5 to +9.3 °C) and similar Tm CO<sub>2</sub> and Th CO<sub>2</sub> data as the C-type FI. Unfortunately, they often decrepitate before final homogenization. Calculated FI isochores suggest trapping of some FI at metamorphic peak conditions, followed their continuous reequilibration during the retrograde path of tectonic uplift. P-T estimates based on chlorite chemistry agree well with FI isochores.

This study was realized within the scope of the EIS project, which is funded by the European Union's Horizon Europe research and innovation program under grant agreement no. 1010557357.

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## EUROPEAN CURRENT RESEARCH ON FLUID AND MELT INCLUSIONS

Dédicated to Jacques Touret