ECROFI 2017

EUROPEAN CURRENT RESEARCH ON FLUID INCLUSIONS

ECROFI 2017 BIENNIAL MEETING

FLUID & MELT INCLUSIONS

23-29
JUNE
2017

NANCY
FRANCE

UNIVERSITÉ DE LORRAINE · cnrs · A.S.G.A. · cregu · CRPG Centre de Recherches Pétrographiques et Geochimiques · geo Ressources

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EDITO

First held in Bern in 1969, ECROFI is back in Nancy for the third time following successful meetings in 1978 and 1997.
ECROFI 17 (European Current Research on Fluid Inclusions, 24th edition) will take place in Nancy (France) from 23–29 June 2017, with this year's edition organized by the GeoRessources and CRPG laboratories. This biennial international conference is dedicated to the investigation of fluids and magmas at all scales through the study of fluid and melt inclusions.
Among the many topics addressed during the three days of presentations, fluid and melt inclusions represent the main focus of ECROFI, and highlights will include new developments (analytical, experimental, thermodynamics) and applications in diagenetic, metamorphic, magmatic and volcanic environments and related petroleum, mineral and geothermal systems.
The career of Bernard Poty and Jean Dubessy will be celebrated in special sessions. The meeting will be preceded by a course about fundamentals of fluid inclusions, workshops on selected analytical methods and an excursion to the Sainte-Marie-aux-Mines Mineral and Gem International show. A mid-conference fieldtrip to the Champagne vineyards, with a focus on new frontiers in fluid and melt inclusion studies, is also on the program!
It is with great pleasure that we warmly welcome you to Nancy for ECROFI 2017!

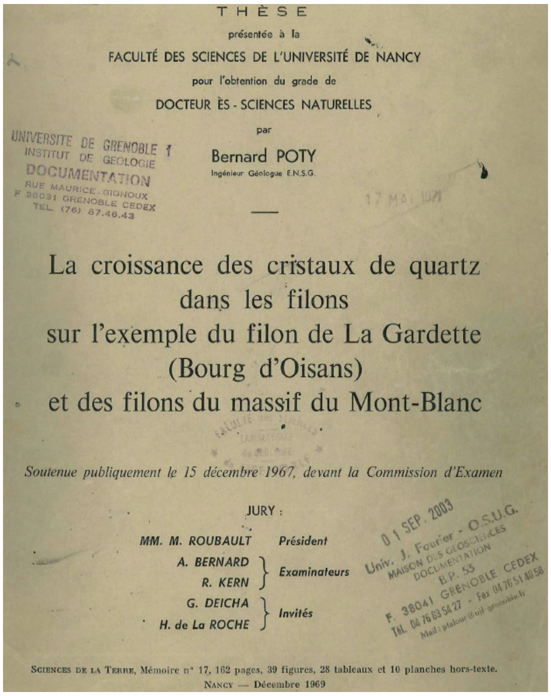
Jacques Pironon
GeoRessources director
CNRS research director

geo Ressources

SPECIAL TRIBUTE TO BERNARD POTY

Bernard POTY is one of the leading specialists in alpine quartz, a subject he has examined from every angle during his career, from his doctorate to his retirement. He advocates for recognition of the role of fluids in crystallogenesis and for promoting interest in the study of fluid inclusions. On 15 December 1967, B. Poty defended his Ph.D thesis on «The growth of quartz crystals in veins: the examples of the La Gardette vein (Bourg d'Oisans) and the veins of the Mont Blanc massif" at the University of Nancy, under the chairmanship of Professor M. Roubault, director of CRPG, and in the presence of G. Deicha. A triple-passion was born, a passion which combined his love of fluid inclusions, the Alps and Russia. His work was profoundly marked by the three months he spent in the USSR in 1963, with Professor N. P. Ermakov in Moscow and Professor Grigoriev in Leningrad. His curiosity also took him to New York, where he was able to compare his knowledge and understanding with that of the American school at the time. He went on to become an internationally recognized expert, and Nancy is today famous for its "infernal trio": B. Poty, A. Weisbrod and J. Touret. Thanks to his persuasiveness and his conviction in the necessity to form links between research and industry, B. Poty created the CREGU centre for uranium research in 1977. There, he led a group of young researchers -M. Cuney, M. Pagel, J. Leroy, J. Dubessy, M. Cathelineau, J. Pironon, to name but a few- who themselves went on to host numerous ECROFI conferences, following in his footsteps.

In 1989, thanks to his charisma and drive, he was elected mayor of the small town of Gondreville, near Nancy, a position he held until 2002. Today, Bernard Poty is an honorary research director at the CNRS, an academician of the Lorraine Academy of Sciences (ALS), a member of the French Society of Nuclear Energy and a member of the Scientific Committee of the Museum of Crystals in Chamonix - roles that testify to his ever-strong activity in the field of geosciences.



THÈSE

présentée à la

FACULTÉ DES SCIENCES DE L'UNIVERSITÉ DE NANCY

pour l'obtention du grade de

DOCTEUR ÈS - SCIENCES NATURELLES

par

Bernard POTY

Ingénieur Géologue E.N.S.G.

La croissance des cristaux de quartz
dans les filons
sur l'exemple du filon de La Gardette
(Bourg d'Oisans)
et des filons du massif du Mont-Blanc

Soutenue publiquement le 15 décembre 1967, devant la Commission d'Examen

JURY :

MM. M. ROUBAULT Président
A. BERNARD, R. KERN Examinateurs
G. DEICHA, H. de La ROCHE Invités

SCIENCES DE LA TERRE, Mémoire n° 17, 162 pages, 39 figures, 28 tableaux et 10 planches hors-texte.
NANCY — Décembre 1969

Cover of Bernard Poty's thesis

CONTENTS

WELCOME TO NANCY!

City of art and culture

The capital city of the dukes of Lorraine, Nancy lays claim to a rich cultural heritage. Due to its fine eighteenth-century architecture, the heart of the town has been declared a UNESCO World Heritage site, and, in the form of Place Stanislas, the city boasts one of the most beautiful town squares in the world. Nancy also played a seminal role in the Art Nouveau movement, and in the Ecole de Nancy museum, visitors can view outstanding works by Gallé, Daum, Majorelle, Prouvé and Vallin.
Live entertainment, terraced bars, renowned and diverse restaurants - Nancy also offers all of the excitement you might associate with a thriving and energetic university town with more than 45,000 students!

The conferences will take place in campus ARTEM: Art, Technology & Management

ARTEM is an alliance between three of Nancy's Grandes Écoles: École Nationale Supérieure d'Art et de Design de Nancy, Mines Nancy and ICN Business School.

The three schools are joined by the city's international centre for research on materials and one of GeoRessources' team also works in campus ARTEM.

ARTEM is an ambitious project for education and research, founded on the opening up of new pathways between the different disciplines.

ECROFI 2017
AT A GLANCE

2 Workshops

1 Ice breaker

5 Sessions

1 Gala dinner

2 Field trips

1 Champagne tasting

COMMITTEES

Scientific committee

Robert J. BODNAR - Prof. Blacksburg University, VirginiaTech, USA

Larryn W. DIAMOND - Prof. Institute of Geological Sciences, University of Bern, Switzerland

Maria Luce FREZZOTTI - Prof. Dipartimento Scienze della Terra, Università di Milano, Italy

Alfons VAN DEN KERKHOF - Dr Geowissenschaftliches Zentrum der Universität Göttingen, Germany

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Csaba SZABÒ - Prof. Department of Petrology and Geochemistry, Eötvös University, Budapest, Hungary

Benedetto DE VIVO - Prof. Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse-DiSTAR, Università di Napoli Federico II, Italy

Alexander SOBOLEV - Prof. Institut des Sciences de la Terre (ISTerre) Université Grenoble Alpes-CNRS, France

Organizing committee

Jacques PIRONON - GeoRessources - CNRS

Antonin RICHARD - GeoRessources - Université de Lorraine

Alexandre TARANTOLA - GeoRessources - Université de Lorraine

Marie-Camille CAUMON - GeoRessources - Université de Lorraine

François FAURE - CRPG - Université de Lorraine

Véronique ERNEST - GeoRessources - Université de Lorraine

Maria-Anna REINA - GeoRessources - Université de Lorraine

ECROFI 2017 SCHEDULE

	Friday 23rd	Saturday 24th	Sunday 25th		Monday 26th	Tuesday 27th	Wednesday 28th	Thursday 29th
				7:45 8:00		Bus trip to Champagne		
Morning	Field Trip to Sainte-Marie-aux-Mines	Workshop R.J. Bodnar Fundamentals of fluid inclusions	Worshop Methods	8:00 8:30	Registration			
				8:30 10:00	Opening ceremony		Session 3	Session 4
				10:00 10:30	Coffee break		Coffee break	Coffee break
				10:30 12:00	Session 1	Coffee break Session 2	Session 3	Session 5
Lunch				12:00 13:30	Lunch	Lunch & Champagne tasting	Lunch	Lunch
Afternoon				13:30 15:00	Session 1	Visit : insight into the world of Champagne	Session 3	Session 5
				15:00 15:30	Coffee break		Coffee break	Plenary discussion & Closure ceremony
				15:30 17:00	Session 3	Vineyard tour	Session 4	
				17:00 18:30	Poster session	Return trip to Nancy	Poster session	
Evening			Ice breaker at CRPG Laboratory & registration	18:30 22:00			Gala dinner	

FRIDAY
JUNE 23rd

Sainte-Marie-aux-Mines

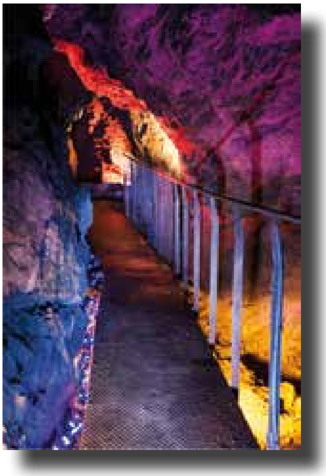
The field trip will guide participants to Sainte-Marie-aux-Mines in the Vosges mountains, a place with a rich geological and cultural heritage linked to intensive past mining activities.

The trip will start with an underground guided tour along 800m of remarkable mine galleries from the 16th century (the Saint-Jean Engelsbourg silver mine).

Visiting this mine presents no specific difficulties for participants. In the afternoon, participants will attend the outstanding Mineral & Gem International Show, one of the world's premier mineral shows!

Mineral & Gem International Show, Outdoor area. © Mineral & Gem website

The complex is built upon the site which was discovered in the 16th century when silver veins where found resulting in what was later called "The Silver Fever". In the core of the Neuenberg mountain, visitors will learn about what initiated incredible technological, social and cultural development.



SATURDAY JUNE 24th

FUNDAMENTALS OF FLUID INCLUSIONS

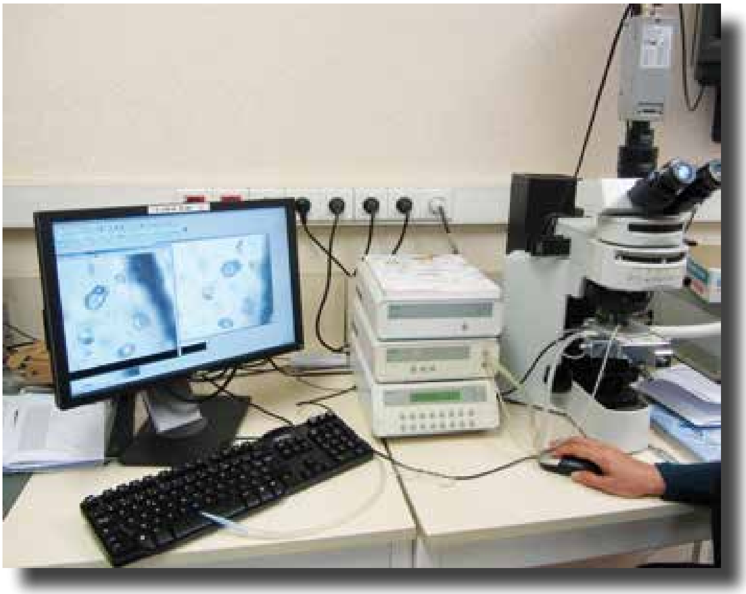
Larryn Diamond is a Professor of Rock–Water Interaction at the University of Bern, Switzerland. For many years, he has been interested in developing fluid inclusion research as a means to learn more about paleofluids in the Earth's Crust. As well as having carried out experimental and theoretical studies on the behaviour of fluid inclusions in general, he has analysed natural fluid inclusions to help understand hydrothermal ore deposits, diagenesis, ocean-floor alteration and other rock-water interaction phenomena, including applications to geothermal energy and geological repositories for radioactive waste.

This one-day workshop will introduce our understanding of how fluid inclusions form in nature and what kind of information can be extracted from them. The principles of fluid inclusion petrography, microthermometry and phase-diagram analysis will be explained to enable the reconstruction of paleofluid properties at the time of inclusion entrapment, such as density, pressure, temperature, chemical composition and phase state. With this information the course participants will be able to design their own research projects, understand the literature that reports fluid inclusion analyses and interpretations, and hopefully, understand the talks and posters in the following ECROFI Conference.

SUNDAY JUNE 25th

METHODS

Researchers of GeoRessources and CRPG laboratories will organize courses and demonstrations of tools used for fluid and melt inclusion characterization: Ion probe and stable (O, H, C) isotopes at CRPG, microthermometry, UV fluorescence and cathodoluminescence, confocal scanning laser microscopy, Raman and infrared spectrometries at GeoRessources.



MONDAY JUNE 26th

PROGRAM

8:00 - 8:30 ▶ Registration

8:30 - 10:00 ▶ Opening ceremony

Opening speeches :
Pierre Mutzenhardt, President of the Université de Lorraine
Jacques Pironon, director of GeoRessources

OC.T01. **Bernard Poty** ▶ Fluid inclusions science during the last hundred years. Considerations of a veteran.

OC.T02. **Cyril Deicha** ▶ Georges Deicha: pionneer of fluid Inclusions

10:00 - 10:30 ▶ Coffee break

10:30 - 12:00 ▶ Session 1: Theoretical / Experimental / Analytical studies (in honor of recently-retired Jean Dubessy)

S1.T01. **Wälle M.**, Schlöglova K., Rauchenstein-Martinek K., Heinrich C.A. - **Keynote** ▶ Recent developments in laser ablation ICP-MS analyses of fluid inclusions

S1.T02. Harlaux M., **Mercadier J.**, Borovinskaya O., Richard A. ▶ LA-TOF-ICPMS: a promising instrument for multi-elementary analysis of fluid inclusions

S1.T03. **Marshall D.**, Boucher B., McFarlane C., Hewton M. ▶ On the use of laser ablation inductively coupled plasma mass spectrometry chemical-mapping to identify the relative timing of healed mineral fractures and contained fluid inclusion assemblages

S1.T04. **Heath C.**, Bourdet J., Myers M. ▶ Raman spectroscopy of CH_4-CO_2-H_2O fluids between 22-250 °C and 4-690 bar

S1.T05. El Mekki M., **Ramboz C.**, Lenain J.F. ▶ Lifetime of superheated aqueous solutions in micrometric synthetic fluid inclusions under static conditions

12:00 - 13:30 ▶ Lunch

13:30 - 15:00 ▶ Session 1: Theoretical / Experimental / Analytical studies (in honor of recently-retired Jean Dubessy)

S1.T06. **Guillerm E.**, Gardien V., Caupin F., Ariztegui D. ▶ A new paleothermometer for evaporitic halite: Brillouin spectroscopy

S1.T07. **Sublett D.M.**, Bodnar R.J. ▶ Liquid-vapor partitioning of Na and Ca in the H_2O-NaCl-$CaCl_2$ system at 500-700 °C and 550-750 bars

S1.T08. **Balitsky V.S.**, Pironon J., Pentelei S.V., Balitskaya L.V., Randi A. ▶ Metamorphic transformation of oil in relation with temperature, pressure and oil/water ratio: experiment using synthetic fluid inclusions

S1.T09. **Sendula E.**, Lamadrid H.M., Bodnar R.J. ▶ In situ monitoring of the olivine to magnesite reaction using synthetic fluid inclusions as microreactors

S1.T10. **Musiyachenko K.**, Korsakov A., Zelenovskiy P., Shur V. ▶ 2D and 3D Raman imaging of fluid inclusions in K-bearing tourmaline

S1.T11. **Káldos R.**, Guzmics T., Váczi T., Berkesi M., Dankházi Z., Szabó C. ▶ Raman mapping as a tool for studying melt inclusions

15:00 - 15:30 ▶ Coffee break

15:30 - 17:00 ▶ Session 3: Magmatic, magmatic-hydrothermal and volcanic environments

S3.T01. **Sobolev A.V. - Keynote** ▶ Inclusions of mantle derived melts: challenges and recent results

S3.T02. **Asafov E.V.**, Sobolev A.V., Gurenko A.A., Arndt N.T., Batanova V.G., Portnyagin M.V., Garbe-Schonberg D., Krasheninnikov S.P., Wilson A.H., Byerly G.R. ▶ Olivine-hosted melt inclusions in the ancient komatiites - the potential key to the Archaean mantle composition

S3.T03. **Andreeva O.A.**, Andreeva I.A., Yarmolyuk V.V. ▶ Redox parameters of magma crystallization at Changbaishan Tianchi volcano, China-North Korea

S3.T04. **Créon L.**, Levresse G., Remusat L., Carrasco-Nuñez G., Bureau H. ▶ Silicate melt inclusion homogenization: A new mathematical approach coupling X-ray microtomography, geochemistry and thermodynamics

S3.T05. **Valetich M.**, Mavrogenes J., Arculus R. ▶ Recalculating boninitic melt inclusion compositions from Chi-chi jima, Japan: the role of post entrapment crystallisation

17:00 - 18:30 ▶ Poster session / refreshments

Opening ceremony

The opening ceremony will welcome you to ECROFI 2017. It will feature speeches by:

Pierre Mutzenhardt
President of the Université de Lorraine

Jacques Pironon
Director of GeoRessources

Bernard Poty
Fluid inclusions science during the last hundred years.
Considerations of a veteran.

Cyril Deicha
Georges Deicha, pionneer of Fluid Inclusions

Session 1 in honor of recently-retired Jean Dubessy

Jean Dubessy was Director of Research at the National Center for Scientific Research (CNRS) in France. After obtaining his doctorate on the subject of ophiolites in 1977 at the University of Strasbourg, he joined CRPG in 1978 and then CREGU at its creation in 1979. Jean became a pioneer in the use of Raman for the localized analysis of fluid inclusions, work that led to the development of calculation codes to quantify concentrations and predict the states of equilibrium between phases. On the basis of this work, he was awarded his “State Thesis” at the National Polytechnic Institute of Lorraine in 1985, and was then recruited to the CNRS, where he obtained the Bronze Medal in 1990. Jean went on to spent a one-year sabbatical at the Geophysical Laboratory (Carnegie Institution of Washington, USA) where he studied the spectroscopy of water up to 500 °C and 2 kbar. He continued his work, first at the UMR G2R and then at GeoRessources, on (i) the characterization of the chemistry of palaeo-fluid circulations associated in particular with ore deposits by combining the LIBS technique with laser ablation coupled to ICP-MS ; (ii) the study of high pressure and temperature fluids and their speciation; (iii) the representation of thermodynamic data through state equations based on molecular interactions; and (iv) the study of natural examples, involving in particular the circulation of brines, molten salts or quasi-anhydrous fluids. Jean Dubessy was vice president of the GeoRaman International Science Advisory Committee, which organized the last GeoRaman Congress in Novosibirsk (Russia) in June 2016, he was president of the “Société Française de Minéralogie et Cristallographie” in 2004/2005, and was associate editor for the European Journal of Mineralogy from 2000 to 2010.

Session 1 will be dedicated to Jean Dubessy to celebrate his career.

OC.T01. Fluid inclusions science during the last hundred years, considerations of a veteran

Poty B.[1]

[1]Université de Lorraine, CNRS, CREGU, GeoRessources Lab., 54506 Vandoeuvre-les-Nancy, France

The first scientific work on fluid and solid inclusions is Sorby's paper in 1858. This important work has been forgotten during fifty years at least. Why ? Very probably because available techniques for the study of these microscopic objects were lacking. So this field of study could not help the development of geological sciences.

Rejuvenation of these studies came first in Soviet Union. This coutry made great efforts to get high quality quartz crystals, which were found in the Oural mountains. Thus Laemmlein in 1929 began a series of studies on fluid inclusions, mainly on these extraordinary crystals of alpine type, as in the Alps. We should not forget also that Königsberger and Müller published in 1906 the first chemical analysis of a metamorphic fluid (from a leachate) in a quartz crystal from the Alps. It took seventy years to reproduce this analysis ...

In the fifties the soviet production of fluid inclusion studies was abundant. Researchers of this field were working in every geology faculty of this country...

In the West fluid inclusions were barely studied.

In France a Russian scientist, G.Deicha, emigrated from Moscow after the 1917 revolution, initiated this field of study in Paris in the late forties. There is no doubt that he was aware of the scientific production of his russian colleagues. This field of study started in Nancy in the sixties after the three month stay I made at Ermakov's laboratory in the Moscow university. My work was dedicated to the best material for this kind of study : alpine type crystals.

In North America several geologists attempted to develop the field (F.G. Smith, E. Ingerson). But it was E. Roedder who gave to fluid inclusion studies their nobility, thanks to the design of accurate microthermometry systems, chemical procedures and ... a hard work.

At that time the lack of consideration from our geological colleagues was truly uncomfortable. Studying fluid inclusions was not taken seriously.

Evolution of microscopic techniques, and their use at a large scale were the key for making fluid inclusion studies useful for geologists :

- commercial disposal of accurate microthermometry systems
- introduction of chemical analyses of leachates
- use of Raman microspectrometry
- LIBS analyses
- fluid inclusion synthesis
- elaboration of equations of state for complex fluids

The results obtained with all these techniques help participate to larger multidisciplinary studies and contribute to better understanding of fluid rock interactions, fluid pressure in tectonic problems, etc ...

OC.T02. Georges Deicha, pionneer of fluid inclusions

Deicha C.[1]*

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This year would be the centenary of the birth of Georges Deicha (1917 - 2011), the pioneer of fluid inclusions in France.
In the middle of the last century, the interest about liquids and gases trapped inside of minerals was going to be forgotten[1]. Georges Deicha, was the first in France to understand their importance and initiate a revival[2]. Published by Masson in 1955 his work “Les Lacunes des Cristaux et leurs Inclusions Fluides”[3] was the first french Book on the subject. Georges Deicha also developed technical tools in particuliar the “crushing stage”[4]. The book and the tool gave many a student or prospector the opportunity to test the new methods and discover their “own” inclusions[5]. Since then, numerous studies and applications were initiated all over the world and especially here in Nancy.
In 1960, at the IGC in Copenhagen, Georges Deicha met with Ed. Roedder[6] and N.P. Ermakov[7], who, almost simultaneously with him, but independently of each other, had discovered the importance of inclusions. Georges Deicha played a very central role in this worldwide collaboration in ensuring the optimal communication. They established the "Committee on Ore-Forming Fluids in Inclusions: COFFI" .
Georges Deicha's research, initially solitary, had led to a discipline in its own right, which has found application in all fields of Earth Sciences[8]. The new generation of specialists will remember the forerunner of the study of fluid inclusions in France, who was also the initiator of the worldwide collaboration in this field.

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2 Deicha G., Observations préliminaires sur une recherche pétrographique systématique des inclusions. C.R.somm. Soc.géol.Fr., (1950), 57,59.
3 Deicha G. (1955) Les lacunes des cristaux et leurs inclusions fluides. In 8°, 126 p., 13 Fig., , 12 Tab., Masson &Cie Paris 1955
4 Deicha G., Essais par écrasement de fragements minéraux pour la mise en évidence d’inclusions de gaz sous pression. Bull.Soc.franç.Minér. Crist.,(1950),LXXII,439-45,1fig.
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7 http://ore.geol.msu.ru/page/24.html
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S1.T01. Keynote - Recent developments in laser ablation ICP-MS analyses of fluid inclusions

Wälle M.[1,2]*, Schlöglova K.[2], Rauchenstein-Martinek K.[2], Heinrich C.A.[2]

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The potential of laser ablation ICP-MS for the analysis of fluid inclusions was already recognised by early adopters of the technique. Over the years, the technique has matured and several labs are using LA-ICP-MS today to analyse fluid inclusions. Increasing instrument sensitivity and fast wash-out laser ablation cells, leading the higher signal to noise ratio, expand the application to smaller inclusions and/or lower concentrated elements. The resulting short transient signals demand a high scanning speed of the ICP-MS instrument to avoid and minimize sampling errors, due to the sequential recording of different masses in the MS, also referred to as spectral skew (Pettke, 2000). This requires adaptions to the measurement protocol, specifically on the chosen dwell times and the number of elements analysed. Dwell times of several tens to 100 ms result in lower limit of detections (LOD) and more precise concentrations to the cost of fewer elements analysed to avoid too much of the afore mentions spectral skew. By focussing on getting as low as possible LOD for an element, it is possible to achieve absolute LODs for e.g. Au in the sub femtogram region.

A recently introduced instrument, a time of flight (TOF) ICP-MS, offers a solution to avoid spectral skew at all. Its potential to analyse fluid inclusions has been demonstrated by Harlaux et al. (2015). We also had the opportunity the test this ICP-TOF-MS for fluid inclusion analyses. The relative standard deviation of well determined elements within an assemblage was reduced to just a few percent using the ICP-TOF-MS, compared to 20 to 40 percent by a similar sensitive quadrupole ICP-MS.

Getting estimate concentrations for an assemblage of fluid inclusions from the individual measured inclusions often has the challenge that a few up to many or almost all inclusion resulted in concentrations below the LOD. This is a consequence of the higher abundance of small inclusions compared to big ones. To circumvent this issue, an approach of summing up the measured signals of the individual inclusions from one assemblage prior to their evaluation was applied to achieve more accurate concentrations of low abundant elements (e.g. Au). Statistical method which deals with censored data were also evaluated and compared, although they seem to have difficulties with the high scatter in LA-ICP-MS data of fluid inclusions and result in higher concentrations than the summation method.

References:

Pettke T. et al. (2000) J. Anal. At. Spectrom. 15, 1149-1155.
Harlaux M. et al. (2015) J. Anal. At. Spectrom. 30, 1945-1969.

S1.T02. LA-TOF-ICPMS: a promising instrument for multi-elementary analysis of fluid inclusions

Harlaux M.[1], Mercadier J.[2*], Borovinskaya O.[3], Richard A.[2]

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Determining the chemical composition of geological fluids trapped in fluids inclusions remains currently an analytical challenge. Indeed, the latter represent micro-cavities of generally 10-100 µm in diameter, which contain small quantities of liquids (pl to nl) with variable compositions and concentrations of chemical elements. Laser ablation and "classical" quadrupole mass spectrometry analysis (LA (Q) ICPMS) of fluid inclusions generate very short transient signals, typically of a few seconds. However, (Q) ICPMS remain the most widely used technique for the analysis of minerals and fluid inclusions due to its high sensitivity, speed and multi-element capabilities (Heinrich et al., 2003; Pettke et al., 2012). More recently, sector-field (SF) ICPMS has also shown improvements for fluid inclusion analysis with higher sensitivities and lower limits of detection compared to Q-ICPMS (Wälle and Heinrich, 2014; Harlaux et al., 2015). However, these two types of sequential mass spectrometers are limited by their acquisition times requiring a compromise between the signal duration and the number of isotopes that can be measured (typically < 20), which can yield to a non-representative sampling of the fluid inclusion.

In this work (Harlaux et al., 2015), we compare the capabilities of Q- and SF-ICPMS, both equipped with a standard cylindrical ablation cell, with a prototype of orthogonal time-of-flight (TOF) ICPMS (Borovinskaya et al., 2013), equipped with a fast washout ablation cell. Analyses were performed on synthetic solutions sealed in silica capillaries and on homogeneous natural fluid inclusions from the Alps and Zambia using the same 193 nm Excimer laser ablation system coupled alternatively with the three ICPMS configurations. The results demonstrate that the TOF-ICPMS system presents both advantages of having rapid and quasi-simultaneous acquisition for all isotopes (from ^{6}Li to ^{238}U) in a very short cycle time down to 30 µs. Precisions are better than for Q- and SF-ICPMS and limits of detection are slightly lower or even similar than SF-ICPMS for heavy isotopes (m/Q > 85) and small fluid inclusions (< 25 µm). In particular, LA-TOF-ICPMS reveals to be a very promising instrument for the multi-element analysis of fluid inclusions, especially for very small (< 10 µm), multi-phase and low-salinity, providing fast and complete information on the fluid inclusion composition.

References:

Borovinskaya O. et al. (2013) J. Anal. At. Spectrom. 28, 226-233.
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Heinrich C. et al. (2003) Geochim. Cosmochim. Ac. 67, 3473-3497
Pettke T. et al. (2012) Ore Geol. Rev. 44, 10-38.
Wälle M. and Heinrich C. (2014) J. Anal. At. Spectrom. 29, 1052-1057.

S1.T03. On the use of laser ablation inductively coupled plasma mass spectrometry chemical-mapping to identify the relative timing of healed mineral fractures and contained fluid inclusion assemblages

Marshall D.[1*], **Boucher B.**[2], **McFarlane C.**[2], **Hewton M.**[1]

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Healed fractures in fluid inclusion studies are important for classifying fluid inclusions and fluid inclusion assemblages (FIAs) as secondary and pseudosecondary (Roedder, 1967) to establish fluid evolution, changes and relative timing of different fluid generations (Goldstein, 2003). Although healed fractures commonly intersect, the relative ages of the intersecting fractures are often ambiguous. The most common techniques used to establish relative timing are overprinting of the contained FIAs (c.f. Goldstein, 2003; Diamond, 1990), cathodoluminescence (CL) emission variations in the host mineral due to trace impurities, or by inference from petrographic studies. Unambiguous occurrences of overprinting of FIAs are very rare and in general healed fractures do not display significant CL variations.

Zoned emerald crystals from the Mountain River emerald occurrence (Hewton et al., 2013) contain abundant intersecting pseudosecondary and secondary fluid inclusion trails. Fluid inclusions contained along these trails are very small and not overly abundant. Hence, the relative chronologies of the intersecting trails could not be determined via normal petrographic methods. Our preliminary work via Laser ablation inductively coupled mass spectrometry (LA-ICP-MS) mapping of trace elements in host minerals can delineate healed fractures and shows cross-cutting relationships. The technique shows significant promise for other minerals commonly hosting fluid inclusions and used in fluid inclusion research such as quartz, calcite, and garnet. Despite its obvious advantages, caution should be exercised as the technique is destructive to the sample surface and neighboring fluid inclusions (Lambrecht et al., 2008). Hence, LA-ICP-MS mapping should be used as a final technique on samples. Optimally, thicker samples can be repolished after laser mapping, but damage or changes to affected fluid inclusions will likely persist.

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S1.T04. Raman Spectroscopy of CH_4-CO_2-H_2O fluids between 22-250 °C and 4-690 bar

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Confocal Raman Microspectroscopy has been used extensively to study fluid inclusions due to its high spatial resolution and its ability to detect species commonly occurring in geo-fluids such as CH_4, CO_2, N_2, H_2O and H_2S. Many spectroscopic features such as peak position, peak separation and ratios are revealed to be correlated with fluid composition, pressure and density inside fluid inclusions. Critical work has been done for pure or binary gas systems and ternary aqueous systems (CH_4-H_2O-NaCl, CO_2-H_2O-NaCl). However, the thermodynamic and spectroscopic behaviour of gas mixtures and water, such as the CH_4-CO_2-H_2O system, are not as well explored. For instance, the impact of the co-presence of CO_2 on the CH_4 shift, or on its solubility are not well known.

In order to develop a Raman calibration for the CH_4-CO_2-H_2O system we have enclosed known gas mixtures containing CH_4 and CO_2 in the presence of pure water in a silica capillary cell. Pressures from 4 bar to 690 bar and temperatures from 20 to 250 °C have been explored in order to simulate a wide range of sedimentary basin conditions and the relationships between spectroscopic features, composition and PT conditions have been investigated.

We found that the CH_4 peak shift or CO_2 diad spilt distances were nearly linearly correlated with gas density, however we noticed significant deviations in the case of the CH_4 peak position due to the CO_2 content that could have an important impact on density derivations if neglected. Interestingly, the CH_4 peak shift with pressure is almost unaffected by the CO_2 content, at room temperature for pressure up to about 250 bars. This has important consequences for the validity of the pressure estimation within gas inclusions or within the vapour phase of water inclusions, when the co-presence of CO_2 has not been detected. We have also investigated the solubility of the gases in water and found that CH_4 solubility can actually increase with the co-presence of CO_2 for low CO_2/CH_4 ratios. However, with higher CO_2/CH_4 ratios the solubility of CH_4 in water decreases as expected.

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S1.T05. Lifetime of superheated aqueous solutions in micrometric synthetic fluid inclusions under static conditions

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We have studied the lifetime of superheated aqueous solutions (τ) in five synthetic fluid inclusions (FI) with different shapes, volumes, densities and compositions. Four FI were synthetized by the crack method (secondary FI, SFI method, see Shmulovich et al., 2009; 380 < V = FI volume < 8600 μ^3). One primary FI (PFI, V = 9000 μ^3) was trapped in a synthetic quartz overgrowth. In each FI, the homogenization temperature T_h (disappearance temperature of the vapour bubble on heating) was measured, together with the vapour nucleation temperature T_n on cooling the FI below T_h at a rate of 2 to 5 °C.mn^{-1}. The metastability range ($T_h - T_n$) of the selected FI was between 21.5 and 85.5 °C, all the larger as stretching conditions at Tn (noted Pn) are larger (i.e., as P_n is more negative; $-78 < P_n < -115$ MPa for SFI; –17.4 MPa for the PFI).

Each FI was then placed in the metastable field by isochoric cooling at four or five fixed temperature steps above Tn and the τ's were measured repetitively (21 to 30 measurements). For all T-steps in every FI, the distribution of the τ's was consistent with a survival law $P(t) = e^{-2t}$ where t is the elapsed time and $1/\lambda$ is the mean lifetime, noted τ_m. The nucleation flux at T_n (J_0) is constant, comprised between 1.3 and 2.710^{13} m^{-3} s^{-1} ($J0=1/V\tau_m$ and $J= J0\ e^{-Eb/kT}$, where E_b is the energy barrier of nucleation). A unique kinetic law for superheated liquid water and solutions in FI, only dependant on P_n, is defined:

$\mathrm{Ln}\ J= \mathrm{Ln}\ [J(P_n)] -(4.207+0.032^* P_n)^*(T - T_n)$ with $J(P_n) \sim 2\ 10^{13}$ m^{-3}s^{-1} and $\mathrm{Ln}\ [J(P_n)] \sim 30.5$.

Our experimental data (V, P_n, T_n, τ) can be fitted with the Classical Nucleation Theory (CNT; Debenedetti, 1996), provided that surface tensions are adjusted to fit with experimental τ's. ElMekki et al. (2013) previously calculated Eb/kT= 58 in one pure water FI. Present work confirms an Eb-value of ~ 60 kT for nucleation within FI-hosted water and solutions, whatever their composition and for FI-volumes varying over one order of magnitude (OM).

Herbert et al. (2006) previously emphasized that measured Pn's in FI-hosted water and solutions are consistent with the value predicted by the CNT, but are about 3 times higher than measured Pn's by any other experimental technique. Here we show that nucleations in aqueous FI occur over a large Pn-range and at constant J_0, whereas nucleations measured by any other method occur at near constant Pn (22±6 MPa) and with J_0's varying over 14 OM.

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S1.T06. A new paleothermometer for evaporitic halite: Brillouin spectroscopy

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The reconstruction of changes in Sea and Lake Surface Temperatures (SST and LST, respectively) is critical for our knowledge of past climatic changes. Most of these reconstructions are based on bio and or geochemical proxies. In ancient evaporitic basins however, where proxies based on fossil life are unusable, microthermometry on subsurface minerals fluid inclusions (FIs) appears to be the most adequate paleothermometry alternative. FIs are present in virtually all rock minerals, including halite - a major constituent of evaporitic series -, and are commonly used to constrain Formation Temperature (Tf) of crystals, via the microthermometry technique. This approach assumes that the vapor bubbles contained in biphasic FIs disappear, during heating, at a given Homogenization Temperature (Th) corresponding to the FI Tf. Halite samples generally contain monophasic FIs, hence they are cooled in a freezer to nucleate a vapor bubble in the FIs, prior to gradually heating them to reach the Th. Although this technique is widely used, it also faces several limitations. First, bubble nucleation is an unpredictable and scarce event. Second, the observed values of Th in a single sample form a broad distribution, covering a wide temperature range; this may be due to damages caused by cooling. The latter is the main limitation of the microthermometry approach. Conflicting views about the true formation temperature are found in the literature: some authors recommend to use the mean of the Th distribution (Roberts & Spencer, 1995), others its maximum (Lowenstein et al., 1998).

We have used FIs in synthetic and semi-natural halites to demonstrate the potential of a novel technique, Brillouin spectroscopy, in determining the formation temperature of fluid inclusions in evaporites. The main asset of this new method is that it is free from the above limitations because it does not depend on the formation of vapor bubbles (El Mekki-Azouzi et al., 2015). The use of both Brillouin and microthermometry techniques on the same samples of synthetic halites has confirmed the advantage of Brillouin spectroscopy and its extended use on natural evaporites. Indeed, in contrast to microthermometry, the Brillouin technique gives a narrow distribution of Tf values (± 3 °C), consistent with the known precipitation temperatures of the synthetic and natural samples. Brillouin spectroscopy thus provides a unique tool for SST and LST reconstructions in evaporitic sequences.

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S1.T07. Liquid-vapor partitioning of Na and Ca in the H_2O-NaCl-$CaCl_2$ system at 500-700 °C and 550-750 bars

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The partitioning behavior of Na and Ca between two coexisting immiscible fluid phases in the H_2O-NaCl-$CaCl_2$ system at 500-700 °C, 550-750 bars, and for Na:Ca molar ratios of 2:1, 1:1, 1:2, and 0:1 (i.e. on the H_2O-$CaCl_2$ binary) was determined using the synthetic fluid inclusion technique. For most of the studied PTX combinations, a single-phase fluid underwent phase separation into a high density, high salinity liquid and a low density, low salinity vapor, each of which was then individually trapped in the form of fluid inclusions as the fractures in the host quartz healed. At room temperature, the inclusions that trapped the vapor phase always contain a vapor bubble and a small amount of liquid that condensed from the vapor during quenching, and the inclusions that trapped the liquid phase contain a liquid, vapor, and either a halite daughter mineral or both halite and antarcticite ($CaCl_2 \cdot 6H_2O$) daughter minerals, depending on the composition of the liquid at the experimental run conditions.

Significant scatter in the halite dissolution temperatures on the order of ~ ± 50 °C has been found for most PTX conditions of interest. For a given starting bulk fluid composition, the resulting compositions of the coexisting liquid and vapor phases formed during immiscibility must lie along a tie line in the H_2O-NaCl-$CaCl_2$ ternary that connects the liquid and vapor compositions and passes through the starting bulk composition. The range observed in the halite dissolution temperatures results in calculated compositions of the liquid phase that violate this behavior, as well as giving inconsistent partitioning behavior of Ca and Na within a single sample. This variability is likely due to the formation of wollastonite ($CaSiO_3$), which has been observed in many samples and is verified via Raman spectroscopy. At higher temperatures and moderate pressures, $CaCl_2$ undergoes hydrolysis and forms $Ca(OH)_2$ which can then react with the host quartz and form wollastonite, with the total reaction resulting in a net loss of both $CaCl_2$ and H_2O, which shifts the dissolution temperature of the halite daughter minerals in the liquid-rich FI to higher temperatures. To account for the formation of wollastonite and the apparent shift in the halite dissolution temperature that results, FI showing the lowest halite dissolution temperatures in a given sample are used to determine the composition of the liquid phase in equilibrium with vapor at the experimental PT conditions. Preliminary results indicate that Ca preferentially partitions into the vapor phase and Na preferentially partitions into the liquid phase.

S1.T08. Metamorphic transformation of oil in relation with temperature, pressure and oil/water ratio: experiment using synthetic fluid inclusions

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It is known that oil at increasing depth is subjected to metamorphic changes with the increase of temperature. According to numerous studies, these changes in endogenous conditions are connected with irreversible processes of oil cracking. Ultimately, this leads to its destruction with the formation of residual solid bitumen (up to graphite), methane and carbon dioxide. At the same time, many questions of oil cracking and its metamorphic transformations in the earth's interior still remain unresolved. In particular, it has not been experimentally proven whether oil cracking is a kinetic process affected by the presence of water. What is the effect of the thermobarometric parameters and water on the phase composition and hydrocarbon states in the earth's interior and, to what extent can these factors determine the depths of oil and gas stability in the earth's interior? In the presented report, an attempt was made to solve these and other issues of oil and gas geochemistry on the basis of synthetic water-hydrocarbon inclusions in quartz, grown simultaneously with the interaction of aqueous solutions with oil and oil-parent rocks. Our experiments were carried out by the hydrothermal method of the temperature gradient using a heat resistant autoclave with a volume from 50 to 280 ml. Autoclaves were heated in shaft electric furnaces equipped with two independent heaters with an accuracy of temperature measurement of ± 2 °C. The pressure in the autoclaves was controlled by the coefficients of filling determined by the P-V-T diagrams for pure water and solutions of the relevant compositions. Charge quartz rods of the ZY-orientation were placed in the autoclave. A seed quartz rod was hung along the whole length. After the experiments, synthesized crystals and residual solutions were removed from autoclaves. After synthesis, fluid inclusions have been reheated by an autoclave treatment at temperatures higher than 380 °C. This treatment led to i) the precipitation of bitumen, ii) the production of methane and iii) the disappearance of liquid oil when water was absent, whereas liquid oil remains unchanged in samples with high proportion of water. It can be concluded that water/oil volumetric ratio governs the oil cracking phenomena. When oil is the main phase, it acts as a solvent and when it is the minor phase it becomes a solute, preserving oil from thermochemical reaction of cracking.

S1.T09. In situ monitoring of the olivine to magnesite reaction using synthetic fluid inclusions as microreactors

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Sub-surface storage of CO_2 in various geological settings is proposed to be effective for long-term storage of CO_2. The conversion of CO_2 into carbonate minerals is the most preferred mechanism to ensure the long-term stability of the geologically trapped CO_2. The mineralization of CO_2 requires the reaction of divalent cations (e.g. Ca^{2+}, Mg^{2+}, Fe^{2+}) with the dissolved CO_2. Olivine and pyroxene are two major rock-forming minerals that have the largest potential to fix significant amounts of CO_2 by mineral trapping due to the high molar proportion of divalent cations in their structures. Therefore, ultramafic and mafic rocks (e.g. peridotites and basalts) containing large quantities of these minerals are now also being considered as possible targets for CO_2 sequestration. In order to maximize the efficiency of CO_2 storage in mafic and ultramafic rocks, the characteristics of the fluid-rock reactions between the injected CO_2 and the host rocks should be well characterized, including the reaction rates of silicate mineral carbonation and the effect of different chemical and physical parameters that control the reactions.

In this study, we used a recently developed experimental approach that uses synthetic fluid inclusions as micro-reactors to follow the reaction of olivine with CO_2 in real time. The technique allows us to monitor the reaction progress in situ as well as quantify the amount of CO_2 being consumed by the reaction. Fluid inclusions containing a synthetic seawater composition and CO_2 were synthesized in olivine (Fo85) at 700 °C and 2 kbar with the nominal CO_2 concentrations of 20 mol% and 11 mol%. The reaction between the olivine host mineral and the fluid was followed by monitoring the change of the density of the free CO_2 phase within the inclusion by measuring the splitting of the Fermi diad of CO_2 using Raman spectroscopy. In order to measure the effect of temperature on the reaction rate, the reaction was followed in situ at temperatures relevant to CO_2 sequestration (100 °C and 50 °C) using a high temperature stage. Our preliminary data show a measurable decrease of CO_2 density in the fluid inclusions as a result of the reaction of the CO_2-bearing aqueous phase and olivine. Magnesite formation was observed in several hours at 100 °C and most of the reactions occurred within two days. At 50 °C, however, magnesite nucleation and precipitation required weeks to months to start, and the reaction rate was about an order of magnitude slower than in the experiments at 100 °C.

S1.T10. 2D and 3D Raman imaging of fluid inclusions in K-bearing tourmaline

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K-bearing tourmaline (maruyamite, Shimizu & Ogasawara, 2005) from the Kokchetav metamorphic rock could be a clue to the reconstruction of the P-T metamorphic condition of the tourmaline assemblage formation (Korsakov et al., 2009; Marshall et al., 2009). In addition to its wide stability field, tourmaline has a property to preserve its inclusion phases. Therefore, fluid inclusions found in the high-K zone of tourmaline likely correspond to the conditions of tourmaline crystallization (Marschall et al, 2008; Ota et al, 2007). Apart from pressure and temperature one of the critical agent of tourmaline formation is a composition of the fluid phase, because only fluid could be considered to be a source or a transporting phase for the required B.

Fluid polyphase inclusions were found in the dravite tourmalines from sample G278 collected in the mining gallery of the Kumdy-Kol microdiamond deposit (Kokchetav Massif, Northern Kazakhstan, Sobolev & Shatsky, 1990). Except for the fluid phases, tourmaline also contains microdiamond, quartz and K-fieldspar inclusions. In this study we investigate chemical composition of the inclusion phases in the K-bearing zones of tourmaline. Origin of this tourmaline is a matter of controversy between the geoscientists. Hence, an investigation of the mineral-forming fluid is the next step to the comprehension of metamorphic mineral growth.

A Raman spectroscopy method was used in a detailed study of the polyphase inclusion composition. The confocal Raman images were collected using a Confocal Raman Microscope alpha 300R at WITec GmbH (Ulm, Germany). The system was equipped with a frequency doubled Nd:YAG laser emitting at 532~nm which was fiber coupled to the instrument. A 100X (NA 0.9 air) objective was used for excitation and detection and the Rayleigh light was rejected using an edge filter. In all measurements, the laser with a power of approximately 10~mW was employed. Vapor, liquid and mineral spectras were recorded and identified. Also we have obtained a 3D model of polyphase inclusion consisting of liquid water, graphite,carbonate and unknown organic phase. This study was supported by a grant from the Russian Science Foundation (RSF 15-17-30012).

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S1.T11. Raman mapping as a tool for studying melt inclusions

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Raman spectroscopy is one of the few methods that enable qualitative non-destructive analysis of both solid and fluid phases, therefore it has been widely used for the identification of minerals and volatiles within melt and fluid inclusions (Berkesi et al., 2017; Burke, 2001; Frezzotti et al., 2011). For a better understanding of petrogenetic processes, it is essential to find all mineral phases in the melt inclusions trapped in magmatic or volcanic rocks (Káldos et al 2015a).

Raman spectroscopic point measurements in melt inclusions revealed the presence of daughter phases, but Raman mapping can provide information even on their size, shape and distribution as well (Káldos et al., 2015b). Unheated multiphase melt inclusions of magmatic and volcanic rocks were imaged using Raman mapping (including 3D mapping) with high spatial resolution (< 1 μm step size in XYZ directions). The clear recognition of small (< 1 μm) mineral phases is problematic optically, it often requires other techniques such as SEM, but SEM images surfaces only and the exposure of all such small phases is unlikely. The analysis below the surface of the host mineral is especially useful because we can avoid the possible loss of sensitive (e.g. water soluble) phases and the contamination of the melt inclusions. Moreover, unexposed melt inclusions are suitable for further analytical measurements (e.g. EPMA, microthermometry).Through Raman mapping, we can create 2D or 3D Raman images showing the spatial distribution of different mineral (and fluid) phases of the melt inclusions, thus we can get an insight into post-entrapment crystallization processes that contribute to a more precise description of the evolution of magmatic rocks.

Confocal HR-Raman mapping of melt inclusions can open new perspectives in studying melt inclusions and our goal is to demonstrate the many advantages of this powerful technique.

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S3.T01. Keynote - Inclusions of mantle derived melts: challenges and recent results

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Melt inclusions were repeatedly used to address composition of mantle sources and processes of mantle melting. The results of these studies made significant contribution to our understanding of the role of volatiles in the Earth mantle, the dynamics of mantle melting, the crucial role of crustal recycling in the origin of mantle heterogeneities, the global dynamics of mantle convection and compositional evolution of mantle since Neoarchean time. These findings were possible because of spectacular evolution of in-situ analytical techniques: EPMA (major and minor elements), SIMS (concentrations of volatiles (trace elements and isotopes of H, O, B, C and Pb), LA-ICPMS (trace elements, isotopes of Sr and Pb), FTIR and RAMAN (H_2O and CO_2 contents). Application of all these techniques to carefully selected and prepared melt inclusions and their host minerals (mostly olivine and less often spinel) reveal significant compositional and isotopic diversity of melt inclusions trapped in the most Mg-rich minerals and drastically decreasing of such diversity during magma evolution. This feature together with the data on coexisting compositionally and isotopically diverse melt inclusions in the single olivine phenocryst imply for continuous magma mixing and poor preservation of true primary melts in the magmatic systems. Important implication of these studies has been that the melt inclusions are actually representative of the source rocks in the mantle rather than being products of crustal interactions or portions of the boundary layer on the interface of growing crystals. Another implicit assumption is that such melt inclusions can preserve chemical characteristics of parental melts formed in the mantle, thus delivering information about the chemical (and isotopic) composition of magma sources in the mantle. However, both of the above assumptions have been challenged in numerous studies.

In this talk I will present the most influential findings in mantle petrology and geochemistry made by study of melt inclusions during the last decade. I will also assess the main challenges and problems of melt inclusions implication using both new data and published results. I will demonstrate that olivines generally trap their melt inclusions during shallow crystallization in the crust during fast growth in the thermal boundary layers of mixing magma batches. The chemical boundary layer effects do not present in artificial inclusions larger than 5 microns trapped in olivine in the temperature range between 1300-1550 oC. The original composition of trapped melt could be successfully reconstructed and it may indeed represent primary melt composition. The time scales in the magmatic system are commonly short enough to preserve the abundances of highly and moderately incompatible elements inherited from primary melts. Concentrations of heavy REE and Y in some cases do show post-entrapment modification in some inclusions and should be used with caution. The melt inclusions study remains the only way to assess contents of highly mobile elements (K, Rb, Ba, Pb) and volatiles in the Archean mantle.

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S3.T02. Olivine-hosted melt inclusions in the ancient komatiites - the potential key to the Archaean mantle composition

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Komatiites are volcanic rocks derived from ultramafic magmas (mainly in the Archaean) first recognized in the late sixties by Viljoen&Viljoen (1969) in the Barberton Mountainland of South Africa. Since that time, the mode of their origin and the water contents of komatiites have been a subject of considerable debate. Essentially, the concept of komatiite as hot (over 1500 °C) and dry magma ascending from the mantle as plumes is broadly accepted (Arndt et al., 1998; Connolly et al., 2011). The main obstacle in the unilateral acceptance of this model is a lack of direct information on the volatile contents in komatiites due to the absence of volcanic glass in their groundmass. Thus, melts trapped in the remnants of crystalline phases (mainly olivine) hold the potential to give definitive alternative information on the petrogenesis of komatiites.

Here we report new data on melt inclusions hosted in olivine crystals from the 2.7 Ga Reliance Formation (Belingwe Greenstone Belt, Zimbabwe) komatiites and komatiites of the 3.3 Ga Weltevreden Fm. of the Barberton Greenstone Belt. Reconstructed melt compositions contain significant amounts of water (up to 0.3 wt.% and up to 0.8 wt.% respectively in these two occurrences). However, elevated chlorine contents (compared to estimates for contemporary mantle) were detected in both cases suggesting the possibility of contamination by altered subducted oceanic crust. However, melts trapped in the most primitive olivines at the onset of the crystallization show no (or only minor) contamination signature and may be considered as a good proxy for the initial melts of the Belingwe and Barberton komatiites. Our calculations, based on these early inclusions, yield 0.2 wt.% of water for Belingwe and 0.1 wt.% for Barberton primary melts. These numbers exceed the expected water contents inferred from the Ce and K_2O concentrations by a factor of 5-6. We propose a plume origin for the komatiites of the Belingwe and Barberton Greenstone Belts that probably incorporated water enriched material from the transition zone of mantle as suggested by Sobolev et al. (2016).

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S3.T03. Redox parameters of magma crystallization at Changbaishan Tianchi volcano, China–North Korea

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Changbaishan Tianchi volcano (known as Paektusan in Korean) on the Chinese–North Korean border is composed of lavas and pyroclastic rocks of the trachybasalt–trachyte–pantellerite–comendite composition.

We used our data on melt inclusions in minerals of the rocks to estimate the composition of the melts that produced the trachybasalts, trachybasaltic andesites, comendites, and pantellerites of Changbaishan Tianchi volcano. All of the analyzed melts are rich in alkalis and FeO. The sulfur content of the mafic melts varies from 0.08 to 0.13 wt %. The pantellerite melts are sulfur-free but the groundmass of the pantellerites contains pyrite crystals. Some of the mafic melts are dry (0.1-0.2 wt % H_2O), while others contain H_2O (1 wt %). The H_2O content of the comendite melts varies from 3.1 to 4.8 wt %, and the pantellerite melts contain 0.2-0.6 wt % H_2O.

The estimated crystallization parameters of the melts as follows from our data of melt, fluid and crystalline inclusions studies correspond to broad temperature and pressure ranges of 1220-700 ºC and 3100-1000 bar. The redox parameters $\Delta\log f_{O2}$ relative to the NNO buffer are +0.92 to +1.42 log units for the basalt melts, –1.61 to –2.09 log units for the trachybasaltic andesite melts, –2.63 to –1.89 log units for the comendite melts, and –2.09 to –3.15 log units for the pantellerite ones.

The crystallization of the magma is proved to have been associated with dramatic changes in the redox parameters, which depended on the degassing of the magma. Degassing was responsible for variations in the contents of water and sulfur in the melts. As the pressure decreased, the gas phases became progressively enriched in H_2O and S, and the S oxidation state was thereby principally changed. Sulfur degassing in the form of SO_2 at decreasing pressure should have resulted in Fe^{3+} reduction to Fe^{2+}. The redox regime was also controlled by the presence of H_2 in the system, with hydrogen produced by water dissociation at the pressure decrease.

Our evaluations of the oxygen fugacity and certain features in the behavior of volatile components in the magmatic system based on our data on crystalline, fluid, and melt inclusions in minerals of the rocks led us to conclude that the magma of Changbaishan Tianchi volcano evolved in relatively shallow chambers (which occurred at depths of 13 to 3.5 km), when the pressure decreased from 3100 to 1000 bar at temperatures of 1220-700 ºC, and with melt degassing continuously changing the redox regime and, correspondingly, the redox conditions of magma crystallization from oxidized to reduced ones.

S3.T04. Silicate melt inclusion homogenization: A new mathematical approach coupling X-ray microtomography, geochemistry and thermodynamics

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Silicate melt inclusions (SMIs) trapped in minerals and bought up to the surface by volcanism are routinely studied in order to determine pre-eruptive volatile budgets of volcanic systems.

SMI affected by post-entrapment processes such as crystallization (PEC) and formation of a bubble are generally discarded. Conversely, they can be re-homogenized using experimental high temperature approach. However, this method has controversies regarding the leakage of volatiles during experiments by diffusion through the host crystal toward a volatile-free (or volatile-saturated) external atmosphere.

The new multi-disciplinary approach developed in this study allows avoiding the leakage of volatiles. The approach associates: (1) X-ray microtomography for measuring phase proportion, (2) NanoSIMS for measuring C and H concentrations in glass as a proxy for CO_2 and H_2O, (3) EPMA for major and volatile element concentrations in all the phases and, (4) thermodynamical modelling using Rhyolite-MELTS for volatile saturation determination.

In order to test this approach we studied Los Humeros (East Mexican Volcanic Belt) volcanic complex SMIs to determine the conditions of the magma chamber. Three dimensions (3D) petrographic observations of the studied SMIs highlight a linear relationship between SMIs and bubble volumes in all the samples. This relation indicates that all the SMIs contained the same volume proportion of vapour, and suggests that the bubble were generated in the SMI after trapping. 3D petrography also shows that minerals inside the SMIs have been crystallized from SMI and are not the result of a heterogeneous trapping. According to these petrographic evidences, the mathematical re-homogenization of the SMIs follow the equation: $X_{SMI} = \Sigma[V_{Mineral(i)} * X_{Mineral(i)}] + [V_{Glass} * X_{Glass}] + [V_{Bubble} * X_{Bubble}]$.

PEC correction is confirmed if $Kd_{host\ mineral-melt} \leq 0.3$; if $Kd_{host\ mineral-melt} < 0.3$ the volume of PEC is adjusted by the correction of olivine PEC at SMI rim. PEC of large minerals inside SMIs agree with low cooling rates of the SMIs; hence, exsolved volatiles were able to diffuse toward the bubble and maintain equilibrium between the melt and the bubble before the glass transition. The volatile pressure determined in X_{SMI} and, using Rhyolite-MELTS is therefore equal to the bubble one. The volatile mass in the bubble is thus determined and the last step is the addition of this bubble volatile content into the PEC-corrected melt composition. The recalculated initial SMI compositions allow using volatile saturation pressures (Rhyolite-MELTS) to determine magma ponding and SMIs trapping at MOHO (~13 km) and shallower depths (~6-8 km) which are in agreement with geophysical interpretations of Los Humeros volcanic area.

S3.T05. Recalculating boninitic melt inclusion compositions from Chi-chi jima, Japan: The role of post entrapment crystallisation

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Boninite magmas form in nascent subduction settings, where hydrous components of a newly subducted slab flux melting of depleted mantle hartzburgite. As such, boninite magmas reflect a distinct subduction overprint and therefore provide insight into the contribution of volatiles and metals from the subduction component. Chi-chi jima is the type locality of low-Ca boninites, where some of the most primitive (>20% MgO) melt inclusions have been found hosted in chromite (Umino et al., 2015). This sample suite also contains melt inclusions hosted in orthopyroxene, clinopyroxene, magnetite and plagioclase that record the magmatic evolution from a depleted, low sulfur and FeO melt, to a sulfide saturated evolved melt. Melt inclusions offer an opportunity to follow the melt evolution from inception to eruption. How low sulphur, low FeO melts evolve to sulfide saturation remains unclear especially considering the inverse relationship between sulfur solubility at sulfide saturation and pressure (Mavrogenes and O'Neill, 1999). Analysis of melt inclusions is likely the best method for understanding this process.

Host phases affect melt inclusions, and accounting for this is vital if melt inclusions hosted by different phases are to be tracked from primitive (~20% MgO) to evolved (<1% MgO). A series of homogenisation experiments and major and trace element analyses has shown that post entrapment crystallisation of the host is variable and while it affects pyroxene hosted inclusions dramatically, chromite hosts show little to no post-entrapment crystallisation. A range of techniques can be employed to remove post-entrapment modification, however some are more damaging than others. Re-homogenisation experiments yield excellent major element estimates, however some trace and volatile phases are readily mobilised during these experiments (e.g. Spandler et al., 2007; Chen et al., 2011). To study the evolution of volatile phases such as sulfur, water and the chalcophile elements (e.g. Cu and Ag), a more delicate approach is required. Using high resolution Field Emission-SEM imaging coupled with electron microprobe and LA-ICP-MS analyses, the post entrapment history of exposed melt inclusions can be better understood and re-calculation is possible. Recalculating the major and trace element abundances to account for daughter crystallisation and crystallisation of the host provides equivalent results to homogenisation experiments, whilst preserving volatile trace elements.

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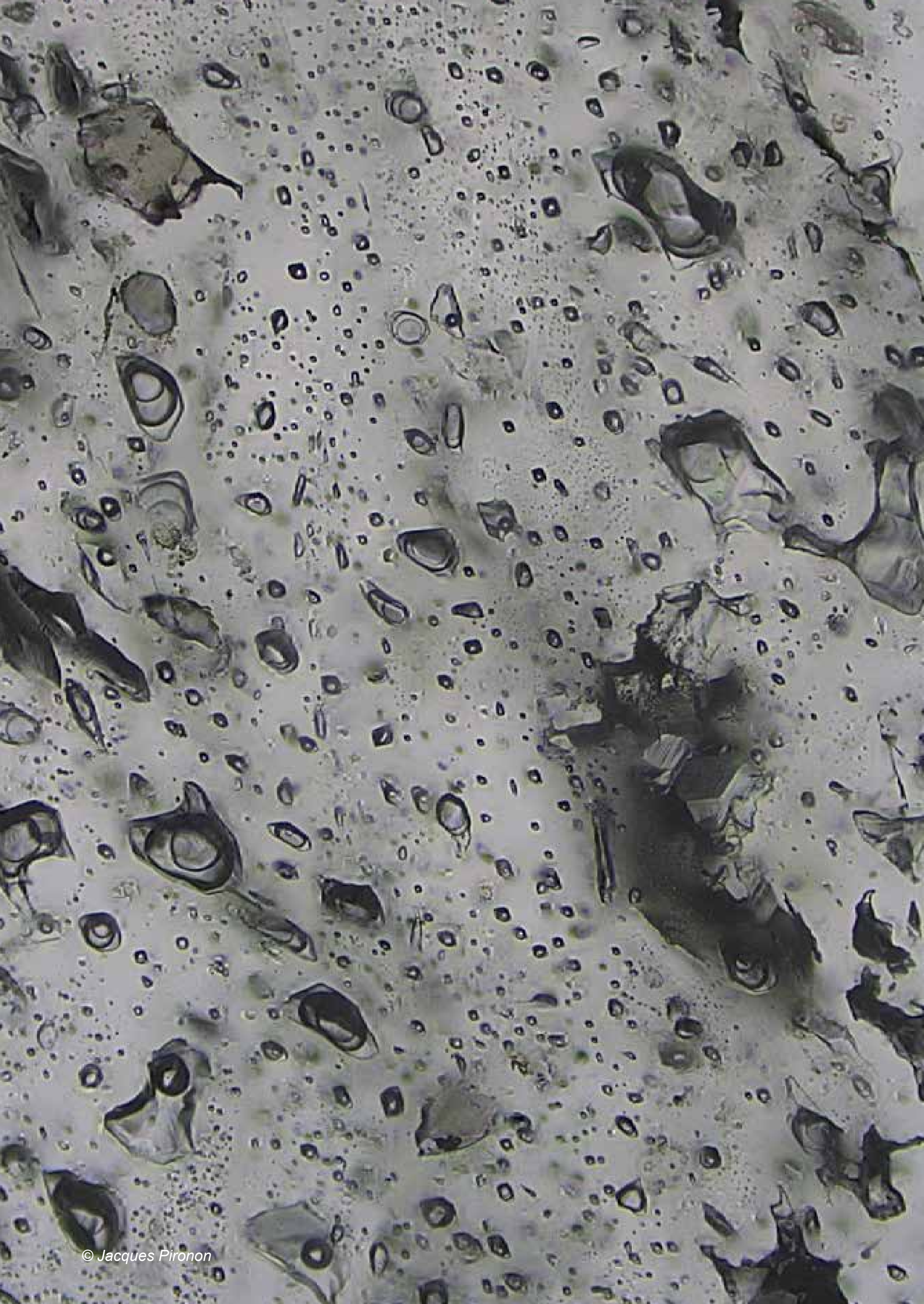

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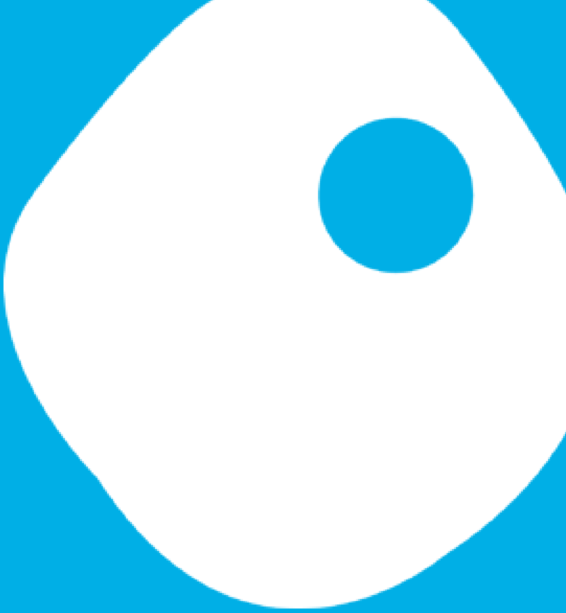

TUESDAY
JUNE 27th

PROGRAM

7:45 - 10:30 ▸ Bus trip to Champagne

10:30 - 10:45 ▸ Coffee break

10:45 - 12:15 ▸ Session 2: New frontiers in inclusion research

S2.T01. Perret A., **Bonhommeau D.A.**, Nuzillard J-M., Cilindre C., Cours T., Alijah A., Liger-Belair G. - **Keynote** ▸ Molecular dynamics simulations and ^{13}C NMR spectroscopic measurements for the study of CO_2 and ethanol diffusion in Champagne wines

S2.T02. Bobo E., Tissandier L., Faure F., **Coquerel G.** ▸ Inclusions in minerals vs inclusions in organic single crystals: what can we learn from each other?

S2.T03. **Giuliani G.**, Dubessy J. ▸ Fluid inclusions study of «trapiche» and non- «trapiche» rubies from Mong Hsu, Myanmar

S2.T04. **Faure F.**, Tissandier L., Florentin L., Devineau K. ▸ A magmatic origin for silica-rich glass inclusions hosted in porphyritic magnesian olivines in chondrules: an experimental study

S2.T05. **Florentin L.**, Deloule E., Faure F., Mangin D. ▸ 3D-imaging of glass inclusions from Allende (CV3) olivine via SIMS: a new insight on chondrule formation conditions.

12:15 - 14:00 ▸ Lunch and Champagne tasting

14:30 - 16:15 ▸ Visit: insight into the world of Champagne

16:15 - 17:15 ▸ Vineyard tour

16:30 - 18:30 ▸ Return trip to Nancy

Tour of Champagne

The day will lead participants to the Champagne region for a tour of the Champagne vineyards and cellars.
Scientific explanations of bubble nucleation and behavior in champagne bottles and glasses will be given, followed by a chance to sample some champagne at a tasting party.

S2.T01. Keynote - Molecular dynamics simulations and ^{13}C NMR spectroscopic measurements for the study of CO_2 and ethanol diffusion in Champagne wines

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Carbon dioxide (CO_2) diffusion is the main physical process responsible for the formation and growth of bubbles in sparkling beverages such as Champagne wines. Though multicomponent by nature since composed of a broad variety of species, going from monatomic ions and alcohol to proteins and amino acids, champagnes can be considered in first approximation as hydroalcoholic solutions supersaturated with CO_2.

In this context, classical force field molecular dynamics simulations have been performed in mixtures composed of water, described within the SPC/E and TIP5P models, ethanol (EtOH) and CO_2 at temperatures ranging from T = 277 K (fridge temperature) to T = 293 K (ambient temperature) to attempt to evaluate CO_2, and to a lesser extent EtOH, diffusion coefficients. Theoretical diffusion coefficients reckoned from the calculation of mean squared displacements of CO_2 and EtOH are first reported and compared to experimental results obtained from recent ^{13}C NMR spectroscopic measurements on brut champagnes. The influence of temperature and water models on theoretical results is then investigated to evaluate the interplay between water, EtOH and CO_2, and demonstrate that EtOH is the main species, apart from water, that governs the value of CO_2 diffusion coefficients in brut champagnes.

As a complement, hydrodynamic radii of CO_2 and EtOH are derived from the Stokes-Einstein relationship by using (i) diffusion coefficients and viscosities deduced from molecular dynamics simulations, or (ii) experimental data from NMR and viscometry measurements.

Future works on molecular diffusion as well as evaporation of droplets on top of glasses filled with champagne are eventually suggested as an opening of the present study.

References:

Perret A. et al. (2014) J. Phys. Chem. B 118, 1839-1847.
Bonhommeau D. A. et al. (2014) J. Phys. Chem. Lett. 5, 4232-4237.

S2.T02. Inclusions in minerals *vs.* inclusions in organic single crystals: what can we learn from each other?

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Fluid and melt inclusions trapped in minerals are markers of the rocks history as they have been continuously appearing since the solar system formation about 4.56 Gyr ago. On the other way round, fluid inclusions can also be found in organic crystals where they are at the origin of problem of purity for the fine chemical industries. Every field, apparently far apart, has separately developed experimental tools to understand the phenomenon of the formation of inclusions and converging questions remain for both the geological and organic fields: Why is a fluid inclusion formed in olivine or in organic single crystals? Do they have the same properties even if they are formed under different conditions (two magnitudes of order different in terms of temperature and pressure)? What can we learn from each other?

The data collected show interesting analogies in terms of thermal behaviour or mechanism of formation of the vacuoles (Faure, 2005, 2007; Bobo, 2015, 2016).

However, every field has to deal with several drawbacks due to the properties of olivines or organics that limit the investigations. For example, the monitoring of the crystal growth of minerals is difficult due to conditions of formation (up to 2000 °C and several kbar); whereas the crystallisation of organic crystals is more suitable for data acquisition at room temperature and room pressure. Conversely, organic crystals are generally not appropriate for experiments at temperature above 100 °C due to chemical degradations, and the characterization of their properties (chemistry, structure…) is harder since they are much more quickly evolving systems compared to minerals.

Since our goals are similar, our purpose is to use the benefits of each domain of science to deepen our understanding about fluid inclusions. This means that a broader approach will lead to develop new research axes.

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Bobo E., Lefez B., Caumon M-C., Petit S. and Coquerel G. (2016) Cryst. Eng. Comm. 18, 5287-5295.

S2.T03. Fluid inclusions study of «trapiche» and non- «trapiche» rubies from Mong Hsu, Myanmar

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The Mong Hsu ruby mines are famous for their "trapiche" (TR) and non- «trapiche» (NTR) rubies (Tin Hlaing, 1991). The Spanish word "trapiche" is used for minerals such as Colombian emerald having a texture resembling the grooved millstone used for sugar cane crushing. Mong Hsu "trapiche" rubies are rare, disconnected from NTR, have never been described in situ and sold in Burma gem-markets. The texture of the crystals on a section perpendicular to the c-axis, is characterized by a central core, six arms i.e. growth sectors, and dendrites between the arms and around the core (Sunagawa et al., 1999). The NTR hosted in marble are well-known for their color zoning with violet to blue color bands (Peretti et al., 1995). These rubies formed during the Himalayan metamorphism in the amphibolite facies of carbonate platform series (Garnier et al., 2008).

Fluid inclusions (FI) investigations were performed on both TR and NTR. Primary and pseudo-secondary (Type I) and secondary (Type II) FI were recognized on the basis of their respective chronology. There are commonly two-phase but sometimes mono-phase FI (liquid and vapor carbonic phases). Type I inclusions occur as isolated or oriented FI throughout the growth zones of the crystals for NTR and in the dendrites and growth sectors for TR. Type II FI occurs along healed fracture planes which are secant to several crystal limits or growth zones.

Microthermometry and Raman spectrometry of the two types of FI enable the recognition of the same fluid composition for TR and NTR as already found for rubies from southeast Asia (Giuliani et al., 2003; Garnier et al., 2008): CO_2-H_2S-COS-S_8-AlO(OH)-bearing fluids with native sulphur and diaspore, without visible water. The presence of diaspore and COS (Raman peak at 857 cm-1) in the fluid inclusions indicate that a small amount of water was present in the paleofluid. In the TR, the concentration of H_2S in FI from the growth sector (7 to 15 wt.%) is higher than that from the dendrites (7 wt.%). The presence of H_2S-COS-S_8 species indicates the contribution of evaporites in their generation at high temperature metamorphism.

Even the «trapiche» rubies have not been described in situ in the marbles or other rocks, the present study indicates that their parental fluid is similar to the one of non-"trapiche rubies".

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Peretti A; et al. (1995) Gems & Gemmology 31, 2-26.
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S2.T04. A magmatic origin for silica-rich glass inclusions hosted in porphyritic magnesian olivines in chondrules: an experimental study

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Chondrites are the most primitive and oldest rocks formed in the Solar System. Chondrules, which can constitute up to 80 vol.% of a chondrite, are essentially ferromagnesian silicate spherules of igneous origin and are classified as magnesian (type I) or ferroan (type II). Rare silica-rich glass inclusions ($69 < SiO_2 < 82$ wt. %) are described within porphyritic magnesian olivines of Type IA chondrules. These glass inclusion compositions are clearly out of equilibrium with their host Mg-olivines and their presence within the olivines is generally attributed to an unclear secondary process such as a late interaction with nebular gases. We performed dynamic crystallisation experiments that demonstrate that these Si-rich glass inclusions are actually magmatic in origin and were trapped inside olivines that crystallized slowly from a magma with a CI, i.e. solar, composition. Their silica-rich compositions are the consequence of the small volumes of inclusions, which inhibit the nucleation of secondary crystalline phase (Ca-poor pyroxene) but allow olivine to continue to crystallize metastably on the walls of the inclusions. We suggest that Si-rich glass inclusions could be the only reliable relicts of what were the first magmas of the solar system, exhibiting a CI, i.e. non-fractionated, composition.

S2.T05. 3D-imaging of glass inclusions from Allende (CV3) olivine via SIMS: a new insight on chondrule formation conditions

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Natural glass inclusions - hosted in Mg-rich olivines from Allende (CV3) type I chondrules - and synthetic melt inclusions - trapped in forsterite crystallized from CMAS (CaO-MgO-Al_2O_3-SiO_2) melts - were mapped by Secondary Ion Mass Spectrometry (SIMS) 7F (Institut Jean Lamour, Nancy) and 1280 (CRPG, Vandœuvre-lès-Nancy) for CMAS major oxides. First ever 3D chemical images of extra-terrestrial glass inclusions were drawn, along with chemical depth profiles for each oxide. Results show similar patterns for synthetic glass inclusions (trapped in olivine formed by slow crystallization in a magmatic liquid) (Faure and Tissandier, 2014) and natural inclusions from Allende olivines. In a both cases, no boundary layer or diffusion pattern was observed. The absence of boundary layer suggests that inclusions were trapped near equilibrium conditions with their hosts and thus that olivine hosts grew slowly in a homogeneous environment. This is a further argument in favor of olivine from chondrules formed initially from a slowly crystallized melt on planetesimals (Libourel and Krot, 2007, Johnson et al., 2015).

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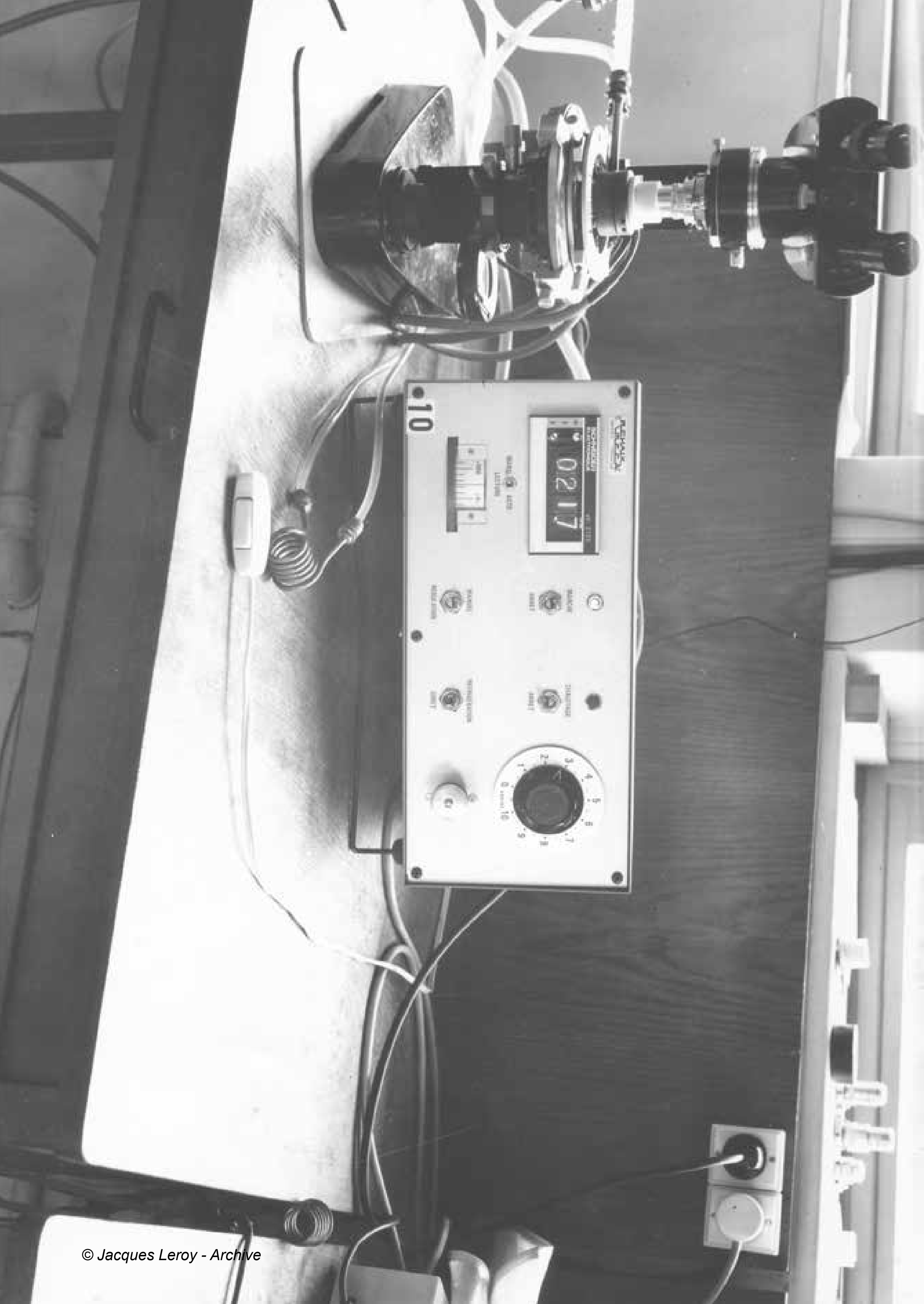

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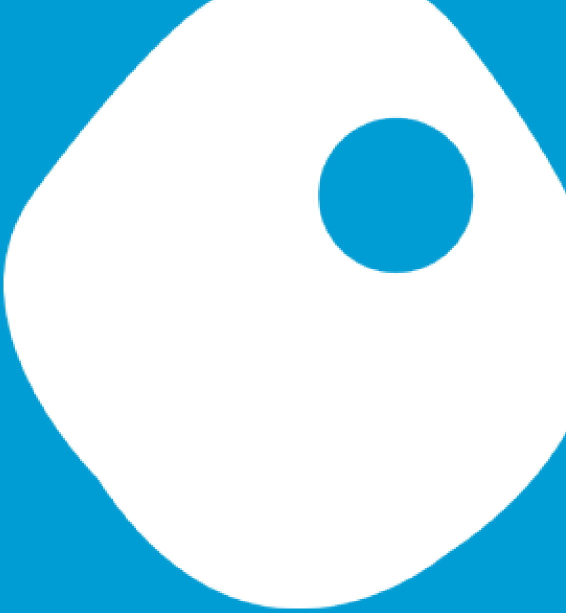

WEDNESDAY
JUNE 28th

PROGRAM

8:30 - 10:00 ▶ Session 3: Magmatic, magmatic-hydrothermal and volcanic environments

S3.T06. **Cannatelli C.**, Aracena C., Leisen M., Moncada D., Barra F., Morata D. ▶ Evolution of magma at Copahue volcano (Chile/Argentina): insights from melt inclusions

S3.T07. **Nizametdinov I.R.**, Kuzmin D.V., Timina T.Y., Shevko A.Y., Smirnov S.Z. ▶ The features of melt inclusions composition from Menshiy Brat volcano basalts, Iturup Island, Southern Kurile Islands

S3.T08. **Bali E.**, Hartley M.E., Halldórsson S.A., Guðfinnsson G.H., Jakobsson S. ▶ Deducing volatile content of the central Iceland mantle source from silicate melt inclusions of the 2014-2015 Holuhraun eruption

S3.T09. **Herms P.**, Giehl C., Appel P., Möller A., Raase P. ▶ Polymineralic inclusions indicating a melting event in eclogite-facies rocks from a 2 Ga old subducted oceanic crust

S3.T10. **Guzmics T.**, Káldos R., Szabó C. ▶ Study of mafic melt inclusions from Kerimasi Volcano (Tanzania)

S3.T11. **Neyedley K.**, Hanley J.J., Falck H., Bodnar R.J., Fedele L. ▶ Fluid and melt inclusion record of volatile and intercumulus melt evolution in a barren gabbro, Caribou Lake, Northwest Territories, Canada

10:00 - 10:30 ▶ Coffee break

10:30 - 12:00 ▶ Session 3: Magmatic, magmatic-hydrothermal and volcanic environments

S3.T12. **Mavrogenes J.**, Mernagh T. ▶ High temperature fluids and melts in the Grasberg porphyry Cu-Au deposit

S3.T13. **Kaufmann A.**, Pettke T., Baumgartner L.P. ▶ The magmatic-hydrothermal transition at the Torres del Paine igneous complex, Chile - documented by silicate melt and aqueous fluid inclusions in miarolitic quartz

S3.T14. **Korges M.**, Weis P., Lüders V., Laurent O. ▶ The magmatic-hydrothermal evolution of the ore-forming fluids of the Zinnwald Sn-W-Li deposit, Germany

S3.T15. **Legros H.**, Richard A., Mercadier J., Tarantola A., Kouzmanov K., Vennemann T., Bailly L., Marignac C., Charles N., Wang R-C., Cuney M., Lespinasse M-Y. ▶ Origin and evolution of ore-forming fluids in the Maoping and Piaotang W-Sn deposits (Jiangxi, China)

S3.T16. **Cathelineau M.**, Marignac C., Rolland J-M., Boiron M-C., Dejean M., Carocci E. ▶ Are we sure to know the fluids responsible for W mineralization at Panasqueira (Portugal) : the case for loss of information due to intense quartz recrystallization and FI natural decrepitation

S3.T17. **Fan H-R.**, Liu X., Hu F-F., Yang K-F. ▶ Ore-forming fluids in the giant Dexing porphyry Cu-Mo-Au deposit, Southeastern China

12:00 - 13:30 ▶ Lunch

13:30 - 15:00 ▶ Session 3: Magmatic, magmatic-hydrothermal and volcanic environments

S3.T18. **Moncada D**. - **Keynote** ▶ Fluid inclusions from active and fossil hydrothermal system in Chile

S3.T19. **Redina A.A.**, Prokopyev I.R. ▶ Fluid inclusion study of fluorites from the Mushugai-Khuduk carbonatite complex (Southern Mongolia)

S3.T20. **Bazarkina E.F.**, Prokofiev V.Y., Szabo C., Kaldos R., Kovalenker V.A., Dubessy J. ▶ Raman-investigation on fluid inclusions in quartz of Sr-Ba carbonatites of the Murun complex, Eastern Siberia, Russian Federation

S3.T21. **Richter L.**, Diamond L.W. ▶ Hydrothermal epidosites in the oceanic crust: products of alteration by seawater or magmatic brines?

S3.T22. **Kerr M.J.**, Hanley J.J., Kontak D.J., Fayek M. ▶ Upgrading of an orogenic gold-quartz-carbonate vein system by magmatic-hydrothermal fluids in the Hope Bay Greenstone Belt, Nunavut, Canada

15:00 - 15:30 ▶ Coffee break

15:30 - 17:00 ▶ Session 4: Deep fluids and metamorphic environments

S4.T01. Van der Kerkhoff - **Keynote** ▶ Deciphering fluid inclusions in high-grade rocks

S4.T02. **Berkesi M.**, Czuppon G., Szabó C., Kovács I., Ferrero S., Pfeiffert C., Boiron M-C. ▶ Pargasite in fluid inclusions of mantle xenoliths from northeast Australia (Mt. Quincan): sign of interaction of asthenospheric fluid

S4.T03. **Aradi L.E.**, Berkesi M., Szabó C. ▶ Fluid inclusions in mantle xenoliths from the Styrian Basin (W-Pannonian Basin) as remnants of metasomatism

S4.T04. **Touret J.L.R.**, Huizenga J-M., Piccoli F., Kehelpannala K.V.W. ▶ Vein-type graphite deposits in Sri Lanka: the ultimate fate of granulite fluids

S4.T05. **Prokofiev V.Y.**, Banks D.A., Lobanov K.V., Borovikov A.A., Chicherov M.V. ▶ Gold-rich fluid inclusions in gold-bearing quartz from the Kola superdeep borehole (SG-3), Kola Peninsula, Russian Federation

17:00 - 18:15 ▶ Poster session / refreshments

19:15 - 22:30 ▶ Gala dinner

22:45 ▶ Rendez-vous Place Stanislas

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Gala Dinner

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S3.T06. Evolution of magma at Copahue volcano (Chile/ Argentina): insights from melt inclusions

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Copahue volcano is an active stratovolcano in the Andean Southern Volcanic Zone (SVZ), straddling at the border between Central Chile and Argentina. The volcano's eruptive style during its history has changed from mainly effusive in the Pleistocene to explosive in the Holocene. The prehistoric eruptions can be divided into preglacial (PG), synglacial (SG) and postglacial (PM) stages, with products ranging from basaltic andesites to andesites. In order to investigate the evolution of the magma source and volatiles through time, we have focused our study on the eruptive products from the SG to the 2014 eruption (SUM2014).

Sampled rocks are glomeroporphyritic, with a paragenetic mineral sequence of feldspars, ortho and clinopyroxene, and olivine in order of abundance. All samples present a variable number of vesicles, with SUM2014 samples containing the biggest amount. Feldspar composition varies from Na-rich (andesine) in SG to Ca-rich (labradorite) in SUM2014. Two pyroxene types are present in SG and PM samples (augite and enstatite), while SUM2014 presents augite, pigeonite and enstatite. Thermobarometric estimation, based on mineral chemistry, show a bimodal distribution for SG and SUM2014 (P=10-12 kbars and 5-8 kbars) and only one interval for PM (P=7-8 kbars).

Melt Inclusions Assemblages (MIAs) are found in all mineral phases, mostly recrystallized, with one or more bubbles and daughter oxide minerals. Compositions vary from trachyandesitic to dacitic for SG, andesitic to trachydacitic for PM, and basaltic andesitic to trachydacitic for SUM2014. Major elements systematic show the existence of a bimodal distribution of pyroxene and feldspar hosted-MIA in SUM2014, which together with the co-presence of pigeonite (low-Ca pyroxene) and augite and the bimodal distribution of P, can be interpreted as evidence of mixing of two types of magmas, evolving at different depths. Trace elements systematic for MIA in SG, PM and SUM2014 show a negative anomaly for Nb and Ti and a positive one for Pb, characteristic of rocks produced by arc basaltic volcanism. The Ba/Th vs La/Sm systematic show a dual influence of fluid release and partial melts of subducted sediments for SUM2014, while the source of both SG and PM seem to be related to melting of subducting sediments, with less H_2O fluxing.

S3.T07. The features of melt inclusions composition from Menshiy Brat volcano basalts, Iturup Island, Southern Kurile Islands

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Menshiy Brat volcano is located in the Medvezhia caldera in the north-eastern part of the Iturup Island. It is composed of isolated andesitic lava dome that is covered by scoria cones: Korotyshka and Vostok, which produced multiple lava flows. These flows consist of olivine-pyroxene-plagioclase basalts and basaltic andesites. Basic lavas and tephra of the Menshiy Brat volcano consist of high-Mg basalts, which are scarce among the products, erupted in Kurile-Kamchatka Island Arc. This paper represents the results of a melt and fluid inclusion study which aims to deciphering of the origin of these basalts.

The earliest mineral assemblage of the basalts is represented by olivine phenocrysts with numerous inclusions of chromium spinel (Cr# 0.34-0.85). Olivine Mg# reaches up to 90 mol %. This evidences for crystallization of the olivine from melt that is in equilibrium with the SSZ mantle reservoir rocks. Primary melt inclusions in olivine have basic compositions. Silica and Mg contents sometimes reach values of picrobasaltic compositions. Typically these melt inclusions show smaller SiO_2 contents than the bulk rock compositions.

The later mineral assemblage includes augite (#Mg 0.6-0.75), enstatite (#Mg 0.56-0.6) and plagioclase (An75-95). Chemical compositions of melt inclusions in these phenocrysts vary from dacite to rhyolite and their SiO_2 contents are higher than those of the bulk rocks. Such a contrast between bulk rock and melt inclusion compositions from plagioclase and pyroxenes cannot be explained by fractional crystallization or post-entrapment transformations of melt inclusions.

Comparison of phenocryst assemblages and the melt inclusion compositions demonstrates that the high-Mg basalts of the Menshiy Brat volcano contain two phenocryst assemblages with different origin. First assemblage consists of olivine and chromium spinel, and was crystallized from mantle basaltic melt. The second one comprises augite, enstatite and An-rich plagioclase, which were formed with participation of high-SiO_2 melts. The contrasting assemblages can be explained by mixing primary high-Mg basaltic magma with products of partial melting of earlier rocks and formation of TTG melts [Beard and Lofgren, 1991;Turkina, 2000]. This mixing occurred before the eruption of the high-Mg basalts of the Menshiy Brat volcano.

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S3.T08. Deducing volatile content of the central Iceland mantle source from silicate melt inclusions of the 2014-2015 Holuhraun eruption

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The 2014-15 Holuhraun eruption of the Bárðarbunga volcanic system, central Iceland, lasted 6 months. It is the first moderate to large scale flood basalt (i.e. >1 km^3) eruption to have been observed, monitored and sampled in real time. We present volatile and trace element abundance data (obtained with EPMA and SIMS) from crystal-hosted silicate melt inclusions collected between 31 August 2014 and 22 January 2015 during the eruption.

We combined fractional crystallisation modelling and the ratios of magmatic volatiles to similarly incompatible trace elements (CO_2/Nb, H_2O/Ce, Cl/K, F/Nd and S/Dy) to estimate the undegassed primary volatile content of the Holuhraun parental melt(s). Based on our calculations, this parental melt contained 1500-1700 ppm CO_2, 0.07-0.2 wt% H_2O, 10-98 ppm Cl, 150-280 ppm F and ~800 ppm S.

The most primitive melt inclusions preserve the CO_2, Cl and S contents of the parental melt, but they do not preserve either the primary H_2O or F concentrations. In melt inclusions collected in the first 10 days of the eruption there are positive correlations between H_2O and K, and between F and Nd, but these correlations disappear for samples collected at later stages of the eruption. This suggests diffusive loss and/or gain of these volatiles in the melt inclusions, probably during the transport of the host minerals to the surface. On the basis of the diffusivity of H^+ in plagioclase and olivine, Hartley et al. (submitted) calculated a minimum of 0.02 to 25 days residence time for the host crystals in the magmatic conduit.

The estimated CO_2, H_2O and S contents, and the lower-end estimates for Cl and F, are consistent with 5-10% melting of a depleted MORB mantle (DMM) source (e.g., Salters and Stracke, 2004). However, higher-end estimates for Cl and F require the presence of a mantle source component which is somewhat enriched in these volatiles compared to DMM. Our estimates suggest that the central Iceland mantle source may contain between 58 and 171 ppm CO_2, 39-212 ppm H_2O, 0.3-10 ppm Cl, 9-31 ppm F and 120-170 ppm S.

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S3.T09. Polymineralic inclusions indicating a melting event in eclogite-facies rocks from a 2 Ga old subducted oceanic crust

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Partial melting events in metamorphic rocks can sometimes only be detected by the occurrence of polymineralic inclusions representing a crystallized melt. The polymineralic inclusions under investigation have been found in garnet porphyroblasts of eclogite-facies metapelites from the Usagaran Belt, Tanzania. Distinct from other occurrences of polymineralic inclusions which indicate partial melting of continental crust, the investigated inclusions in metapelites associated with eclogites represent an ancient subducted oceanic crust (Möller et al., 1995). For these rocks, peak metamorphic conditions of 1.8-2.0 GPa and 750-800 °C have been deduced by Möller et al. (1995). During uplift, the temperatures must have increased to at least 900 °C, judged from the bulk composition of large antiperthite crystals in leucosome veins. In the metapelite with the mineral assemblage garnet+kyanite+K-feldspar+quartz +biotite, the roughly euhedral polymineralic inclusions in garnet have variable assemblages but two main types can be distinguished: Type I Quartz+plagioclase+biotite ±kyanite ±carbonates. Type II Dolomite+quartz+kyanite. In Type I inclusions the volume percentage of carbonate is < 10%. In Type II inclusions carbonate is a main constituent and reaches about 30 vol%. To get an idea of the melt composition, preliminary piston cylinder experiments were aimed to re-homogenize the polymineralic inclusions. At a pressure of 1.5 GPa, temperatures have been varied from 750 to 900 °C. Backscatter images show that at 900 °C some of the Type I inclusions homogenized nearly completely with an associated bubble while others were partly molten and glass is found in between rounded quartz, plagioclase and biotite relics. EMS analyses of glass give a peraluminous, siliceous melt composition. The re-melting experiments confirm the silicate-rich inclusions as former melt inclusion. Type II inclusions, however, show numerous porosities but no indication of re-homogenization at 900 °C and 1.5 GPa. These inclusions may have been formed by reaction of a carbonaceous fluid or melt with the garnet host. Associated with the polymineralic inclusions in garnet are pure CO_2 fluid inclusions with Ca/Mg-carbonate daughter minerals enclosed in fluid inclusions (Herms, 2002). This points to the presence of Ca and Mg components in the original fluid.

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S3.T10. Study of mafic melt inclusions from Kerimasi Volcano (Tanzania)

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Numerous papers have dealt with melt inclusions of alkaline silicate-carbonatite rocks (Guzmics et al 2012, Nielsen et al 1997), however, to our best knowledge none of the studies observed melt inclusions (MI) containing parental melt of an alkaline-carbonatite system, though knowing that the initial melt composition is of essential to understand their petrogenesis. In our preliminary study we show clinopyroxene-hosted MIs from alkali-rich basalt collected from the eastern slopes of the Kerimasi volcano.

The studied basalt consists of clinopyroxene (green and brown), olivine, spinel phenocrysts and interstitial matrix. Clinopyroxene (Cpx) and spinel host primary MIs. Two types of MIs are in the Cpx. Type-A is a well-crystallized MI and hosted by the green Cpx, whereas Type-B is a glassy MI and hosted by the brown Cpx. The brown Cpx is strongly zoned and contains large number of MIs (>50 MIs present in a 250 μm^2 large area). Numerous apatite microcrysts, minor amount of sulfides and spinels occur along zones of the brown Cpx. Green Cpx is, hardly zoned, containing much lesser MIs than brown Cpx and never contains apatite inclusions. Spinel and sulfides rarely occur in the green Cpx rims. We have studied the unexposed MIs by HR Raman spectroscopy applying mapping technique in order to identify all daughter phases in the MIs at ambient temperature. MI-Type-A contains clinopyroxenes, Si-glass, calcite, spinel, apatite, rutile, mica, S-bearing phases and CO_2-rich liquid. MI-Type-B consists of Si-glass, clinopyroxene, spinel, sulfides, apatite and CO_2-rich liquid. During Linkam stage heating experiments, MI-Type-A homogenized between 1250 and 1270 °C, however, homogenization of MI-Type-B was observed between 1150 and 1160 °C. Most MIs (e.g. size > 20 microns) did not homogenize completely as melting of the host-clinopyroxene started at >1270 °C (green) and >1165 °C (brown). Spinel-hosted MI has very similar in composition to the MI-Type-B.

Our results suggest that MI-Type-A represents a carbonated mafic melt, which composition may be close to the parental melt of the Kerimasi volcanic system. In contrast, MI-Type-B likely represents a mafic melt that came through strong decompression and decarbonation (e.g. CO_2-relase by melt represented by MI-Type-A), leading to the invasion-like precipitation of apatite.

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S3.T11. Fluid and melt inclusion record of volatile and intercumulus melt evolution in a barren gabbro, Caribou Lake, Northwest Territories, Canada

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Mafic pegmatites in the Caribou Lake Gabbro (CLG), Slave Province, NT, Canada, consist of irregular pods and patches composed of coarse-grained clinopyroxene, plagioclase, apatite, Fe-Ti oxides, with minor orthopyroxene, biotite, and sub-economic Ni-Cu-sulphides. Fluorine-rich apatite (X_F = 0.73-1.0) hosts primary and secondary fluid inclusions that trapped polyphase aqueous brine (9-28 wt% NaCl equiv.) and carbonic liquids (CO_2-CH_4). While some inclusion types preserve both fluids that were immiscibly trapped (coeval), other inclusion types show only carbonic-dominant or brine-dominant compositions with no heterogeneous entrapment. Cumulus apatite occurs in a fine- to medium-grained gabbro and hosts primary silicate melt inclusions.

Major element analyses of melt inclusions show gabbroic to syeno-dioritic compositions. However, trace element analyses indicate that while base metals (Ni, Cu, Co) are slightly depleted (by ½ order of magnitude) compared to MORB, HFSE are highly enriched compared to MORB (by 1 order of magnitude). Possible explanations for the low base metals and high HFSE are: i) a low degree of partial melting of source region; ii) crustal contamination (for high HFSE only) ; and/or iii) the early saturation of a sulphide liquid (for low base metals only). The HFSE, W and Cs were also detected in immiscible brine-carbonic fluid inclusion assemblages, possibly sequestered from late stage intercumulus melt during fluid-melt interaction.

Estimated entrapment conditions for primary melt and fluid inclusions are ~910°-1200 °C and ~3.2-4.5 kbar, indicating the emplacement depth was between 5.9-16.6 km. In contrast, secondary fluids are estimated to be entrapped at ~455°-1200 °C and ~1.5-4.1 kbar (5.6-15 km depth), indicating a protracted fluid evolution history. The high temperature of entrapment for fluid inclusions suggests that volatile activity is magmatic in origin and not related to a later hydrothermal event. Similar brine-carbonic fluid inclusions, including those recording brine-carbonic fluid immiscibility, have been documented in mafic-ultramafic intrusions hosting world-class Ni-Cu-PGE deposits (Ballhaus and Stumpft, 1986; Hanley et al., 2008) where they occur in evolved pegmatitic phases. However, since the CLG is sub-economic, the presence of these fluid types in layered mafic-ultramafic systems are not necessarily related to mineralization potential. On the other hand, the PGE may be remobilized from primary magmatic sulphides by such fluids.

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S3.T12. High temperature fluids and melts in the Grasberg porphyry Cu-Au deposit

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The Grasberg Cu-Au deposit is located in the Ertsberg-Grasberg district in Papua Indonesia. Grasberg is a pipelike body approximately 950 m in diameter, and more than 1000m vertically. A quartz-magnetite-anhydrite with Au-bearing, chalcopyrite + bornite stockwork vein system, is centred on the axis of the Main Grasberg Intrusion. These veins account for the bulk of the copper and gold in the Grasberg deposit.

This study focused on quartz-hosted hypersaline fluid inclusions from deep in the Grasberg System that partially homogenize by vapor disappearance at temperatures (up to 1300 °C), well above reasonable arc temperatures. The hypersaline inclusions contain 20 - 40 vol.% vapour, halite, sylvite, anhydrite, an unidentified salt, hematite, sulfides and silicates.

Upon heating the hypersaline inclusions, sylvite is the first crystal to dissolve between 147 °C and 292 °C. As heating progresses the halite crystal dissolves between 538 °C and 605 °C. Anhydrite dissolves next at temperatures between 600 °C and 648 °C. Hematite is the last solid to dissolve by 990 °C, leaving a bubble, salt melt and a small rim of silicate melt. At this point (1400 °C; the heating stage limit) only two immiscible liquids remain.

We propose that these inclusions form by heterogeneous entrapment of silicate and salt melts. This is supported by the formation of two immiscible fluids, a hypersaline brine, and a clear fluid (silicate liquid?) above 900 °C. Homogenisation temperatures may be increased due to post-entrapment modification. A significant number of inclusions were trapped at pressures below 400 bars, within the vapour + halite field. Under these conditions salt melt had formed as evidenced by the coexistence of water-absent, salt melt inclusions and vapor-rich inclusions containing small amounts of salt melt. A comparison with the more complex $NaCl-KCl-FeCl_2$ system shows that salt melts exist down to temperatures as low as 309 °C. LA-ICPMS analyses show these salt melts to have high metal contents.

Similar inclusions have been reported from the Cerro de Pasco district, Peru (Rottier et al., 2016), the Metaliferi Mountains, Romania (Pintea, 2013), the Zaldivar Deposit, Chile (Campos et al., 2006), and the Duobuza porphyry, Northern Tibet (Li et al., 2011). The role of these melts remains obscure but may be crucial to the formation of porphyry type deposits.

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S3.T13. The magmatic-hydrothermal transition at the Torres del Paine igneous complex, Chile - documented by silicate melt and aqueous fluid inclusions in miarolitic quartz

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The study of coexisting inclusions of multiple fluid phases (aqueous liquid, vapour, salt, and silicate melt) allows for direct quantification of the partitioning behaviour of elements between residual water-saturated melt and aqueous fluid at the magmatic-hydrothermal transition. This stage is decisive for the mass transfer of elements between geological reservoirs and is central to ore deposit forming processes.

The Torres del Paine bimodal igneous complex intruded as laccoliths at a depth of 2-3 km (~0.75 kbar) between 12.43 and 12.59 Ma (Leuthold et al., 2013). It is characterised by numerous fluid exsolution features exposed in the field, including miarolitic cavities, frothy zones, and pegmatoid features, which record magmatic-hydrothermal processes from 750 °C down to <300 °C as revealed by local occurrence of zeolite minerals. The complex is thus a perfect natural laboratory to investigate processes in very shallow subvolcanic magma reservoirs that may ultimately trigger porphyry-type ore deposit formation (e.g. Audétat et al., 2008).

SEM-VPSE images visualise distinct growth phases of miarolitic quartz, (a) magmatic quartz associated with feldspar in graphic texture domains, (b) high temperature magmatic-hydrothermal quartz characterised by irregular, patchy patterns, (c) rhythmically zoned hydrothermal growth, and a dark, terminal overgrowth. Seven inclusion types can be distinguished based on phase composition at room temperature. These include dominantly aqueous fluid inclusions ranging from vapour-rich inclusions (Type I) over 2-phase vapour-liquid (Type II) to simple and complex brines (Type IV+V), as well as CO_2-bearing 3-phase-fluid inclusions (Type III), crystallised silicate melt inclusions (Type VI) and rare inclusions, which supposedly contain a complex hydrous salt phase (Type VII). Combination of quartz growth textures, inclusion petrography, and microthermometry represent the sound framework into which LA-ICP-MS inclusion data measured on inclusion assemblages will be placed to constrain the element partitioning behaviour between fluid phases and its evolution with progressive cooling of the laccoliths at Torres del Paine.

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S3.T14. The magmatic-hydrothermal evolution of the ore-forming fluids of the Zinnwald Sn-W-Li deposit, Germany

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The Zinnwald granite in the Erzgebirge (Germany/Czech Republic) is a highly evolved Li-F granite of Variscan age, hosting a Sn-W-Li deposit in its roof zone. The mineralization is associated with large greisen bodies and sub-horizontal veins, containing economical contents of cassiterite, wolframite and zinnwaldite (Dolejs and Stemprok, 2001; Monecke et al., 2007). To quantify the hydrological and chemical evolution of the ore-forming hydrothermal system, we analysed fluid inclusions from samples of the German part of the Zinnwald deposit (mainly quartz veins) by microthermometry and LA-ICP-MS of fluid inclusion assemblages (FIAs) associated with the precipitation of the tin and tungsten ore.

The most common primary fluid inclusions in the quartz veins show homogenization temperatures between 360 °C and 380 °C and high variability in salinity (1 - 8 wt% NaCl eq.). This inclusion type can be found throughout the entire deposit (in veins as well as in greisen) and can in places be petrographically related to ore deposition. Microthermometric measurements using near infrared (IR) light microscopy of FIAs hosted in cassiterite and wolframite reveal similar temperature ranges of T_h but higher salinities of about 12 wt% NaCl eq. Furthermore, a few samples contain boiling assemblages of brine (up to 35 wt% NaCl eq.) and vapor-rich inclusions. Brine-bearing aqueous inclusions homogenize at temperatures between 300 °C and 340 °C. In contrast, some euhedral quartz crystals contain boiling assemblages showing higher temperatures of about 470 °C and higher salinities of ca. 40 - 45 wt% NaCl eq., similar to those described by Heinrich et al. (1999).

On-going LA-ICP-MS measurements of FIAs in quartz and ore minerals provide further information about the chemistry of the different fluid types and can help to quantify the nature and composition of the ore-forming fluid. The presentation will show first results from this fluid inclusion study and discuss the hydrothermal ore-forming processes of the Zinnwald deposit.

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S3.T15. Origin and evolution of ore-forming fluids in the Maoping and Piaotang W-Sn deposits (Jiangxi, China)

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The implication of magmatic vs non-magmatic fluids in the ore-forming process in vein-type W-Sn deposits is still controversial. The Jiangxi province (South China) is currently the world's leading tungsten producer and hosts several major deposits, including Maoping and Piaotang. Wolframite ($(Fe, Mn)WO_4$) and cassiterite (SnO_2) in the deposits occur in quartz veins associated with composite Early Yanshanian granitic intrusions.

This study focuses on acquiring fluid inclusion microthermometric, Raman spectroscopy and stable isotopes data in both transparent gangue and opaque ore minerals from the successive paragenetic stages at Maoping and Piaotang deposits (Legros et al., 2016).

The fluid inclusion study has been performed in quartz, cassiterite, wolframite, topaz and fluorite in both deposits to unravel multi-stage magmatic-hydrothermal processes associated with mineralization and subsequent events. Fluid inclusions in both deposits have similar characteristics and occur as pseudo-secondary trails of two-phase aqueous-volatile inclusions in the $NaCl\text{-}H_2O$ system. No phase transitions related to presence of CO_2, CH_4 or N_2 have been observed even if small amounts were revealed by Raman spectroscopy. Homogenization of the volatile phases to liquid (Th) occurs between 136 and 349 °C, while ice melting temperatures (Tm_{ice}) range between –14.2 and 0.0 °C, implying salinities ranging from 0 to 12.6 wt.% NaCl equiv. Oxygen and hydrogen isotopic compositions of the fluids range between –3.6 and 9.1 ‰ and from –76.5 to –55.2 ‰ respectively. A model of fluid-rock interaction and mixing of external and magmatic fluids is proposed for the main mineralization stages in the two deposits where processes involved in the deposition of gangue and economic minerals appear to be separated.

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Legros H. et al. (2016) Lithos 264, 108-124.

S3.T16. Are we sure to know the fluids responsible for W mineralization at Panasqueira (Portugal): the case for loss of information due to intense quartz recrystallization and FI natural decrepitation

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The Panasqueira W-Cu-Sn deposit, one of the main W repository in West Variscan Europe, has been for long the subject of many FI studies, intended to reconstruct P-T-X evolution and reveal ore depositing conditions (Kelly and Rye, 1979; Bussink, 1984; Noronha et al., 1992; Polya et al., 2000; Lourenço, 2002). These studies were done on transparent minerals. IR-study of wolframite-hosted FI (Lüders, 1996) has shown however that FI trapped in wolframite differs from those found in surrounding quartz. The deposit history is long and complicated, with nearly systematic superimposition of later on stages onto the earlier. As a consequence, quartz dissolution-recrystallization is found to be the rule, as is the consecutive disappearance of first-formed inclusions, the phenomenon being so pervasive as to destroy all traces of the earliest hydrothermal event. It appears in addition that all preserved FI from the earliest mineralizing stages (main wolframite stage) were decrepitated sometimes in the deposit history. Indeed, all previous works on Panasqueira FI exclusively concerned such late FI, but meaning that the earliest conditions of ore deposition remain unknown at present.

Towards the end of the deposit history, a wolframite-cassiterite-arsenopyrite-Li-Fe-muscovite stage is widespread and characterized by the pervasive development of a Li-Fe-muscovite at the expense of dissolved quartz, as spectacular selvages or vugs. Most of the observable (not decrepited) FI (Lw-c) are from this stage. Most frequent are two-phase volatile-bearing (H_2O-CO_2>>CH_4>N_2) FI homogenizing in the liquid (water) state at temperatures close to 300 °C, and similar to those described in the cited literature. Unrecognized until now are pure volatile liquid FI (CH_4>N_2>>CO_2) homogenizing at –85 °C, which appear coeval to the Lw-c FI. Thus, intersecting the isochores of the two families allow (for the first time) a robust estimation of the trapping conditions for the late cassiterite stage: 400±50 °C, 140±20 MPa (considered lithostatic, i.e., c. 5.3±0.1 km depth). This would mean a very high geothermal gradient (c. 75±10 $°C.km^{-1}$), likely related to heat advection by a concealed granite. Combined with the exhumation under extensional conditions of the Late Carboniferous, it may be speculated that this thermal event was responsible for the generalized decrepitation of all the former FI.

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S3.T17. Ore-forming fluids in the giant Dexing porphyry Cu-Mo-Au deposit, Southeastern China

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Dexing porphyry Cu-Mo-Au deposit, one of the largest Cu deposits in China, is located adjacent to the Neoproterozoic suture of South China Block. It has similar characteristics in terms of hydrothermal veins and alteration types to those of typical porphyry Cu deposits but fluid compositions and properties are distinct. Through petrographic observation on the mineralized veins and phenocryst quartz, five types of fluid inclusions were recognized, i.e. multi-phase high salinity inclusions (A type) which was subdivided into A_1 (containing only halite as daughter mineral) and A_2 (containing halite and opaque daughter minerals) subtypes, vapor-rich inclusions (B type), CO_2-bearing inclusions (C type), LV inclusions with vapor to liquid ratio of ~20% (D type) and LV inclusions with vapor to liquid ratio less than 10% (E type). The earliest barren quartz veins with potassic halos contain primary A1 and C type inclusions; primary fluid inclusions in the Q+Py+Mo±Cp veins consist of C type inclusions in coexistence with minor A1 type inclusions; primary inclusions in the Q+Py+Cp±Cc veins with sericitic selvages are A_2 and B type inclusions; fluid inclusions in phenocryst quartz are secondary, and consist of D, A_2, B and E type inclusions. Laser Raman spectroscopic investigation revealed that daughter minerals within the A type inclusions include anhydrite, siderite and magnetite; vapor in B type inclusions contains CO_2. Microthermometry revealed that A type inclusions were predominantly homogenized by halite dissolution. These inclusions exhibit variations in both halite melting temperatures (Tm, halite) and liquid to vapor homogenization temperatures (ThL-V). They are interpreted to originate from heterogeneous trapping of halite-saturated solutions, and subjected to post-entrapment stretching. Pressure calculations suggest A and C type inclusions formed at great pressures of >150 MPa, which resulted in the retention of more CO_2 in the exsolved fluids than those of shallow porphyry Cu systems. Compositions of hydrothermal fluids were possibly in the "L+V+H" field of the H_2O-NaCl-CO_2 ternary system, thus leading to immiscibility to produce halite-saturated solution, halite crystals and CO_2-bearing vapor. The barren quartz veins and potassic alteration represented by A1 subtype and C type inclusions formed at a temperature range of 450 to 500 °C and pressure of ~265 to 300 MPa. Later, a decrease in temperature to 300 - 400 °C and pressure to ~220 MPa resulted in the precipitation of molybdenite. Subsequently, a decrease in temperature (to ~200 - 250 °C) and pressure (to ~150 MPa) occurred during chalcopyrite precipitation and pervasive sericitic alteration. Pyrite-dominated veins and barren carbonate quartz veins formed in response to influx of meteoric waters, and were the last stage hydrothermal activities at Dexing.

S3.T18. Keynote - Fluid inclusions from active and fossil hydrothermal system in Chile

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Our understanding of the physical and chemical processes associated with formation of both active terrestrial hydrothermal systems and their fossil equivalents has advanced significantly through a combination of studies of well-characterized deposits. Chile host numerous geothermal, epithermal precious and base metal, polymetallic, and porphyry cooper deposits. Here we describe the fluids and fluid inclusions from the north to the south of Chile. The geothermal systems the Cerro Pabellón, Irruputuncu and Olca located between Calama and Iquique (Northern part of Chile) at more than 4,000 meters above sea level. Thin sections from samples of these geothermal systems were examined using a petrographic microscope, and fluid inclusion and mineralogical evidence for boiling of the hydrothermal fluids was recorded. Located in the same area the Collahuasi mining district host the Rosario porphyry copper-molybdenum deposit. Preliminary results shows evidence of fluid inclusions assemblages (FIAs) in quartz and were classified at room temperature: (1) Halite-bearing inclusions indicating high salinity fluids; (2) Chalcopyrite daughter mineral; (3) Liquid-rich aqueous inclusions with trapped solid; (4) Coexisting halite bearing and vapor-rich inclusions with a broad range in liquid-to-vapor ratios indicating fluid-phase separation; (5) Coexisting liquid-rich and vapor-rich inclusions with a broad range in liquid-to-vapor ratios indicating fluid-phase separation; (6) Vapor-rich inclusions indicating flashing of the fluid. The Río-Blanco-Los Bronces porphyry Cu(-Mo) deposit is part of the Central Chilean Mio-Pliocene Metalogenic Belt and the third largest Cu deposit in the world. The petrographic shows (1) Secondary vapour-rich inclusions with solids and (2) Secondary FIAs of coexisting halite bearing and vapour rich fluid inclusions and solids. Situated within the Coastal Range of Central Chile the epithermal precious metal deposit Chancón shows evidence of (1) coexisting liquid-rich and vapor-rich inclusions with a broad range in liquid-to-vapor ratios indicating fluid-phase separation; (2) Vapor-rich inclusions indicating flashing of the fluid. The polymetallic Alhué mining district shows increments in Ag-Cu related to hypersaline fluids (~ 33 wt.% NaCl) in the Lorena vein. The Maqui vein shows Ag-Ba-Cu-Mn-Fe related to low salinity fluids (~ 5% wt. % NaCl). The Tribuna Este shows Ag-Al-Fe-Cd related to intermediate salinities (~18 wt. % NaCl). Finally, The Chilean Patagonia hosts numerous polymetallic and epithermal environment resources, among these the Cerro Bayo District in the Aysén Region. A detailed fluid inclusion petrography, gangue mineral textural characterization and mineralization paragenesis study was conducted on the ore bearing Fabiola and Dagny vein. Areas of most intense boiling are associated with colloform and bladed calcite textures. These observations were incorporated into a geographical information platform to define potential geospatial correlations between the fluid inclusion characteristics, the gangue mineral textures and ore grades.

S3.T19. Fluid inclusion study of fluorites from the Mushugai-Khuduk carbonatite complex (Southern Mongolia)

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Alkaline carbonatite volcano-plutonic complex Mushugai-Khuduk is located in Southern Mongolia (Gobi desert), and it is a part of the Late Mesozoic Central Asian carbonatite province. The complex contains magnetite-apatite-REE mineralization. Melt inclusion study shows that the rocks of the complex were formed due to the crystallization differentiation as well as the silicate, silicate-phosphate and silicate-salt liquid immiscibility processes, and the salt magma was characterized by the high P, Cl, F and S contents (Andreeva, 2007). In this abstract, we present the first fluid inclusion TX-data obtained using microthermometry, SEM and Raman spectroscopy methods.

Fluorite from calcite carbonatites forms cubic crystals and idiomorphic grains (0.5-1.5 mm) of dark blue tint, which are situated in the calcite matrix. Primary crystal-fluid inclusions (7-12 μm) are located along the crystal growth zones, contain NaCl (cubic crystal), solution, CO_2 (L) fluid phase (5-10 vol.%) and usually 1-3 small anisotropic daughter-phases (1-5 vol.%): celestite, ankerite, thenardite and bastnäsite (REE-fluorcarbonate). The fluids have the high homogenization temperatures 500-530 °C, and high salinity of 20-40 wt.% NaCleq. Secondary gas-liquid fluid inclusions are traced as healed cracks in the fluorite crystals and contain CO_2-H_2O fluid phase, which fills 12-20 vol.% of the inclusions. Homogenization temperature is 250-270 °C, and salinity dropped to 6.5-7.1 wt.% NaCleq. Fluorite grains (blue and violet color, 0.5-2 mm) from hydrothermal veinlets include rare primary crystal-fluid inclusions (5-15 μm), containing CO_2 (G) fluid phase (10-15 vol. %), solution, cubic crystal NaCl and 1-2 small mineral phases (~1-2 vol.%) of calcite, siderite, phosphosiderite, and magnetite. Primary inclusions were homogenized at 360-420 °C, and have salinity of 10-20 wt. % NaCl-equ. Healed cracks and planes in fluorite are traced by numerous of secondary gas-liquid fluid inclusions. The fluids were homogenized at the 295-320 °C, have a salinity of 13-16 wt.% of NaCl-equ. The fluid phase contains CO_2 (G).

Fluid inclusion study point to the oxidized state of the hydrothermal fluids, and has revealed the changes of the ore-forming fluid solution from chloride-carbonate-sulphate to carbonate ferrous (Fe3+)-chloride composition during the evolution from orthomagmatic (550-530 °C, 30-20 wt.% NaCleq.) to hydrothermal (270-250 °C, 7.1-6.5 wt.% NaCleq.) stages.

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S3.T20. Raman-investigation on fluid inclusions in quartz of Sr-Ba carbonatites of the Murun complex, Eastern Siberia, Russian Federation

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Mesozoic Sr-Ba carbonatites from the Murun alkaline massif (Irkutsk district, Russia) are related to the unique in the world charoite deposit. These carbonatites form intrusive bodies are situated inside of multistage magmatic alkaline complexes (Prokofev and Vorobiov, 1991). The endogen carbonate rocks (carbonate component counts at least 50%) contain Na-pyroxene (aegirine-augite), feldspar, amphibole, phlogopite, forsterite, apatite, magnetite and occasionally, in contact zones, quartz.

The quartz contains two types of primary fluid inclusions: 1) multiphase inclusions with carbonate water-saturated melt presented by multiple anisotropic solid phases, vapor bubble and interstitial aqueous solution; and 2) single-phase gas inclusions. Homogenization temperature of multiphase inclusions is 650-610 °C. Gaseous inclusions consist of dense nitrogen and homogenize into liquid phase at temperatures from –164.5 to –149.5 °C that corresponds to nitrogen density 0.64-0.48 g/cm^3. At 650-610 °C the pressure of nitrogen inside these gaseous inclusions arrives up to 5.5-2.4 kbar.

Composition of the multiphase fluid inclusions was studied by FIB-SEM and confocal Raman spectroscopy methods in Lithosphere Fluid Research (Budapest, Hungary) and GeoRessources (Nancy, France) Laboratories, correspondingly.

Among solid phases we identified nahcolite, barite (with some Sr amounts), siderite, anhydrite, pyrite and sphalerite. Moreover, two rare phases containing Fe-S and K-Al-(S) were detected. The one of them was identified as ferrotychite, $Na_6Fe^{(II)}_2 (SO_4) (CO_3)_4$. The other K-Al-(S) phase was not identified. The composition of the gas bubble inside multiphase inclusions (in mol%) is N_2 (98-92), CH_4 (1-7), and CO_2 (~0.5).

Using high-resolution Raman spectroscopy we identified also calcite and traces of graphite, ions SO_4^{2-}, H_2S, HS^- and $NH^3{*}H_2O^0_{(aq)}$ in the aqueous phase.

Our results confirm the nonordinary chemical composition of these rocks and provide new insights into volatile composition of carbonatite melts containing high concentrations of nitrogen and sulfur in various states.

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S3.T21. Hydrothermal epidosites in the oceanic crust: products of alteration by seawater or magmatic brines?

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Hydrothermal seafloor alteration is best preserved in obducted oceanic lithosphere. Among the alteration types in the basaltic crustal section of ophiolites are rocks which have been completely altered to epidote + quartz ± titanite ± Fe-oxides, so-called epidosites. These rocks have been interpreted to form within the base of hydrothermal discharge zones that ultimately feed black-smoker seafloor vents (Richardson et al., 1987). Cowan and Cann (1988) and Juteau et al. (2000) observed boiling assemblages of high-salinity liquid + low-salinity vapor inclusions in epidotised trondhjemites in the Troodos and Oman ophiolites, respectively, and concluded that these brines transformed the adjacent sheeted dikes into massive epidosites.

We have sampled non-epidotized trondhjemites and massive epidosites in pillow lavas in the Semail ophiolite of Oman, as described by Gilgen et al. (2016). Igneous quartz in the trondhjemites contains the same brine + vapor assemblages as described by Juteau et al. (2000). In contrast, epidote in the massive epidosites hosts primary, homogeneously trapped L-V inclusions. Their final ice melting temperatures (T_m(Ice)) range from –2.7 to –1.6 °C, implying salinities from 2.7 to 4.6 wt.% $NaCl_{eq}$.. Homogenization (L-V into L) occurs from 300 to 315 °C and constitutes a minimum trapping temperature. Coeval quartz crystals host pseudosecondary, homogeneously trapped fluid inclusion assemblages with T_m(Ice) from –1.8 to –1.5 °C (corresponding to 2.6 to 3.1 wt.% $NaCl_{eq}$.) and T_h into the liquid phase from 275 to 290 °C.

In contrast to previous models, our results show that massive epidosites in oceanic crust are caused by a homogeneous liquid with chlorinity similar to that of seawater. We conclude that the brine + vapor phases exsolved by the trondhjemites, play no role in formation of the massive epidosites. Accordingly, low-salinity fluids, rather than brines, should be the basis of any genetic model that includes epidosites in the hydrothermal circulation path leading to seafloor vents and VMS deposits.

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S3.T22. Upgrading of an orogenic gold-quartz-carbonate vein system by magmatic-hydrothermal fluids in the Hope Bay Greenstone Belt, Nunavut, Canada

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Evidence of secondary gold grade enhancement in an orogenic quartz-carbonate vein system by later stage magmatic-hydrothermal fluids is demonstrated in the Madrid deposit hosted in the Hope Bay Greenstone Belt in Nunavut, Canada. In-situ microanalytical approaches (SEM, Raman spectroscopy, microthermometry, LA-ICPMS, SIMS) were used to characterize the mineralogy and fluid inclusion systematics associated with the upgrading event, a feature suggested but rarely characterized in orogenic gold systems. High-grade (upgraded; ~62 gpt Au avg.) laminated to brecciated orogenic quartz veins contain electrum but also a texturally-later Ag-Te-sulfosalt-electrum-quartz±sericite assemblage in which quartz is texturally distinct from orogenic quartz. This mineral assemblage is absent in low-grade veins (~1 gpt Au avg.) that contain only electrum. Quartz-hosted fluid inclusions (H_2O-NaCl±CO_2) of intermediate salinity (16.7±1.2 wt.% NaCl equiv., n=93) were identified only in high-grade veins and are present along healed planes associated with sulfosalt-electrum-quartz assemblages. In-situ SIMS O-isotope analyses, combined with T constraints from mineral equilibria and fluid inclusion data, show late quartz subdomains and orogenic vein quartz precipitated from fluids with $\delta^{18}O$ of 2.4-7.3 ‰ and 4.4-9.6 ‰, respectively. This suggests that meteoric fluids had a negligible influence on fluid compositions responsible for gold precipitation. Microthermometry and Raman spectroscopy show that overprinting fluids are distinct in composition from the metamorphic/orogenic fluids (H_2O-NaCl-CO_2±CH_4±N_2; 4.6±1.6 wt.% NaCl equiv., n=33) and Canadian Shield basement brines (H_2O-NaCl; 22.4±1.2 wt.% NaCl equiv., n=12) also identified in the fluid inclusion record at Hope Bay. LA ICP-MS analyses indicate fluids associated with gold upgrading were more enriched in As-Sb-Zn-Pb-Cs-Ba-Sr-Rb than late basement brines, with elevated Cs-Ba-Rb consistent with fluids exsolved from felsic magmatic systems. Trace element mapping of pyrite and associated principle component analysis confirms a strong correlation between Au and Ag-Te-Sb-Bi-W(-As) in upgraded areas, whereas only Au and As strongly correlate in low-grade veins. Gold upgrading (new gold or remobilization) by late magmatic-hydrothermal fluids is suggested by the accessory mineral, fluid inclusion and pyrite chemistry data consistent with intrusion-related (Hart and Goldfarb, 2005), porphyry (Pudack et al., 2009), or intermediate sulfidation epithermal settings (Pudack et al., 2009). This work provides insights into a possibly unrecognized but perhaps common process of gold enrichment in orogenic ore systems.

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S4.T01. Keynote - Deciphering fluid inclusions in high-grade rocks

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The study of fluid inclusions in metamorphic rocks is especially challenging as the host minerals have been normally subjected to deformation, recrystallization and fluid-rock interaction so that primary inclusions, formed at the peak of metamorphism are rare. The larger part of the fluid inclusions found in metamorphic minerals is typically modified during uplift. These late processes may strongly disguise the characteristics of the “original” peak metamorphic fluid. A detailed microstructural analysis of the host minerals, notably quartz, is therefore indispensable for a proper interpretation of fluid inclusions. The first studies of fluid inclusions in metamorphic rocks already demonstrated large variations in fluid inclusion densities on the micron scale (e.g. Touret, 1971). Fluid inclusion mapping by distinguishing different fluid densities is a useful approach in order to identify inclusions with the highest density and to locate their position among re-equilibrated inclusions of lower density. Sometimes, the highest-density inclusions occur in the same cluster together with low-density inclusions. This type of high-density inclusion cannot be easily recognized as they do not show primary characteristics, but occur as unremarkable relic inclusions among decrepitated ones (Harlov et al., 2014). For more than two decades, cathodoluminescence (CL) techniques combined with trace element analysis of quartz (EPMA, LA-ICPMS) applied to fluid inclusion plates or their counterparts have been applied in deciphering the rock-fluid evolution (e.g. van den Kerkhof and Hein, 2001). The main trace elements in metamorphic quartz are Al, Ti, K, and Fe. The interaction with fluids may result in the local redistribution of trace elements or the development of secondary quartz with a different trace element content compared to the precursor quartz. These changes produce variations of the CL wavelengths and intensities, which can be visualized in images. Whereas high-grade metamorphic quartz may have relatively high contents of trace elements like Ti and Al, low temperature re-equilibrated quartz typically shows reduced trace element concentrations. The resulting microstructures in CL can be basically distinguished in diffusion patterns (along microfractures and grain boundaries), and secondary quartz formed by dissolution-reprecipitation. Most of these textures are formed during retrograde fluid-controlled processes between ca. 220 and 500 °C, i.e. the range of semi-brittle deformation (greenschist-facies) and can be correlated with the fluid inclusions. In this way modified and re-trapped fluids can be identified, even when there are no optical features observed under the microscope.

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S4.T02. Pargasite in fluid inclusions of mantle xenoliths from northeast Australia (Mt. Quincan): sign of interaction of asthenospheric fluid

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Mantle-derived xenoliths hosted by Cenozoic basaltic rocks are widespread in eastern part of Australia. Among the xenoliths-bearing localities, Mt Quincan, which belongs to the 3 Ma Atherton Tablelands Volcanic Province (ATVP), is extensively studied. Previous geochemical studies indicate that sampled mantle is a depleted MORB source as the Nd, Sr and Os isotope systematics broadly overlap with MORB source mantle (Handler et al., 2005) and noble gas composition of the released fluid inclusions are MORB-like (Czuppon et al., 2009).

In this study we have carried out detailed investigations on the fluid inclusions of these xenoliths to reveal further charactersitics of asthenospheric fluid. Extreme high density ($\rho \geq 1$ g/cm^3) CO_2-N2-H_2O fluids are present in the orthopyroxene porphyroclasts along with clinopyroxene and spinel exsolution lamellae. Although these lherzolites were previously described of being free from any volatile-bearing minerals, pargasitic amphibole associated with clinopyroxene lamellae was found together with the studied fluid inclusions. In addition, synchrotron FTIR imaging revealed the presence of pargasite within the fluid inclusions pointing out that pargasite formation could be the result of an interaction between clinopyroxene and fluid from the asthenophere.

Major and trace elements of the constituent minerals as well as exsolution lamellae suggest that metasomatic imprint, followed by the ancient melt extraction, resulted in the enrichment of LREE and LILE in clinopyroxenes. The same elements were found to be related to fluid inclusions by LA-ICPMS and the extent of the metasomatism on the clinopyroxene is in positive correlation with the amount of fluid inclusions in the xenolith. Our results support the idea that fluids from the asthenosphere are capable to overprint pre-existing mantle signature of the xenoliths including the mineral association.

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S4.T03. Fluid inclusions in mantle xenoliths from the Styrian Basin (W-Pannonian Basin) as remnants of metasomatism

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Plio-Pleistocene alkali basaltic volcanism brought mantle-derived xenoliths to the surface at five distinct volcanic fields within the Carpathian-Pannonian Region (CPR, e.g. Szabó et al., 2004). The Styrian Basin Volcanic Field (SBVF, Eastern Austria and Northern Slovenia) is the westernmost one, situated at the transition zone between the Eastern Alps and the Pannonian Basin, above the suspected already detached Penninic-slab (e.g. Qorbani et al., 2015). Amphibole-rich peridotite from Gnas (SBVF) enclose fluid inclusions, both hosted by orthopyroxene and amphibole, abundantly. In addition to the presence of amphibole, modal metasomatism is evidenced by the presence of phlogopite and apatite.

Fluid inclusions are found in two petrographic positions in the studied rocks: (1) hosted in the rim of amphibole lamellae rich orthopyroxenes and (2) in the amphiboles. In this study we present detailed observations on petrography and measurements by microthermometry, Raman microspectroscopy and focused ion beam (FIB) scanning electron microscopy (SEM) on both types of fluid inclusions. Inclusions in both amphibole and orthopyroxene contain one (liquid) or two visible phases (liquid + solid) at room temperature, and show high CO_2 density (0.77 - 1.02 g/cm^3). Besides, the inclusions contain detectable amount of H_2O (<1.3 mol%) and N_2 (<0.3 mol%) in the liquid phase. Raman mapping and FIB-SEM revealed the presence and distribution of different solid phases within the inclusion cavity of orthopyroxene-hosted fluid inclusions such as magnesite, quartz, glass, Fe-Ni sulphide and anhydrite. On the other hand, in amphibole-hosted fluid inclusions a more complex mineral assemblage was identified, consisting of alkali-hydrocarbonates (e.g. nahcolite) and various sulfate minerals (e.g. Na-bearing thenardite), and are all interpreted as post-entrapment precipitates of an alkaline and volatile-rich fluid. The fluid system found in amphibole-hosted fluid inclusions may represent a residual fluid-rich phase, from which the hydrous metasomatic assemblage (amphibole, phlogopite, apatite) might have formed in the shallow lithospheric mantle.

Our study agrees with previous studies (e.g. Berkesi et al., 2012; Frezzotti et al., 2012), that upper mantle fluids are mainly dominated by CO_2. This fluid phase can be also enriched in significant amount of Na, H, N and S. In the Styrian Basin various examples of subduction-related volcanism and upper mantle metasomatism suggest that the lithospheric mantle of the region may have been in a mantle-wedge position, where fluids may have been released from the subducted slab.

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S4.T04. Vein-type graphite deposits in Sri Lanka: the ultimate fate of granulite fluids

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The world-best vein graphite deposits in Sri-Lanka occur scattered through the high-grade terrain of the Wanni and Highland Complexes of Sri-Lanka. The Wanni Complex (amphibolite to granulite grade) consists of ~770-1100 Ma metagranitoids, metagabbro, charnockite, enderbitic gneisses, migmatites, clastic metasediments, including garnet-cordierite gneisses, rare to minor calc-silicate rocks as well as late to post-tectonic granites (Kröner et al., 2013). Higher metamorphic grade, reaching in places UHT-conditions (T>1000 °C) characterizes the Highland Complex. Peak metamorphism occurred during the Neoproterozoic Pan-African orogeny (~620-535 Ma), which led to the accretion of terrains in Sri Lanka and played a key role for the amalgamation of the Gondwana supercontinent (Tsunogae and Santosh, 2010). Structurally disposed in extensional fractures post-dating the Pan-African ductile structures (Kehelpannala, 1999), the graphite veins equilibrated at relatively low temperature (500-600 °C). However, the presence of mesoperthites indicate that graphite precipitation may have started at higher temperature.

Samples from khondalite host rocks and quartz co-precipitated with graphite from the Bogala and Kahatagana graphite mines in the Wanni Complex were studied. Host-rocks show spectacular decompression reaction aureoles around feldspars and garnet. They contain small CO_2 inclusions in garnet cores or quartz in decompression reaction aureoles. Larger, highly transposed brine inclusions are more abundant and are responsible for metasomatic features (feldspar leaching and deposition) observed in the aureoles. Fluid inclusions in vein minerals are dominantly aqueous, rarely mixed $H_2O + CO_2$. Fluid inclusions and petrographic data suggest that graphite has been deposited from fluids at decreasing pressure and temperature at relatively reduced redox conditions. Carbon isotope data indicate a dominant mantle source, mixed with small quantities of light C-bearing fluids. It has been proposed that large quantities of mantle-derived CO_2 fluid have infiltrated the lower crust during the final stage of Gondwana supercontinent amalgamation (Touret et al., 2016). Formed during strong decompression at the end of a long (up to a few 10 Ma) period of isobaric cooling, the graphite veins in Sri-Lanka (and elsewhere in the former Gondwana) reflects the escape of these granulite fluids to higher crustal levels. In this respect, they are comparable to the quartz-carbonates mega-shear zones found in other granulite terranes (Newton and Manning, 2002). Depending on the redox conditions, former lower crustal fluids (mantle-derived CO_2 and/or brines) may either result in mid to upper-crustal quartz-carbonate or graphite veins.

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S4.T05. Gold-rich fluid inclusions in gold-bearing quartz from the Kola superdeep borehole (SG-3), Kola Peninsula, Russian Federation

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In the drillcore of the Kola super-deep borehole (SG-3, 12262 m depth) gold bearing rocks of Archaean age have been located at depths of 9.5-11.0 km. These rocks were overprinted by Proterozoic regional epidote-amphibolite facies metamorphism at 500-650 °C and 3.5-6. kbar.
Quartz veins, located between 9052 and 10744 m, within this gold zone, contain fluid inclusions with exceptional gold concentrations as high as 1500 ppm as colloidal particles. There are 4 types of fluid inclusions (FI's) : 1) gas inclusions of dense CO$_2$, 2) liquid-vapour two-phase aqueous inclusions, 3) three-phase inclusions with NaCl daughter crystals, and 4) CO$_2$ - aqueous inclusions. CO$_2$ FI's homogenized into the liquid phase at temperatures ranging from +30.8 to –45.0 °C with TmCO$_2$ from –56.7 to –60.3 °C and a density of 0.37-1.14 g/cm^3. The salinity of the aqueous phase of vapour FI's is 3.4-4.1 wt.% eq. NaCl. The composition of the gas phase of these inclusions was determined by Raman spectroscopy indicating a small amount of nitrogen (3.3-1.9 mol%) present in the carbonic phase of all gas inclusions throughout the section under consideration, but methane and hydrogen sulfide are absent. Microthermometry indicates the two-phase inclusions are brines containing Na, Ca chlorides with Te from –55 to –74 °C and T$_{mice}$ from –20.7 to –63 °C, corresponding to salinities of 21.6 to 30.2 wt.% eq. CaCl$_2$, Th was between 137-228 °C. Three-phase inclusions have T$_{hhalite}$ at 123-381 °C and Thvapour at 137-264 ºC. They also contain Na and Ca chlorides with T$_e$ of ca. –64 °C and salinities of 25.9-45.4 wt.% eq. NaCl. CO$_2$ aqueous inclusions have T$_h$ between 203-356 °C and salinities of 3.6-18.8 wt.% eq. NaCl. Individual FI's analyzed by LA-ICP MS, indicates the elemental ratios of the 4-FI types are reasonably consistent and confirm the major cations are Na, K and Ca, with several 100's to a few thousand ppm of Fe, Cu, Zn, Pb in the higher salinity fluids. However, there are extremely high concentrations of Au in all FI types analyzed. In the high salinity FI's the average concentration is ca. 300 ppm and as high as 1500 ppm. These measurements are consistent with results of an experimental study of gold in synthetic fluid inclusions by Hanley et al. (2005), that at 600 °C and 1.5 kbar may exceed 1000 ppm. We suggest these fluids could be a precursor of "Orogenic gold fluids" which, at the Au concentrations determined, would reduce the requirements for large volumes of metamorphic fluids to form such ore deposits. The gold is currently present as colloids and may be proof that such a state can transport greater amounts of gold than true solution.

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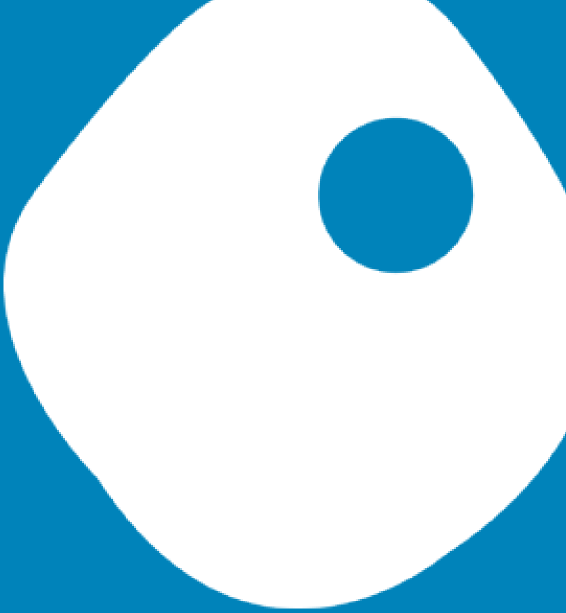

THURSDAY
JUNE 29th

8:30 - 10:00 Session 4: Deep fluids and metamorphic environments

S4.T06. **Shchepetova O.**, Korsakov A., Zelenovskiy P., Shur V., Mikhailenko D. ► Raman spectroscopic study of fluid inclusions from diamond bearing kyanite gneisses

S4.T07. **Frezzotti M-L.**, Ferrando S., Tiraboschi C., Oglialoro E., Villa I.M. ► Carbon, halogens and sulfur: key volatiles in the lithosphere

S4.T08. **Althoff F.J.**, Dubois M., Hadlich I.W., Ronchi L.H., Ronchi F.C. ► Constraints on the evolution of the Itajaí-Perimbó shear zone, southern Brazil, provided by fluid inclusions

S4.T09. **Mullis J.**, De Capitani C., Dubessy J. ► Fluid immiscibility in the Central Alps

S4.T10. **Burisch M.**, Gerdes A., Walter B.F., Neumann U., Fettel M., Markl G. ► Methane and the origin of five-element veins: Mineralogy, age, fluid inclusion chemistry and ore forming processes in the Odenwald, SW Germany

S4.T11. **Scheffer C.**, Tarantola A., Vanderhaeghe O., Voudouris P., Rigaudier T., Photiades A. ► Magmatic to meteoric fluid reservoirs during exhumation of the Cyclades: Implications for the deposition of the Pb-Zn-Fe-Cu-Ag district (Lavrion, Greece)

10:00 - 10:30 Coffee break

10:30 - 12:00 Session 5: Sedimentary and diagenetic environments

S5.T01. **Diamond L.W.**, Wanner C., Eichinger F., Aschwanden L. ► Trapping mechanisms of primary fluid inclusions in calcite: Insight from gas and oil inclusions in scales from a geothermal well

S5.T02. **Martz P.**, Cathelineau M., Mercadier J., Boiron M-C., Tarantola A., Géraud Y., Quirt D., Gerbeaud O., Doney A., Ledru P. ► Multiple fluid flow events and localized circulation around major graphitic Hudsonian fault: a key for the formation of the Cigar Lake U deposit (Athabasca basin, Canada

S5.T03. **Sośnicka M.**, Lüders V. ► TSR-controlled Zn-Pb mineralization in Zechstein carbonate (Ca2) in the Lower Saxony Basin, Germany

S5.T04. **Hanley J.**, Trottier C., Burke J., Ootes L., Zajacz Z., Sharpe R., Fayek M. ► Polymetallic (U-As-Ni-Co-Ag-Bi-Sb) vein deposits preserve inclusion evidence of basement infiltration of formation brines and metal-enriched hydrocarbons from former overlying intracratonic sedimentary basins

S5.T05. **Costanzo A.**, Feely M., Linder F., George J., Parnell J., Bowden S.A., Owens P. ► Hydrocarbon bearing fluids trapped in vuggy quartz euhedra from the Miocene Snoqualmie Granite hosted Green Ridge Breccia, King County, WA, USA.

S5.T06. **Gui L.**, Lu X., Liu K., Meng Q. ► Differential Hydrocarbon Charge history in the Thrust and Slope Belts in the Kuqa Foreland Basin, Western China: Insight from fluid inclusion analysis and reservoir diagenesis investigation

12:00 - 13:30 Lunch

13:30 - 15:00 Session 5: Sedimentary and diagenetic environments

S5.T07. **Bourdet J. - Keynote** ► Gas, salinity and temperature evolution of formation water in gas-rich basins: lessons on quartz cementation

S5.T08. **Fan J.**, Lu X., Ma X., Hua T., Zhuo Q., Zhao M. ► Discovery and significance of bitumen - methane two-phase inclusions of the Sinian Dengying Formation in the Sichuan Basin

S5.T09. **Fall A.**, Ukar E., Lopez R., Gale J.F.W., Manceda R., Laubach S.E. ► Bed-parallel beef veins and cross-cutting vertical fractures in the Vaca Muerta Formation, Argentina: a fracture opening and cementation history

S5.T10. **Lu X.**, Zhao M., Zhuo Q., Fan J., Yu Z. ► Different accumulation mechanisms of the typical deep reservoirs in Tarim Basin according to fluid inclusion analysis and trapping pressure recovery

S5.T11. **Pironon J.**, Renard S., Salardon R., Carpentier C., Sterpenich J., Bellahsen N., Gaucher E.C. ► How fluid inclusions can help us to reconstruct geodynamics in the French Western Pyrenees?

S5.T12. **Huang Y.**, Wang W., Lu W. ► Charge history of CO_2 and CH_4 in Lishui sag, East China Sea Basin: Evidence from Raman quantitative analysis of CO_2 and CH_4 bearing fluid inclusions

15:00 - 16:00 Plenary discussion and closing ceremony

S4.T06. Raman spectroscopic study of fluid inclusions from diamond bearing kyanite gneisses

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Kokchetav Massif (KM) is a spectacular example of diamond- and coesite-grade ultrahigh pressure metamorphic (UHPM) complexes (Sobolev and Shatsky, 1990). KM was subdivided into two domains: diamond-bearing Kumdi-Kol and diamond-free Kulet (Dobretsov et al., 2006). The Barchi-Kol terrane is a part of Kumdi-Kol block and consists of different types of rocks, such as eclogites, garnet-clinopyroxene rocks and gneisses (Korsakov et al., 2002). Kyanite gneisses contain kyanite (Ky) and garnet (Grt) porphyroblasts in quartz (Q)-feldspar-mica matrix. The peak metamorphic PT-conditions for diamond-bearing rocks estimated as high as >4 GPa and 900-1000 °C (Korsakova and Hermann, 2006). Under such high PT-conditions there is no sharp distinction between aqueous fluid and hydrous melt.

Abundant fluid inclusions (FI) (up to 10 μm) were found in rock-forming minerals and investigated by Raman spectroscopy method. This method allows us to investigate not only the composition of FI, but also the residual pressures and CO_2 density. The composition of FI is independent from host mineral and represents the gases±liquid water mixtures in different proportions: $CO_2+N_2+CH_4$, CO_2+CH_4, $CO_2+H_2O_{liq}$ or pure CO_2/H_2O_{liq}.In different minerals FI have various CO_2 densities. In Ky the CO_2 density is 0.99-1.19 g/cm^3, in Grt ~0.79 g/cm^3, in matrix Q ~0.59-0.99 g/cm^3, in Q inclusions in Grt ~0.99-1.19 g/cm^3.The pressure values estimated by CO_2 phase diagram (Yamomoto et al., 2002) vary from 0.02 to 0.2 GPa. The CO_2 density differentials can be explained by diversity in rheological properties of host minerals. The most attractive finding in FI from matrix Q was optically undetectable disordered graphite, which is likely precipitated on the FI walls as thin film during the quenching on the retrograde metamorphic stage. The Raman imaging of FI in Q and Ky, using a Confocal Raman Microscope alpha 300R (WITec), reveals the presence of calcite and mica (~20 vol.%) besides gases±liquid water. It is likely that near the peak metamorphic conditions CH_4 rich fluid coexisted in equilibrium with Grt-Ky-Phe assemblage. Redox reactions led to diamond/graphite formation and liberation of H_2O, which promoted partial melting of rocks. This study was supported by a grant from the Russian Science Foundation (RSF 15-17-30012).

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S4.T07. Carbon, halogens and sulfur: key volatiles in the lithosphere

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The role of volatiles (C-O-H-S-halogens) in the lithosphere is crucial to upper mantle geodynamic evolution, metasomatism, and melting. Although it is clear that halogen (± sulphur)-rich aqueous fluids exert a key influence on the geochemical signature of the lithosphere in subduction zones, the composition and the distribution of fluids and/or volatile-rich melts in the oceanic and continental lithospheric mantle in intraplate and extensional tectonic settings have been taken into account only in recent times. Potential tracers of the nature of volatiles include fluid and melt inclusions in peridotite xenoliths, which represent proxies for mantle volatiles at lithospheric depths. Here, we present fluid/melt inclusion studies in peridotite xenoliths in intraplate and extensional tectonic regions of active magmatism, that include Ethiopia, Hawaii and the Canary Islands. Mantle fluids are CO_2-rich, but contain significant, although variable, amounts of H_2O, halogens, and sulphur species. Chlorine represents the most abundant halogen (mole fraction up to 0.04), and sulphur is present either as H_2S, SO_2, or sulphates. Such compositions are unknown from intraplate and extensional settings and show unexpected similarities to fluids preserved in kimberlitic diamonds. Data delineate changes in volatile speciation and redox conditions in the lithosphere, and yield improved insights on how ascending hydrous carbonate-rich melts exsolve aqueous-carbonic fluids enriched in halogens and sulphur, which may be locally immiscible. The composition and the distribution of lithospheric fluids suggest a possible role of recycling in transporting predominantly CO_2, H_2O, and some fluid mobile elements via paleo-subduction events in the convective mantle.

S4.T08. Constraints on the evolution of the Itajaí-Perimbó shear zone, southern Brazil, provided by fluid inclusions

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The Itajaí-Perimbó shear zone (IPSZ) is exposed in the Catarinense Shield, southern Brazil. It defines the contact between the Dom Feliciano Belt (Cryogenian) and the Itajaí Foreland Basin (Ediacaran). The IPSZ evolved from oblique-thrust to strike-slip fault during the Brasiliano / Pan-African orogenic cycle, and was reactivated affecting Late Permian rocks in the Paraná basin (Rostirolla et al., 2003). The oldest rock known in the Dom Feliciano belt is the A-type Parapente granite (843 +/- 12 Ma; Basei et al., 2008), that outcrops inside the IPSZ. The Parapente granite is older than the IPSZ and suffered only brittle- (feldspars) plastic (quartz) deformation, with development of low grade mylonites and phyllonites.

The pressure-temperature (P-T) conditions throughout the evolution of the IPSZ were evaluated using fluid inclusions from the Parapente granite. Different quartz generations were identified according to their microstructural features. Homogenization temperatures range from 193 °C in quartz from the less deformed granite (FIP 25), 224 to 180 ºC in quartz from a deformed vein in accordance with the granite foliation (FN6), 180 to 169 ºC in quartz from a deformed vein that cuts the granite foliation (FIP 29), and 165 to 138°C in quartz porphyroblasts from the phyllonite (FIP 6 and FIP 22). All fluid populations are mainly saline waters of low to medium salinity (1-10 wt% eq. NaCl), with exceptionally a low gas content (CO_2 and N_2) in one sample (FN6). Depths estimated from fluid inclusion isochores indicate at least three crustal levels where the shear zone may have been active (from ~20 km to ~10 km). P-T conditions of formation of phyllonites are estimated at 350 °C and 4 kbar and probably determine the end of the evolution of the IPSZ. The variation in depth of almost 10 km implies that the shear zone operated as a thrust fault

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S4.T09. Fluid immiscibility in the Central Alps

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Multicomponent fluids in the Swiss Central Alps show miscibility gaps at temperatures between 150 and 350 °C. Systematic studies revealed fluid immiscibility in four distinct fluid environments. They are:

1. HHC-H_2O-salt in diagenetic higher hydrocarbon (HHC) bearing sedimentary rocks,
2. CH_4-H_2O-salt in diagenetic and low-grade anchizonal CH_4 bearing sedimentary rocks,
3. CO_2-H_2O-salt in carbon and carbonate bearing metasedimentary rocks at high-grade anchizonal and greenschist facies conditions,
4. N2-H_2O-salt in ammonium and carbon bearing metasedimentary rocks at anchizonal and greenschist facies conditions.

In addition to the major volatile component, fluids may contain relatively small to very small amounts of CH_4, CO_2, N_2 and H_2S. The dissolved electrolyte species is mainly NaCl.

Fluid inclusion studies, reconstruction of their VX properties (Krader, 1985; Diamond, 2001) and their interpretation in terms of PT conditions of paleofluid circulations permit to distinguish four different geological processes that lead to fluid unmixing:

1. Isobaric decrease in temperature
2. Isothermal decrease in pressure
3. Volatile production during cracking of kerogen and higher hydrocarbons and by decarbonation and oxidation or reduction of carbonaceous matter
4. Channeled influx of allochtonous volatile-rich, but not of salt-rich fluids.

In rocks containing little or no volatiles, process 4 is connected to fractures and faults.

Depending on the tectono-metamorphic and lithologic environment, fluid immiscibility in the Central Alps is controlled by one or several unmixing processes (Mullis et al. 1994):

1. In HHC bearing diagenetic rocks, unmixing processes 2 and 3 are dominant
2. In CH_4 bearing diagenetic and low-grade anchimetamorphic rocks, unmixing processes 1 to 3 are dominant
3. In CO_2 bearing rocks of high-grade anchizonal and greenschist facies conditions, unmixing process 2 is dominant
4. In N_2 bearing rocks of greenschist facies conditions, processes 2 and 3 are dominant.

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S4.T10. Methane and the origin of five-element veins: Mineralogy, age, fluid inclusion chemistry and ore forming processes in the Odenwald, SW Germany

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Five-element veins (Ag, Bi, Co, Ni, As) have been valuable mineral deposits since medieval times and typically consist of native metals (up to dm) surrounded by a succession of Ni-Co-Fe-arsenides. The exact formation process of these specific vein types is yet not well understood. However, a new model including methane as a reducing agent is applied to the five-element veins of the Odenwald, SW Germany. These veins were analyzed in terms of ore textures, mineral chemistry, fluid inclusion compositions (microthermometry and Raman spectroscopy), stable isotopes (C, O and S) and in-situ U-Pb age dating of calcite and prehnite.

The majority of five-element veins (e.g. Bou Azzer, Cobalt, Erzgebirge) have in common that up to dm-sized, often dendritic native metals are overgrown by a succession of arsenides, followed by carbonate and often sulphides. The succession of arsenides show a distinct spatial and temporal chemical trend in their composition. This trend evolves from Ni- to Co- and finally Fe-dominated compositions from the core to the rim.

In-situ U-Pb age dating of low-U calcite and prehnite was applied to constrain the age of hydrothermal mineralization. The five-element veins of the Odenwald formed at 170-180 Ma, which relates the vein formation to a Jurassic period of extension and crustal thinning caused by the opening of the North Atlantic. Results of fluid inclusion analyses imply that the investigated veins precipitated from Na-Ca-Cl fluids at ~290 °C, salinities of ~27 wt.% and Ca/(Ca+Na) ratios of 0.30 to 0.35 in the presence of methane. Furthermore, it could be constrained that the ore fluid consists of a mixture of a metal-rich basement brine (fluid A), a sulfide-bearing (H2S and HS-) basinal/sedimentary brine (fluid B) and methane-dominated fluid/gas (fluid C). Mixing of such chemically contrasting fluids results in a strong chemical disequilibrium of the mixed fluid ABC, which potentially leads to rapid precipitation of native metals and arsenides with these specific ore textures, as the system tries to re-attain equilibrium. Hydrochemical modelling was carried out to predict the chemical evolution of the fluid during/after mixing, which shows that the predicted mineral succession is in perfect agreement with the textural observations. Consequently, the reduction of metal-rich fluids, in many cases related to mixing with methane-bearing fluids, is one of the most important parameter that leads to the genesis of five-element veins in hydrothermal systems.

S4.T11. Magmatic to meteoric fluid reservoirs during exhumation of the Cyclades: Implications for the deposition of the Pb-Zn-Fe-Cu-Ag district (Lavrion, Greece)

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The formation of the Lavrion Pb-Zn-Fe-Cu-Ag detachment-related district is linked to the evolution of fluid-rock interactions associated with Miocene post-orogenic exhumation of the Attic-Cycladic Metamorphic Core Complex. The structural position of the mineralization indicates progressive deposition from ductile to brittle deformation. Ductile-brittle mineralization enclosed within the mylonitic marble is related to magmatic fluids leading to carbonate replacement and skarn ore deposits. Previous studies assumed that brittle deposits as epithermal veins resulted from mixing of magmatic and surficial fluids. In this contribution, we discuss the nature and the origin of the fluids responsible for the formation of late cataclastic Pb-Zn-Fe-Cu-Ag epithermal ore deposits on the basis of petrography, REE+Y contents of fluorite and calcite gangue minerals, fluid inclusion investigation, stable isotopes and crush-leach analyses. Fluorite and calcite are characterized by only one type of primary fluid inclusions. REE content of fluorite and calcite gangue minerals and fluid inclusions suggest that they precipitated from a hydrothermal fluid below 200 °C at a salinity between 20.0 and 0.0 mass% NaCleq. Fluid inclusions trapped in fluorite display low δD signatures comprised between –82.1 to –52.6 ‰ V-SMOW and δ^{18}O in the range –10.4 to –6.7 ‰ V-SMOW testifying a meteoric origin. Cl/Br ratio measured by crush-leach analyses is too low to be consistent with magmatic or secondary brines and more probably suggest an interaction with Br-enriched carbonaceous material. These new data confirm our previous model elaborated on the basis of structural investigations in Lavrion area favouring polyphased ore deposition resulting from the superposition of successive hydrothermal systems. The first one is initiated by the Plaka granodiorite intrusion leading to magmatic fluid genesis and thus magmatic-dominated mineralization in a ductile-brittle deformation stage. The following pure brittle deformation is marked by the invasion of warmed meteoric fluids and is associated with a second hydrothermal system leading to cataclastic epithermal calcite and fluorite-rich mineralization. Finally, late supergene mineralization occurred by downward penetration of cool ground water.

S5.T01. Trapping mechanisms of primary fluid inclusions in calcite: Insight from gas and oil inclusions in scales from a geothermal well

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Interpretation of the fluid inclusion record in diagenetic and hydrothermal minerals relies on understanding of the mechanisms by which inclusions become trapped. Fluid inclusions in mineral scales in geothermal wells provide an opportunity to verify and quantify these mechanisms, as the physicochemical conditions during inclusion formation are relatively well known. Here we present observations of primary fluid inclusions in calcite scales from the casing of the Kirchstockach geothermal well, situated 15 km SE of Munich, Germany.

The investigated scales formed during 98 days of geothermal production at flow rates of 80–90 L/s. The weakly saline Na–HCO_3-type thermal fluid (~ 0.05 wt.% total dissolved solids), including rare droplets of oil and gas, is produced from the Malm carbonate aquifer at 3900 m depth. The cause of scaling is attributed to cavitation in the downhole pump, which generated a vapour phase, stripped aqueous CO_2 and induced supersaturation (Wanner et al., 2017).

The scales contain three types of mutually saturated fluid inclusions in heterogeneously trapped assemblages: N_2–CO_2 vapour, colourless oil and brown oil. The liquid-rich oil inclusions homogenize (LV→L) at 137.6 ± 1.5 °C, in excellent agreement with the downhole fluid temperature (137.5 °C) and in fair agreement with $^{18}O/^{16}O_{\text{calcite–water}}$ fractionation (134 ± 3.4 °C). Evidently, the specific downhole conditions at this temperature (pH = 6.74, molar $[Mg^{2+}]/[Ca^{2+}] = 0.25$, saturation state $\Omega_{\text{calcite}} = 2.5$ and precipitation rate = 8.55e–11 $\text{mol}_{\text{calcite}}/\text{s/cm}^2$) promoted smooth crystal growth surfaces, such that no aqueous inclusions were trapped. At the same time, adhesion of vapour and oil droplets to the crystal surfaces allowed selective entrapment of these rare phases, even at the elevated fluid flow velocity of 1.9 $\text{m}\cdot\text{s}^{-1}$.

This case study reinforces several principles that can be used to interpret primary fluid inclusions in calcite from other geological settings: (1) the aqueous parent fluid is not trapped by actively growing crystals at a saturation state as low as $\Omega_{\text{calcite}} = 2.5$; (2) fluid inclusions faithfully record the presence of even very minor non-aqueous phases; (3) the relative proportions of the fluid phases that bathe the growing host crystal are not reflected by the relative proportions of the fluid inclusion types; (4) the standard methodology of using assemblages of heterogeneously trapped inclusions to determine their trapping temperature (i.e. T_h of liquid end-member = T_{trap}) works well for water-dominated geological settings even in the absence of aqueous fluid inclusions.

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S5.T02. Multiple fluid flow events and localized circulation around major graphitic Hudsonian fault: a key for the formation of the Cigar Lake U deposit (Athabasca basin, Canada)

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Most of the unconformity-related uranium deposits are located within or right above major ductile-brittle graphitic shear zones near the unconformity between the Athabasca Basin and the underlying Archean to Paleoproterozoic basement. These shear zones are related to the TransHudson Orogeny (THO) between 1.86 and 1.70 Ga (Annesley et al., 2005) and have been reactivated at multiple stages. Microfracturing and fluid inclusion distributions in and around shear zones and their host rocks located close to the giant Cigar Lake uranium deposit were studied. In particular, Fluid Inclusions Planes (FIPs) in magmatic quartz from granitic pegmatites occurring in and off this structure contain predominantly C-O-H-N fluids. The distributions of the density of carbonic FIPs (i.e. number of FIPs by surface unit) and the subsequent reconstructed fracture paleoporosity in the quartz show increases from the damage zone toward the fault core, in the central part of the ductile-brittle structure related to a first brittle reactivation. This event is characterized by the evolution from a dense and pure CO_2 fluid toward a cooler and lighter C-O-H-N fluid responsible for hydrothermal graphite precipitation. Fluid inclusions record the overall late and probably quick subsequent exhumation of the basement as a rather high geothermal gradient of ≈70 °C/km that is inferred from P-T reconstruction. This episode is thought to have occurred within the 1775 to 1700 Ma range. After basement uplift, erosion, and formation of the Athabasca Basin, at circa 200-300 Ma after the exhumation (e.g., at ca. 1600-1400 Ma), evaporated seawater-derived basinal fluids percolated into the basement (Richard et al., 2012). Such brines were found in FIPs and whose densities show a progressive and correlated increase from the distal part of the damage zone towards the brittle fault core of the early shear zone. Brine migration was therefore focused in previously-damaged zones during this secondary reactivation at ca. 1600-1400 Ma.
timing of U deposition in the Athabasca basin (Alexandre et al., 2007). This study emphasizes the critical role of Hudsonian structural preparation in the overall basinal fluid migration and therefore the processes involved in the uptake, transport, and deposition of uranium.

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S5.T03. TSR-controlled Zn-Pb mineralization in Zechstein carbonate (Ca2) in the Lower Saxony Basin, Germany

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The Lower Saxony Basin (LSB) is a W-E-trending sub-basin of the Southern Permian Basin. The LSB is the most important oil and gas province in Germany where gas is mainly produced from tight gas reservoirs in Upper Carboniferous sandstone or Zechstein carbonate reservoirs. The latter reservoirs locally contain considerable H_2S or CO_2 contents. Hydrothermal Zn-Pb and metasomatic Fe mineralization hosted in lower Zechstein carbonate (Cas) occurs surface-near adjacent to uplifted Upper Carboniferous blocks in the area west of Osnabrück and was mined from the 16th until the early 20th century. However, similar considerable mineralization at greater depth was accidentally drilled in various parts of the LSB during gas exploration in LSB in the second half of the 20th century. This study investigates the origin and formation of Zechstein carbonate-hosted Zn(-Pb) ore in the centre of the basin as well as at its western margin, where Zechstein-hosted massive Zn(-Pb) ore directly overlies Upper Carboniferous sediments. Fluid inclusion and isotopic studies of ore and gangue minerals from the study areas aim to constrain the geochemical controls of ore formation in the frame of an integrated geological-tectonic, geochemical and ore petrological study founded by the Federal Ministry of Education and Research (BMBF).

Colourless, yellowish to dark brown sphalerite form massive orebodies or occur in vein-type mineralization together with galena, as well as minor chalcopyrite, pyrite, anhydrite, calcite and/or fluorite. Studied sphalerite samples from Zechstein boreholes host high-salinity aqueous two-phase fluid inclusions showing homogenization temperatures in the range between 158 and 214°C. It is noteworthy that fluid inclusions in sphalerite samples from the basin centre tend to have higher Th values than inclusions in sphalerite samples from the western margin of the LSB. Gas-rich inclusions were not observed in sphalerite but are abundant in associated gangue minerals such as fluorite, anhydrite and/or carbonates and show considerable H_2S contents besides CH_4 and CO_2. The $\delta^{13}C_{(CH4)}$ values of gas-rich inclusions in gangue minerals are highly variable (–25 to –7 ‰) suggesting that H_2S in inclusions (and reservoirs) was derived by TSR (thermochemical sulphate reduction). This is also supported by highly variable $\delta^{34}S$ values (–11.8 to +8.5 ‰) measured in various ore minerals. Thus it is likely that ore formation in Zechstein carbonate was controlled by mixing of ascending metal-rich brines with TSR derived H_2S in the Zechstein carbonate unit. The absence of sulphide mineralization in fracture-fill mineralization hosted by Upper Carboniferous strata supports this idea.

S5.T04. Polymetallic (U-As-Ni-Co-Ag-Bi-Sb) vein deposits preserve inclusion evidence of basement infiltration of formation brines and metal-enriched hydrocarbons from former overlying intracratonic sedimentary basins

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Polymetallic, uranium-bearing "five-metals" type hydrothermal vein systems in the Northwest Territories of Canada show widely contrasting grade and tonnage characteristics from one deposit district to another, with historically world-class deposits at Great Bear Lake (Eldorado-Echo Bay, Contact Lake, Terra-Norex, Silverbear, Normin). Integration of a variety of microanalytical methods (CL, SEM, fluid inclusion microthermometry, SIMS, LA-ICPMS) is focused at revising the current model for this deposit style, specifically with respect to metal sources, precipitation mechanisms, and reasons for variability in metal tenor at a regional scale.

Preliminary study has focused on characterizing the onset of U and Ni-Co-As co-precipitation. Fluid salinity (~20-30 wt% $CaCl_2$ eq.) and entrapment conditions (< 0.5 kbar and 200 °C) varied little with time during vein formation, however, "fluid" $\delta^{18}O$ values increased by >15 ‰ at the onset of U-Ni-Co-As mineralization. Fluid inclusions in mineralized quartz-carbonate veins are enriched in Ca-Sr-Ba-Mn-Pb-Zn but contain only sub-ppm concentrations of ore metals. Coeval bitumen (now solid hydrocarbon) inclusions, in contrast, are metal enriched, containing thousands of ppm of U-Ni-Co-Bi-Ag-Sb-As-Mo-Cu. Integration of all data types strongly suggests that the precipitation of metals and bitumen was triggered by isothermal mixing of basement (metal-poor) and ^{18}O-rich basinal-type brines that were transporting metal-rich bitumen colloids or oil droplets. Oxidation of this hydrocarbon phase resulted in metal precipitation. The basinal brines and associated metal-rich bitumen are thought to be derived from former overlying outliers of the Athabasca-Hornby Bay-Thelon sedimentary basins that now only outcrop ~300-1000 km away from the study areas. Co-precipitation of metals and bitumen highlight the role of hydrocarbons in transporting U and other metals in these polymetallic vein systems. Importantly, high-grade polymetallic vein systems of this variety may be linked to the metal budgets of previously overlying sedimentary basins rather than the basement rocks in which the deposits are hosted. This work provides a direct confirmation from the fluid inclusion record for the involvement of basinal ore fluids, based on recent geochronology (Gandhi et al., 2013).

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S5.T05. Hydrocarbon bearing fluids trapped in vuggy quartz euhedra from the Miocene Snoqualmie Granite hosted Green Ridge Breccia, King County, WA, USA

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The Green Ridge Breccia cuts the composite Miocene Snoqualmie Granite in King County, WA, USA. The granite is ~17-20 Ma (Tabor et al., 1995) and the crosscutting NW trending breccia contains large angular blocks of the host granite (<1 metre in longest dimension). The breccia blocks are in their original orientation and are cemented by quartz euhedra (<10 cm in longest dimension) bearing vugs. The clear quartz euhedra can have terminations marked by purple amethyst zones. A notable feature of these quartz euhedra is the presence of centmetric scale yellow oil inclusions imparting a citrine appearance to the quartz. Fluid inclusion studies of the euhedra using Transmitted Light Petrography, UV Microscopy, Microthermometry, Laser Raman Microspectrometry and Gas Chromatography record the paragenesis and fluid composition of three fluid inclusion types: Type 1 (liquid rich two-phase (L+V) aqueous inclusions), Type 2 (black solid-bearing two-phase (S+L) inclusions) and Type 3 (yellow oil bearing two-phase (L_{oil}+L_{aq}) inclusions). Type 1 are primary (commonly display negative crystal shapes) and contain traces of CO_2 and CH_4. They homogenise to the liquid phase at ~200-250 °C and have calculated salinities of <10 eq. wt% NaCl. Laser Raman microspectrometry identified the secondary Type 2 as bituminous bearing inclusions. Type 2 are cut by microfractures that host the yellow oil bearing Type 3 inclusions. Gas chromatography of the yellow oil in Type 3 indicates the presence of immature hopanes and steranes formed close to the beginning of the oil window. The paragenesis and source of these three fluid types will be discussed.

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S5.T06. Differential Hydrocarbon Charge history in the Thrust and Slope Belts in the Kuqa Foreland Basin, Western China: Insight from fluid inclusion analysis and reservoir diagenesis investigation

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Hydrocarbon inclusions are minute petroleum fluids trapped during reservoir diagenesis. Hydrocarbon inclusions are currently being extensively used to investigate hydrocarbon charge timing and contributions of different hydrocarbon charges. On the basis of oil physiochemical properties, reservoir diagenetic sequence and fluid evolution, the hydrocarbon accumulation processes in the two belts were investigated using geochemistry, microscopy, SEM, XRD and X-ray micro-CT imaging. Both paleo and present hydrocarbons were investigated using fluorescence microscopy and FT-IR spectroscopy in conjunction with bulk geochemical analysis and Principal Component Analysis. Using Quantitative fluorescence techniques for detecting residual oils and reconstructing hydrocarbon charge history.

The study area initially experienced shallow burial over a prolonged period, was then buried rapidly around 5 Ma and uplifted since the Quaternary. The reservoir is characteristic of diagenesis Stage A (moderate diagenesis phase) with the diagenetic sequence characterized by an early calcite cementation→ feldspar dissolution → quartz overgrowth → kaolinite → late calcite cementation → dolomite precipitation → anhydrite precipitation → microcrystalline quartz formation. Three types of hydrocarbon inclusions are present including yellow and blue fluorescing oil inclusions and gas inclusions, representing three episodes of hydrocarbon charges in the Thrust Belt and two episodes of charges in the Slope Belt. The oil charge in the Thrust Belt occurred at 18 Ma and 5 Ma, and the gas charge occurred after 2 Ma. Reservoir oils have higher maturity than the blue fluorescing inclusion oil, indicating that later high-maturity hydrocarbon charge dominated the oil accumulation. The reservoirs in the Thrust Belt were initially charged with oil at 18 Ma with a subsequent high-maturity oil around 8-5 Ma. The oil reservoirs were subsequently destroyed by intense tectonic compression, followed by high to over-mature coal-derived gas charge in the Quaternary. The Slope Belt received a high-mature oil charge around 8-5 Ma and a gas charge since 3 Ma, characterized by a huge amount of gas charge into relatively small oil reservoirs.

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S5.T07. Keynote - Gas, salinity and temperature evolution of formation water in gas-rich basins: lessons on quartz cementation

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Fluid inclusions in quartz cement is one of the most direct method to investigate palaeo-fluids in sedimentary basins. Some of the most common applications include petroleum reservoir quality prediction, palaeo-temperature estimation and timing derivation of hydrocarbon charge (Walderhaug, 1994). There are many examples of research presenting this approach, including discussions about possible resetting of fluid inclusion in quartz (Osborn and Haszeldine, 1993, 1995; Walderhaug, 1995; Worden, 1995). Lander and Walderhaug (1999) developed a kinetic model based on simulation of the crystal growth anisotropy and nucleation surface that provides a predictive tool of quartz cementation. However, two opposed views exist on growth of quartz cement in sandstones, being continuous versus episodic phenomenon (Worden and Morad, 2000).

The progress in analytical techniques has been significant in the last 20 years, especially regarding micro-analysis and modelling. Raman spectroscopy development for the detection and quantification of dissolved gas in water inclusions alongside with development of thermodynamic fluid models enable the calculation of fluid phase envelops which in turn provide better constrains on fluid composition and palaeo-pressure derivation.

Palaeo-pressure and temperature, salinity and gas content of water inclusions trapped in quartz cements within or below hydrocarbon reservoirs in Australia provided data informing about the fluid evolution and cementation patterns taking place in sedimentary basins. It appears that episodic heat pulse is a common mechanism associated with hydrocarbon charge. However, this view has consequences on the applicability of fluid inclusion techniques for deriving palaeo-temperature and timing, on quartz cementation prediction and fluid flow in basin modelling.

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S5.T08. Discovery and significance of bitumen - methane two-phase inclusions of the Sinian Dengying Formation in the Sichuan Basin

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In recent years, large-scale natural gas reservoirs have been discovered in the Sinian-Cambrian Cambrian strata of Gaoshiti-Moxi area in the Sichuan Basin, China, which is the largest gas field discovered in the Sichuan Basin for more than half a century. The controlled reserves in Denying Fm. Of simian strata is about 2042.9 × 108 m^3, showing the great potential of deep gas exploration. It can be seen that deep gas exploration potential may be far more than expected. However, there are controversies over hydrocarbon accumulation evolution in the area. In order to get better understanding to the gas accumulation in the Sinian Fm in the Sichuan Basin, a great deal of samples of this area are analyzed by microscopic observation, fluid inclusion analysis and Raman spectrum measurement.

According to the microscopic observation, the homogenization temperature measurement of the brine inclusions and the laser Raman spectroscopy analysis, a series of asphalt-methane two-phase inclusions were found in the Sinian Dengying Fm in the Moxi area, Sichuan Basin, which provide the direct evidence for the gas reservoir genesis. The uniform temperature of the brine inclusions in the sample is similar to that of the methane inclusions. The uniform temperature of the brine inclusions is obviously distributed in two intervals, and the Raman shift peak position of the bitumen inclusions is obviously different. Besides, it is noted that the peak of the methane inclusions is concentrated in two intervals 2910-2911 cm^{-1} and 2915-2916 cm^{-1}. Captured pressure of these inclusions are reconstructed by using the laboratory-established methane Raman spectra and pressure formula and Duan's EOS, these inclusions capture pressure are 15-20 MPa and 65-80 MPa, respectively. This again verifies the pressure of gas reservoir evolved from the overpressure to normal pressure. In summary, the discovery of bitumen-methane two-phase inclusions provides direct evidence for the evolution of hydrocarbon accumulation in the region, this can offer new way for the further exploration of natural gas.

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S5.T09. Bed-parallel beef veins and cross-cutting vertical fractures in the Vaca Muerta Formation, Argentina: a fracture opening and cementation history

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Natural fractures are pervasive in low-porosity reservoirs, such as shales. Such fractures locally provide flow pathways between source and reservoir layers during gas charge or between matrix pores and hydraulic fractures and the well bore during production, and even where sealed may significantly influence engineering operations. Fractures form in sedimentary basins as a result of various combinations of tectonic, burial and thermal loading (stress), pore fluid pressure, and evolving rock strength. In naturally cemented fractures fluid inclusions are a key to unlocking the history of fracture growth. Correlated with burial and thermal history models, fluid inclusion temperature sequences provide evidence for timing of fracture opening and cementation.

The black shales of the Late Jurassic-Early Cretaceous Vaca Muerta Formation, Argentina, contain widespread horizontal, bed-parallel, fibrous calcite-filled fractures (beef) as well as bed-normal fractures. The antitaxial cements of the beef have textural zones that record progressive opening. Wide calcite-filled beef veins are cut by narrow bed-parallel, and somewhat younger microfractures. Of the four sets of bed-normal opening-mode fractures present, the oldest E-W trending set shows evidence of reactivation, suggested by the presence of early microfractures that are overlapped by late blocky calcite and/or ankerite. The latest N-S trending set retains up to 65% fracture porosity; fractures are lined by a thin veneer of idiomorphic calcite crystals that grew into open space. All fracture cements contain coexisting aqueous fluid and hydrocarbon gas inclusions.

Microthermometry of aqueous fluid inclusions in the beef shows homogenization temperatures (T_h) that range from ~175 °C to 208 °C. The later horizontal fractures have T_h ranging from ~165 °C to 183 °C. Inclusions in the vertical fractures are small, and show overall T_h ranges from ~142 °C to 161 °C. Fluid salinities in all fractures are at ~ 15 wt% NaCl equivalent. Hydrocarbon inclusions are liquid at room temperature with homogenization temperatures ranging from ~ –75 °C to –65 °C. This suggests that the gas is primarily methane dominated, with the possible presence of low amounts of ethane and/or propane.

T_h of aqueous inclusions coexisting with hydrocarbon inclusions correspond to the trapping temperature, coinciding with fracture opening and cementation. Crosscutting relations, temperature and cement texture correlations, and correlations with burial history models suggest the following timing of fracturing: beef formed between 94 and 62 Ma around maximum burial, during Late Cretaceous, followed by the set of E-W-striking vertical fractures. Late horizontal fractures that crosscut Set E-W formed at ~ 60 Ma; Sets NW-SE and N-S vertical fractures formed at ~ 56-60 Ma, during the Paleocene.

S5.T10.Different accumulation mechanisms of the typical deep reservoirs in Tarim Basin according to fluid inclusion analysis and trapping pressure recovery

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Fluid inclusions are a direct historical record of diagenetic reservoir fluids, which can provide information such as fluid temperature, pressure and composition during oil and gas migration and filling, which has become an important method in oil and gas accumulation history research (Parnell, 2010). Using the fluid inclusions technology to obtain the information of the paleo-pressure of the fluid, combined with the fluid inclusions homogeneous temperature and stratigraphic burial and thermal history simulation results to determine the inclusions trapping time, so as to track the paleo-temperature and pressure evolution history.

Two methods for paleo-pressure recovery based on fluid inclusions were introduced, as well as the required parameters and their advantages and disadvantages. (1) PVTX simulation of the inclusions: for oil and gas inclusions, PVTX simulation techniques can be used to recover the paleo-trapping temperature and pressure conditions of hydrocarbon inclusions in the case of accurate testing of homogenization temperature and gas-liquid ratio. (2) Direct measurement of methane inclusions ancient pressure by Laser Raman: for gas inclusions or methane containing aqueous inclusions, the paleo-pressure can be determined by using methane Raman shift to calculate the internal pressure of the inclusions at room temperature (Lu et al., 2007), then use Duan's equation of state (Duan et al., 1992) on the CH_4-H_2O-NaCl system under homogenization temperature conditions to calculate the paleo-pressure.

Taking the Cretaceous deep gas reservoirs in Kelasu tectonic zone, Kuqa depression, the Ordovician condensate gas reservoirs in Tazhong I # fault zone, the Halahatang Ordovician oil reservoirs in Tabei uplift as typical deep reservoirs examples, using the paleo-pressure recovery methods based on fluid inclusions, combined with reservoir systematic analysis, the accumulation mechanisms and pool-forming processes of the three different types of deep reservoirs were analyzed. (1) For the Cretaceous gas reservoirs in Kelasu tectonic zone, the gas was accumulated in the late stage when deeply buried with super pressure and strong charging, which is the true deep layer hydrocarbon accumulation under HPHT and tight reservoir condition. (2) For the Halahatang Ordovician oil reservoirs in Tabei uplift, oil was charged in normal pressure, and accumulated in the early stage when shallowly buried and then was deeply buried in the late stage. (3) For the Ordovician condensate gas reservoirs in Tazhong I# fault zone, it have the features of weak overpressure charging, the deep cracking gas flew along the faults and then filled in the Ordovician carbonate fracture and cave reservoir.

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S5.T11. How fluid inclusions can help us to reconstruct geodynamics in the French Western Pyrenees?

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The chemistry of fluid percolating in basins or in orogenic belts acts as a major controlling factor on the diagenesis and petrophysics characteristics of surrounding rocks. It helps us for the reconstruction of geodynamical models in complex geological settings like foothills and foreland environments. Such setting can be found in the North Pyrenean Zone where a phase of rifting preceded a phase of orogenic development. This area provides a unique opportunity to study the link between fluid evolution and lithospheric deformation. The data collected here correspond to the Chaînons béarnais to the South (foothills) and Rousse gas field to the North in the Pau area (foreland).

Petrographic and structural observations, Raman and micro-thermometry analysis on fluid inclusions, chemical fingerprint of paragenesis have been mixed to characterize cements precipitated during each episode in the two domains. In Chaînons béarnais (Salardon et al., 2017) saddle dolomite and chlorite precipitated in fractures during the Aptian-Cenomanian hyper-extension corresponding to the thermal peak at temperatures higher than 300 °C. The isotopic signature, the high CO_2 content, the occurrence of H_2S and the high salinity of parent fluids suggest ascending magmatic fluids percolating across Triassic evaporites. The late and post hyper-extensional phase is characterized by hydraulic brecciation in dolomitic formations, a decrease in temperature and salinity, a maintain of reducing conditions during the precipitation of quartz, pyrite and calcite. The Pyrenean compressive phase associated with the third fracturing stage induced a reopening of the diagenetic system and favoured a return to oxidizing conditions and infiltrations of meteoric fluids from Santonian to Eocene. The diagenetic materials of Rousse gas field showed a predominance of carbonates associated to quartz, clays and pyrite. The fluid inclusion data concluded a double-time fluid circulation at 170 °C with a first stage during the Late Jurassic to Early Cretaceous for the reservoir rock corresponding to the rifting period of the Aquitaine basin and a second stage during Paleocene in breccias corresponding to the Pyrenean compression period.

A lot of similarities are observed between the two areas in terms of petrophysics and paragenesis. However the main differences are controlled by the distance to the rift system and are marked by strong temperature and fluid composition differences.

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S5.T12. Charge history of CO_2 and CH_4 in Lishui sag, East China Sea Basin: Evidence from Raman quantitative analysis of CO_2 and CH_4 bearing fluid inclusions

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Quantitative Raman spectroscopy can be used to analyse the composition and density of CO_2 and CH_4 bearing fluid inclusions, providing us the quantitative information to understand the gas charge history. In this study, both gas-rich inclusions consisting of CO_2 and/or CH_4, and aqueous inclusions containing dissolved CH_4 and CO_2 in the fractures of quartz were found in the sandstone reservoirs from Lishui sag, East China Sea Basin. The density and the composition of gas-bearing fluid inclusions were then determined with Raman spectroscopy (Ou et al., 2015; Zhang et al., 2016; Guo et al., 2016), the density of pure CO_2 fluid inclusions was calculated from the distance between Raman peaks of the Fermi doublet, while the salinity and concentration of dissolved gases in aqueous inclusions were determined from the Raman spectra collected at homogenized state (above the homogenized temperature).

Based on the measured density and composition, isochores were established for each fluid inclusion assemblages. Trapping pressures of each assemblages were determined. Based on buried history, we obtained the charging periods of carbon dioxide and methane. For structure LS36-1, the charge periods of carbon dioxide are late Paleocene (~ 58 Ma) and early Miocene 18-15 Ma respectively, the charge periods of methane are middle Eocene 46 Ma; For structure LS35-7, the charge periods of carbon dioxide is late Paleocene (~ 56 Ma) and early Miocene 20-18 Ma, the charge periods of methane are late Eocene (~ 42 Ma).

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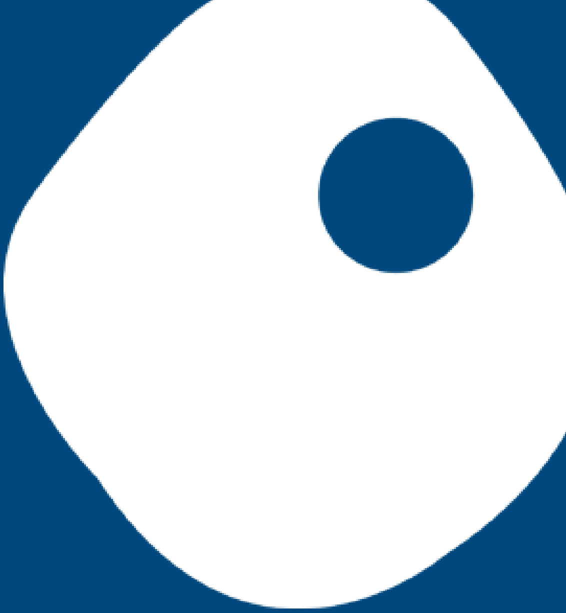

POSTERS

S1.P01. Thermochemistry of individual fluid inclusions: experimental study and thermodynamic modeling

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Natural fluid inclusions represent microprobes of the paleo hydrothermal system, i.e. natural aqueous solutions performing important mass transfer and concentrating in the crust. However, due to very small size of these probes (10^{-6} to 10^{-9} g) analytical possibilities that can be directly applied to individual inclusion are limited. Such important data as pH, fO_2, fS_2 and metal speciation cannot be measured in such a small volume. However, these parameters at hydrothermal T-P conditions at which natural fluids exist are highly important. Here, we propose to couple the analytical techniques such as Raman and infrared spectroscopy and LA-ICP-MS with the special thermodynamic calculation code (modification of HCh, Yu.V. Shvarov) in order to open a new opportunity to quantify thermochemistry of natural paleofluids. This last requires calculation of equilibrium in multisystem inside an individual inclusion along the isochoric paths using quantified total chemical composition.

The new analitycal methods to quantify an individual fluid inclusion composition are proposed. These methods include Raman and IR spectroscopy coupled with LA-ICP-MS and traditional microthermometry of the individual fluid inclusion to estimate crucial physical-chemical parameters (pH, fO2, fS2 as well as ratios HCO_{3-}/CO_3^{2-}, $H_2S/HS-$, H_2S/SO_4^{2-}) and total salt load of the entrapped paleo-fluid (Ramboz et al., 1985; Dubessy et al., 1987, 1989; Leisen et al., 2012). To extrapolate these ambient data to the hydrothermal conditions that correspond to the trapping parameters of the fluid special algorithm of equilibria computation in multicomponent systems at isochoric conditions was developed. The possibilities of the approach would be demonstrated using real fluid inclusions from different geological settings.

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S1.P02. A new relation between CO_2 density and Fermi diad Raman shift from experimental HPOC analyses. Application to natural CO_2-H_2O-NaCl fluid inclusions.

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Rich carbon dioxide fluids are met in many geological settings. The molar volume and composition (*VX* properties) at room temperature obtained via combined microthermometric and Raman spectroscopic analyses provide constraints to the pressure and temperature (PT) conditions of entrapment. In the present work, the change of the CO_2 Fermi diad splitting measured on Raman spectra is correlated to CO_2 density, at varying pressures and temperatures (0.5-60 MPa; 22-40 °C). The experimental device combines a Raman spectrometer with a HPOC (High Pressure Optical Cell) (Chou et al. 2005). The HPOC system is composed of a gas compressing system connected to a vacuum line, a gas reservoir, two pressure transducers and a fused silica capillary. The capillary is set on a heating-cooling stage (Linkam CAP500). The Raman acquisition parameters (time, number of accumulations, resolution, peak fitting) are optimized to reduce uncertainties. The results are compared to literature data and discussed on the basis of modifications in instrumentation and analytical protocols (Garrabos et al., 1980; Rosso and Bodnar, 1995; Kawakami et al., 2003; Yamamoto and Kagi, 2006; Song et al., 2009; Fall et al., 2011; Wang et al., 2011; Lamadrid et al., 2016). The present method is validated by comparing the density determined by Raman spectroscopy to that derived from microthermometric analysis of natural CO_2-H_2O-NaCl fluid inclusions from Camperio (Italy). With this new tool, we demonstrate that the reconstruction of all fluid inclusion properties within the CO_2-H_2O-NaCl system is possible at room temperature by Raman spectroscopy only (composition, salinity, pressure and dissolved carbon dioxide in the aqueous phase).

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S1.P03. Rapid multi-element analysis with laser ablation inductively coupled plasma time-of-flight mass spectrometry (LA-ICP-TOFMS) – A powerful tool for the study of fluid inclusions

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The technique of inductively coupled plasma time-of-flight mass spectrometry (ICP-TOFMS) is increasingly gaining interest as a new analytical tool in the Earth Sciences (e.g., Wiedenbeck 2016). In contrast to conventional mass spectrometers, such as quadrupole and sector field instruments that measure a limited number of isotopes sequentially, time-of-flight instruments can measure the entire mass spectrum simultaneously. The rapid acquisition of all elements has great benefits for the study of fluid inclusions because they typically produce complex and fast-changing signals, often originating from a mixture of liquid, vapor, and solid components.

The recently commercialized icpTOF instrument (TOFWERK AG, Thun, Switzerland) extracts full mass spectra at every 30 µs and is thus well-adapted for recording such transient signals from fluid inclusions. In order to further capitalize on the high acquisition speed of the icpTOF, it can be coupled to advanced laser ablation systems equipped with fast-washout cells that greatly reduce sample aerosol dispersion. This essentially compresses the signals from fluid inclusions, thereby improving signal-to-noise ratios.

The technique of LA-ICP-TOFMS has been shown to be applicable to the study of fluid inclusions, with precision and detection limits being competitive with those of quadrupole and sector field instruments (Harlaux et al., 2015). Here, we further corroborate the applicability of the method to the study of fluid inclusions by presenting new icpTOF data on synthetic capillaries and natural fluid inclusions. These data are compared to results produced with more conventional LA-ICP-MS setups.

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S1.P04. Solubility of methane in hydrocarbons by coupling infrared microspectroscopy with microcapillaries

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Fluid inclusions are the control of the paleofluids responsible for crystallization or recrystallization of minerals. When they are isochorous and closed systems since the inclusion seal, they can be used to reconstruct the history of fluid migration in a sedimentary basin. Hydrocarbon inclusions are frequently observed in oil reservoirs. Their composition and phase equilibria are related to the PVTX conditions (Pressure, Molar Volume, Temperature, Composition) at the time of trapping. Fluid inclusions are the only direct pressure and temperature markers in diagenetic environments (Teinturier et al., 2002, Bourdet et al., 2010). For PVT reconstruction, i) aqueous inclusions are analyzed by microthermometry and their dissolved gases are detected by Raman microspectrometry and ii) hydrocarbon inclusions are analyzed by microthermometry, infrared microspectroscopy (Pironon and Barres, 1990, 1992, Pironon et al., 2001) and confocal laser scanning microscopy.

Coupling Fourier Transform Infrared Microspectroscopy (µFT-IR) with capillaries is used for the first time to study the solubility of gas in hydrocarbons. This technique, used to calibrate the methane content of aqueous inclusions by Raman spectrometry (Caumon et al., 2014), is adapted to the hydrocarbon inclusions which cannot be studied by this technique because of their intense fluorescence. The capillary used is a fused silica tube of 100 microns internal diameter sealed at one end. It is connected to a pressure line that allows the injection of water or gas. The fused silica is transparent in the infrared beyond 2000 cm^{-1}, which allows the capillary to be positioned on the plate of the IR microscope. This spectral window makes it possible to visualize the absorption bands (stretching) of hydrocarbons, water, CO_2 and methane.

First results are obtained with octane and octane/water with methane pressure up to 300 bar. Absorption bands of the stretching vibrations of CH_4 and those of the CH_2 and CH_3 groups of octane are partly superimposed in the infrared spectra. After subtracting the octane spectrum, the areas of the methane bands are integrated to monitor their variation as a function of pressure.

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S1.P05. Negative pressures, supersaturation and precipitation in halite fluid inclusions: unsuspected phenomena and their implications for paleothermometry

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As fluid inclusions are comprised in rather rigid compartments, they are assumed to be quasi-isochoric systems. Upon cooling, the liquid in its compartment occupies a larger volume than it would at equilibrium with its vapor. A negative pressure develops, and the liquid is in a metastable state which ends when cavitation (the nucleation of vapor) occurs. This phenomenon explains the frequent occurrence of biphasic fluid inclusions in minerals, and the nucleation of a bubble in monophasic inclusions when cooled.

If the assumptions of unchanged volume and composition remain true for inclusions in quartz, they become precarious regarding halite FIs. Another phenomenon arises when the liquid is an aqueous solution saturated with respect to a very soluble solute. Because the saturated solute concentration is a function of temperature and pressure, part of the solute may precipitate out of solution upon cooling. This changes both the solution volume and its mass, modifying the pressure generated in the inclusion. For sodium chloride solutions, we calculate that the actual pressure is 50 % more negative than without precipitation. In the same way, supersaturated fluids when entrapped may lead to dramatically negative pressures through post-entrapment re-equilibration. We validate our analytic model using Brillouin spectroscopy on fluid inclusions in salt crystals. Our results have implications on the use of these fluid inclusions for reconstruction of past temperatures. The large negative pressures generated can damage the inclusions and yield inaccurate values for the past temperatures. We show how Brillouin spectroscopy solves this issue.

S1.P06. Laser-induced photolysis and oxidative coupling in CH_4-H_2S-S_8 inclusions

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Laser-induced photolysis accompanied by oxidative coupling was observed in fluid inclusions in metamorphic quartzite from the Western Bastar Craton, India (Randive et al., 2015) in gaseous inclusions adhered to Cr-muscovite crystals. Raman spectroscopy confirmed dominant CH_4 accompanied by minor amounts of H_2, C_2H_6, cyclooctane/cyclohexane, water and nitrogen. Occasional daughter crystals (< 0.3 µm in size) corresponded to orthorhombic (cycloocta-S) α-sulfur. Additional S-rich compounds have been detected in the S-H-stretching region according to strong bands at 2610 ± 2 (H_2S), 2604 ± 2 (compound A), 2572 ± 2 (compound B), 2501 ± 2 (compound C), and 2484 ± 2 cm^{-1} (compound D). H_2S and compound B are dissolved in methane liquid, whereas compounds B, C and D are bound to sulfur particles. Compound B, however, also occurs dissolved in the CH_4-rich liquid of S_8-free inclusions. Compound A exhibits vibrations at 4116 and 4144 cm^{-1} diagnostic of the H-H bonding.

All S-H species and methane were almost completely decomposed after 100-600 secs long exposition by a 13 mW, 532 nm laser to produce surplus hydrogen and sulfur. The photolytic effect was irreversible. After heating to 200 °C, CH_4 and H_2S recovered at the expense of molecular hydrogen, but other S-H species did not. Instead, strong vibrations were revealed between 1050 and 1170 cm^{-1} diagnostic of S=C stretching, C-H in-plane bending and C-C stretching/bending of aromatic hydrocarbons. The C-H stretching and C-C bending modes were also observable as shoulders at 1350 and 1582 cm^{-1}, corresponding either to disordered graphite or to polycyclic aromatic hydrocarbons.

Photolytic effect is typical of polysulfanes, which decompose into H_2S and elemental sulfur during flash photolysis. H_2 is produced by the breakdown of H_2S (Steudel, 2003). In our inclusions, the photolytic effect is accompanied by the CH_4 breakdown by the mechanism of oxidative coupling with sulfur (Anderson et al., 1993) triggered by weakly bound sulfur capable of activating methane C-H bonds (Zhu et al., 2013). However, none of vibration bands recorded prior to complete photolytic reaction corresponded to those of polysulfanes and/or typical products of the oxidative coupling, such as C_2H_6 and CS_2. The formation of aromatic C-C rings after thermal treatment is also enigmatic. Further research must be done to reveal compositions of S-H compounds coincidental with reducing high-PT metamorphism and capable of surviving the cooling to ambient temperature in hermetically sealed fluid inclusions.

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S1.P07. Fluid inclusions in structural geology studies: an example of the Antei Mo-U deposit (southeastern Transbaikalia, Russia)

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Recently in literature the results of fluid inclusion planes (FIPs) studies are published (Lespinasse, 1999; Lespinasse et al., 2005). FIPs are the mode I microcracks in rocks which trapped secondary fluid inclusions and formed distinctly shown systems (Tuttle, 1949). Due to the fact that orientation of FIPs is determined by variations in the stressed-strained state parameters (Petrov, 2011), it becomes possible to use them as a structural markers for reconstruction of the previously acting stress-strain field axes positions, recreating of the rock permeability chronology and reconstruction of the fluid migration pathways geometry.

In total with the obtained microthermometric data on secondary fluid inclusions this approach allows to determine the dynamics of changes in thermobaric and physicochemical conditions at the identified deformation stages of geological bodies.

Spatial parameters of FIPs were established using the modular software integrated into GIS and developed by authors (Ustinov and Petrov, 2015). Samples of rocks for realization of the considered approach must be oriented in space.

The Antei Mo-U deposit is located in the southeastern Transbaikalia within the Strel'tsovkaya caldera, which was formed during the late Mesozoic tectonic and magmatic activation of the region. The vein-stockwork deposit is localized in the granite basement of the caldera.

Oriented samples were selected along profiles at hypsometric levels of the 9th and 11th horizons of the deposit, at depths from the surface 550 m and 670 m, respectively.

It was established that the sequence of formation of microstructures and their participation in the process of fluids migration within the 9th and 11th horizons of the deposit is as follows: microcracks of the sublatitudinal orientation formed at the beginning of the hydrothermal process and trapped fluid inclusions with the highest homogenization temperatures (T_h~360-300 °C); at the next stage the NW (T_h~280-240 °C) and NE (T_h~260-200 °C) microcracks were formed; the last stage of hydrothermal process includes formation of sublatitude (second generation), NW (second generation) and submeridional microstructures with fluids of 220-160 °C interval of homogenization temperatures.

The obtained data can form the basis for creation of a detailed structural and fluidodynamic model of the Antei deposit containing unique reserves of Mo-U ores.

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S1.P08. Li isotopes in fluid inclusions as tracers for crustal fluids: An exploratory study

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Lithium isotopes in hydrothermal vents and ground waters are extensively used to trace fluid migrations and fluid/rock interactions in the shallow Earth's crust (Tomascak et al., 2016). Yet, Li isotopes in deep crustal fluids, commonly preserved as fluid inclusions, remain under-exploited (Masukawa et al., 2013; Teng et al., 2006; Yang et al., 2015).

Here, samples containing a wide range of fluid inclusion compositions representative of a variety of deep crustal fluid environments, from high-grade diagenetic, metamorphic to magmatic-hydrothermal conditions (~ 150 to 600 °C and ~ 5 to 78 % salts), have been investigated in order to provide the first overview of the range in Li isotopic composition.

Fluid inclusion leachates, from pure quartz and dolomite separates, of twenty-three samples worldwide were extracted and analysed using an innovative approach including: (i) bulk crush-leach (1-2 g) extraction of fluid inclusions; (ii) Na, K, Ca, Mg, Li and Sr analysis and Li elution using an automated high-performance ion chromatography and (iii) Li isotopes analysis by multi collector - inductively coupled plasma mass spectrometry.

Reconstructed Li concentrations and δ^7Li values of fluid inclusions (respectively 12 to 653 mg.l^{-1} and –1.4 ± 0.2 ‰ to +41.3 ± 0.8 ‰) are broadly compatible with previously established models for the origin of the fluids, fluid pathways and fluid-rock interaction in the studied localities. δ^7Li values are independent from conservative tracers (e.g. Br/Cl, I/Cl) and other parameters (e.g. temperature, salinity, Na/Ca, Na/K, Na/Mg, Na/Li and Na/Sr).

The results show that, in conjunction with other parameters, the Li isotopic compositions of fluid inclusions are potentially powerful tracers of deep crustal fluid migrations and fluid-rock interactions within a wide range of possible environments, for example, from sedimentary basins to ore-forming magmatic-hydrothermal systems but also possibly in seafloor hydrothermal systems and subduction zones.

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S1.P09. Advances in 3D imaging and volumetric reconstruction of fluid inclusions by high resolution X-ray computed tomography

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In this work we show the capabilities of 3D X-ray computed tomography for: (i) imaging the distribution of fluid inclusions in a crystal, to identify the different generations of fluid inclusions; (ii) determining the orientations of secondary fluid inclusion planes (healed microfractures) with respect to microfracturing and stress field; (iii) characterizing the shapes of fluid inclusions and identifying growth and re-equilibration features and (iv) volumetric reconstruction of fluid inclusions and determination of liquid/gas ratios at room temperature, an important parameter for the reconstruction of fluid densities and P-T reconstruction. We use a series of hand specimens and chips (ca. 5 mm × 5 mm × 0.3 mm) of natural and synthetic transparent (quartz, feldspar, garnet, emerald) and opaque (arsenopyrite, wolframite) minerals. 3D X-ray tomography was carried out using a Nanotom 180kV (Phoenix-General Electrics) X-ray microtomograph installed at GeoRessources (Giuliani et al., 2015; Morlot et al., 2016; Harlaux et al., 2017). With this equipment and the relatively small sample size, the resolution achieved reached 3-5 µm. Therefore, only relatively big fluid inclusions > 10 microns in diameter can formally be identified and fluid inclusions > 20 microns can reasonably be reconstructed in 3D for volumetric characterization. Data and image processing was carried out using Avizo software (®FEI). Fluid inclusions can be imaged in all tested transparent and opaque samples and liquid phases can be distinguished from gas phases. Hence, two-phase fluid inclusions can readily be distinguished from solid inclusions and empty pores / microfractures and decrepitated inclusions. Volumetric reconstruction of liquid/gas ratios in an oil-bearing inclusion using both 3D confocal imaging and 3D X-ray tomography show compatible results. Secondary fluid inclusion planes can be mapped and oriented in 3D. Preliminary results for microthermometry coupled with X-ray tomography and the influence of resolution on volumetric reconstructions will be presented.

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S1.P10. Raman densimeter for fluid inclusions of CO_2-H_2O system: The temperature and pressure effects

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Most CO_2-rich inclusions containing some water, which can be detected at the temperatures higher than 150 °C via Raman spectroscopy, although several Raman densimeters of pure CO_2 have been developed based on the relationship between CO_2 density and its Fermi diad split, the effects of temperature, pressure and content of H_2O were not well understood. In this study, Raman spectroscopic observation from 3 to 50 MPa and from 25 to 200 °C shows that the Fermi diad split of CO_2 decreases with increasing pressure and temperature in same density, and the maximum difference varying with temperature and pressure can be 0.5 cm^{-1}. Thus, the density of CO_2 calculated from Fermi diad split is affected by pressure and temperature. The Fermi diad split reduces about 0.02-0.1 cm^{-1} when CO_2 contains saturated H_2O in different pressure and temperature. New models taking pressure and temperature effects into account for calculating CO_2 density in pure CO_2 and CO_2-H_2O system were built. The models were applied to evaluate the CO_2 activities for a reservoir in the East China Sea Basin.

S2.P01. Reasons of formation of the fluid inclusions in the crystals of synthetic quartz with high germanium content

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The paper discusses the causes of the formation of fluid inclusions in quartz crystals with a high content of germanium (10-36 wt. %). Such crystals are a new promising piezoelectric material that has better piezoelectric characteristics and better performance at higher temperatures and pressures than conventional natural and synthetic quartz (Balitsky, 2005, 2007; Camdon and Haines 2017). Crystals of high germanium quartz are grown in supercritical aqueous solutions at temperatures of 500-650 °C and pressures of 120-250 MPa on seeds parallel to the faces of the trigonal prism and the trigonal pyramid, as well as on narrow Y-bars. One of the main macro defects of crystals is fluid inclusions. Their formation is associated mainly with the loss of morphological stability by almost all rough surfaces. The most sensitive of them with respect to the thermobaric growth conditions and the composition of the solutions is the surface of the base pinacoid. In alkaline solutions at temperatures above 370-390 °C these surfaces is covered by small regeneration growth pyramids, composed of the faces of the main rhombohedras, trapezohedra, hexagonal prism, trigonal prisms and trigonal pyramids. The high anisotropy of the growth rates of these facets leads first to the appearance in the growth sector of the base pinacoid of numerous cavities in which after fluid inclusions are formed. To a lesser extent, similar inclusions are formed in the growth sectors of other faces.

When crystals grow in fluoride (alkaline) solutions, the surface of the base pinacoid is covered by closely adjacent growth associates, is folded by the faces of the positive trigonal pyramid. This makes it possible to prevent the formation of fluid inclusions in crystals. Even more resistant to the occurrence of fluid inclusions are crystals grown on seeds, parallel to the faces of trigonal prisms and pyramids.

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S2.P02. Fluid inclusions in radioactive rocks and geobiotropy

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Some fluid inclusions located near radionuclides contain H_2, CO_2, N_2 and H_2O and show connected organic matter called "bitumen". Uranium is also observed inside some inclusions. The origin of this organic matter is not always well known. Some questions arise: Is it abiotic or biotic? Does it contain only hydrocarbons?

It is shown here that this organic matter may contain polymers of amino-acids, and may be linked to the field of prebiotic chemistry. Several experiments form the basis of this hypothesis. First, laboratory mixtures of CO, N_2 and little H_2O, when excited with particles of matter or interaction of the cosmic radiation, lead to deposits of macromolecular structures which show amino-acids after acid hydrolysis. With proton, helium ion and electron beams, the yield increase with the total energy absorbed by the gaseous mixture. The G-value for glycine is of the same order of magnitude with gamma rays at low dose rate, < 5 $gray.h^{-1}$ ($5\ J.kg^{-1}.h^{-1}$). The highest G-value is obtained with Ne beams at 310 $gray.h^{-1}$ and gamma rays at 78 $gray.h^{-1}$ on liquid mixtures of methanol, ammonia and water (Kobayashi 2008). Following the 1983 Schlesinger and Miller experimental suggestion, it has been shown that CO is the necessary reactant and not CO_2 (Fig5 of Kobayashi 1990). Second, it has been experimentally demonstrated that CO can form from hydrothermal hydrogenation of CO_2 (at 250°C & 250 bars in liquid phase, Fu & Seyfried, 2009, at 500°C & 1 bar in gas phase, Chen, 2000). Thus, pores inside rocks can concentrate CO_2, H_2, N_2 and H_2O and lead to CO and CH_4 in hydrothermal conditions. When located next to radionuclides such as uranium, gamma and alpha excitations can activate nitrogen (Bassez, 2003) and the activated mixture can lead to polymers of amino-acids as in Kobayashi's experiments and in the process of geobiotropy which is the evolution of rocks in symbiosis with the synthesis of components of life (Bassez, 2017 and refs MP Bassez herein).

Thus it seems quite relevant to analyze for amino acids content, the organic matter observed inside or nearby inclusions which are hosted by radioactive rocks. The cases of Athabaska, Canada and Witwatersrand basin, South Africa, are currently under experimental study.

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S2.P03. Inclusions in minerals vs inclusions in organic single crystals: state-of-the-art of surprising similarities

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Fluid inclusions are studied in olivines since their discovery by H. C. Sorby in 1858. More recently, the organic field showed an increasing interest about inclusions that decrease the purity level of the single crystals (Waldschmidt, 2011) or for the use of defective crystals as microcontainers (Seidel, 2015). Surprisingly, the data collected so far highlight converging results about the behaviour of fluid inclusions that were formed under far different conditions (ca. 1500°C and possibly high pressures for olivines versus room temperature and room pressure for organics).

Indeed, if we consider the thermal behaviour of inclusions, upon heating both kinds of inclusions show the drop in size of the gaseous bubble until complete disappearance. The temperature of homogenisation (T_h) has still a controverted meaning for geologists (Massare, 2002), but for the case of organic crystals no correlation can be made between T_h and the temperature of crystallisation or temperature of formation of the defects (Bobo, 2016). Moreover, the changing of shape of the vacuole towards negative crystal was observed in both olivines and organics during heating. This is due to the minimisation of the surface energy between the host and the fluid trapped. Another common point is the displacement of the inclusions when the crystal is under a thermal gradient: at the “hot” point the host crystal dissolves in the liquid phase whereas at the “cold” point the cavity crystallises. Concerning the mechanism(s) of formation of the inclusions in the olivine and organics, several studies tend to show that a high rate of growth is implied in the process (Faure, 2007; Bobo, 2015).

On the basis of these converging data, our purpose is to establish the state-of-the-art of the similarities as well as the differences about the fluid inclusions studied in geology and in organics and inorganics.

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S3.P01. Fluid inclusion studies of the Tin Felki rare - metal pegmatite (Iskel Terrane, Tuareg Shield-South Algeria)

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The Tin Felki Beryl-REE pegmatite belongs to Li-Cs-Ta enriched "LCT" type of Cerny and Ercit (2005) and associated to the very late Pan-African Taourirt granites (Boissonnas, 1973).

The Pan-African Tuareg Shield (Hoggar) hosts rare metal granites (RMG) and pegmatites (Be–Ta–Li) (Rare-Metal Pegmatites, RMP. Most known RMP are located in the Central Hoggar. A new field of beryl-topaz-garnet-bearing pegmatite dykes has recently been discovered at Tin Felki (in the Iskel terrane, Western Hoggar). The arc-type Iskel terrane consists mainly of Neoproterozoic volcanic rocks.The TinFelki pegmatite field is located along the western boundary of the Iskel terrane defined by the 4° 13 lithospheric fault. It consists of more than 100 subvertical pegmatites and aplite dykes, cutting the late Pan-African Tioueine granite and an isoclinally folded sequence of steeply dipping micaschists. The pegmatites contain the same minerals: quartz, feldspars, garnet, Al-Li-micas, beryl, phenakite, topaz, apatite, zircon, rutile, tourmaline (schorl), allanite, fluorite, cassiterite and columbite-tantalite. Quartz and feldspars constitute up to 85% in volume of the pegmatite minerals. Opaque minerals were identified as Nb-Ta-oxides (columbite-tantalite). They are included in topaz, albite, lepidolite or cassiterite, or filling the contact between cassiterite and albite.

Fluid inclusions are studied in quartz, beryl and topaz minerals and they are of the Lw, LwS, Lw-c, Lw-cS and Lc-w types.The different types usually coexist as isolated clusters within the host-mineral and may therefore be interpreted as primary. The included solids are frequent, with up to four different solid phases observed in a single inclusion. They are still not identified. One strongly anisotropic phase with hexagonal shape is frequently encountered in Lw-cS FI from the beryl, and could be Sassolite $B(OH)_3$. There are no signs of dissolution or melting of all these solid phases during heating runs up to 420°C and more, meaning that they are not daughter minerals, but were heterogeneously trapped from supersaturated fluids. Beside the fluid inclusions, apparent melt inclusions in beryl and topaz were found. Homogenization temperatures are various for the different types of FI, and differ according to the hosted mineral, from 140° to 280°C in quartz and from 270° to 420°C in beryl and topaz.

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S3.P02. Comendite melts of the Sant bimodal magmatic association, Central Mongolia: chemical composition, crystallization parameters, trace elements, and volatile components

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Using various methods of melt inclusion investigation, including electron and ion microprobe techniques, we estimated the composition, evolution, and formation conditions of melts producing the comendites of the bimodal volcanic association in the Sant area, central Mongolia. Rocks of a bimodal basalt–comendite association were found as large fields in the North Gobi Depression in central Mongolia. The association is spatially constrained to the North Gobi array of northeast-trending faults and occurs within a linear zone more than 180 km long. The bimodal association is located in the eastern part of Sant region and composes a volcanic field 20 X 12 km in area. The volcanic rocks of the bimodal series are basaltoids, trachytes, comendites, pantellerites, tuffs, and ignimbrites.

Primary melt inclusions were studied in quartz from three comendite samples taken from various parts of the vertical section of the volcanic sequence. Phenocrysts in the comendites were determined to crystallize within the temperature range of 880–960°C. Glasses in the homogeneous melt inclusions were determined to correspond mostly to rhyolite and more rarely to trachydacite in composition and contain 65–76 wt.% SiO_2, 10–14.6 wt.% Al_2O_3, 1.5–4.8 wt.% FeO, 3.1–6.5 wt.% Na_2O, and 4.4–6.3 wt.% K_2O. The glasses of all of the melt inclusions have similar chondrite-normalized multi-element patterns and are richer than chondrite in most trace elements (Zr, Rb, Nb, Ta, Th, U, Y, and REE) and depleted in Ba, Sr, Eu, and Ti. Glasses of melt inclusions hosted in the quartz phenocrysts from the three our samples differ from one another in concentrations of several trace elements and define three continuous groups of melts. Their trace element concentrations vary as follows: 1400–3200 ppm Zr, 290–650 ppm Rb, 190–650 ppm Nb, 200–400 ppm Y, 40–70 ppm Th, and 170–370 ppm Ce. The glasses of melt inclusions show distinctive volatile compositions (H_2O and F). Some of the melts enriched in these components (1.2–2.4 wt% H_2O and 0.8–1.1 wt% F), and other are depleted in them (0.1–0.3 wt.% H_2O and 0.1–0.5 wt.% F).

The melts show strong positive correlations between the concentrations of several trace elements (Zr, Rb, Nb, Ta, Th, U, Y, B, and Be) and REE, on the one hand, and the Nb concentrations, on the other. The melt inclusions provide a «record» of certain evolutionary episodes of the comendite melt, with this evolution controlled first of all by crystallization differentiation. The variations in the concentrations of volatile components were likely controlled by the degassing of the melts in response to a pressure decrease.

S3.P03. Evolution of magmas of the basalt-trachydacite-pantellerite rock series of Dzarta-Khuduk bimodal volcanic association (Central Mongolia): evidence from melt inclusions

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This contribution focuses on the compositions and evolutions of magmas from the Late Paleozoic bimodal volcanic association of Dzarta Khuduk, central Mongolia. A sequence of felsic agpaitic volcanics rests on subalkali basalts and consists of intercalating alkaline trachydacites, pantellerites, and comendites. Their mineralogical and chemicall characteristics correspond to silicic peralkaline rocks of the K-Na series with an agpaicity coefficient (K_a) of >1 and high contents of F, Zr, Li, Rb, and REE.

Primary melt inclusions were found in plagioclase from basalts, in anorthoclase from trachydacites and in quartz from pantellerites and pantelleritic tuffs. Thermometric experiments with melt inclusions were conducted in a one-atmosphere heating stage allowing rapid quenching (1-2 s). The inclusions in phenocrysts of basalts were completely homogenized at temperatures of 1150-1170 °C. The phenocrysts of the trachydacites and pantellerites crystallized at temperature of 1060-1000 °C.

During thermometric experiments with quartz-hosted melt inclusions from the pantellerites, the formation of immiscible silicate and salt (fluoride) melts were observed at a temperature of 800 °C. Homogeneous melt inclusions in plagioclase from basalts have both trachybasalt and basalt trachyandesite compositions. The glasses of melt inclusions in anorthoclase from trachydacites have both trachydacite and rhyolite compositions. Homogeneous melt inclusions in quartz from pantellerites and pantelleritic tuffs have rhyolitic compositions.

Analysis of the compositions of homogeneous melt inclusions in minerals of the above rocks allowed us to distinguish an undeniable geochemical relation between rocks of various composition of the bimodal volcanic association of Dzarta Khuduk. This relation is explained by the process of crystal fractionation. It was determined that the parental melts for the whole rock series were of alkaline basaltic composition. The origin of silicic rocks of the Dzarta Khuduk massif was related to the occurrence of shallow peripheral magmatic chambers providing conditions for profound differentiation of the parental basaltic melts that resulted in trachydacites and pantellerites enriched in Na, F, Li, Zr, Rb, Y, Hf, Th, U, and REE. During the late differentiation, when the magmatic system was saturated with respect to ore elements, Na-Ca fluoride melts were separated. These fluoride melts extracted considerable amounts of Li.

S3.P04. Fluid inclusion characteristics of ore-forming fluids in the Kyzyl-Tashtig VMS-polymetallic deposit, Eastern Tuva, Siberia, Russia

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Au-Ag-VMS-polymetallic Kyzyl-Tashtig deposit is located in the Lower Cambrian rhyolite-basalts in Ulugoy VMS-bearing zone of the Eastern Tuva (Kuzebny et al., 2001). We studied ore-bearing veins from the main ore body (no 4). Fluid inclusions trapped in quartz from the primary pyrite-sphalerite ores are $MgCl_2$-NaCl-H_2O (Borisenko, 1977) with a salinity of 8–11 mass % NaCl-eq (Bodnar and Vityk, 1994), and temperatures of homogenization 260–300 °C.

The following Cu-Zn and Cu ores are synchronous but isolated from each other in the area of the deposit. They dissect and cement pyrite-sphalerite ores and overprinted by later polymetallic ores (Kuzebny et al., 2001). The fluids trapped in quartz from these ore veins are aqueous with Na and K chlorides; homogenization temperatures are 160–200°C (Cu-Zn) and 160–180 °C (Cu), and salinities are 3.5–6.5 mass % (Cu-Zn) and 5.4–8 mass % NaCl-eq (Cu).

Polymetallic and the latest polymetallic-barite ores were formed due to NaCl-H2O and NaCl-KCl-H_2O fluids with a similar salinity of 3–8 mass % NaCl-eq, and temperatures of fluid inclusion homogenization 150–270 and 140–170 °C, respectively. These data are adjusted with published results of fluid inclusions in barite (Simonov and Kotlyarov, 2013).

The pressure of mineral formation calculated for Cu-Zn ores is 0.91 kbar (Kuzebny et al., 2001), and ΔT for the homogenization temperatures is 80 ºC (Potter, 1977). If approve that the depths of pyrite-sphalerite, Cu-Zn and polymetallic ores are close, therefore their temperatures of formation are 340–480, 240–280 and 180–250 °C, respectively.

Thus, fluid inclusion study of ore mineral associations in Kyzyl-Tashtig deposit clarified the reduction of the temperatures of formation and fluid salinities from the primary pyrite-sphalerite to the later polymetallic-barite ores. The close fluid characteristics indicate the common fluid source for different ore types of Kyzyl-Tashtig deposit. The presence of Mg and K chlorides and higher fluid salinity may be related to a magmatic contribution.

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S3.P05. An exploration model for porphyry copper deposits in the Collahuasi Mining District, Chile, based on petrography of fluid inclusions

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The search for mineral deposits is a time consuming, risky and very expensive process. Any technique that can help the exploration teams to quickly and inexpensively discriminate between areas with high potential for economic mineralization and those with lower potential provides a competitive advantage to those applying new technology. We recently developed a technique based on petrographic characteristics produced during immiscibility of the fluid “boiling events”, that can be applied in exploration for porphyry copper deposits.

We applied this new technique working on Collahuasi district in northeastern Chile. Three porphyry copper-molybdenum deposits are present there with high level epithermal copper-silver-gold veins, and paleogravel hosted exotic Cu deposits over an area of more than 120 km^2. The Quebrada Blanca, Rosario and Ujina are currently in production. The Rosario has mining reserves of 1,661 Mt at 0,91 percent copper (Dec. 2015). The Rosario is characterized by a K-feldespar altered core to secondary biotite-albite-magnetite assemblage surrounded by epidote-chlorite assemblage, overpinting by qz-sericite-pyrite alteration. To the south contains high-sulfidation epithermal veins quartz-alunite-pyrophilite-pyrite. This hydrothermal system known as Rosario West suggest of a second blind intrusion. More than 300 samples where collected from drill core from Rosario and Rosario West to characterize the fluid inclusions, alteration, type of rock and mineralization.

Preliminary results shows evidence of fluid inclusions assemblages in quartz and were classified at room temperature: (1) Halite-barring inclusions indicating high salinity fluids; (2) Chalcopyrite daughter mineral; (3) Liquid-rich aqueous inclusions with trapped solid; (4) Coexisting halite bearing and vapor-rich inclusions with a broad range in liquid-to-vapor ratios indicating fluid-phase separation; (5) Coexisting liquid-rich and vapor-rich inclusions with a broad range in liquid-to-vapor ratios indicating fluid-phase separation; (6) Vapor-rich inclusions indicating flashing of the fluid. These observations were incorporated into a geographical information platform to define the three dimensional relationship between the fluid inclusion characteristics, type of alteration, rock and mineralization. These results may be used to predict ore grades based on petrographic observations of fluid inclusion and mineral textures and provide a relatively simple and rapid tool for evaluating veins along unexplored portions of the Rosario and Rosario West to locate the blind intrusion.

S3.P06. Determination of the origin of fluids by noble gas isotope analyses: case studies of carbonatites (S India) and VMS deposits (N Italy, Albania)

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Isotope ratios of noble gases (He, Ne, Ar) measured in fluid inclusions of magmatic or hydrothermal formations may reveal the origin of fluids (e.g. mantle, crustal, seawater). Two study areas have been selected for noble gas isotope studies: (1) the Neoproterozoic carbonatite complexes from Sevattur and Samalpatti, Tamil Nadu, S India, and (2) Jurassic volcanogenic-massive sulfide deposits (VMS) from the Neotethyan region (N Italy and Albania). Noble gas isotope measurements have been carried out at the Institute for Nuclear Physics using a MAP-215 noble gas mass spectrometer. Noble gases have been released by in vacuo crushing and step heating (400-1200 °C) following detailed fluid inclusion investigations.

Primary fluid inclusions in apatite and secondary incluisons in calcite were analysed in the Sevattur carbonatites. The $^{3}He/^{4}He$ ratios range from 4.5 to 7.4 R_A, and show a broadly negative correlation with the $\delta^{13}C$ values of the host carbonate. Apatite appears to hold higher $^{3}He/^{4}He$ than coexisting calcite (4.3 versus 2.9 R_A).The Ne isotope systematics are consistent with the presence of a nucleogenic component, apparent in $^{22}Ne/^{20}Ne$ ratios lower and $^{21}Ne/^{22}Ne$ ratios higher than air. This component could represent the Ne isotope signature of the original fluid composition implying that the parental fluid already carried this feature. Alternatively, nucleogenic Ne could have been produced in the crystal lattice and had diffused into fluid inclusions a some later stage.

Quartz and calcite crystals from stockwork feeder zones of VMS deposits were studied in order to determine the characteristics and origin of the hydrothermal fluid. Results of fluid inclusion study as well as stable isotope geochemistry are yet inconclusive regarding the involvement of magmatic fluid. However, preliminary He–Ne–Ar isotope ratios (RA<<1, $^{22}Ne/^{20}Ne$ ~8.2-9.8; $^{21}Ne/^{22}Ne$ ~0.029, and $^{40}Ar/^{36}Ar$ ~270-320) in pure quartz crystals indicate no mantle component in the mineralizing fluids.

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S3.P07. Numerical simulation of a fossil geothermal system in northern Chile

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As a result of numerous studies over the past 3 decades of both active terrestrial geothermal systems and their fossil equivalents, the epithermal precious and base metal deposits, there is now a large database of fluid and mineral properties in these systems. Coupled with the numerical modelling of thermal-hydrological-chemical processes we have a good tool to understand the formation of hydrothermal systems.

We use fluid inclusion data, chemical compositions of base metal sulphides and flow rates to constrain a numerical model to predict thermodynamic and geochemical conditions of a fossil geothermal system, the Patricia Zn-Pb-Ag deposit located in northern Chile. This deposit consists of quartz and base metal sulfides veins of hydrothermal origin with structural control hosted in a volcanic succession. A detailed fluid inclusion study indicates that the hydrothermal fluids had circulation temperatures that range from 215 to 140 ºC, and salinities between 22 to 1 wt.% NaCl, with no evidence of boiling in the system (Chinchilla et al., 2016).

Models of the fluid-rock interaction were made using the reactive-transport code Toughreact to identify the most relevant geochemical and transport parameters controlling the formation of the fossil geothermal system. The paragenesis of the deposit is mimicked by a sequential model consistent with the observed mineral assemblage distribution and fluid inclusion data.

A preliminary result suggests that the precipitation of base metal sulphides is primarily controlled by fluid upflow rate and in minor degree by the fluid metal content. An acid fluid enriched in Zn and Pb, with the same salinity and circulation temperature inferred from the fluid inclusions is injected in an andesitic rock, with a permeability of 10^{-12} m^2 and enthalpy of 897 J/g. At low fluid flow rates <100 L/sec the pH varies from 3 to 7 (controlled by the fluid-rock interaction), with low pH values and high metal contents at the deeper levels of the system, and sulphide precipitation at those deeper levels. At higher fluid flow rates >100 L/sec, the injected fluid controls the pH of the system, with homogeneous pH values ~ 4 and high metal contents along the vertical profile of the system, with significant sulphide precipitation (up to 6 % of galena and 10-15 % of sphalerite in volume fraction) along the profile. Quartz precipitation is higher (~15-20 %) at deeper levels than near the surface at low fluid flow rates, but at faster flow rates is homogeneous along the whole profile (~10 % volume fraction).

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S3.P08. Fluid inclusion studies in the Cerro Bayo low sulfidation precious metals epithermal district of the Chilean Patagonia: Exploration applications

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Modern society demands ever more resources as the global population grows and expands. In particular, precious metals are showing increasing demand for technological devices, hence a strong push on exploration success. The Chilean Patagonia hosts numerous polymetallic and epithermal environment resources, among these the Cerro Bayo District in the Aysén Region. At Cerro Bayo, rocks of the Upper Jurasic Ibañez Formation are host to low sulfidation epithermal Ag-Au veins, a major system that is spread in over 100 sq.Km. The quartz veins are mostly subvertical, with a N to N-W strike(Townley, 1996; Poblete 2014). To asses applications of fluid inclusion studies in early determination and recognition of potential Ag-Au bearing veins and discrimination from non-potential ones, a detailed fluid inclusion petrography, gangue mineral textural characterization and mineralization paragenesis study was conducted on the ore bearing Fabiola and Dagny veins. More than 70 samples were collected from drill core and underground mine over a strike length of 350 m and to depths of 70 m. Each sample was assayed for Au and Ag. Thin sections of each sample were examined using a petrographic microscope, and fluid inclusion and mineralogical evidence for boiling of the hydrothermal fluids was recorded. Preliminary result show the paragenetic sequence in Dagny vein consists in 2 main mineralizing events of pyrite ± chalcopyrite ± quartz ± bladed calcite. Primary fluid inclusion assemblages (FIAs) were classified at room temperature, as well as jigsaw secondary FIAs, these consisting of coexisting liquid-rich and vapor rich inclusions. The late event shows quartz ± fluorite ± chlorite ± hematite ± magnetite. The fluorite shows primary FIAs containing liquid-rich fluid inclusions. The paragenetic sequence in Fabiola vein consists of at least 2 main mineralizing events of rhombohedral calcite ± adularia ± pyrite ± native gold ± sphalerite. Fluid inclusions were characterized by primary liquid-rich FIAs hosted in euhedral quartz. Secondary FIAs consisting of coexisting liquid-rich and vapor rich inclusions were found in euhedral quartz. The late barren assemblage shows quartz ± fluorite ± calcite ± hematite ± pyrrhotite. The fluorite shows primary FIAs containing liquid-rich inclusions. Areas of most intense boiling are associated with colloform and bladed calcite textures. These observations were incorporated into a geographical information platform to define potential geospatial correlations between the fluid inclusion characteristics, the gangue mineral textures and ore grades. These results may be used to predict ore grades based on fluid inclusion and mineral textures and provide a relatively simple and rapid tool for evaluating veins along unexplored portions of the Cerro Bayo District.

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S3.P09. Magma composition and role of volatile degassing in Deccan Large Igneous Province: A melt inclusion approach

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Numerous studies of melt inclusions in Large Igneous Provinces (LIPs) in the different part of the world have been documented in the literature (Sobolev et al., 2011). Present study carried out in the upper formations (the Wai subgroup) of Western Ghats, Deccan LIP. Melt inclusions study from Deccan LIP can provide new insights into the evolution of this important LIP. The Deccan LIP was fissure eruption mainly emplaced over a very short duration at 66 Ma (Schoene et al., 2015) and constitute one of Earth's largest continental flood basalt provinces (Glišović and Forte, 2017). Melt inclusions represent the sampling of magma and provide information about pre-eruptive volatile content of source. The inclusions are primary and range in shape and size varies from a few microns, up to 100 microns. The inclusions are crystalline, and contain daughter phases. Some are glassy, with or without a shrinkage bubble. The glassy inclusions are brownish to murky in color. Among the daughter phases, there are opaque phases which include ilmenite, magnetite and titanomagnetite. Shrinkage bubbles are usually distorted, possibly a result of pressure changes inside the inclusion (Wallace et al., 2015). The melt inclusions show substantial variations in major element composition. Inclusions are significantly enriched in TiO_2 (3.68 to 0.08 wt.%) and FeO (18.3 to 2.63 wt.%). SiO_2 ranges from 43.4-66.8 wt%. Al_2O_3 ranges from 9.7- 22.4 wt % and MgO 18.3-1.6. EPMA measurements demonstrated the presence of daughter crystals, such as magnetite and titanomagnetite and high FeO, TiO_2 and CaO within melt inclusions. Volatile concentrations were measured by FTIR, both plagioclase-and pyroxene hosted melt inclusions show a wide variable range of volatiles (up to 2 wt.% H_2O_{total} and 1808 ppm CO_2). Moreover, the variability in composition and volatiles in a different flows suggests that trapped melts were significantly affected by degassing and the post-entrapment changes. After each hiatus of the magmatic flows, the differentiated residual magma was enriched in Fe- Ti. Fractionating tholeiitic lavas follow a trend that reflected by iron saturation until Fe-Ti oxides start to precipitate. Compositions are affected by diffusion from the plagioclase host into the inclusion, e.g. precipitation of host, resulting in the high Al_2O_3. Melt inclusions showed evolved fractionated melt with the presence of aggregated crystals indicating that formation of these Fe-Ti oxides has occurred in an aqueous condition (Choudhary and Jadhav, 2012). As well, the formation of daughter mineral assemblages (titanomagnetite, and magnetite crystallization inside the inclusions) promotes the diffusion of hydrogen.

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S3.P10. Fluid inclusion studies in ore minerals from the polymetallic epithermal Pirquitas Sn-Ag deposit, Jujuy Province, NW Argentina

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The Pirquitas epithermal Sn-Ag deposit is located near the Bolivian border in the Argentinian Puna Plateau and was one of the most economic Sn-Ag-Zn producing mines in Argentina until it´s closure in 2017. Mineralization at Pirquitas is hosted in metamorphosed Ordovician metasedimentary rocks and is made of polymetallic veins, hydrothermal breccias and disseminated ore. The Pirquitas deposit is considered to be an analogue to the Bolivian Sn-Ag epithermal deposits but the origin of the ore-bearing fluids is still controversial. Although it is believed that the vein hosted mineralization at Pirquitas is related to Miocene magmatism, no direct association with magmatism was observed so far, e.g. a 800 m deep borehole did not confirm the existence a subvolcanic body beneath the Pirquitas open pit. The closest intrusion is the granodioritic Cerro Galàn some 12 km to the east of the Pirquitas mine (Soler et al., 2008).

Fluid inclusions hosted in quartz, Sn-Ag minerals (hocartite-pirquitasite, miargyrite, pyrargyrite) and sphalerite from several vein systems have been studied in transmitted and near infrared light. Microthermometric data of aqueous two-phase inclusions in different minerals show variable ranges of salinity from 10.6 to 0.8 wt.% NaCl equiv. and homogenous temperatures between 274° and 190° C probably due to mixing of saline (magmatic?) metal-rich fluids with meteoric water.

Fluid inclusion evidence for boiling as suggested in a previous study from the Cortaderas breccia body in the northern part of the deposit (Slater, 2016) was not observed in samples from vein-type mineralization in the southern part of the deposit. All results obtained are in agreement with fluid inclusion data from Bolivian epithermal Ag deposits such as the Potosi deposit with a range of homogenization temperatures and salinity of 174-311° C and 6.6-9.5 wt. % NaCl equiv., respectively and the San Rafael deposit near the Argentine border with a range of Th values between 157 and 317° C and salinity of 1.2-16 wt. % NaCl equiv. (Sugaki and Kitakaze, 1988).

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S3.P11. The magmatic-hydrothermal transition reflected in coexisting fluid and melt inclusions from erupted quartz grains at Corrida de Cori (Argentina)

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Understanding the exsolution of volatiles from melts and the transition from magmatic to hydrothermal realms is of utmost importance: It imparts a geochemical signature to the fluids that influences their potential to generate mineral deposits (Audétat et al., 2008; Cline and Bodnar, 1991). Rapidly quenched, coexisting melt and fluid inclusions provide pristine samples of the magmatic-hydrothermal transition that will inform about immiscibility in magmatic systems and allow determination of element partition coefficients between melt and fluid.

The Corrida de Cori volcanic chain between Chile and Argentina is an area of recent volcanic activity and intense fumarolic alteration, which indicates ongoing magmatic activity at depth (Richards and Villeneuve, 2002). Samples originate from the dacitic, ca. 460 ka Escorial Ignimbrite. Because the ignimbrite is poorly welded, not only decompression but also cooling at the surface was likely fast.

Large (cm-sized) quartz grains from the ignimbrite are tentatively interpreted to be magmatic products. Although growth zoning that outlines euhedral crystal morphology is visible with the naked eye, cathodoluminescence imaging reveals only faint features, as may be characteristic of plutonic signature (Frelinger et al., 2015). Moreover, lack of luminescence contrast around inclusion trails points to entrapment under similar (magmatic) conditions as for crystal growth. The quartz grains acted as large, stable containers that shielded the inclusions during eruption. Good preservation of inclusions is related to rapid pressure and temperature quenching, which prevented re-equilibration due to extrusion, interaction with later fluids, or alteration.

Silicate melt, dense brine, and vapor inclusions in quartz largely follow secondary trails that cross-cut growth zoning and often extend to the margin of the grains. Coexistence is evidenced by occurrence within the same trails and heterogeneous entrapment. Heterogeneously entrapped inclusions do not homogenize even at high temperatures (Richards 2003). However, all three inclusion types may also occur within separate assemblages. Daughter crystals in brine inclusions comprise halite, anhydrite, carbonate, Fe-chloride, and other, unidentified phases, as determined with transmitted light and Raman microscopy. Silicate melt inclusions can be variably devitrified. Even in glassy inclusions, their water contents appear to be low, according to Raman spectroscopy.

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S3.P12. Mineralizing fluids from the Alhué mining district, Chile

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During the past half century numerous fluid inclusions studies of hydrothermal precious and base metal deposits were conducted, and our understanding of the physical and chemical context of metal transport and deposition has evolved greatly from these studies. This project involves the understanding of different mineralization events and fluid sources from the Alhué mining district which is located within the Coastal Range of Central Chile. More than 200 samples were collected from surface outcrops, underground mines and recent drill cores. Three veins where sampled: Maqui, Lorena and Tribuna Este. Most of the samples (~ 75 %) were assayed for Au, Ag, Cu, Pb, Zn, As, Sb. Petrographic evidence shows that the sulfide-mineralization corresponds to sphalerite, galena, chalcopyrite and pyrite. The features associated with those events show the evidence of Fluid Inclusion Assemblages (FIAs) at room temperature and were classified at room temperature and during heating experiments. In quartz: (1) Secondary liquid-rich FI that homogenize by vapor disappearance. ThL→V ranging from 183 to 419 °C (2) Secondary vapor-rich FI that homogenize by liquid disappearance. ThV→L from 431 to 455 °C (3) Secondary vapor-rich FI bearing halite crystals where halite disappearance is above > 520 °C and ThV→L ranges from 359 to 418 °C (4) Secondary liquid-rich FI bearing halite crystals and solids. ThL→V ranging from 213 to 467°C and Tmhalite between 211 and 387 °C (5) Secondary liquid-rich FI bearing rounded chlorides and solids. ThL→V ranging from 253 to 273 °C and Tmchloride ranging between 307 to 364 °C (6) Secondary FIAs of coexisting liquid-rich and vapor-rich FI where the ThL→V ranges from 384 to 415 °C (7) Primary FIAs of coexisting halite bearing and vapour rich FI. ThL→V ranges from 381 to 446 °C and Tmhalite is >500°C (8) Secondary FIAs of coexisting halite bearing and vapour rich FI. The ThL→V ranges from 381 to 387 °C and Tmhalite is >500 °C. In sphalerite: (9) Primary liquid-rich FI with homogenization temperatures (Th) ranging from 209 to 311 °C and final ice melting temperature (Tm) ranges from –20.7 to –17.6 ºC (10) Secondary liquid-rich FI. Th ranges from 180 to 340 °C and Tm ranges from –11.9 to –2.1 ºC. Laser ablation ICP-MS in fluid inclusions shows increments in Ag-Cu related to hypersaline fluids (~ 33 wt.% NaCl) in the Lorena vein. The Maqui vein shows Ag-Ba-Cu-Mn-Fe related to low salinity fluids (~ 5% wt.% NaCl). The Tribuna Este shows Ag-Al-Fe-Cd related to intermediate salinities (~18 wt.% NaCl). Petrographic evidence of FIAs in all the vein has close correlation between boiling/flashing and economic metal for exploration. The different in electrolytes and Th observed shows the contribution of different types of fluids where some of them are related to deeper mesothermal conditions overprinted by an epithermal environment.

S3.P13. Reconstructing the PTX conditions of a possible Archean porphyry-type deposit: the 2740 Ma Côté Gold Au(-Cu) Deposit, Canada

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The Côté Gold deposit is a newly discovered (2009) low-grade (~1 g/t) and high-tonnage Au(-Cu) deposit (+8 Moz Au) related to a 2740 Ma diorite-tonalite intrusive complex near western margin of the gold-rich Abitibi Subprovince of northern Ontario (Canada). Based on our previous integrated field, petrological, lithogeochemical and geochronological (U-Pb: magmatic zircon, hydrothermal titanite; Re-Os: molybdenite) work supplemented with isotopic (i.e., $\delta^{18}O_{quartz}$ = +6 to +12 ‰) studies, the deposit has been interpreted as a high-level, subaqueous magmatic-hydrothermal system. The nature of the mineralization (breccia, stockwork, vein) and alteration (potassic, phyllic, sodic), which reflect a temporal-spatial overlap between magmatic and hydrothermal activity at 2740 Ma, suggest the deposit represents an Archean analogue of Phanerozoic gold-rich porphyry deposits. In this context, several outstanding aspects relating to this model remain to be addressed, including a better estimate of the level of the paleo-ore system and the nature/origin of the ore fluids. The present fluid inclusion (FI) study aims to address these important issues.

A detailed petrographic study of about 50 samples with thermometric measurements reveals H2O and CO_2±H_2O secondary (S) and pseudosecondary (PS) types of FIAs are present in miarolitic quartz and vein quartz ± carbonate ± tourmaline ± sulfide samples as follows: (1) PS aqueous L-V (L:V ~0.9); (2) S aqueous with variable L-V ratios (0.9, 0.8, 0.6); and (3) S CO_2±H_2O- with variable ratios (~0.9-0.5). Locally H_2O and CO_2-H_2O types decorate healed fracture planes. In addition, halite ± other solid phases are relatively common in each FIA. Thermometry indicates the following: 1) H_2O type FIAs have variable salinities (~7 to 35 wt.% eq. NaCl) and Na:Ca ratios (1 to 0.9) and Th = 65 to 375 °C with Th(L)<Th(H); and 2) H_2O-CO_2 type FIAs have Tm_{CO2} of ~–57.0 °C and Th_{CO2} = 5 to 30°C; Tm_{clath} was not possible and inclusions decrepitate around 300-350 °C. SEM-EDS analyses of 100s of evaporate mounds indicate fluid chemistry (normalized to 100 wt.%) is dominated by Na and Ca (Na:Ca = 1.0-0.2) with <10 wt.% K; in addition there is a few wt.% levels of F, S, Fe and Mn. These data suggest the following: 1) mixing of at least two fluid types (H_2O, CO_2-H_2O) with possible unmixing of the carbonic type; 2) a magmatic component based on the presence of F reflecting F-phases in the breccia (e.g., fluorite, bastnaesite); 3) modification of the H_2O fluid due to fluid: rock interaction increasing its salinity through dehydration (i.e., wallrock hydration) and increasing its Ca:Na ratio via albitization of the host rocks; and 4) fluid emplacement at <1 kbar based on homogenization of Th(L) vs. Th(Halite).

S3.P14. Volatile concentration of magmas in the Veiðivötn fissure swarm, Iceland based on fluid and silicate melt inclusions

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Volatile concentrations in silicate melt and fluid inclusions, as well as groundmass glasses, were measured in three plagioclase-olivine-clinopyroxene phyric tephra samples from the 8-9 ka Brandur, Fontur and Saxi tuff cones within the Bárðarbunga-Veiðivötn volcanic system in the Eastern Volcanic Zone of Iceland.

The H_2O concentration in the melt inclusions and the groundmass glass is between ~0.1 and ~0.53 wt.%. No correlation is observed between the H_2O contents of melt inclusions and any major components in melt inclusion glass. This suggests that the water content of the inclusions was modified by both diffusive loss and gain of H^+ (Danyushevsky et al., 2002; Hartley et al., 2015) during the transport of the host minerals towards the surface.

CO_2 concentration in melt inclusions is from ~179 ppm up to ~1063 ppm, with the majority of the inclusions containing less than 750 ppm CO_2. CO_2 content in groundmass glasses is below detection limit. CO_2 contents in melt inclusions do not correlate with major elements due to extensive degassing starting at more than 5 km depth, as estimated based on CO_2 density in coexisting fluid inclusions (Gunnarsson et al., this volume).

S concentration varies from ~300 ppm to ~1700 ppm in groundmass glass and ~800 ppm to ~1400 ppm in melt inclusions. The relationship between S and MgO indicates enrichment of S via extensive fractional crystallization followed by S degassing.

Cl concentration is between ~16 ppm and ~104 ppm in melt inclusions and between 0 and 250 ppm groundmass glasses. Cl/K varies between 0 to 0.16. This range is larger than that estimated for mid-ocean ridge basalts (between ~0 and ~0.08, Michael & Cornell, 1998). The average Cl/K, as well as its variation, is higher in primitive melt inclusions (0.055, $1\sigma = 0.026$) than in the more evolved ones (0.045, $1\sigma = 0.017$). This relationship is consistent with extensive variation in Cl/K of the mantle source.

These volatile concentrations are similar to those measured in melt inclusions and groundmass glasses from the 2014-2015 eruption at Holuhraun (Bali et al., submitted), which occurred in the same volcanic system (Sigmarsson & Halldórsson, 2015). The only difference is that the variability in Cl/K is larger in these melt inclusions than in those from Holuhraun. This difference might be the result of slight differences in the mantle source.

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S3.P15. Magma storage conditions in the Veiðivötn fissure swarm in Iceland

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We have studied the chemical composition of silicate melt and fluid inclusions, their host minerals, as well as the composition of groundmass glass in three plagioclase-olivine-clinopyroxene phyric tephra samples from the 8-9 ka Brandur, Fontur and Saxi tuff cones of the Bárðarbunga-Veiðvötn fissure swarm in the Eastern Volcanic Zone of Iceland. The objective of the study is to determine magma storage conditions for these events and compare these conditions to those observed for the 2014-2015 eruption at Holuhraun, which has the geochemical fingerprint of the Bárðarbunga-Veiðivötn system, despite its location within the southern segment of the Askja fissure swarm (Sigmarsson & Halldórsson, 2015).

Magma storage conditions were calculated with a number of thermobarometers, including:

a) an improved version of the olivine-plagioclase-augite-melt (OPAM) barometer of Yang et al., (1996) (Harley et al., submitted);

b) the new clinopyroxene(cpx)-melt barometer of Putirka and Neave (2017);

c) CO_2 saturation pressure in silicate glasses (Shishkina et al., 2014);

d) CO_2 density in fluid inclusions;

We observe that there is an excellent agreement between the results of cpx-melt and OPAM barometries where both methods are applicable. In contrast, CO_2 saturation pressures in silicate glass are lower than either cpx-melt or OPAM barometries over the pressure of 50 ±40 MPa.

OPAM and cpx-melt thermobarometry indicate crystallization of the microphenocrysts at a mean pressure of 140 ±150 MPa and temperature of ~1180 °C. This implies that microphenocrysts last equilibrated with the erupted melt composition at approximately 4 km depth, hence on course towards the surface. Pressures and temperatures calculated from melt inclusions give higher values, on an average 270 ±130 MPa and ~1230 °C, respectively, corresponding to an average entrapment depth of 7.7 km. The highest recorded inclusion entrapment pressure was 480 ±130 MPa, suggesting magma storage conditions as deep as 15 km. Fluid inclusions indicate 5 km entrapment depth at most.

Comparing these results to the products of the 2014-2015 eruption at Holuhraun, we conclude that magmas, erupted by the Bárðarbunga-Veiðivötn volcanic system more than 8000 years apart, were stored at identical conditions.

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S3.P16. Mineralogy, geochemistry and fluid inclusion analyses of the NamXe rare earth mineral prospect - preliminary data

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The NamXe rare earth deposit situated in North West Vietnam is described as carbonatitic dyke system. These pristine carbonatitic dykes are hosted by dominantly basaltic rocks (Triassic) and contain various types of rare earth element (REE) minerals such bastnaesite, parisite, synchysite and monazite (Juskowiak 1986).

Previous studies that were constrained to a small number of surface samples defined two major compositional groups of carbonatitic dykes, both hosted in a thick sequence of andesitic basalt breccia. Calciocarbonatite dykes are composed of mainly calcite with aegerine, biotite, apatite, arvedsonite and magnetite. Ferrocarbonatite dykes, on the other hand, consist of calcite, ankerite, REE-fluorcarbonates, albite, apatite, iron oxides, and Ba- and Sr-sulfates (Thi et al., 2013 and references therein). This description is complemented in the present study by systematic sampling of two complete drill cores that cut through the deposit.

The dykes are texturally and mineralogically very heterogeneous showing usually a barren outer rim and an inner core that is very rich in REE-fluorcarbonates. The contact between basalt and dyke is usually sharp with signs of wall rock alteration. The rim zone of the dykes is often characterized by large euhedral biotite crystals growing into the direction of the dyke center. In some dykes the biotite of the rim zone is detached from the selvage, with the resultant gap filled by sparitic calcite. The biotite crystals from the outer rim are overgrown by large euhedral calcite crystals. In some dykes, massive barite or ankerite occur in the place of calcite. REE mineralization is confined to the inner core of the dykes. This core zone has a highly irregular corroded contact to the calcite-rich outer core zone. The inner core zone comprises of very fine-grained rare earth fluorcabonates associated with equally fine-grained barite, celestine or a solid solution of both (bario-celestine) and calcite.

Euhedral calcite from the calcite and outer rim zones exhibit abundant liquid-vapour fluid inclusions, which are between 5 and 20 µm in size. Detailed microthermometric analyses of fluid inclusions are currently carried out to constrain the temperature and fluid composition during dyke formation. Laser Raman spectroscopy will be used to qualitatively determine the composition of the gas phases present in the fluid inclusions. By combining petrography, geochemistry and fluid inclusion studies we aim to constrain the ore-forming processes to place constraints on the genesis on REE-minerals at the Nam Xe deposit.

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S3.P17. Mineralogy and fluid inclusions of amethyst veins, Auvergne, Central Massif France: Implication for hydrothermal evolution and genesis

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Most amethyst deposits are closely related to granitoids. The Vernet-la-Varenne Amethyst (Auvergne district, French Massif Central) is hosted by several granite and grano-diorite sub-types with few aplite/pegmatite occurrences. Amethyst veins have been mined between the 17th and the 20th centuries, but the ore genesis and the hydrothermal evolution remain poorly understood because of the lack of systematic studies of field geology, mineralogy and geochemistry.

In the studied area, amethyst veins are mainly oriented N110-N130 and are intimately related to silicified zones with progressive change of quartz colour ranging from milk to purple.

Two main paragenetic stages of amethyst formation have been recognized based on petrographic observations. The first paragenesis Si-S-Cu-As-Sb-rich is composed of milky-quartz, pyrite and Cu-Fe sulphides solid solutions with an As end-member (tennantite) and a Sb end-member (tetrahedrite), whereas the second paragenesis is As-Sb-free and mainly composed of milky-quartz and chalcopyrite.

The fluid inclusion study reveals that the amethyst veins were formed from low temperature (100 to 300 °C) and low (<3.5 % equiv. wt.% NaCl), to high-salinity fluids (18 to 22 eq wt.% NaCl). A subordinate aqueous fluid of moderate salinity has been also recorded (14 eq wt.% NaCl).

Temperature and salinity variations suggest the occurrence of mixing and dilution of early magmatic fluids with external fluids (meteoric and/or evaporate leaching). Further oxygen and hydrogen isotopic data are needed to precise the proposed hypothesis.

S3.P18. Porphyry style Mo-Cu mineralization in the Paleoproterozoic Eglab massif, SW Algeria: evidence from fluid inclusions

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The Paleoproterozoic Bled M'Dena igneous complex, located in the Eglab massif of SW Algeria, contains disseminated and stockwork vein-hosted Mo-Cu mineralization. Several characteristics suggest that the mineralization is of porphyry style. These include: i) the monzodioritic to granodioritic composition of the intrusive rocks, ii) their calc-alkaline geochemical affinity, iii) the interpreted island-arc geodynamic setting, and iv) the high Sr/Y ratio and low Yb concentration of the units, typical of Cu ± Mo ± Au porphyry (e.g. Richards, 2011). Main sulphides include pyrite, molybdenite, chalcopyrite and galena, the latter being generally associated with chalcopyrite but not with molybdenite. Other minor ore minerals disseminated in the granitoids and in the veins, identified by SEM-EDS, include scheelite, powellite, sphalerite, hematite, native gold and tellurides of Ag, Sb, Bi, Zn and As, plus barite, celestite, fluorite and anhydrite (Lagraa et al., 2017). Selvages of propylitically altered rock surround the stockwork veins.

Euhedral to subhedral quartz crystals in the stockwork veins contain primary fluid inclusions that mark growth zones. The fluid inclusions are mostly aqueous, although CO_2 was detected in inclusions with high V/L ratios. Fluid inclusions containing with one or more daughter minerals were also identified. These solid phases include salts (halite and sylvite), carbonates (calcite and siderite), sulfides (molybdenite and chalcopyrite) and anhydrite. Homogenization temperatures of fluid inclusions ranged from 130 °C to 400 °C, for densities from 0.96 to 0.7 g/cm^3, respectively. Based on the data, at least two different fluids were interpreted to have circulated in the veins: a high-temperature, saline fluid (Th up to 400 °C; >22 wt.% eq NaCl), and a lower-temperature fluid of moderate salinity (Th ~280 °C; 5 % to 10 wt.% eq NaCl) containing Ca and CO_2. Relatively high-temperature, sulphide-bearing brines are characteristic of orthomagmatic fluids from many porphyry deposits worldwide. Similarly, Ca-bearing fluids containing carbonic gases are consistent with the propylitic alteration around the veins. This is one of very few Precambrian porphyry occurrences described in Africa, particularly in the West African Craton and, to our knowledge, the only case of a porphyry Mo on the continent.

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S3.P19. Study of fluid-rock interaction in a Variscan biotite granite from Beiras Uraniferous subprovince (Portugal). Preliminary results.

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Several hydrothermal alteration stages such as: albitization, muscovitization, sericitization, chloritization, epidotization, hematization and silicification were identified (Maia, 2014) in the late to post-tectonic biotitic granite of Freixosa–Mesquitela (Mangualde region Central Portugal). The granite is peraluminous and belongs to the Cota-Viseu granitic massif (U-Pb data of 306 Ma) (Valle-Aguado et al., 2005). The main regional tectonic structure is characterized by two main tectonic fractures systems: NNE-SSW and WSW-ESE. Quartz veins with U mineralizations were exploited in the last century in the Viseu area (e.g., Cunha Baixa, Quinto do Bispo, etc).

The fluid inclusions study on both magmatic and hydrothermal quartz was carried out in order to evaluate the fluid-rock interaction. Fluid inclusion planes (FIPs) in hydrothermal quartz show a NW-SE, and N-S striking, whereas the magmatic quartz shows a NNE-SSW striking.

Two generations of fluids were identified in two phase inclusions in the magmatic quartz: aqueous fluids of moderate salinity (2.57-9.61 wt.% eq NaCl) in NW-SE FIPs; and aqueous fluids of low to moderate salinity (0.53/7.45 – 1.74/10.24 wt% eq NaCl) in N-S/NNE-SSW FIPs. The Th pointed on 3 intervals corresponding to a minimum temperature: 100-140 ºC, 220-240 ºC and 300-340 ºC respectively.

The FIPs with NW-SE/N-S strikes observed in hydrothermal quartz contain one-phase and two-phase fluid inclusions with low-salinity (2 wt.% eq NaCl) and high-salinity (26 wt.% eq NaCl) fluids. The measured Th pointed on 4 intervals for the minimum trapping temperatures on this fluid: 100-140, 180-220, 300-340 and 400-420 ºC.

The hydrothermal alteration stages identified in the biotitic granite of Freixosa–Mesquitela resulted from the interaction of aqueous fluids with of different salinities with the granite along the main fracture systems. The hottest and low salinity fluids being related to the albitization of the granite and the coldest and more saline to epidotization and hematitization.

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S3.P20. Pilot data from fluids in faults from above the Chilean triple junction show shallow flashing

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The Liquiñe-Ofqui fault zone (LOFZ) is located in Chilean Northern Patagonia and runs a length of ~1200 km from north to south and is coincident with the major Southern Volcanic Zone (SVC). Assessment of the geologic and geodynamic setting including the structural analysis focused primarily on geothermal targets in this investigation. Hydrothermal fluids in faults and fractures provide important insight into how the LOFZ operates because fluid pathways are critical for the productivity of geothermal reservoirs which are commonly controlled by structures. The LOFZ has many geological implications including geohazards (as a seismic source) to being a source for geothermal energy. Here we present the first time ever results of fluids that were a trapped in fluid inclusions in the LOFZ near the Chilean Triple Junction (CTJ).

Here we present a detailed petrographic study of fluid inclusion from within the fault core of the LOFZ Secondary vapor-rich Fluid Inclusion Assemblages (FIAs) hosted in quartz indicating flashing of the fluid. Primary liquid-rich FIAs hosted in bladed calcite with homogenization temperatures (T_h) ranges from 190 to 200 °C. These observations suggest liquid fluids were from near lithostatic pressure and decompress passing to the vapor phase immediately “flashing”. Gradually decrease in temperature to touch the liquid vapor curve producing bladed calcite. The T_h indicates a minimum pressure of 12-15 bar (126-165 m depth), which perhaps formed during fault rupture. What this means is that the flashing occurred a shallow depth which suggests a) there is perhaps a high geothermal gradient here as suggested from some geophysical studies, and b) that during fault ruptures that fluids rich in calcium migrate through and precipitate in the fault zone.

Through studying the faults within LOFZ and the fluids found there we can better understand how heat is distributed in the crust and we hope that our preliminary data provides new insight into fault behavior and perhaps provides mechanisms for the rapid uplift (thermal) along the LOFZ.

S3.P21. Fingerprinting W-Sn-Nb-Ta-Sb mineralization by coupled fluid inclusion – trace element investigation of vein quartz: The Echassiere granitic complex (Massif Central, France)

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The Echassiere granitic complex (Allier, Massif Central, France) consists of the two-mica - cordierite Colettes granitic pluton (7 km^2 approx., intruded into the Sioule nappe shales during the Namurien / Westphalian; Cuney et al., 1992) and, further south, the younger rare-element-bearing Beauvoir granite (0.1 km^2 approx., dated at 317 ± 6 Ma by Melleton et al. 2015). The latter was strongly affected by a greisen episode that altered the two granites, and produced a set of sub-vertical miarolitic quartz veins and a sub-economic, disseminated Nb-Ta-Sn mineralization (Cuney et al., 1992). In the area, also occurs a W-Nb-Ta-bearing vein stockwork, which is interpreted to represent a hydrothermal system related to a concealed intrusive body, the La Bosse granite, emplaced prior to intrusion of the Beauvoir granite (Aubert, 1969). A last set of veins intersects the Colettes pluton and the schist at a more distal scale. These veins are relatively large, have a constant strike of N 150 - N 40, and are mineralized in W, Sn, Sb and other rare metals.

In order to trace the hydrothermal events that produced the different mineralized vein sets, we undertook a detailed geochemical study of quartz from these veins, coupled with a fluid inclusion investigation. Similar signatures (high Li/Na and Ge/Ti ratios) and fluid characteristics (moderate temperatures and low salinities) suggest a genetic link between distal greisen alteration and the regional vein network (N 150 - N 40). On the contrary, most quartz from the La Bosse stockwork shows textures and chemistry (lower Li/Na and Ge/Ti ratios) that differ from those of the hydrothermal quartz in the altered granites. Quartz textures observed by SEM-CL indicate that most veins underwent multiple reactivation, and the chemical signatures of successive quartz generations could be related to multiple mineralizing stages. In addition, fibrous quartz texture and heterogeneous fluid-inclusion populations in some of these quartz generations indicate boiling of the fluid, providing a viable mechanism for decreasing rare-metal solubility and initiating precipitation of W, Sn and Sb. The sulphur present in the host schist scavenged by the greisen fluid (originally very S-poor) permitted the crystallization of stannite and stibnite.

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S3.P22. Characterization of selected fluid inclusions belonging to the Los Bronces porphyry Cu(-Mo) deposit, Chile

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The Río-Blanco-Los Bronces porphyry Cu(-Mo) deposit is part of the Central Chilean Mio-Pliocene Metalogenic Belt and the third largest Cu deposit in the world (Camus, 2002).It was probably formed by magmatic-hydrothermal fluids exsolved from unexposed composite plutons, which entered the San Francisco batholith (SFB) host rock of Miocene age (Deckart et al., 2005), where hydrostatic pressure exceeded combined lithostatic load and tensile strength of the host rock, leading to brecciation of the SFB. Subsequent hydrothermal alteration and mineralization by breccia cementation and dissemination rather than stockwork formation took place (Serrano et al., 1994; Frikken, 2003). The aim of this study is to understand the PVTX, conditions and physical separation of the two immiscible fluid phases leading to precipitation of the economic minerals. A detailed petrographic study of fluid inclusions of the Los Bronces cluster at room temperature shows different Fluid Inclusion Assemblages (FIAs) in quartz, which were classified: (1) Secondary vapour-rich inclusions with solids and (2) Secondary FIAs of coexisting halite bearing and vapour rich fluid inclusions and solids. The presence of solid in the fluid inclusions might suggest the fluid that formed the economic mineralization. Fluid inclusions in anhydrite also contain (3) Primary FIA of coexisting liquid-rich and vapor-rich fluid inclusions, which can be paragenetically associated with ore mineralization. Some unidentified, red one-phase inclusions are associated with mineralization as well. Microthermometry will be conducted to know the PVT properties of the fluid and Raman microspectrometry will be used to obtain volatile content. LA-ICP-MS will be used to evaluate fluid composition for individual FIAs from veins at different hydrothermal stages and TitaniQ temperatures for quartz (Thomas et al., 2010) to compare with microthermometry.

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S3.P23. Characterization of mineralized fluids from Chancón mining district; applications in energy-related technologies

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Critical and strategic minerals do change with time. To develop new technologies, some elements are needed to produce, transmit, store and conserve energy. In recent years a wide variety of rare metals, including indium, selenium and tellurium, have found important applications in energy-related technologies such as advanced photovoltaic solar cells (Jaffe et al., 2011). These metals are produced commercially as a byproduct in the refining of porphyry copper and similar ores, and from indium- selenium- and tellurium-rich epithermal deposits. The Chancón mining district is located within the Coastal Range of Central Chile and shows characteristics and mineralization that can be produced as by-product from the gold mineralization (e.g. tellurium or selenium) to the base metal mineralization zinc (e.g. Indium). The proposed study involve analyses of In, Se, and Te from well-characterized fluid inclusions from the La Leona vein to identify differences in fluid chemistry, which may help to better understand metal transport and deposition in the Coastal Range systems. The La Leona vein shows the shallow part has minerals assemblages quartz-calcite, and pyrite, with gold and silver mineralization. While in the deepest levels sampled shows chlorite-epidote, chalcopyrite, sphalerite and galena. Three stages of mineralization have been defined: (1) pre-ore stage is characterized by pyrite and chalcopyrite, (2) Au-Ag and base metal stage; characterized by pyrite, chalcopyrite, sphalerite, galena and Au-Ag in quartz, pyrite and chalcopyrite, (3) post-ore stage; characterized by rhombic calcite, chlorite and epidote. Samples were assayed by 62 elements include indium mineralization range from 0.04 to 12.5 ppm, selenium range from 3.7 to 22.8 ppm and tellurium range from 2.2 to 11 ppm. A detailed petrographic study of fluid inclusion shows primary and secondary Fluid Inclusion Assemblages (FIAs) hosted in quartz and were classified as containing: (1) coexisting liquid-rich and vapor-rich fluid inclusions shows a homogenization temperatures (T_h) ranges from 250 to 245 °C and final ice melting temperature (T_m) ranges from –4.8 to –3.7 °C; (2) secondary assemblages consisting of only vapor-rich inclusions, (3) liquid-rich inclusions with consistent liquid-to-vapor ratios hosted in sphalerite shows the Th ranges from 240 to 235 °C and T_m ranges from –6.5 to –6.1 °C. Laser ablation ICMPS in fluid inclusions shows enrichment of critical elements in sphalerite. The In range from 0.2 to 276.8 ppm, Se range from 37.1 to 482.5 ppm, Te range from 0 to 99.5 ppm, Au range from 0.1 to 8.1 ppm and Ag range from 13.1 to 1640.6 ppm. Secondary fluid inclusions in quartz only shows enrichment in Ag range from 2.8 to 9 ppm. These suggest that some critical elements might be important in this area.

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S3.P24. Relationship between magma and Cu-mineralization in Eastern Jbilet (Morocco)

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Copper hydrothermal vein deposits are orebodies formed by precipitation of metal sulphides from hydrothermal fluids released from cooling magmatic sources, eventually mixed with fluids of other sources. Several processes are controlling the precipitation of Cu-hosting minerals including fluid mixing, temperature, Eh and pH changes.

Identifying new Cu deposits in Morocco is extremely essential for the country economy. However, the discovery of new deposits is limited by the lack of understanding of metallogenic processes involved in some districts like the one of Eastern Jbilet, the target of the present work.

The Eastern Jbilet area, belonging to the Moroccan Hercynian belt, hosts numerous Cu-mineralized veins. These veins are distributed over more than 20 km around the city of Kelaa Sraghna. Up to now no genetic model of these Cu-veins has been proposed for such deposits.

Veins hosting sulfide mineralization show multiphase precipitation process mainly of pyrite, chalcopyrite, with minor bornite, covellite, and chalcocite. Gangue minerals are represented by quartz and carbonates including calcite, dolomite, ankerite and siderite.

Our recent field investigations show discreet occurrence of both volcanic and plutonic rocks. The present work focusses on the genetic relationship between Cu-veins versus the local magmatism occurrences, and will discuss implications for spatial distribution of the mineralization.

Field work combining mapping/geophysical exploration and drilling campaign shows that the mineralization process could be linked to small appendices of plutonic rocks probably belonging to a large volcanic system (pillow-lava and basic dykes). A comparison of fluid inclusion results, performed on hydrothermal quartz coming from outcrops and shallow galleries (down to –77 m), provides evidence of PTX fluid signatures with temperature less than 200 °C, depth less than 4 km and high NaCl (>20 %) content. No boiling process have been detected.

From a genetic point of view copper could be transported as Cl-complexes and the precipitation of sulfide-bearing minerals seems to be temperature and pH-dependent. These data suggest that the lateral and in-depth distribution of the mineralization could be linked to a large magmatic system and give key perspective for further exploration work in Eastern Jbilet.

S3.P25. Structural and metallogenic context of the Bakoudou gold deposit (Gabon)

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Gabon is a country in Central Africa whose geological history is part of the spatial and temporal framework of the geology of the African continent. The age of the geological formations outcropping in this country vary from Archean to Cenozoic, and include important natural resources such as the gold deposit of Bakoudou and the Manganese deposit of Comilog, located in the southeast of the country in the Archean Chaillu massif.

The Bakoudou gold deposit, owned by MANAGEM group since 2005-2006, is hosted by Archean (2.7 Ga) granites and gneisses of the Chaillu Massif, which is an extension of the Congo Craton. The massif is composed by a granite-gneiss basement including tonalitic orthogneiss with few amphibolite layers and by biotite +/- amphibole granitoid intrusions. The whole formations are affected by subhorizontal to steeply dipping foliation, high-grade metamorphism and ductile to brittle shear zones. The gold mineralization occurs as free grains hosted in quartz structures localized within shear zones affecting biotite granitoids. Hydrothermal alteration in the proximity of the mineralized structures is marked by a strong silicification and chloritization of the host rocks.

Mapping the metamorphic foliation around the Bakoudou deposit shows a dome-shaped structure with a central zone where foliation is subhorizontal and external areas where the cleavage becomes steeply dipping. The mineralized quartz structures are localized in normal ductile and brittle shear zones, striking 135-140 °N. The mineralized structures, steeply dipping in the outer parts of the dome, become subhorizontal in its inner part. Southeast of the deposit, the northwestern block of the dome is thrusted on the southeastern block by a reverse fault striking 35-40 °N. These preliminary results suggest that the genesis of the gold mineralization was contemporaneous with the exhumation of the granite-gneiss dome.

Microscopic and petro metallogenic study reveals that gold, our main interest, is disseminated in free grains present in quartz, plagioclase, biotite and amphibole of surround rocks and so abundant in quartz facies, which is consistent with a magmatic origin of the gold. That does not exclude the contribution of hydrothermal fluid because it is shown very lowly in some blades that gold is related to chlorite from hydrothermal origin. Sulphides contained in the blades are low quantities. Part of these latters is related to magmatic origin and a greater amount is related to hydrothermal origin. The study of quartz-hosted fluid inclusions associated with the massive sulfide ore bodies from Bakoudou gold deposit revealed the contemporaneous trapping of early fluid inclusions characterizing three fluid systems of complex and variable composition. The P-T trapping conditions for the fluids are estimated at 1.5-3.0 kb, 350-470 °C.

S3.P26. Preliminary silicate melt inclusion study in phenocrysts from the Csomád (Ciomadul) volcano (Eastern Carpathians)

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The last volcanic eruptions in the Carpathian-Pannonian Region took place between 60-30 ka at Ciomadul volcano situated in the south-eastern end of the Călimani-Gurghiu-Harghita volcanic chain (Eastern Carpathians) (e.g. Szakács et al., 1993; Seghedi et al., 2011; Harangi et al., 2015a). The long-lived high-K dacite of Ciomadul was produced both by effusive and explosive volcanic activity/eruptions, where the magmatic function could begin 1 Ma ago and long breaks divided its volcanic activity. The latest studies detected a geophysical anomaly beneath the volcano which was suggested as representing a melt-bearing crystal mush (e.g. Popa et al., 2012; Harangi et al., 2015b).

Two types of crystal clots are present in the crystal-rich dacite which were identified as a felsic and a mafic component. The felsic crystal clots consist of plagioclase, amphibole, biotite, titanite, zircon, and apatite +/- K-feldspar and quartz which are originated from the silicic crystal mush. The mafic component is represented by clinopyroxene, olivine, Cr-spinel +/- orthopyroxene deriving from primitive basaltic intrusions (e.g. Vinkler et al., 2007; Jankovics et al., 2011; Kiss et al., 2014).

Silicate melt inclusions were trapped in the phenocrysts of the felsic crystal clots as biotite, amphibole and plagioclase found in a pumice-bearing pyroclastic flow deposit. The petrography shows the presence of large number of primary SMIs containing glass + bubble, together with primary fluid inclusions (FI). Based on the textural observations, the silicate melt inclusions formed in multiple steps.

The main goal is to study the nature and the origin of these SMI and FI, which seems to generated in an open system, where happened accumulation and mixing of different magmas with intensive melt/fluid-rock interaction.

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S3.P27. Fluid inclusion analyses on hydrothermal quartz in Latala epithermal base and precious metal deposit, kerman copper belt, Central Iran

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The Latala base and precious metals deposit is hosted by quartz veins associated with a porphyry pluton intrusive into a Cenozoic volcanic sequence. In these veins, euhedral quartz with sulfide mineralization such as pyrite, chalcopyrite, galena and sphalerite, with minor sulfosalts occurs as open space fillings and minor replacement bodies.

Progressive growth of the quartz crystals is evidenced by cathodoluminescence imaging. Fluid inclusions show decreasing homogenization temperature from 350 °C in the core to 135 °C along the edge overgrowths of the quartz crystals (Padyar et al., 2017). The presence of CO_2 vapor suggested by the thermometric analysis is confirmed by Raman spectrometry. Solid phases identified in fluid inclusions by petrography have been analysed by Raman spectrometry studies indicating the presence of phyllosilicates (presumably muscovite and illite), chlorite, quartz, and carbonate-minerals such as (natrocarbonate, dawsonite). Halite was identified in two fluid inclusions. These mineral phases, together with the presence of CO_2, are pointing to hydrothermal fluids formed during magma degassing (Sirbescu and Nabelek, 2003; Coveney and Kelly, 1971).

For the Latala vein type base and precious metals deposit, homogenization temperatures and salinity vary between 131 to 380 °C and 0.17 to 10.6 wt.% NaCl equiv. respectively. The Latala base and precious metals deposit has formed at a pressure between 200 and 100 bar, corresponding to a depth less than 1 km. The properties of fluid inclusions are coherent with a magmatic hydrothermal fluid circulating from depth to shallower environments. The sulphur isotopic composition for sulfide minerals varies between –9.8 and –1.0 ‰, which correspond to values of magmatic sulfur. The $\delta^{34}S$ values of sulfides from 1.7 to –9.2 ‰ are in the hydrothermal fluid domain. It suggests that magmatic water mixed with modified meteoric water was responsible for transportation of metals in Latala. Epithermal mineral precipitation during boiling, mixing and water-rock interaction was forming hydrothermal quartz and sulfide mineralization. These features are consistent with a progressive transition of the hydrothermal fluids from magmatic to epithermal in the region.

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S3.P28. Tracking wehrlitization process using silicate melt inclusions in upper mantle xenoliths from Nógrád-Gömör Volcanic Field (Northern Pannonian Basin)

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The Nógrád-Gömör Volcanic Field (NGVF) is situated in the northern part of the Pannonian Basin, and is one of the five known xenolith bearing Plio-Pleistocene alkaline basalt occurrences in the region. In addition to the dominant lherzolites, a great number of wehrlite xenoliths, with particular textural and geochemical features, have also been collected in the central part of the NGVF. According to the detailed petrographic, major and trace element analyses, wehrlitization must have been associated with an extensive mafic melt metasomatism, which led to the transformation of NGVF lherzolite into wehrlite.

Clinopyroxenes and olivines in wehrlite xenoliths, in contrast to those in lherzolite xenoliths from the region, host silicate melt inclusions (SMI). Distribution of the SMIs in both host minerals are scattered, occurring individually or in clusters. The clinopyroxene-hosted SMIs are between 20-60 µm in diameter, have negative crystal-shaped and are partially crystallized, containing 1-5 µm clinopyroxene, spinel, amphibole, ± mica and ± apatite daughter phases and a bubble. The olivine-hosted SMIs range between 15-50 µm in diameter and show rather spherical shape. They are dominated by glass, though minor amounts of clinopyroxene, spinel and small bubble also occur.

In order to obtain a better understanding on the role of trace elements during mantle metasomatism, 135 SMI (110 in clinopyroxene and 25 in olivine hosts), from twelve representative wehrlite xenoliths, were selected for detailed trace element analyses using LA-ICP-MS. The results revealed enrichment in incompatible elements, especially in LIL (e.g. Ba, Sr, Pb) and HFS (e.g. Nb, Ta, Zr) elements compared to the host mineral associated with the SMIs. SMIs hosted by olivines have lower trace element content compared to clinopyroxene hosted ones.

All SMIs contain a CO_2 dominated fluid phase based on Raman spectroscopy.

According to our results the metasomatic melt has lower trace element content than the host alkaline basalt. Therefore, they are interpreted to represent different melt packages of the same volcanic activity beneath the NGVF.

S3.P29. Scaling of fluid-flow pathways related to Streltsovsk Uranium District, Russia

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The main aim of this contribution is to combine data on scaling relationships between four different sets of fluid-conducting discontinuities developed within the Streltsovsk Uranium District in southeastern Transbaikalia (Petrov et al., 2008, 2010, 2013). Here, the unique volcanic-type uranium deposits are located within the limits of the Mesozoic Streltsovsk caldera. The scaling relationships have been identified from satellite and metric to centimetric and micrometric scales using different, but complementary approaches.

Four main tectonomagmatic cycles (TMC) characterizing by inherent stressed-strained state of the rock mass and faulting regimes were recognized within the District namely Proterozoic, Caledonian, Variscan, and Late Mesozoic. The generation and activation (reactivation) of fluid-conducting fault zones occurred on a step-by-step basis during these cycles.

Particular importance of fluid Inclusion planes (FIPs) (Lespinasse and Pecher, 1986; Lespinasse, 1999; Lespinasse et al., 2005) of different directions (tectonomagmatic cycles = ages) for understanding the evolution of fluid flow through discontinuities are shown. For instance, NE-SW-trending FIPs were fashioned during Proterozoic TMC (FIPs 1) into the NE-SW fault zone of initial ductile deformation (schistosity) as well as during Late Mesozoic regional TMA (FIPs 4) inside the reactivated brittle segments of the zone. NNE-submeridional and NW-SE-trending FIPs were gradually formed most likely during Caledonian (FIPs 2) and Variscan (FIPs 3) TMCs due to structural planes of maximal permeability were positioned along these directions. In addition, it was found that intersection nodes of the NE-SW schistosity zone and the NNE-submeridional oblique-slip zones form areas of long-term volumetric circulation of uranium-bearing solutions. Here there are prerequisites for revealing Proterozoic-Early Paleozoic vein-disseminated uranium mineralization modified, probably, during Variscan episode of the caldera basement formation and/or during Mesozoic tectonothermal events leading to Streltsovsk caldera creation (Lespinasse et al., 2015; Petrov et al., 2017).

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S3.P30. Fluid and melt inclusions study related to the magmatic-hydrothermal apatite-anhydrite association from Voia porphyry Cu-Au (Mo) deposit (Metaliferi Mountains, România)

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In the Tertiary (Fe)-Cu-Au(Mo) porphyry copper deposit from Voia, situated in the Metaliferi Mountains (South Apuseni Mountains, România), anhydrite and apatite form various mineral associations in the country rocks and mineralization structures as well. Firstly, there are apatite microcrysts embedded in plagioclase and other petrogenetic minerals, containing silicate glass inclusions mainly biphasic or monophasic (glass + vapor or only glass). Secondly, apatite phenocrysts besides Fe-Ti oxide minerals as glomeroporphyric aggregates in the andesitic and/or microdioritic rocks, are characteristic. Frequently, they show stratified microtexture in biotite or tecoblastic mixture in plagioclase, most probably generated during the magma mixing (mingling) between a felsic silicate mush and a sulphate suprasaturated basic influx in the magma chamber and volcanic conduits. Vapor rich inclusions containing birefringent microcryst were almost melted and recrystallized during heating-quenching cycles up to 950-1000 °C, under the microscope. Most probably the microphases are anhydrite precipitated (?) from the vapor magmatic phase at high temperature. Thirdly, specific anhydrite-apatite-quartz- albite- (Fe-Ti) oxides and sulphides occur in the potassic alteration zone in millimetric veinlets from the main stockwork structure. They contain several fluid and melt inclusion assemblages studied here in two samples, collected from two different sites in the two central drill-holes digged many years ago in the Voia prospect (Berbeleac et al., 1985). Glassy and silicate melt inclusion microthermometry show Th between 800- 950 °C, sometimes more than 1000 °C. Brine inclusion microthermometry show Tm halite between 323- 594 °C and Ws = 40 - 72 wt.% NaCl eq, respectively. Minimum trapping temperature range between 436 and 973 °C by vapor homogenization and between 429° and 594 °C by halite homogenization, suggesting a continuous brine (salt melt) separation from silicate melt by immiscibility and successive boiling episodes, vapor counterparts being always present. Calculated pressure suggested a mediated depth of brine inclusion entrapment around 3 km, as in other similar porphyry copper deposit worldwide (i.e. El Teniente, Rabbia et al., 2009).

There are at least two generations of anhydrite - apatite association (or parageneses ?) formed in the magmatic-hydrothermal stage at high P-T conditions, most of them deposited from a hydrous silicate - sulphate - chloride melt exsolved as vapor rich fluid from the silicate magma. Specifically, anhydrite and apatite contain silicate glass and vapor - rich inclusions assemblages, which combined with characteristic microtexture features of the hosts, are indeed suggestive for their deposition from a vapor dominated melt. Their study is in progress.

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S3.P31. Gas components of gold deposits mineralizing fluids in geological history of Earth

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The published data on the physicochemical parameters and chemical composition of the hydrothermal mineralizing fluids of gold deposits were collected and analyzed in terms of the geological history of the Earth. The data array included 5570 definitions of parameters for 360 gold deposits of various ages, from different regions of the Earth and the various genetic types: orogenic, shear zone related, epithermal, porphyry, "carlin", intrusion-related, IOGS and others. The dataset of the Raman definitions of gas composition consists of more than 500 tests. The general trends in the changes of physicochemical parameters and the chemical composition of the mineral-forming fluids in the Earth history are revealed. They are partly associated with increasing of the erosion level of hydrothermal systems with increasing of their age, which is consistent with the conclusions of the article (Kesler and Wilkinson, 2006). The point is primarily about the increasing of the average quantities of mineral-forming fluid pressure from the Cenozoic deposits to the Proterozoic ones, the absence of low-pressure fluid in the Precambrian deposits and the prevalence of weakly mineralized fluids in young fields. The data of the Raman-microanalysis of gas inclusions show the change in the average composition of the gas phase of fluid inclusions in the quartz from gold deposits with their age (mol %): Archean – CO_2 78.8, CH_4 20.7, N_2 0.4, CO_2/CH_4 3.8 (n=114), Proterozoic – CO_2 71.5, CH_4 13.5, N_2 14.5, CO_2/CH_4 5.3 (n=103), Paleozoic – CO_2 92.2, CH_4 5.8, N_2 2.0, CO_2/CH_4 15.9 (n=177), Mesozoic – CO_2 77.5, CH_4 5.0, N_2 17.5, CO_2/CH_4 15.5 (n=63), Cenozoic – CO_2 94.4, CH_4 0.8, N_2 4.8, CO_2/CH_4 120.0 (n=97). There is a regular increase of the CO_2/CH_4 ratio for fluids from the ancient gold deposits to the young ones. The revealed regularity is associated not only with different erosion sections of the deposits and the depth of capture of fluids into inclusions. The composition of the gas phase is affected by the general trend of the fluid regime change in time, associated with an increase in the proportion of oxidized forms of carbon from the early epochs to the late ones. This is consistent with the data of the carbon isotope studies of fluid inclusions in quartz of Archean and Proterozoic African gold deposits. These studies have shown the presence of different geochemical reservoirs of carbon dioxide, from which it enters the Archean and Proterozoic ore-forming systems of African gold deposits (Lüders et al., 2015). This study was supported by the Russian Science Foundation (project N° 17-17-01067).

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S3.P32. Characteristics of Fluid Inclusion of the Lugokan Au-Bi Deposit (Eastern Transbaikalia)

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The Lugokan deposit is located in the south-eastern part of Transbaikalia within the Aga-Borzya zone of the Mongol-Okhotsk orogenic belt. The deposit is hosted within the Lugokan granodiorite-granite-porphyry massif. The Au-Bi mineralization is found in quartz-carbonate and quartz-adularia veins and veinlets and is associated with three mineral associations (from earlier to later): gold-pyrite-chalcopyrite-arsenopyrite (Au-Py-Cpy-Apy), gold-polymetallic (Au-Zn-Pb) or gold-bithmuth (Au-Bi) (Redin, 2015). The aim of this study is to describe the PTX-conditions of the formation of Au-Bi mineralization at the Lugokan deposit using microthermometry and Raman spectroscopy.

Primary fluid inclusions, tracing the crystal-growth zones and forming separate groups within individual grains in quartz and carbonate, were selected for this study. A variety of fluid inclusions was classified by phase composition at room temperature: vapor-rich fluid inclusions contain a large vapor bubble (70–90 vol.%); gas-liquid fluid inclusions contain a solution and a vapor bubble (5-20 vol.%); brine fluid inclusions contain a solution, a vapor bubble and a halite crystal; three-phase gas-liquid fluid inclusions are complex inclusions, containing liquid H_2O, liquid CO_2 and gas CO_2 phases. The fluid inclusion studies of ore-bearing quartz and carbonate has revealed a gradual decrease in the ore-bearing fluid temperature (from 300-390 to 170-220 °C) and salinity (from 19 to 5 wt.% NaCl-equiv.). Fluid salt composition comprises Na, K, Fe and Mg chlorides as defined by eutectic melting temperatures between –41 and –37 °C. The fluid phase contains CO_2 (G), rare N_2 (G) (up to 25 mol.%) or H_2O (G). The variations in pressure estimation are between 650 and 1500 bar, which corresponds to the depths about 2.4-5.4 km (hypabyssal conditions). A summary of fluid inclusion data from a variety of mineral associations points out to the deep source of the ore-bearing fluid and to the initial solution dilution by meteoric waters during migration.

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S3.P33. Fluid inclusion characteristics of hydrothermal platinum group element remobilization in an alkalic Cu-Pd-Au porphyry deposit, Afton, British Columbia, Canada

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Alkalic Cu-Au porphyry deposits show enrichment in platinum-group elements (PGE), notably Pd and Pt (Thompson et al., 2001). Microthermometry, SIMS, LA-ICPMS, and SEM are being used to characterize the composition, timing, and physical properties of fluids that transported, deposited, and remobilized PGE at Afton.

Early hydrothermal apatite hosted in mineralized porphyry rock hosts primary fluid inclusions with salinities of 0.6-7.0 wt.% NaCl eq. (avg. 3.9±2.3σ.) and minimum entrapment temperatures of 156-371 °C (avg. 251.9±37 °C). Late stage carbonate-hosted fluid inclusions may be synchronous to PGE mineralization based on presence of platinum group minerals in carbonate-quartz veins. Carbonate inclusions have salinities of 0.4-27.5 wt.% NaCl eq. (avg. 12.4±8.9σ.) and minimum entrapment temperatures of 84-195 °C (avg. 117±24 °C). Carbonate veins contain low salinity assemblages comparable to apatite, and high salinity assemblages.

The $\delta^{18}O_{qtz}$ values for late quartz-carbonate veins containing PGE minerals, obtained in-situ by SIMS, show two compositional ranges. Sample UA44 343 contains chalcedonic quartz surrounding blocky calcite with an average $\delta^{18}O_{qtz}$ of 8.2‰, a $\Delta_{qtz-cal}$ of 1.7 ‰, and a calculated equilibration temperature of 220°C (avg. microthermometry: 133 °C). Sample UA06 307.6 has blocky calcite forming around quartz, with a $\delta^{18}O_{qtz}$ value of 15.8 ‰, a $\Delta_{qtz-cal}$ of 2.3‰, and an equilibrium temperature of 153 °C (avg. microthermometry: 148 °C). Using isotope thermometry $\delta^{18}O_{H2O}$ is between –2.2 and +0.5 ‰, suggesting involvement of low latitude meteoric water or a mixture of this meteoric water with a more ^{18}O-enriched fluid. Cl/Br ratios of apatite range from 60-427 (avg. 168.6±61.6σ, n=159), in agreement with a fluid mixing environment.

Trace element composition of apatite shows a relationship to cross-cutting apatite-magnetite veins and suggests that PGE remobilization may have occurred during apatite-magnetite veining that formed after porphyry ore. The lower temperature of entrapment of carbonate-hosted fluid inclusions and O stable isotope systematics suggests that precipitation of PGE with carbonate-quartz veins occurred in a cooling environment involving meteoric water mixing.

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S3.P34. Evidence of the interaction between deep magma and fluid: ultrabasic rocks of the Uitkomst Complex, South Africa

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The problem of the genesis of the parent magmas, their composition and the thermodynamic conditions for the formation of layered ultramafic complexes is still debatable. We studied the satellite intrusion Uitkomst in the Bushveld Complex where melt inclusions could preserve in olivine cumulates of chemically primitive rocks, such as dunites and harzburgites.

Olivine contains 4 types of inclusions. The first type is single primary natural-crystallized melt inclusions. Among daughter phases, olivine and orthopyroxene were analyzed. At heating, a melting of the phases was observed in interval 1130 ≥ 1430 oC. A similar behavior was observed in the silicate part of the coexisting combined inclusions (Sp+silicate). The melt contains 54-56 wt.% SiO_2. The main difference between the composition of melt from previously published model composition of the parental Bushweld magma is higher concentration MgO (16-18 %) and an excessively high concentration of alkali (up to 4.5 wt.%).

Inclusions of the second type often have a typical crystallographic outlines and a size of 5 to 50 microns. The composition of small inclusions corresponds to albite-oligoclase, without signs of crystallization. These inclusions do not undergo any changes at heating up to 1230 oC (crystal inclusions). Large inclusions are finely crystallized in various degree and contain Ab, Cpx, Cl-Ap, sphene, perovskite, amphibole, rutile, and ilmenite. At heating, the melting of phases was accompanied by the appearance of multiple fluid bubbles. The homogenization temperature varies between 1190-1250 oC. Melt of such inclusions is characterized by high concentrations of SiO2 - up to 65 %, alkali (up to 9 wt.%), and not less than 1 % of H_2O.

The variations of the paired ratios of the components normalized by Na (Me/Na-Al/Na) showed that the high-magnesian inclusions form compact fields, while the inclusions of acid melt including albite lie on a single trend. Moreover, their position depends on the degree of crystallization and the size of the inclusions, as well as the homogenization temperature. However, a different picture is observed for the K/N ratio on the diagram K/Na-Al/Na. All inclusions (acid and high-magnesian) form a single trend. The high concentration of Na_2O, K_2O and H_2O in the inclusions suggests addition of hot Na-K rich fluid to the melt during or after olivine crystallization on the floor of the magma chamber. This is consistent with the presence in olivine of fluid inclusions and polycrystalline inclusions (types 3 and 4) containing water-saturated phases (Ol+Opx+Amph+Flg+pectolite ($Ca_2NaSi_3O_8[OH]$) + Ab and glass and fluid.

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S3.P35. Looking for strategic elements in pegmatites from Puyuhuapi, Chile

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The worldwide concern for climate change and consequent increase in need for alternative energy have led to the development of better methods for mining, storage and processing of strategic minerals and have stimulated research on the role that these elements play in clean energy. Rare elements in pegmatites may be enriched in incompatible elements such as HREE and LLRE and many of these elements are strategic metals (London, 2008). The pegmatite used for this study was sampled near the village of Puyuhuapi in the Aysen Region, which is structurally controlled by the Liquiñe-Ofqui fault. The aim of this study is to characterize the fluids originating from the pegmatitic deposit and assess the potential for exploiting strategic elements in Chile. Petrographic observations show that the pegmatite is composed of quartz (45 %) and feldspar (35 %), with a minor plagioclase (15 %), muscovite (4 %) and biotite (1 %). The feldspar has a graphic texture, intergrowths of plagioclase and quartz, and subhedral textures, while the quartz exhibits subhedral textures, with some areas having a milky to vitreous appearance. Bulk chemical analysis of quartz and feldspar using 50 elements shows there is an enrichment of Rb and trace minerals such as Ba, Th and Se.

A detailed petrographic study of fluid inclusions (FIs) in quartz shows 8 types of fluid inclusion assemblages: (1) Primary liquid-rich FIs exhibiting consistent liquid to vapour ratios, with final ice melting temperatures (Tm) ranging from –20 to –16 °C and homogenization temperatures (Th) ranging from 233 to 201 °C; (2) Primary liquid-rich FIs having consistent liquid to vapour ratios and an irregular shape, showing decrepitation and trapped solids, with ranges of Tm from –21 to –9 °C and Th from 250 to 167 °C; (3) Secondary FIs in a single quartz grain having consistent liquid to vapour ratios and trapped solids, with ranges of Tm from –38 to -30 °C and Th from 230 to 200 °C; (4) Secondary FIs that are petrographically similar to the previous ones but have ranges of Tm from –31 to -22 °C and Th from 240 to 188 °C; (5) Secondary vapour-rich FIs; (6) Secondary CO2-bearing aqueous FIs; (7) Secondary FIs that have both liquid-rich and CO_2-bearing inclusions, with ranges of Tm from –25 to –23°C and Th from 230 to 191 °C; and finally (8) Secondary FI, that have consistent liquid to vapour ratios and cut several quartz grains, with ranges of Tm varying from –17 to –12 °C and Th from 200 to 165 °C. Raman analysis shows that in (6) and (7) FIs, a minimum pressure can be estimated that was found to range from 16 to 56 bars. Laser ablation ICPMS in (2) FIs shows an enrichment in B (252-633 ppm), which is absent in secondary inclusions. A systematic increase in Sr and Ba is observed from primary to secondary inclusions. Therefore, based on the lack of exotic mineralization and limited enrichment of rare elements, the pegmatite from Puyuhuapi does not represent a strategic element deposit worthy of exploitation.

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S3.P36. Role of rhyodacitic melts in formation of andesitic and dacitic rocks: evidence from inclusions in minerals from the Shiveluch and Ichinsky volcanic centers, Kamchatka

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Shiveluch is the northernmost active volcano in Kamchatka, located at the junction of the Kurile-Kamchatka and Aleutian island arcs (Gorbach et al., 2013). Active Ichinsky volcano is confined to the Miocene-Quaternary volcanic belt of the Sredinny Range, the rear part of the modern subduction zone.

More than 150 analyses were obtained for groundmass glasses and quenched melt inclusions in minerals of pumices of an eruption of Shiveluch at 3500 14C years and the caldera-forming eruption of Ichinsky Volcano (Q1). Inclusions were studied in plagioclase, amphibole, clinopyroxene, and biotite. All inclusions glasses are rich in H_2O (4-7 wt.% according to ion microprobe data). The average element contents in the melts of Shiveluch and Ichinsky are very simiar: 70.7 wt.% and 71.9 wt.% SiO_2, 13.3 and 13.0 Al_2O_3, 1.3 and 1.1 FeO, respectively. There are slightly greater differences in MgO (0.23 and 0.33) and K_2O (2.77 and 3.44). The whole-rock compositions show 60 wt.% SiO_2, 4.1 wt.% MgO, and 1.2 wt.% K_2O for Shiveluch and 68 wt.% SiO_2, 2.0 wt.% MgO, and 3.1 wt.% K_2O for Ichinsky.

This difference in the composition of magmatic products can be attributed to several reasons. 1. The presence in the Shiveluch andesites of a significant amount of xenogeneic mafic material, as well as abundant phenocrysts indicating possible crystal accumulation. 2. Differences in the degree of initial melt fractionation, which is reflected in the compositions of glass inclusions in different minerals. In Shiveluch, melt inclusions in plagioclase, clinopyroxene, and amphibole have almost identical compositions, but the groundmass glasses are more differentiated. This indicates rapid subcotectic crystallization. In Ichinsky, inclusions in pyroxene and amphibole contain the least differentiated melts, and the composition of groundmass glass is the same; more differentiated melts were observed in inclusions in biotite and plagioclase. These features may indicate a combination of crystallization and magma mixing.

The obtained results demonstrate that melts of similar degrees of differentiation can produce rocks that differ significantly in bulk composition and fall within different petrochemical groups.

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S3.P37. Au-Bi deposits at the North-East of Russia: PTX parameters and sources of hydrothermal fluids

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The intrusion-related Au-Bi deposits of Verkhoyansk-Kolyma folded region are located in or close to the apical parts of Jurassic-Cretaceous granitoid stocks and are divided to bismuth-arsenide-sulpharsenide (Chepak, Chistoe, Kandidatskoe), bismuth-sulphatelluride-quartz (Dubu, Kurum, Ergelyax, Tuguchak, Basagunya) and bismuth-siderite-polysulphide (Arkachan) types based on mineral ore composition.

The fluid inclusions (FI) in quartz from different Au-Bi deposits were studied. Fluid inclusions mainly range from 10 to 15 µm in size and display irregular, rounded or negative crystal shapes. Four types of the primary inclusions have been recognized at room temperature (+21 °C). Type I is two-phase FI consisting of H_2O liquid and CO_2 vapour and three-phase FI with H_2O liquid, CO_2 vapour and CO_2 liquid. Type II is vapour-rich CO_2 one- or two-phase FI with minor CH_4 and N_2, sometimes with a thin liquid rim. Type III of FI is two-phase liquid-vapour aqueous inclusions. Type IV is three-phase FI consisting of H_2O liquid, gas bubble and solid halite. Types I and II of FI are located in the same growth zone of minerals that suggests their contemporaneous trapping. Thus, minerals crystallized under conditions where two immiscible fluids coexisting in the system apparently were products of aqueous–carbon dioxide–salt fluid separation into two phases: substantially liquid and substantially gaseous.

Gold ores were formed at 495-155 °C and 1.7-0.09 kbar from fluids with a salt concentration from 1.1 to 46 wt.% equiv. NaCl. At Dyby and Kurum deposits fluid contains from 4.6 to 1.5 mol/kg solution CO_2 and from 2.5 to 0.4 mol/kg solution CH_4. The aqueous extract from quartz of bismuth-sulphatelluride-quartz deposits (Dubu, Kurum, Ergelyax) are enriched in ore components; ratios vary respectively Ag/Sb – 16.1-14.4-13.6; Au/Ag – 0.01-0.006-0.004; Pb/Zn – 0.03-0.02-0.01; Fe/As – 6.3-4.1-3.2; Co/Ni – 0.13-0.14-0.25.

The $\delta^{18}O$ values for quartz of studied deposits are +10.8 to +13.6 ‰. Calculated values of isotopic composition of mineral forming fluid vary from +5.5 to +8.3 ‰ at 350 oC. These data coincide the typical values for magmatic fluids ($\delta^{18}O_{H2O}$=+5 to +10 ‰) and for intrusion-related gold deposits.

Total REE contain in quartz (ICP-MS data) is 0.2-4 ppm, La/Yb=1.7-8.6 and Eu/Eu*=0.25-0.77. Fluids derived from felsic magmas as well as high-temperature fluids have negative Eu anomaly. Amplitude of Eu anomaly corresponds with depth of magmatic chamber.

Thus, the obtained data indicate high temperatures and salt concentration in the ore-forming fluids, shallow level of the deposit formation, predominant magmatic sources of the fluids and correlation of fluid composition with depth of magmatic chamber.

S3.P38. The large Svetlinsk Au-Te deposit, South Urals: fluid composition and formation conditions

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The Svetlinsk is the large gold-telluride deposit with veinlet-disseminated ores located within the volcano-sedimentary rocks metamorphosed up to amphibolitic facies (amphibolite, biotite-bearing schist, etc.). The gold-sulfide-telluride-quartz veins and veinlets are superimposed on the disseminated pyrite-pyrrhotite mineralization. This deposit is a sample of polygenic and polychronic mineral system (Sazonov et al., 1989).

The fluid inclusions in quartz from different mineralization stages were studied. At room temperature primary fluid inclusions (1-18 μm) are divided into two types: (I) H_2O_L +CO_{2L} or H_2O_L+CO_{2V}+CO_{2L} and (II) CO_{2V}. Fluid inclusions of both types are confined to the same growth zones of quartz and, thus, were captured simultaneously, when two immiscible fluids enter to system. They were formed due to phase separation of a parent H_2O+CO_2+NaCl fluid. Abundant primary-secondary and secondary fluid inclusions were subdivided into three types: (i) H_2O_L-CO_{2V}±CO_{2L}, (ii) rich CO_{2V} and (iii) H_2O_V+H_2O_L.

According to the study of primary fluid inclusions, the early assemblages (quartz-pyrite-pyrrhotite megastage) were formed at 405-255 °C and 5-1 kbar from the fluid with a salt concentration from 1.2 to 15.1 wt.% equiv. NaCl. Later assemblages (gold-tellurides megastage) were formed from fluids with salinity 4.8-19.8 wt.% equiv. NaCl at 320-130 °C.

The aqueous extracts from quartz of ore veins are enriched in As (42-73 ppm), Sb (27-53), Cu (236-264), Zn (1630-1700), Au (10), Ni (5-13), Fe (126) in comparison with barren veins according to ICP-MS.

Fluid composition was defined with using LA-ICP-MS with NaCl content as internal standard. Two-phase fluid inclusions (type I) with salinity of 3.4 wt. % equiv. NaCl are enriched (in ppm) B (150), S (3970), K (370), Fe (18600), Zn (580), Au (190). The gaseous inclusions (type II) contain B, Mg, K, Mn, Fe, Ni, Cu, Zn, As, Sr, Ba, W, Pb, Bi.

Fluid inclusion study demonstrates complicated evolution of Svetlinsk hydrothermal system. Mineral assemblages formed under decreasing P and T within each stage from immiscible fluids of H_2O-CO_2-NaCl-$MgCl_2$-$CaCl_2$-N_2-CH_4 system. The high nitrogen (7.9-18.1 mol/kg of solution) content in the solutions was likely caused by interaction of the hydrothermal fluids with host rocks.

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S3.P39. Vorontsovsk Carlin-style gold deposit in the North Urals: fluid inclusions and isotope data for genetic model

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The Vorontsovsk Au-Hg-Sb-As(Tl) deposit is located in mainly carbonate rocks near the contact of the Early-Middle Devonian Auerbah gabbro-diorite-granodiorite massif (Tagil megazone). The Upper Emsian-Eifelian volcano-sedimentary sequence is cut by numerous mostly mafic dykes. The orebodies are confined to a low angle trust-disturbed contact of limestone (foot wall) and thinly interbedded andesite flishoid (hanging wall). They are composed of 8 types of disseminated ores, but the main gold reserves are associated with the following two ore types: gold-pyrite-arsenopyrite in argillic altered tuff-terrigenous rocks and gold-pyrite-realgar ores in chertificated limestone breccia. Early ore assemblages have been formed at 510–240 °C (including magnetite skarn), whereas the late gold-(Fe, As, Hg)sulfide-quartz mineralization was deposited at decreasing temperatures from 260 to 100°C. Fluid inclusion thermocryometry revealed aqueous-carbonic, Ca-, Na- and Mg-chloride compositions of ore-bearing fluid of 4.8-9.3 wt.% eq. NaCl. Co-existence of liquid and gaseous inclusions points to a heterogeneous state of fluid, which occurs in the result of boiling in shallow conditions. Fluid pressures fluctuate from near lithostatic (0.5-0.6 kb) to hydrostatic (0.15-0.2 kb) conditions during tectonically active regime of volcanoplutonic arc.

The main sources of water and carbon dioxide were composed of the fluid derived from the magma chamber and the metamorphic or catagenic water equilibrated with limestone. The bulk of the sulphur was supplied by a mantle-related magma reservoir with $\delta^{34}S$ of sulphides in volcanic flishoid –2.3...+1.3 ‰ and skarn –1.7...+1.6 ‰. The mixing between mantle-sourced sulphur and biogenic-diagenetic sulphur was possible for two ore types – limestone breccia –7.8...+0.6 ‰ and argillic altered volcanic flishoid –3.5...–1.8 ‰. Relatively small input of heavy ^{34}S isotope was found for jasperoid +1.2...+6.9 ‰ related with some addition of sulphur from granodiorite magmatic source.

The lead isotopic compositions of sulfides (n = 13) show a relatively narrow range between 17.99 and 18.11 for $^{206}Pb/^{204}Pb$, 15.57 to 15.59 for $^{207}Pb/^{204}Pb$, and 37.88 to 37.99 for $^{208}Pb/^{204}Pb$. On the $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ diagram they fall on continuation of the linear trend of Lower Silurian VMS deposits corresponding to the mixing line of two types of lead sources: mantle derived (DDM A) and epicontinental andesitoid volcanic arc. Model Pb-Pb ages for the Vorontsovsk deposit sulphides are grouped into two clusters: 425-416 and 398-388 Ma. The latter period corresponds to Emsian-Eifelian age of the host volcano-sedimentary suite as well as U-Pb age for quartz diorite and granodiorite of the Auerbakh complex and coincides the Ar-Ar age of hydromica from the gold-arsenopyrite association 391.1 ± 4.9 Ma.

S3.P40. Geothermal fluids and mineral scales at Irruputuncu and Olca, Chile; searching for strategic minerals

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Geothermal fluids contain dissolved solids under conditions of elevated temperatures and pressure. The most common components present in geothermal systems are silica, calcium carbonate, including in some cases precious and base metals. In geothermal systems in the Andes there is little work related to geothermal fluids and associated mineral and their use for strategic mineral exploration. In our research, we focus on two active hydrothermal systems, the Irruputuncu and Olca volcanoes which are located between Chile and Bolivia. Previous work on these two stratovolcanoes suggest the presence of active hydrothermal systems (Reyes et al., 2011). Regional mapping shows hydrothermal alteration at the surface in Irruputuncu volcano associated with a structural trend N-S to NW-SE fractures, compares with structural trend E-W at Olca.

More than 200 samples were collected from drill cores from these volcanoes. The drill cores PEM 02 and 03 from Olca shows evidence of pyrite and hematite below 400 m. The PGC 02 from Irruputuncu shows evidence of bladed calcite below 350 m and pyrite below 400 m. Thin sections from samples of these cores were examined using a petrographic microscope, and fluid inclusion and mineralogical evidence for boiling of the hydrothermal fluids was recorded.

This evidence included Fluid Inclusion Assemblages consisting of coexisting liquid-rich and vapor-rich inclusions, and the presence of bladed calcite and/or chalcedonic quartz. Thus, the presence of platy/bladed calcite is strong evidence for boiling in the active hydrothermal systems there. The loss of CO_2 to vapor results in the rapid precipitation of calcite, which favors formation of platy or bladed crystals rather than rhombohedral crystals that form during slower growth. These observations are important to understand the area for further exploration and the calcite or quartz scaling mitigation for future components in Andean power plant equipment.

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S4.P01. Fluid inclusions constraints on the origin of Ribeirão da Prata lead and zinc ore deposit (southern Brazil)

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The Itajaí-Perimbó shear zone (IPSZ), in southern Brazil, is the northern boundary of the Brasiliano/Pan-African Dom Feliciano Belt, whose evolution is related to the West Gondwana collage. This NE-SW shear zone is the limit between the Itajaí basin, at NW, and the Brusque group (part of Dom Feliciano Belt), at SE. The Itajaí basin is a Neoproterozoic foreland basin, with sedimentation occurring between 600 to 560 Ma. Brusque group is composed of schists and marbles with granitoids, that evolved from 900 to 540 Ma (Basei et al., 2011ab). The IPSZ hosts a lead and zinc (copper and silver) ore deposit at the Ribeirão da Prata mine. Galena, sphalerite, chalcopyrite and pyrite are the primary ore minerals. Covellite, goethite, malachite azurite (cerussite and pyromorphite) represent the secondary ore paragenesis (Biondi et al., 1992). The formation of this deposit is related to reactivation of the shear zone during the main deformation of the Itajaí basin (530 Ma). The IPSZ evolved from thrust to right lateral fault (Rostirolla et al., 1999) and built up a well marked structural control in the deposit, that is associated to fractured gneiss and granitic rocks with remarkable silicification.

We have examined fluid inclusions within quartz from pre-, syn- and post-mineralization veins to provide constraints on the role of fluid activity and genesis of the deposit. Thirteen fluid inclusions associations from 5 veins, encompassing 630 fluid inclusions were analyzed by Raman spectroscopy and microthermometry. Fluid inclusions have trapped a saline aqueous fluid with salinity ranging from 1 to 10 wt.% eq. NaCl. No gas has been detected in inclusions. Large variations of salinity are observed inside fluid inclusion assemblages (FIA) probably indicating a mixing process between deep and surface waters. Homogenization temperatures are well distributed in the range 100-180 °C.

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S4.P02. Tracing fluid migration pathways in the root zone below unconformity-related hydrothermal veins: insights from trace element systematics of individual fluid inclusions

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The temporal evolution of fracture networks (root zones) below hydrothermal veins and their impact on fluid chemistry, vein mineralogy and ore formation is insufficiently understood for unconformity-related hydrothermal veins in regions of extension, such as the common epithermal sediment- and basement-hosted Pb-Zn deposits. As metals and other trace elements are presumably mobilized during water-rock interaction of highly saline brines with crystalline basement rocks, the evolution of these fracture zones seems to play a major role for hydrothermal ore formation.

To shed light on this topic, laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS) microanalysis of individual, texturally well-characterized fluid inclusions, hosted in fluorite and quartz of the Jurassic-Cretaceous Brandenberg fluorite-barite-quartz-galena-sphalerite vein (Schwarzwald, SW Germany), which was situated at the continental shelf of the Tethys ocean were carried out. Fluid mobile elements (Rb, Cs, Li, W, Ba, Zn, Pb, Sr), preferentially released by the alteration of primary rock-forming minerals (process tracer) were analyzed as well as the Cl/Br ratio (source tracer) of fluid inclusions in genetically early fluorite and later quartz.

A distinct decrease of trace elements within the fluid inclusions with time indicates successive alteration of primary minerals at the fracture wall to clay minerals with consecutive fluid pulses. A maximum concentration of trace elements in the fluid and consequent ore precipitation is associated with the initial phase of formation of a fracture root. Later fluid pulses migrate along pre-existing fractures so that the amount of fresh reactive rock material decreases with each fluid pulse. As a consequence, multiple generations of ore minerals require the formation of new fracture branches in the root zone of hydrothermal veins. Therefore, it seems that cataclastic zones below hydrothermal veins essentially control ore formation, and their tectonically induced dynamics might be one key parameter that governs the temporal interval of ore precipitation.

S4.P03. Fluid inclusion assemblages in the Hujiayu Cu deposit, Zhongtiao Mountains, China: implications for syn-metamorphic Cu remobilization

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Hujiayu Cu deposit in the Zhongtiao Mountains district, southern edge of the North China Craton, is primarily hosted in graphite-bearing schists and carbonate rocks. Four fluid inclusion types were recognized in the chalcopyrite-pyrite-dolomite-quartz veins, including CO_2-rich inclusions (type I), low-salinity, liquid-dominated, biphase aqueous inclusions (type II), solid-bearing aqueous inclusions (type III), and solid-bearing aqueous-carbonic inclusions (type IV). Type I inclusions can be further divided into two sub-types, i.e., monophase CO_2 inclusions (type Ia) and biphase CO_2-rich inclusions, and type III inclusions are divided into a subtype with a halite daughter mineral (type IIIa) and a subtype with multiple solids (type IIIb). Various fluid inclusion assemblages (FIAs) were identified through petrographic observations, and were classified into four groups. The group-1 FIA, consisting of monophase CO_2 inclusions (type Ia), homogenized into the liquid phase in a large range of temperatures from –1 to 28 °C. The group-2 FIA consists of type Ib, IIIb and IV inclusions, and is interpreted to reflect fluid immiscibility. The group-3 FIA comprises type II and IIIa inclusions, and the group-4 FIA consists of type II inclusions with consistent phase ratios. The group-1 and group-2 FIAs are interpreted to be entrapped during mineralization, whereas group-3 and group-4 FIAs probably represent the post-mineralization fluids. The solid CO_2 melting temperatures range from –60.6 to –56.6 °C and from –66.0 to –63.4 °C for type Ia and type IV inclusions, respectively. The homogenization temperatures for type II inclusions range from 132 to 170 °C for group-III FIAs and 115 to 219 °C for group-IV FIAs. The halite melting temperatures range from 530 to 562 °C for type IIIb and IV inclusions, whereas those for type IIIa inclusions range from 198 to 398 °C. Laser Raman and SEM-EDS results show that the gas species in fluid inclusions are mainly CO_2 with minor CH_4, and the solids are dominated by calcite and halite. The calcite in the hosting marble and dolomite in the hydrothermal veins have δ13CV-PDB values of –0.2 to 1.2 ‰ and –1.2 to –6.3 ‰, and $\delta^{18}O_{V\text{-}SMOW}$ values of 14.0 to 20.8 ‰ and 13.2 to 14.3 ‰, respectively. The fluid inclusion and C-O isotopes suggest that the ore-forming fluids were probably derived from metamorphic fluids, which had reacted with organic matter in sedimentary rocks or graphite and undergone phase separation at 1.4-1.8 kbar and 230-240 °C, after peak metamorphism. It is proposed that the Hujiayu Cu deposit consists of two mineralization stages. The early stage mineralization, characterized by disseminated and veinlet copper sulfides, probably took place in an environment similar to sediment-hosted stratiform copper mineralization. Ore minerals formed in this precursor mineralization stage were remobilized and enriched in the late metamorphic hydrothermal stage, leading to the formation of thick quartz-dolomite-sulfides veins.

S4.P04. Fluid evolution and genesis of the North American Emerald Mine (NAEM), NC, USA

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The NAEM is located near Hiddenite, North Carolina and has produced more than 60,000 carats of gemstones. The emeralds occur in cavities in close association with quartz, muscovite and carbonate. Cavities located in Alpine fissure-type quartz veins hosted by Silurian migmatitic metasedimentary rocks interlayered with calc-silicate rocks that reached upper amphibolite facies.

Fluid inclusions (FI) are abundant in minerals forming in cavities. FI in emeralds, carbonates, rutile, tourmaline and quartz were analyzed to characterize fluid composition and its evolution. Based on room temperature phase ratios, the fluid has a composition of ~80-90 mole% CO_2 and 10-20 mole% H_2O. Raman and microthermometry analysis showed that the FIs contain high density CO_2 (average density ~0.77 g.cm^{-3} for quartz, ~0.74 g.cm^{-3} for carbonates and emerald, ~0.88 g.cm^{-3} in rutile, ~0.64 g.cm^{-3} in tourmaline). Low-density CO_2 inclusions (density ~0.26 g.cm^{-3}) and H_2O-NaCl FI were found in quartz only. H_2O-rich inclusions show first melting at ~–23 °C, with a salinity of ~4-6 wt.% eq. NaCl and homogenization temperature ranged from 190-220 °C.

Salinity of FI in carbonates and rutile was estimated to be ~3 wt.% NaCl eq. based on clathrate melting temperatures. Commonly observed minerals in FI are graphite in emerald and nahcolite in quartz. In some emerald samples CH_4 was detected in FI along with high-density CO_2 and graphite. CO_2-C±CH_4 fluid indicates that the fluid characterized by reducing conditions, while presence of nahcolite indicates alkali conditions of the fluid. Graphite is also recognized as a mineral inclusion in coexisting emerald, albite and carbonates from the same paragenetic stage. Temperature evaluated by Raman graphite thermometry varied from 470-600 °C.

Oxygen isotopes were measured for coexisting quartz, rutile and muscovite samples from one emerald-bearing cavity and two cavities without emeralds. For quartz-rutile and muscovite-rutile pairs the isotope equilibrium temperature is 450-510 °C which is consistent with results from fluid inclusions. $\delta^{18}O$ ranged between ~11-12 ‰, indicating either a metamorphic source of fluid or mixture between magmatic and metamorphic fluids. At the estimated temperature, PVTX data for the system H_2O-CO_2 indicate a pressure of emerald formation 1.0-1.5 kbar.

S4.P05. Fluid inclusions of Sb vein-type mineralizations along the Berga Anticline, Eastern Thuringia, Germany

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The antimoniferous vein-mineralizations in the Schleiz and Greiz area, eastern Thuringia, are bound to NE-SW striking Variscan faults zones along the margins of the Berga anticline. The Sb-ores form massive sulfide-sulfosalt-quartz ± carbonate veins, breccias or stockworks within Ordovician and Silurian metasedimentary units, Devonian metabasalts and metagranitoids.

Mineralogical investigations of 52 samples from several mines and quarries near Schleiz and Greiz, Germany show that Sb-Pb-Zn-sulfides are texturally in close association with co-genetic quartz. Stibnite is the major Sb-bearing mineral in all investigated samples. However, lead-dominated Sb-sulfides such as zinkenite, plagionite, semseyite and boulangerite are also present showing a distinct metal zonation. Minerals of the Sb assemblage show replacement of an earlier Zn-Fe-As-Cu-sulfide-quartz assemblage.

Preliminary data of fluid inclusions hosted in quartz and co-genetic stibnite give first insights into the composition and temperature of the mineralizing fluids. Primary fluid inclusion assemblages occur along quartz growth zones and parallel to the main crystal growth direction of stibnite. Variable L/V ratios of the inclusions within the same FIA indicate heterogeneous trapping and fluid immiscibility. The inclusions contain a H_2O-CO_2-NaCl fluid, with T_m(cla) from 8.8 to 9.5 °C, implying eq.wt. (NaCl) of 1 to 2 % (Bozzo et al., 1975) and Th(total) into the liquid phase from 220-225 °C.

Fluid inclusions in Sb-Pb-minerals (boulangerite) show homogeneously trapped three-phase fluid inclusions (L, V and S) in the H_2O-NaCl system, with T_m(ice) from –5.0 to –4.5 °C, yielding eq.wt. (NaCl) up to 7.9 % (Steele-MacInnis et al., 2012) and homogenization into the liquid phase at 145 °C (=min T_{TRAP}). These data show that stibnite and quartz precipitated from a low-salinity H_2O-CO_2-NaCl fluid at around 220 °C, contrary to Pb-bearing Sb-sulfosalts (e.g. semseyite, boulangerite), which precipitated at lower temperatures of T_h(total) = 145 °C . However, the reason for the distinct temporal evolution of the fluid chemistry cannot yet be precisely concluded from the preliminary data. In order to improve the understanding of these ore-forming processes and nature of the fluids, stable and radiogenic isotope studies are planned to be carried out.

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S4.P06. Silicate melt inclusions recording metasomatism in an upper mantle lherzolite xenolith from the northern Pannonian Basin

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In the Carpathian-Pannonian region, upper mantle peridotite xenoliths are brought to the surface by young alkali basalts at five localities, one of which is the Nógrád-Gömör Volcanic Field (NGVF) in the northern edge of the Pannonian Basin. Several types of melt and fluid inclusions from this area have been studied previously, comprising fluid inclusions in basanite xenocrysts (Szabó and Bodnar, 1998), silicate melt inclusions (SMIs) in olivine pyroxenites related to cumulate formation (Zajacz et al., 2007), or olivine-hosted SMIs recording reaction with a subduction-related melt (Szabó et al., 1996).

The peridotite xenoliths of the NGVF can be divided into a lherzolitic and a wehrlitic series, the latter of which is considered the product of metasomatic reaction between wall-rock and a mafic silicate melt (Patkó et al., 2013). Secondary clinopyroxenes and olivines in wehrlites commonly contain SMIs, however, they are almost completely absent in the lherzolite series.

Within the lherzolite series, one metasomatized xenolith contains clinopyroxenes hosting primary, partly crystallized, multiphase SMIs, which are 10-20 μm in diameter with negative crystal shape. Several of these SMIs were analyzed using different techniques, to determine their composition and relation to the wehrlite-forming metasomatic process. The techniques applied include phase determination and mapping with Raman spectroscopy, and slicing the inclusions using focused ion beam (FIB)-SEM methods to acquire a 3D-map of the structure and volume proportion of the constituent phases. Besides the dominant glass phase, crystallized daughter minerals include clinopyroxene, mica, apatite, and a Fe-Ti-oxide. All SMIs contain a bubble, composed mainly of CO_2, with small sulfate crystals (anhydrite, barite) at the contact of the bubble and the glass, indicating their possible reaction. The composition of the SMIs is closely similar to those in the wehrlites, and it is inferred that they were trapped from a basaltic melt of the same intraplate origin, which is also responsible for the metasomatic signature in the mineral constituents of the lherzolite.

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S4.P07. The Sierra de Lujar (Andalusia, Spain) fluorite deposit: a variety of brines in a post-metamorphic alpine deposit, insight from a fluid inclusion study

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The fluorite deposit of the Sierra de Lujar (Andalusia, Spain), is located in the inner zone of the Betic Mountain range, within the Alpujarride nappe complex. The Lujar antiform consists of folded Triassic limestones and is the host for the fluorite ores. The paragenetic sequence is: 1) early fluorite replaces matrix carbonate (mainly dolomitic), 2) dolomite veins and an euhedral calcite overprint the early fluorite, 3) formation of zebra veins (hydraulic fracturing) consisting in regularly spaced, centimeter thick, fluorite veinlet sets, crosscutting the limestone matrix, and coeval fluorite infillings in dissolution cavities, 4) large fluorite veins, and 5) late calcite stage (zoned Pb-bearing calcite infilling cracks).

In the fluorite, two types of brines may be identified (halite-bearing FI): a sodic brine (up to 40 wt.% NaCl) and a calcic brine (up to 40 wt.% eq. NaCl, Ca/Na between 1.3 and 0.7). Both brines exhibit mixing with a moderately saline sodic fluid (~ 15 wt.% NaCl) (Lw FI). A volatile-rich Lw-c FI type is associated with the brines, is also of moderate salinity (~ 20 wt.% NaCl), and, from a Te of ~ -35 °C, is apparently Mg-dominated. The vapor phase contains CO_2, H_2S, (N_2), but no CH_4, and a solid sulphur (S_8) is always present; the H_2S molar fraction in the volatile phase is comprised between 0.02 and 0.55. The same volatiles (at very low density: no clathrate) are also found in all other FI types.

The fluids are interpreted as originating from Triassic evaporites, coming from two levels: a deep one (sole of the Alpujarride nappe?) subjected to late Alpine HT-LP metamorphism and yielding the sulphur from sulphates and the CO_2 from carbonates (expressed in Lw-c FI and volatiles in other FI), and a shallower one, yielding Na-rich brines (halite dissolution) evolving into Ca-brines by a Ca-Na exchange process.

All FI exhibit bulk Th in the 220-260 °C range, and in halite-bearing FI, Tm halite is close to the Th (± 10 °C). Using data from Lecumberri-Sanchez et al. (2012), trapping is found to have occurred between c. 50 MPa and 18-20 MPa, readily interpreted as lithostatic and hydrostatic pressures respectively (i.e., a 2 km depth of formation), at temperatures up to 340 °C.

The deposit likely formed during the Tortonian, in relation with late orogenic extension. Extensional conditions favored the extraction from deep fluids issued from metamorphic reactions and their mixing with shallower brines. Heat advection by the deep fluids explains the high temperatures attained at the shallow level of ore formation.

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S4.P08. Driving forces for dissolution / precipitation of quartz as exemplified on a Alpine fissure from Zinggenstock, Central Alps, Switzerland. A discussion.

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The aim of the present study is to evaluate the driving forces that lead to the dissolution and the precipitation of quartz in an Alpine fissure from Zinggenstock, Switzerland (Mullis, 1996).

Depletion in rock forming minerals occurred to a distance of at least 12 cm from the fissure wall. There, quartz is completely absent documented by void spaces of up to 0.5 cm in diameter. Laterally below the fissure system, large scale rock alteration is also visible. Adjacent to the leached zones, rock forming quartz is strained and broken. Within the Alpine fissure 3 generations of quartz, Q_1, Q_2 and Q_3, precipitated preferentially at the top of the fissure system, filling it up to ≤ 20 %. Early Q_1 is absolutely transparent and large (≥ 50 cm).

Discussion of different possibilities of dissolution / precipitation models

1. Chemical disequilibrium between intruding cooler aqueous fluids from sediments below and granodiorite, leading to the dissolution of quartz in the adjacent rocks (Poty, 2008).
2. Pressure solution due to the difference between the solid pressure of the enclosing host rock (higher) and the fluid pressure in the Alpine fissures (lower) leading to quartz dissolution in the surrounding rock and quartz precipitation in the fissure as suggested by Wangen and Munz (2004), Poty (2008) and Gratier et al. (2009).
3. Dislocation densities and their impact on the internal energy and dissolution of the ± ideally formed Q_1 fissure quartz with respect to the precursor strained quartz of the alteration zone (Wintsch and Dunning, 1985). Dislocation densities vary from low concentrations of ~10^5 dislocations cm^{-2} in natural slowly grown fissure quartz to high values of ~10^{10} cm^{-2} in deformed rocks of low metamorphic grades (Blum et al., 1990).
4. Ripening: Large crystals have a smaller solubility than small crystals because of their smaller surface area per unit mass. The later is 10 to 10^3 larger in the strained host rock quartz than in the well formed and totally transparent Q_1 fissure quartz. According to the Gibbs-Kelvin equation (Nielsen, 1964; Steefel et al., 1990) the origin of the driving force for ripening lies in the internal free energy of the mineral.

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S4.P09. Pro- and retrograde fluid inclusions in the Central Alps, Switzerland

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Careful fabric, host mineral and fluid inclusion analyses of Alpine fissure systems from the Central Alps (Switzerland) enable a critical discussion about their significance during prograde, T-maximum and retrograde formation conditions. Fluid inclusions might change strongly their shape, density and composition due to regional varying tectono-metamorphic conditions during Alpine compression, uplift and erosion since beginning Miocene. They are:

1. Stretched, decrepitated and reset fluid inclusions that formed at an early stage along the prograde path during burial (Wilkins and Barkas, 1978). Heating caused fluid overpressure within fluid inclusions exceeding their confining pressure.
2. Implosed fluid inclusions, that are arranged along SE-NW oriented deformation trails in massif quartz veins or in early grown prismatic quartz of Alpine fissures. Their confining fluid pressures exceeded markedly the internal fluid pressures of already formed fluid inclusions (Sterner and Bodnar, 1989; Tarantola et al., 2010).
3. Stretched and decrepitated high dense fluid inclusions due to rapid more or less isothermal uplift.
4. Stretched and decrepitated high dense fluid inclusions due to episodic decompression in Alpine fissures during late Miocene seismic events (Sibson, 1990).

Fluid inclusions of the 4 mentioned groups do not reflect original fluid composition and density present during trapping. Nevertheless very small and very low dense volatiles inside fluid inclusions might remember the original mineralizing fluid.

5. Non affected fluid inclusions formed at temperature maximum and during retrograde conditions reflect more or less the true density and composition of the originally trapped fluid (Mullis et al. 1994). Since begin of fluid inclusion research in the Central Alps, the uppermost publications refer to this fluid group.

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S4.P10. Properties of ore-forming solutions of the Severnoye gold-uranium deposit, Elkon uranium ore region, Republic of Sakha (Yakutia, Russia)

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The Severnoye deposit is located within the Elkon uranium ore region of the Aldan Shield in the Republic of Sakha (Yakutia, Russia). Its structure involves Archean crystalline basement rocks, where Archaean-Proterozoic northwest-striking linear structure is localized. Development of gold-uranium mineralization is related to Mesozoic stage of Aldan Shield tectonomagmatic activation.

Any conclusions on the conditions of ore formation process can only be based on the data on pre-ore and post-ore mineral inclusions in case of difficulties to locate quite certain fluid inclusions in minerals of metasomatic associations, as well as the absence of vein crystal mineralization during the ore formation stage.

Homogenization of pre-ore and post-ore primary inclusions allows us to evaluate borderline temperature conditions of brannerite mineralization process. According to our data, these conditions correspond to the temperature range T=368 207 °C.

The pressure defined for the associated groups of pre-ore heterogeneous incorporation inclusions amounted to 450-2530 bar. The pressure during development of post-ore mineralization amounted to 630-780 bar.

According to the individual fluid inclusion studies, the following types of fluids are involved in development of pre-ore and post-ore mineralization: 1) markedly aqueous with high concentrations of CO_2, Na, K, Mg chlorides; 2) markedly aqueous with admixed Na and Mg chlorides; 3) markedly CO_2 without significant amounts of admixtures; 4) markedly CO_2 with insignificant amounts of admixed nitrogen or methane. All four types of fluids were involved in development of pre-ore mineralization. Fluids of the first three types were involved in development of post-ore mineralization, while markedly CO2 fluid with admixed nitrogen or methane was not involved.

$\delta^{18}O$ values for pre-ore mineralization quartz fall within the range from 18.2 to 22.2 ‰. $\delta^{18}O$ value for post-ore mineralization quartz amounted to 20.3 ‰. Calculated $\delta^{18}O_{H2O}$ values for pre-ore quartz mineralization fall within the range from 12.3 to 15.6 ‰, $\delta^{18}O_{H2O}$ value for post-ore mineralization amounted to 8.7 ‰. Isotopic composition of oxygen in aqueous phase of the fluid is indicative of its metamorphogenic nature.

Similarity of salt and gas content of solutions of pre-ore and post-ore mineral formation inclusions, as well as similar timing of development of hydrothermal and metasomatic deposits suggest that the determined characteristics of hydrothermal solutions can be applied to the ore formation stage. In this case the fluid involved in development of brannerite mineralization of the Severnoye gold-uranium deposit could be represented by medium and low temperature chloride K-Na-Mg solutions of metamorphogenic origin.

S4.P11. Fluid inclusion analysis of variably altered graphitic pelitic schists in the Dufferin Lake Zone, south-central Athabasca Basin, Canada: implications for graphite loss and uranium deposition

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The highest grade unconformity-type uranium deposits in the world occur in the Athabasca Basin, Canada. They are considered to be the result of mixing between oxidized basinal brines and basement-derived reduced fluids/gases, and/or reduced basement rocks. Meta-sedimentary basement rocks of the Dufferin Lake Zone, directly underlying the Athabasca Group, are variably graphitic pelitic schists (VGPS), which are altered to hematite and chlorite (Red/Green Zone: RGZ). Near the unconformity, these crystalline basement rocks were locally bleached during paleoweathering and/or later fluid interaction. Consequently, graphite was lost from the RGZ and the bleached zone, relative to the original VGPS. To better understand these alteration processes, fluid inclusions were examined within different generations of quartz/quartz veins, using microthermometry and Raman spectroscopy, to characterize and compare the different fluids that interacted with the RGZ and the VGPS. CH_4- and N_2-rich fluid inclusions and CO_2-rich fluid inclusions are present in the VGPS. The former inclusions homogenize into the vapor phase between −100 and −74 °C, and −152 and −125 °C, respectively; whereas the latter homogenize either into vapor or liquid between 20 and 28 °C. CH_4 and CO_2 could be the result of fluid(s) interaction with the graphitic lithologies and the results of the breakdown of graphite. However, N_2-rich fluid is interpreted to be the result of breakdown of feldspars/micas to NH_4+ and N_2. Within the RGZ, the existence of fluid inclusions with low ice melting temperature (−38 to −16 °C) strongly suggest the presence of $CaCl_2$, and the existence of fluid inclusions with halite daughter minerals, that dissolve between 190 and 240 °C, indicate the presence of highly saline fluids. These brine fluids are interpreted to have come from the Athabasca Basin. The migration of carbonic fluids and brines occurred during two different events related to two different P-T conditions of trapping: 1) The carbonic fluids interacted with basement rocks during retrograde metamorphism before deposition of the Athabasca Basin, and 2) the brines circulated after the deposition of the Athabasca Basin. These latter fluids are quite similar in composition to brines related to uranium mineralization at McArthur River. Therefore, in addition to possibly being related to graphite depletion in the RGZ, these brines, in part $CaCl_2$-rich, could be linked to uranium mineralization along the Dufferin Lake Zone.

S4.P12. The physical-chemical parameters and composition of mineralizing fluids of gold deposits in Northern Transbaykalia, Russian Federation

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Fluid inclusions were studied in quartz from quartz-carbonate gold-bearing veins hosted by metamorphic rocks of six gold deposits in Northern Transbaikalia (Uryakh, Dogaldyn, Pervenets, Verninsk, Sukhoy Log and Irokinda).

Generally, 3 types of fluid inclusions are contained in quartz from all deposits, namely, type 1 – high-to medium density, vapor-rich CO_2 inclusions, type 2 – aqueous carbonic inclusion and type 3 – aqueous two-phase inclusions. CO_2-rich type 1 inclusions homogenize into the liquid phase at temperatures between –32.4 and +30.8 °C and show T_{mCO2} between –56.9 and –62.3 °C due to additional minor amounts of N_2 and CH_4 in the inclusions. The densities of type 1 inclusions vary between 0.54 and 1.09 g/cm^3. Aqueous carbonic type 2 inclusions show T_h between +179 and +380 °C and salinities of 1.4-8.6 wt.% eq. NaCl. Aqueous two-phase type 3 inclusions contain $MgCl_2$ and NaCl and show T_e values between –25 and –34 °C and T_{mice} between –2.2 and –12.0 °C, corresponding to salinities of 3.7 to 16.0 wt.% eq. NaCl. Th values of type 3 inclusions fall into the temperature range between +128 and +385 °C.

In addition to the above, there are multiphase H_2O-NaCl-$CaCl_2$-rich inclusions hosted in early quartz of the Irokinda deposit. Multiphase inclusions show halite disapearance between +320 and +389 °C and T_h between +280 and +453 ºC. The liquid phase of multiphase inclusions has T_e values of about –55 °C and salinities of 39.8-46.3 wt.% eq. $CaCl_2$-NaCl. Raman spectroscopy proves there to be nitrogen (0.8-0.6 mole%) and methane (0.1-0.01 mole%) besides CO_2 in gas-rich inclusions in quartz of the Irokinda deposit. Calcite, rhodochrosite and siderite were identified in multiphase inclusions as anisotropic phases. High concentrations of Br in the liquid phase of multiphase inclusions were proven by crush-leach analyses.

The $\delta^{13}C_{CO2}$ values of fluid inclusion gases of five deposits (Uryakh, Dogaldyn, Pervenets, Verninsk, Sukhoy Log) range between –5.5 and –1.9 ‰ and yield a magmatic and/or metamorphic source for CO_2. However, the $\delta^{13}C_{CO2}$ of gas-rich inclusions in quartz from the Irokinda deposit are more positive (–0.6 to +0.7 ‰) suggesting that CO_2 was probably derived by decarbonation of limestones.

The data obtained revealed evidence that fluids of deep crustal origin were the source of gold deposits in Northern Transbaikalian.

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S4.P13. Circulation of primary brines at the origin of the world-class Trimouns talc - chlorite deposit (Pyrenees, France)

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The Trimouns talc deposit, in the North-Eastern French Pyrenees, is one of the largest talc deposit in the world. It results from the Mg-metasomatism of marbles, micaschists and pegmatites due to the circulation of large amount of hydrothermal fluids. Circulation occurred during the mid-Cretaceous, in the context of extreme lithospheric thinning leading to mantle exhumation in the Pyrenean realm during lithospheric stretching prior to the Pyrenean orogeny. The deposit is located in a tectonic contact that separates the lower and upper Paleozoic series and underlined by the Silurian blackschists (footwall: micaschists and pegmatites; hanging-wall: marbles, dolomites and blackschists). Studied materials have been sampled in and around the Trimouns - La Porteille deposit. The main objective of our work is to identify the fluid sources and the processes controlling the fluid composition and to propose a regional fluid circulation model.

A multi-technique approach based on the analysis of individual fluid inclusions has been carried out using microthermometry, Raman spectroscopy, LA-ICPMS together with the analysis of bulk leachates on the host minerals (dolomite, calcite and quartz). Major fluid reservoirs consist in brines (5 to 6 mol/kg H_2O) with a high content of Ca and Na (Na/Ca ranging from 0.5 to 2 molal), depleted in Mg (0.1 molal) and containing traces of N_2, CO_2 and CH_4. Cl/Br molar ratio ranges from 150 to 700. High salinities together with Cl/Br ratio attest for a dominant contribution of primary brines having passed halite saturation. The low Mg contents of fluid inclusions attest for a loss of Mg from the fluid likely during the talc-chlorite precipitation. Traces of gas may suggest interactions between fluid with either local units (dolomite enriched in organic matter and blackschists) and/or with exhumed mantle. The estimated T-P conditions of the fluid circulation are 250-280 °C and 40 to 200 MPa corresponding to 4-7 km depth.

The ubiquity of primary brines in both the deposit and the regional environment suggests large scale circulation in the crust. Evaporitic Triassic level appears as the best candidate to provide such primary brines which are probably mainly expelled during mid-cretaceous extension which led to the hyper-thinning of the crust. However, as suggested by traces of various gases, the tectonic contact where deposit is located can be considered as a major drain in which fluids of various origins have probably circulated.

S4.P14. Preliminary results of study on fluid inclusions in mantle xenoliths from the Perşani Mountains, Eastern Transylvanian Basin

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In the Carpathian-Pannonian Region (CPR) there are five major volcanic areas where basalt volcanoes, active during the Neogene - Quaternary period, brought large numbers of upper mantle xenoliths to the surface (Szabó et al., 2004). Majority of basalt volcanoes, particularly at the edge of the CPR (Styrian Basin, Perşani Mountains), contain frequently amphibole-bearing xenoliths. The easternmost and youngest alkaline basaltic volcanic field is developed in the Perşani Mountains (Eastern Transylvanian Basin, Romania), which provides the xenolith suite to this study. Our main aim is to describe the fluid system, in four selected spinel lherzolite/hornblendite composite xenoliths, that migrated at upper mantle depth in this region during amphibole formation.

The spinel lherzolite contains small amount of interstitial amphibole, whereas the hornblendite comprises occasionally other OH-bearing minerals such as apatite and phlogopite. Orthopyroxene and clinopyroxene of the spinel lherzolitic parts of composite xenoliths enclose randomly distributed negative crystal shaped fluid inclusions. Size of fluid inclusions is ranging between 5 and 30 μm. At room temperature, liquid and solid phases are visible in the smallest (3-10 μm) inclusions under petrographic microscope. The large inclusions (15-40 μm) show decrepitation, thus, partial fluid loss results in liquid and vapor phase present in the inclusion cavity. Microthermometry showed CO_2-dominance with extreme high density (0.99 - 1.02 g/cm^3) for the smallest fluid inclusions. Besides, Raman spectroscopy revealed that inclusions contain small but detectable amount of N_2 (10-15 mol%) in the liquid phase, which support the idea that nitrogen is a common component in mantle fluid (Berkesi et al., 2017). The solid phase of inclusions was identified as anhydrite (8 vol.%).

To sum up our preliminary results, we can state that a C-O-N-S-(H) fluid-rich phase was present beneath the Perşani Mountains during hornblende formation.

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S4.P15. Study of polycrystalline inclusions in garnets from granulites of the Athabasca Granulite Terrane (Canada)

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In the last decade the study of fluid and melt inclusions in crustal anatectic rocks has become a key tool to acquire unprecedented information. In this work a detailed microstructural and microchemical study has been performed on polycrystalline inclusions trapped in peritectic garnets of felsic granulite gneisses from the Upper Deck domain, Athabasca Granulite Terrane (Canada).

Inclusions have been characterized by SEM-EDS and FIB-SEM techniques, and by Laser Raman spectroscopy. The inclusions are very small (≤ 10 μm), they are primary in origin, and do not show evidence of decrepitation. FIB-SEM analyses permitted to recognize the main crystalline phases and their distribution. The polycrystalline assemblage is always made of ferroan magnesite, quartz and graphite, in association with minor amounts of corundum and Zn-spinel. Calcite and dolomite may be present, and pyrophyllite was found only in one inclusion. Quartz and corundum coexistence has been interpreted as the product of metastable growth caused by extremely small size of pores.

Raman spectroscopy revealed the presence of CO_2, with traces of CH_4 and N_2. A good negative correlation between the CO_2 density and the total amount of coexisting solid phases has been observed. The main minerals occur in a relatively constant amount in the investigated inclusions, suggesting the entrapment of a compositionally homogeneous fluid characterized by a high-carbon content.

These tiny carbon-rich inclusions coexist in the same cluster with nanogranite inclusions. Because nanogranites are interpreted to be droplet of anatectic melt formed and trapped during incongruent melting of crustal rocks, the investigated polycrystalline inclusions prove the presence of a carbon-rich fluid during melting of these rocks, possibly in a situation of melt/melt or melt/fluid immiscibility.

S4.P16. Metamorphic and basin fluids trapped in Evia Island alpine quartz crystals during exhumation of the Attic-Cycladic Metamorphic Complex (Greece)

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Alpine fissure is a descriptive term generally used to characterize veins mineralized by large euhedral hydrothermal quartz crystals that formed during Alpine orogeny (e.g. Stalder and Touray, 1970; Poty et al. 1974; Mullis et al., 1994). Such clefts are thus described from Occidental to Oriental Alps and all along the alpine orogenic belt sensu lato. Alpine fissures are associated to late-orogenic evolution and form under retrograde greenschist metamorphic conditions. They form under brittle conditions, either as inter-boundins or as tension gashes, during the last stages of deformation as attested by conservation of eudral crystals (Mullis et al. 1994). VX properties of their hosted fluid inclusions thus provide constraints on PT conditions during late-orogenic evolution of the belt.

Similar alpine fissures are described crosscutting Attico-Cycladic Metamorphic Core Complex. The up to 5 cm crystals presented here were found in Evia Island. Mineral inclusions of biotite and chlorite indicate continuous crystallization from 430 to 250 °C. Two types of two-phase LV aqueous-rich (vapor phase around 10 vol.%) fluid inclusions are found, with Type 1 pseudo-secondary and Type 2 secondary. The salinity is from 0.0 to 2.6 wt% NaCl$_{eq}$. and 1.3 to 6.6 wt.% NaCl$_{eq}$., respectively, with presence of borate, sulfate and bicarbonate ions in Type 1. Homogenization temperatures range from 199 to 142 °C and 165 to 153 °C, respectively. The gas phase is made either by a CO_2-N_2 (Type 1) or by a CH_4-H_2-N_2 (Type 2) mixture. δD values of water from fluid inclusions of each also indicate two defined populations, around –40 and –20 ‰, respectively. Type 1 isotopic values indicate equilibrium with surrounding schists at metamorphic conditions.

Fluid inclusion VX data and isotopic values thus allows reconstructing the last PT steps during exhumation of the Attic-Cycladic belt and shows here a transition from a metamorphic to a basinal reservoir.

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S4.P17. Parameters and composition of fluids of Gold-quartz Deposits Localized in Terrigenous Sequence and Granitoids (North-East Russian Federation)

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Fluid inclusions in quartz of ore veins of gold-quartz deposits of the North-East of Russia, localized in terrigenous rocks (Rodionovskoye, Natalka, Igumenovskoye, Pavlik, age 149-140 Ma), and in granitoids (Shkolnoye, Butarnoye, Dorozhnoye, age 136-125 Ma), were studied. Fluid inclusions of 3 types were found in the quartz of all deposits: 1 - vapor density CO_2, 2 - CO_2-aqueous, 3 - gas-liquid water-salt solutions.

In the quartz of deposits localized in terrigenous rocks, CO_2 inclusions (type 1) are homogenized into the liquid phase at temperatures ranging from +1.8 to +26.1 ° C with T_{mCO2} from –57.4 to –60.5 ° C and density of 0.69 to 0.92 g/cm^3. CO_2-aqueous inclusions (type 2) have T_h between 275-363 °C and salinities of 1.0-10.0 wt.% eq. NaCl. Microthermometry showed that the two-phase inclusions (type 3) are solutions containing chlorides of Mg and Na with T_e from –25 to –34 °C and T_{mice} from –0.7 to –4.4 °C, corresponding to salinities of 1.2 to 7.0 wt.% eq. NaCl, Th was between 135-283 °C.

In the quartz of deposits localized in granitoids, CO_2 inclusions (type 1) homogenized into the liquid phase at temperatures ranging from +3.6 to +28.6 °C with $TmCO_2$ from –57.0 to –60.4 °C and density of 0.46 to 0.91 g/cm^3. CO_2-aqueous inclusions (type 2) have here Th between 245-350 °C and salinities of 2.2-9.2 wt.% eq. NaCl. Microthermometry showed that the two-phase inclusions (type 3) are solutions containing chlorides of Mg and Na with Te from –25 to –38 °C and T_{mice} from –1.2 to –6.3 °C, corresponding to salinities of 2.1 to 9.6 wt.% eq. NaCl, Th was between 221-290 °C.

The gross analysis of the chemical composition of the fluids from the inclusions also showed similarities in the content of the main components between the fluids of the deposits of studied types. Potassium and sodium, and sometimes sodium and calcium are the dominated cations in the fluids of majority of deposits of both types. Among the anions, bicarbonate often prevailed, and its concentrations were significantly higher than chlorine ones. Only at some sites chlorine was the dominating anion. Sulfate appears very rare. There were a lot of gases in the ore-forming fluids, and among them carbonic acid prevailed.

The results of our study indicate the significant role of metamorphism of the enclosing terrigenous carbonaceous strata in the ore formation at both types of deposits. Geochemical similarity of ores and results of fluid inclusions study show that these deposits are derived from one orogenic ore-forming system and are associated with Mesozoic orogeny.

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S4.P18. Study of the Cr-Ni-Fe-Cu and graphite mineralization of the Beni Bousera Massif (internal Rif, Morocco)

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Peridotites in Beni Bousera massif (Morocco) correspond to sub-continental peridotites exhumed into crustal unit from internal domain of the Alpine Rif Cordillera. The rise of mantle peridotites causes their recrystallization by forming a petrographic zonation, from mylonites and Ariégite subfacies at the top of the massif, into Seiland subfacies.

This petrographic evolution has been accompanied by the injection of asthenospheric liquids in peridotites. The injection of asthenospheric fluids formed by volatiles (CO_2, CH_4, and H_2O), sulfur, and alkaline elements and poorer in Fe, Mg and chalcophiles elements in peridotites, resulted in the genesis of the main mineralization (S-G type) which consist of Fe-Ni-Cu sulfides (pyrrhotite, pentlandite, chalcopyrite), with small amounts of arsenides (nickeline, maucherite), sulfoarsenides (cobaltite), and chromite ± graphite, associated to phlogopite pyroxene and plagioclase. The fraction of liquid, which was rich with Fe-Mg, chalcophile elements and noble metals, formed a Cr-Ni mineralization (Cr-Ni type), composed of chromite and nickeline associated with orthopyroxene and cordierite. The injection of acid dykes and late serpentinization between 400 and 200 °C caused mineral and chemical modifications in both Cr-Ni and S-G ores Cr-Ni ores.

Lately, peridotites were strongly affected by serpentinization stage, probably at low temperature (lower than 400 °C). Both Cr-Ni and S-G ores have not escaped this stage of serpentinization. The serpentinization affects all of peridotite massif to various degrees. Serpentinization is concentrated at the top of the peridotites, along the mylonitized zone, and in the NE part of the massif (near the Aaraben fault). It is manifested by the formation of mesh and hour glass textures along the tectonic foliation in the highly serpentinized peridotites, and brecciated texture in the least serpentinized peridotites. Pyroxene minerals are hosting few serpentine veins. These petrographic features are consistent with the geochemical data, marked by the increasing of LOI and decreasing of MgO and FeO toward the top of the massif and Aaraben fault. Raman spectra show that serpentine with the brecciated mesh and hour glass textures correspond to lizardite type whereas the serpentine with the vein texture is formed by lizardite + chrysotile (polygonal serpentine).

S4.P19. Application of fluid inclusions on assessment of deformation condition of thrust sheets in Zagros suture zone

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Assessment of P-T conditions of thrust sheets from the Zagros suture zone located in the central Alpine Himalayan system carried out using thermometry of fluid inclusions within the quartz veins in the fault zones. Structural analysis of the Zagros suture zone resulted in recognition of a thrust system comprising 6 thrust sheets. In this study, fluid inclusions have been utilized to inspect deformation conditions of the thrust sheets, which led to unravel the nature of the Zagros suture zone.

Fluid inclusions are of two liquid and vapor phases and classified to three main types based on their size, shape, ratio of vapor to liquid and CO_2 content. Type I is an irregular to rounded in shape with negative crystal and contain CO_2 vapor phase while type II is larger and do not contain CO_2 vapor phase. Type III is mainly of aqueous inclusions and filled healed fractures thus unlike types I and II are of secondary in origin. Cooling and heating of inclusions have been conducted to define temperature of their entrapment and to compute their density and salinity for P-T conditions of the fault zones. Homogenization temperature of primary inclusions displays up to 220 ºC. This temperature is decrease from the hinward (hinterland side) toward forward (foreland side) thrust sheets. This is interpreted due to presence of vapor phase CO_2 in samples from hinward thrust sheets. The almost constant value of measured final ice melting temperature of all primary inclusions show that in contrast to homogenization temperature, their salinity are not sensitive to density changes and thus they have trapped in a close system. Therefore, the salinity of inclusion has been employed to estimate the pressure at the time of inclusion entrapment.

The presented microthermometry survey demonstrates that physical conditions of deformation do not change significantly but increases gradually from the forward toward hinward thrust sheets. Therefore, the Zagros suture zone is not an abrupt zone but occurs across a transitional zone comprising a thrust system.

S5.P01. Synthetic fluid inclusions and their role in the estimation of oil and gas potential of bituminous rocks

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Experiments on the interaction of aqueous solutions with bituminous rocks of Western Siberia, the Volga-Urals region, the Leningrad Area (Russia) and Lorraine (France) at temperatures of 320-350 °C and pressures up to 100 MPa were carried out using methods for studying synthetic fluid inclusions (Teinturier and Pironon, 2004, Balitsky et al., 2005, 2007, 2011, 2015). Quartz crystals with fluid inclusions were grown simultaneously with the interaction of bituminous rocks with hydrothermal solutions. This, unlike ordinary aquapyrolysis, allowed not only to assess the oil and gas potential of the rocks, but also to observe in situ the changes in the phase composition and states of generated hydrocarbons at temperatures up to 400 °C and pressures up to 90-100 MPa. In particular, it was shown that the share of oil in one kilogram of these rocks can reach 700 ml, that is, they are oil and gas bearing and, moreover, can be used as unconventional hydrocarbon raw materials.

In the studied synthetic inclusions, in addition to the aqueous phase, there are liquid (oil-like) and gaseous hydrocarbons mainly methane, and solid bitumen. The volume relations of the phases in the simultaneously formed inclusions are subject to sharp fluctuations. This indicates a heterogeneous state of the fluids during the capture of the inclusions. According to thermometry, usually in the range 280-330 °C the gas phase disappears first in the inclusions with the transition to the liquid two-phase (oil–water) state. But already in sub- and supercritical conditions (temperature 370-400 °C, pressure 120-150 MPa) liquid hydrocarbons dissolve in the water phase with the achievement of complete homogenization. Cooling the inclusions to room temperature leads to the sequential appearance of the vanishing phases in the reverse order. Hard bitumen remains unchanged.

In general, the studies once again demonstrated the effectiveness of using synthetic fluid inclusions to establish the oil and gas potential of bituminous rocks and to clarify the phase composition and state of hydrocarbons at great depths.

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S5.P02. NaCl-CaCl$_2$-H$_2$O brines in sediment hosted Cu-ores and amethysts from Anti-Atlas, Morocco

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The Anti-Atlas belt is well known for its numerous Cu-ores of various types. Among them, sediment-hosted Cu-deposits occur in the infra-Cambrian cover overlying the Precambrian basement. These are a new challenging ore type for scientists and mining companies because they consist of numerous small volume occurrences with so far undefined genetic model. Recent studies in the Bou Azzer-El Graara inlier have shown that these deposits are not syn-sedimentary but strongly controlled by a late Variscan compression event (Bourque et al., 2015). All mineralization in this inlier are stockwork-related, either located along infra-Cambrian strata or in vertical fault-related structures (type 1 and 2 ores, respectively). This presentation is the first report on fluids associated with these Cu-ores. We performed measurements in type 1 gangue quartz and dolomite and in type 2 quartz. Gangue minerals of both types contain similar NaCl-CaCl$_2$-H$_2$O liquid and halite-saturated inclusions (L and S FI types). All FI showed a eutectic temperature at ~ –50 °C and presented two or three successive meltings: hydrohalite, then ice melting in L FI; ice then final hydrohalite then halite melting in S FI. The nature of these phase changes was interpreted relative to the appropriate ternary phase diagram (Steele-MacInnis et al., 2011). Microthermometric measurements fixed type L FI composition at 7 % NaCl and 11 % CaCl$_2$ and that of S FI at 21 % NaCl and 12 % CaCl$_2$, (by weight) on average. Type 1 and 2 ores yielded different homogenization temperature-ranges for both L and S FI: between 180 to 320 °C and between 100 to 170 °C, respectively. Additionally, we identified compositionally similar type L fluids in the Bou Oudi amethyst deposit hosted in the Tagragra de Tata lower Cambrian series (Ibhi et al., 2009). In the Precambrian basement of Anti-Atlas, similar type S FI were previously described in the Bou Azzer Co-As (En-Naciri et al., 1997; Essarraj et al., 2005) and Zgounder Ag-Hg-Co deposits (Essarraj et al., 1998). As for type L FI, they were observed in Imiter Ag deposit (Essarraj et al., 2016) and also at Bou Azzer.

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S5.P03. Fluid Inclusions in the Crotone Basin Salt Dome and the implications for crystal deformation

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This contribution presents a preliminary microstructural study of evaporite samples from the Verzino area in the Crotone Basin, Southern Italy. The main purpose of this study is to investigate the degree of deformation and recrystallization of halite crystals from four different locations in a diapiric salt wall. Petrographic and fluid inclusion (FI) analyses of thin and double polished sections and Ultra Violet Microspectroscopy (UV) have been used to determine the presence of organic matters trapped in the inclusions. Microcrystalline halite crystals display mosaic texture and sub-millimetre to millimetre size. They display competitive growth pattern (e.g. elongated size and orientation parallel to the water surface) and different degree of deformation as testified by their shape due to various chemical and physical processes (i.e. grain-boundary migration, pressure-solution). These deformations do not erase primary structures, indeed in every sample analysed a number of primary FIs (located parallel to the crystal growth) with negative crystal shape have been observed. Furthermore, a large amount of organic materials has been identified trapped within these inclusions. FIs observed (5 to 60 μm in their longest dimension) are of Type 1 monophase liquid, Type 2 two-phase liquid-rich and Type 3 multiphase solid-rich with occasional matters trapped within. The trapped organic matter have been investigated to provide evidences of the trapping condition and of the depositional history of the diapiric salt wall.

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S5.P04. Evidences of hydrothermal fluid impacts in the Upper Lacq carbonate petroleum reservoir (Southwestern France)

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Fluids circulating in foreland basins can have a strong impact on petroleum systems and reservoir properties. This applies to the Upper Cretaceous Lacq reservoir of the Aquitaine Basin in southwestern France. This 650 m deep oil reservoir is part of a salt-core anticline in a complex area marked by hyper - extension during Early Cretaceous and compression during Late Cretaceous and Paleogene. Productive reservoirs include fractured Coniacian - Campanian limestones and dolomites unconformably overlying Albian-Cenomanian reefs. Seals are provided by Upper Senonian marls and Paleocene shales (Biteau, 2006). However, little is known about the nature, origin and timing of fluid circulation in the basin. This PhD project aims to (1) revisit and reconstruct the diagenetic history of the Lacq field, (2) demonstrate the impact of fluid-rock interactions and thermochemical sulphate reduction (TSR) on reservoir properties and (3) link the involved fluids to the geodynamic history of the basin. Preliminary petrographic observations reveal a paragenetic sequence of 18 phases. After early dolomitization during eogenesis, mesogenesis is marked by brecciation, hydrocarbon remigration, hydrothermal dolomitization, stylolitization and blocky calcite cementation. Telogenesis is noted by dissolution and reopening of burial stylolites. Microthermometry data was obtained from fluid inclusions (FIs) in mesogenetic dolomite and calcite phases (Pecqueur, 2016). Two-phase aqueous fluid inclusions showed 3 groups of homogenization temperatures (Th): (1) FIs in dolomite cores with Th of 80-120 °C and salinities of 0-30 g/L, (2) Th of 140-205 °C and salinities of 0-115 g/L in the outer dolomite rims and (3) Th of 85-160 °C and salinities of 0-65 g/L in the calcite phase. The high Th recorded could possibly reflect the persistence of high temperatures (HT) during hyperextension for 30 Myr, even after the onset of convergence (Vacherat et al., 2014). These HT conditions were favored by mantle exhumation, burial, high thermal conductivity of the Triassic evaporites and the blanket effect of the overlying shales, before Eocene uplift and cooling (Clerc et al., 2015). The transfer of heat by an active fluid circulation in the fracture network appears to be a major process influencing diagenesis. However, to better interpret and reveal the nature and origin of fluids involved, more data is needed from petrography, X-Ray tomography, fluid inclusion microthermometry, RAMAN spectroscopy, ICP-MS and isotope geochemistry.

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S5.P05. An overview of fluid inclusion studies of U, Cu and Pb-Zn deposits in the Proterozoic McArthur Basin (Northern Territory, Australia)

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The objective of this work is to summarize the available microthermometric data on fluid inclusions from a world-class metallogenic province hosting U, Cu and Pb-Zn deposits: the Paleo- to Meso-Proterozoic McArthur Basin, Northern Territory, Australia. This basin shows exceptional preservation and has remained unmetamorphosed and relatively undeformed since ~ 1.5 Ga. To date, about twenty publications have been devoted to fluid inclusions in the McArthur basin. To the North, unconformity-related U deposits show ~ 150 °C, 25-35 wt.% Na-Ca-Cl brines with molar Cl/Br ratios of ~ 140; indicative of an evaporated-seawater origin. Those brines are continuously diluted by a hotter (150-200 °C) low-salinity fluid (Derome et al., 2007). To the South, U and Cu deposits around the Westmoreland conglomerate and its underlying basement show ~250 °C brines chemically similar to those from unconformity-related U deposits; also showing widespread dilution (Mernagh and Wygralak, 2011). There is no fluid inclusion data available for the giant McArthur River (HYC) Pb-Zn deposit yet, but a similar deposit (Century) in the nearby undeformed part of the Mount Isa basin shows also an involvement of 120-150 °C basinal brines and low-salinity fluids (Polito et al., 2006). Similar brines and low-salinity fluids have also been described along regional sandstones and faults, altered volcanics, and other Cu and Pb-Zn deposits within the basin. Collectively, the compiled data attest for large-scale lateral and vertical migrations of basinal fluids at the time of ore-deposit formation. However, it remains to be determined if one or several basinal brine reservoirs have been involved and what was the origin and importance of low-salinity fluids. Further work is planned to establish the metal and halogen content of the fluid inclusions in the different deposits by LA-ICP-MS analysis and to refine the geochronological data on economic and alteration minerals to better constrain the origin and nature of the ore-forming fluids and the timing of fluid flow. Ultimately, it will be established whether the different deposits have formed from single basin-scale diagenetic-hydrothermal system or from distinct systems in space and time.

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S5.P06. Hydrothermal alteration imprint in quartz overgrowths in the Cretaceous fluvial-coastal sandstones of the Oliván Group, Cameros Basin, Spain.

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The combination of fluid inclusion with vitrinite reflectance (Ro) and thermal modelling can considerably improve the understanding of fluid circulation in sedimentary basins. In this work the effects of hydrothermal fluids on the Upper Jurassic-Lower Cretaceous Cameros Basin deposits (north-central Spain) are investigated. It is known that some sectors of the Cameros Basin were affected by one or two low-grade hydrothermal metamorphic events: the first during late Albian-Coniacian (Casquet et al., 1992; González-Acebrón et al., 2011 and references therein) and a second during the Eocene, in relation to the Alpine contraction (Mantilla-Figueroa et al., 2002). This study focuses on the last syn-rift depositional sequence of the basin, the siliciclastic Oliván Group (late Aptian-early Albian), which until now was considered as unaffected by hydrothermal events. However, recent Ro data infer a temperature record clearly higher than what expected by the geothermal gradient (Omodeo-Salè et al., 2015). To improve the understanding of this thermal anomaly a fluid inclusion research has been carried out focused on the primary fluid inclusions in the well-developed syntaxial quartz overgrowths from the subarkoses of the Oliván Group. Six samples have been selected to perform a microthermometric study. Fluid inclusions are very small (generally less than 4 µm) and usually present liquid: vapor homogeneous ratios around 95:5. They homogenize to the liquid in a Th range from 95 ºC to 178 ºC (n=45) and Fluid Inclusion Assemblages (FIAs) present very consistent T_h values. The highest T_h data have been recorded in the stratigraphically-highest samples. Further, by thermal modelling, the temperatures expected as a consequence of burial are considerably lower (75-90 ºC, Omodeo-Salè et al., 2015). These two facts indicate that the Oliván Group was affected by hydrothermal alteration during quartz cementation. Regarding the timing of this process, the homogeneous character of the syntaxial quartz overgrowths under SEM-CL, and the T_h consistency of the FIAs, indicate a unique hydrothermal process; suggesting the Cretaceous one, as far as some quartz cement has to be formed before the Eocene event, and there is no evidence of any Eocene overprint on them.

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S5.P07. Gas physical properties and their implication on gas saturation in deep reservoirs

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It is believed for a long time that about 90% of global oil and gas is stored at the temperature window of 60 °C ~ 120 °C. However, there have been numerous oil and gas discoveries in deep strata with temperature greater than 120 °C with the deepest exploration well reaching 9583 m. Globally reservoirs in over 1000 oil and gas fields are found in the depth range of 4500 m and 8100 m with corresponding recoverable oil and gas reserves accounting for 7 % and 25 %, respectively. The deepest oil well drilled in the Tarim Basin, western China reaches 8400 m. In the Sichuan Basin several giant gas fields have been discovered in the deep Cambrian and pre-Cambrian formations.

From a geological perspective, deep and ultra-deep natural gas resources are generally defined as those occurring in reservoirs below 4500 m and 6000 m, respectively. Deep reservoirs are under high temperature and high pressure settings. What are the key issues and mechanisms affecting the accumulation and preservation of deep hydrocarbons? Can the supercritical fluids change the charge efficiency of hydrocarbon accumulation?

Based on series of experiments and numerical calculation, the gas physical properties (i.e. density, interfacial tension) were obtained and their implication on gas saturation was studied. Furthermore, and evaluation model was established based on the identification of different types of residue water to obtain gas/water saturation in reservoirs. It is concluded that the lower interfacial tension between gas and water helps the gas charges into reservoirs and thus higher gas saturation was observed in the results of calculation. In addition, the more complicated gas saturation variation during burial history was studied. It is found that gas in the reservoir lost during the uplift in burial history.

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S5.P08. Fluid inclusion study of salt rocks from Praid salt mine (Transylvania, Romania)

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The evaporites in the Transylvanian Basin had formed during the event known as the Badenian Salinity Crisis (BSC), which started 13.82 Ma (Peryt et al., 2006). In the shallower parts of the basin gypsum was deposited, whereas in deeper parts halite deposits formed. After deposition the salt went through several salt tectonic movements leading to diapir formation (Krézsek and Bally, 2006). According to petrographic study of salt rock by considering the grain size and morphology of the grain boundaries of halite crystals, three types of textures can be distinguished: primary euhedral, inequigranular sutured mosaic and inequigranular polygonal mosaic. The texture of the samples is heterogeneous, all three texture types often appearing in a single thin section. In halite grains randomly distributed solid inclusions (e.g. dolomite, anhydrite, pyrite, quartz, albite and mica) were identified by Raman spectroscopy and by scanning electron microscopy.

Beside solid inclusions, large number of fluid inclusions trapped in halite were recognized. Based on petrographic observations, two fluid inclusion associations (FIA) can be distinguished: 1) negative crystal shaped, one phase (i.e. liquid, at room temperature) FIA appearing along growth zones are considered as primary fluid inclusions, entrapped during crystallization of the halite, and 2) negative crystal shaped, spherical or irregular shaped fluid inclusions, usually containing two-phases (i.e. liquid+vapor, at room temperature) situated along healed cracks are considered as secondary ones. Both primary and secondary FIAs appear in all three texture types. Raman spectroscopy and microthermometric measurements were performed to study the fluid compositions. Primary, one phase (liquid) inclusions are aqueous fluid inclusions with dissolved SO_4^{2-}, rarely containing brownish droplets of organic matter. Secondary two-phase (liquid+vapor) fluid inclusions are also aqueous fluid inclusions containing dissolved SO_4^{2-} and Mg^{2+} and Ca^{2+} ions besides Na^+. From their vapor phase CH_4, N_2 and CO_2 were identified.

The salt textures, together with the fluid inclusion petrography, suggest a complex deformation history of the salt deposits. The presence of the CH_4, CO_2 and N_2 only in the secondary fluid inclusions indicates that these components were added to the system during deformation event(s) after the salt formation. Further study of these salt samples extended to other sampling sites can be an important tool in the study of salt formation and the diapir forming processes in the Transylvanian Basin.

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S5.P09. Fluid Inclusion-constrained Charging History and Implication for Exploration of Volcanic Reservoir in Songliao Basin, Northeast China

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Many lower Cretaceous volcanic target traps have been drilled and gas fields have been found since late 1990s in Songliao basin, Northeast China, to meet the sharp rising demand of natural gas. The found gas is characterized by variety content of CO_2 from 1 % to 99 %. Based on carbon isotope analysis, CH_4 is sourced from the underlying coal bearing mudstone and CO_2 has two end source members: one has the same source as CH_4 and is characterized by low CO_2 (<5 %) with $\delta^{13}C$ lighter than –10 ‰; the other originate from magma degassing characterized by high CO_2 (>5 %) with $\delta^{13}C$ heavier than –10 ‰. Gas inclusion is used to help choose the gas exploration prospects with high CH_4 but low CO_2. Raman spectroscopy of single inclusion, carbon isotope of group inclusion are used to determine gas component and gas source respectively. Homogenization temperature and burial history are used to determine the time of gas charging.

Two generations of fluid inclusions are observed in the diagenetic minerals. The first one is oil inclusions in calcite cement and authingenic quartz. The second one is gas inclusions in calcite vein and is characterized by high CH_4 (>60 %) and low CO_2 (<2.5 %). The range $\delta^{13}C$ of CO_2 and CH_4 from the gas inclusions is from –15.1 ‰ to –12.7 ‰ and from –27‰ to –22.8 ‰ respectively, showing that both CO_2 and CH_4 in the inclusions originate from underlying coal bearing mudstone. This is in sharp contrast with the reservoir gas with high CO_2, $\delta^{13}C$ of which varies between –7.5 ‰ and –1.8 ‰ indicating inorganic source from magma degassing.

Peak homogenization temperature of aqueous inclusions in calcite cement and calcite vein is at 115 °C and 165 °C respectively. It can be inferred from the burial and thermal history and the homogenization temperature that oil inclusions formed in late Cretaceous and organic gas inclusions formed in Eocene.

Based on geological setting and fluid inclusion study, the geologic process related to hydrocarbon charging can be summarized as: early Cretaceous volcanic eruption and reservoir forming, late Cretaceous sediment burying and organic gas generation, Cenozoic inorganic CO_2 degassing in mantle and migrating along the reactivated faults and accumulating in volcanic rocks. High matured coal bearing source rock controls the hydrocarbon gas distribution and reactivated deep faults control the distribution of inorganic CO_2.

The research result implicates that reactivated deep faults should be avoided and high mature coal bearing source rock should be focused in the exploration of natural gas.

S5.P10. Hydrocarbon charge history and palaeo oil reservoir restoration in Anyue Cambrian gas field in Sichuan basin: detailed evidence from fluid inclusions and quantitative grain fluorescence

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Anyue gas field in the Longwangmiao Formation (L. Fm) of Cambrian, located in the Moxi area of the Sichuan basin, is the largest mono-block carbonate gas field in China, with proved gas reserve exceeding 4400×108 m^3. Gas composition, light hydrocarbon and reservoir bitumen content have evidenced that the gas is dominantly sourced from crude oil cracking gas. The formation process of gas reservoir is complex, and is closely related to the palaeo oil reservoirs. Investigation on palaeo oil reservoirs distribution and hydrocarbon charge history could provide more information for understanding deeply gas accumulation in L.Fm and guiding exploration in future. In this study, a comprehensive fluid study was performed including fluid inclusion analysis (Parnell et al., 1998; Kerkhof et al., 2001), quantitative grain fluorescence (Liu et al., 2013) and Raman spectrum measurement.

In L.Fm, minerals filling sequences in the fracture and karst cavity are predominately from dolomite to solid bitumen, quartz + dolomite. The carbonate rocks contain both hydrocarbon and aqueous inclusion. Most of the fluid inclusions are hosted within just two minerals: dolomites and quartzes. Three types of fluid inclusions are recognized as determined by petrography and microthermometry. Oil and aqueous inclusions within dolomites and clear edge of dolomite with homogenization temperature (T_h) range of 100-120 °C indicates the primary oil charge and accumulation. Quantitative grain fluorescence results shows the oil has a low density. Bitumen, gas-aqueous two phase and aqueous inclusions formed in dolomite vein have a range of 130-170 °C in T_h. That provides an evidence for the secondary hydrocarbon charge during the beginning of oil thermal cracking in the period of late Triassic epoch. Methane and gas-aqueous inclusions within quartz vein have a high T_h range of 200-230 °C. It is the evidence for the third gas charge and accumulation in the period of Jurassic and Cretaceous. The gas predominately sourced from a large number of oil thermal cracking. Present gas reservoirs were finally formed during the period. According to the fluid inclusions analyses, quantitative grain fluorescence and bitumen content measurement, a giant palaeo oil reservoir in L.Fm was restored, which verifies that Anyue Cambrian gas reservoir is a secondary pools with oil cracked in situ.

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S5.P11. Diagenetic fluids within carbonates of the Weißjura-Group (Upper Jurassic) at deep geothermal wells in southern Germany

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Up to now, 21 productive geothermal heat and power plants in the area around Munich use the hot fluid (80-150 °C) of the Upper Jurassic carbonate aquifer (Weber et al., 2016; Birner, 2013). The Upper Jurassic carbonates (Weißjura-Group) dip to the south and can be reached in depths between 2500 to 5000 m south of Munich. The productivity of a geothermal well depend on the flow rate and temperature of the produced fluid, and therefore for the Upper Jurassic aquifer on porosity and depth. Because of the decrease in porosity to the south with growing depth and increasing fluid temperature, geothermal energy production is not possible south of Munich by now. The reduction in porosity can be caused by a change in carbonate facies or by a different grade in diagenesis, which was not yet systematically investigated. In this paper, the diagenesis of the Upper Jurassic carbonates is analyzed within the southern alpine foreland. The primary porosity can be increased by the process of dolomitization (Machel, 2004), hence those secondary processes influencing the carbonates are important to know and to understand. The main parameter influencing the porosity of late Jurassic carbonates is the mineralization, which encompass cementation, recrystallization, dolomitization, migration of silica, and hydrocarbon migration. Due to the alpine tectonics and the development of the alpine foreland basin, there are synsedimentary fault zones and fractures. The fracture and fault systems play an important factor in hydrodynamics as they provide the main flow paths compared to the matrix porosity.

At first, the microfacies (depositional environment) and the primary porosity are evaluated and characterized to understand if and how primary fluid migration through the pore space was possible. In a second step, the calcite and dolomite crystals of 14 deep wells within the alpine foreland basin are measured by microthermometry and cathodoluminescence to analyze the sequence of diagenetic fluids and cements. Preliminary results show for two-phase aqueous fluid inclusions salinities around 1.2-3 % mass NaCl and homogenization temperatures above the recent reservoir temperatures. At some fluid inclusions positive melting temperatures were measured, but, up to now, a possible gas content was not possible to determine with Raman spectroscopy due to a high fluorescence.

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S5.P12. The thermometric study of gas-water inclusions of the Paleozoic rocks of the Caspian basin and the Sakmara zone of Mugodzhar

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The fluid inclusions in calcite and quartz of Silurian, Devonian, Carboniferous and Permian series of East part of Precaspian basin and Sakmara zone of Mugodzhar (South Ural mountain) were studied. By the microthermometry method melting and homogenization temperatures of fluids in crystals, were determined. The biphasic aqueous inclusions (Lw) were sporadically observed in Carboniferous samples (Visean series) and systematically in the Devonian and Silurain. For biphasic inclusions, the salinities range from 2-15 % NaCl equivalent weight, and a great variability of Th (very low to much higher, more than 200 °C). Among the samples of Precaspian basin one group of biphasic fluid inclusions has very low homogenization temperatures (about 65 °C). The second group of fluid inclusions has the average homogenization temperatures of 115 °C. For two-phase inclusions of the samples of the Chanchar and Sakmara suites of Mugodzhar, the salinity of 3-6 % of weight equivalents of NaCl is most typical with the presumed circulation of fluid flows of different composition and mineralization. The homogenization temperature varies from a very low +60 °C to an increased +290 °C with four maxima around temperatures of 100 °C, 130 °C, 175 °C and 285 °C. The interpretation of results of measurements of the samples of Precaspian basin has allowed defining most typical values of pressure and temperature equal, accordingly, 300-500 bar and 80°-130 °C with geothermal gradient about 24 °C/km. Analogous P/T pairs are determined by homogenization temperatures around 120-140°C of samples of the Sakmara zone. However, for the homogenization temperatures of 280-290 °C, the reconstruction of the P/T pair in this zone shows an increase in the paleotemperature values to 340-430 °C and paleopressure to 650-700 bar or more, which corresponds to a geothermal gradient exceeding 40 °C/km.

The presence of many single phase aqueous inclusions and very low homogenization temperatures (65 °C) in Precaspian basin indicate low temperature trapping conditions, consistent with the low degree of maturation of the organic matter (VR < 0.8). The increase in this temperature towards younger suites from the Silurian deposits (samples of the Sakmara suite of the Llandoveri-Ludlowian age) - + 60 / + 225 °C toward the samples of the Chanchar suite of Prague-Em age - +110 / +290 °C, which agrees with the geological evolution of the region. The time of subduction processes of the Ural paleoocean along the Eastern European plate and, accordingly, the increase in temperature regimes occur in the Devonian period.

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