5TH SERPENTINEDAYS 2024
23 - 25 SEPTEMBER 2024, GRANADA

5th SerpentineDays Workshop

23 - 25 September 2024

Granada, Spain

Abstract volume

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Partners and institutions

We acknowledge the EAG (www.eag.org) for their financial support to cover the registration fees of three awarded international PhD students (Shunya Okino, Japan; Serena Cacciari, Italy; Palash Kumawat, Germany).

Venue

The **5th SerpentineDays meeting** will be hosted at

Carmen de la Victoria, Cta. del Chapiz 9, 18010 Granada, Spain
https://maps.app.goo.gl/1fz3Af1GNERPqnWe6

This unique location in the heart of Granada's historic *Albaicin* district impresses with its traditional architecture and offers a beautiful view on the Alhambra. Most roads and alleys in this neighborhood are narrow, often with stairs. Note that car access is restricted to public transport and residents with permit.

The **conference Dinner** (Wednesday 25th) will take place at

„La Chumbera", Camino Sacromonte 107
https://maps.app.goo.gl/DYWFqP3gR417QdnA9

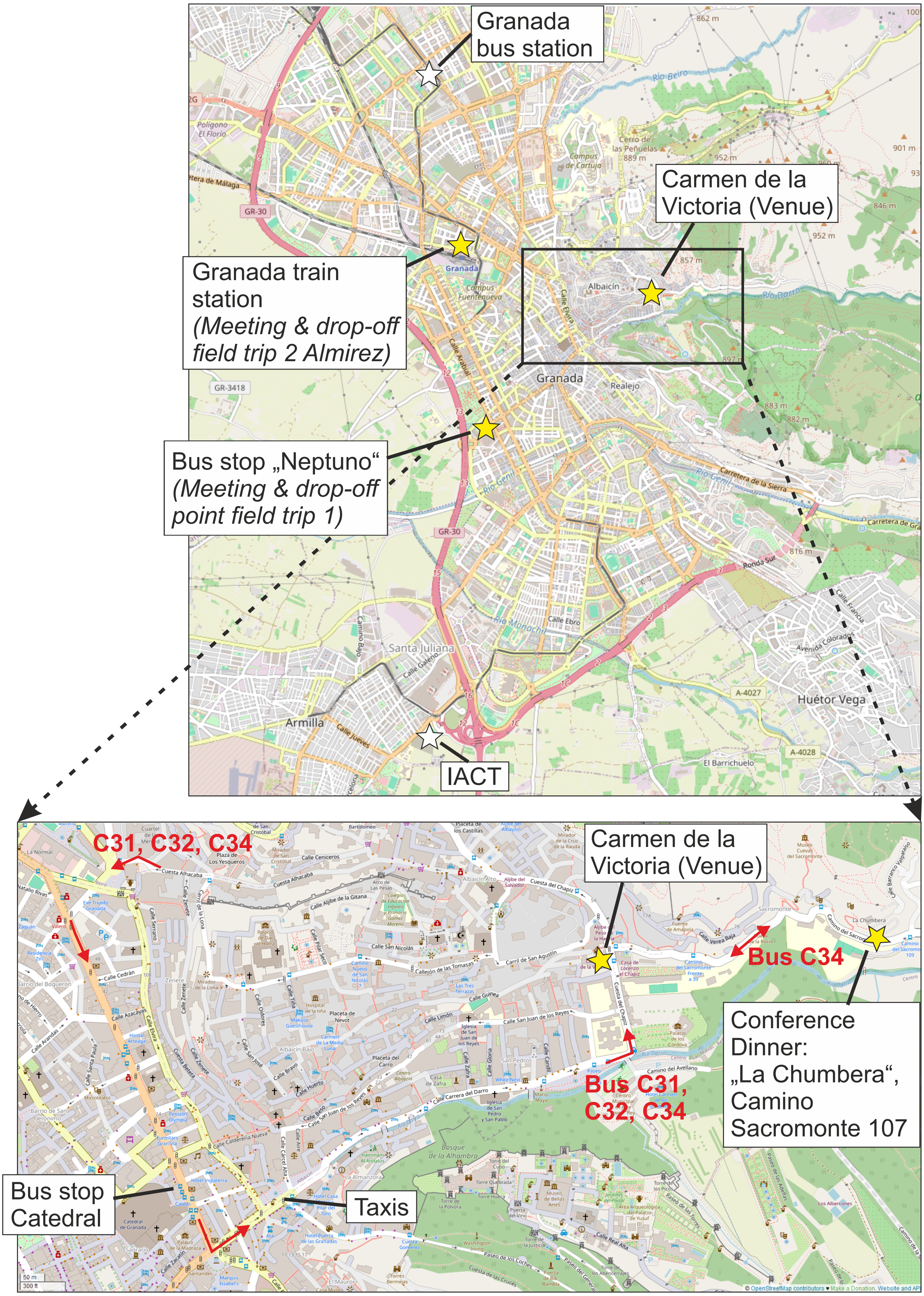
Note that the restaurant is not directly at the main road but a short climb up, either taking a staircase or a small road.

Access

On foot (recommended):
Granada is very well adapted to pedestrians. Reaching the Carmen on foot is the easiest and nicest way, except for persons with restricted mobility (most roads have cobble-stones and stairs). It takes about 20 min to walk from the Cathedral or Plaza Nueva to the Carmen.

By public transport:
Small urban buses connect the center (Cathedral) with the Albaicin: lines C31, C32 and C34. Note that these bus lines are one-way only, making a circle through the district. Tickets can be bought from the driver. More information on urban buses:
https://www.granadadirect.com/transporte/lineas- autobuses-granada/

By taxi:
Taxis (white cars, with green number showing when available;) are affordable (typically around 7 – 15 € from anywhere in Granada). In Albaicin, taxis take the same route as the bus lines.


Granada bus station
Carmen de la Victoria (Venue)
Granada train station
(Meeting & drop-off field trip 2 Almirez)
Bus stop „Neptuno“
(Meeting & drop-off point field trip 1)
IACT
Granada
Albaicín
Realejo
Armilla
Santa Juliana
Huétor Vega
C31, C32, C34
Carmen de la Victoria (Venue)
Bus C34
Conference Dinner: „La Chumbera“, Camino Sacromonte 107
Bus C31, C32, C34
Bus stop Catedral
Taxis

Program overview

Sunday 22 September

07:30 - 18:00 Pre-conference fieldtrip 1: Ronda alkaline springs
18:45 - 19:45 Reception & name badges
19:45 - 22:00 Icebreaker (includes buffet and drinks)
Location: Conference venue, Carmen de la Victoria

Monday 23 September

08:30 - 08:45 Registration & name badges
08:50 - 09:00 Welcome
09:00 - 19:00 Scientific program

Tuesday 24 September

09:00 - 19:00 Scientific program

Wednesday 25 September

09:00 - 16:30 Scientific program
16:30 - 17:30 Discussion & outlook
19:45 - open Conference dinner (La Chumbera Restaurant)

Thursday 26 - Friday 27 September

two days Post-conference fieldtrip 2: Almirez massif (Sierra Nevada, Spain)

Conference dinner

On Wednesday 25th of September we will end the 5th SerpentineDays meeting with a conference dinner. This social event will take place at La Chumbera in Sacromonte, the historic caves neighborhood, within walking distance from Carmen de la Victoria.
After dinner, we will enjoy a high-quality flamenco show performed by an award-winning (El Cante de las Minas) Spanish trio consisting of a dancer, guitarist, and singer.

Registration required.

Field trips

Field trip 1: 22 September 2024

We visit the hyperalkaline springs in the Ronda peridotite massif. During this fieldtrip we discuss low-temperature serpentinization and related processes.
max. 26 participants, registration required (fully booked)

Sunday 22, 7:30	Departure by bus from Granada (*Note time change from 8:00 before*).
Sunday 22, 18:00	Return to Granada

The bus has limited space. Please bring only what you need for the trip and leave any larger luggage item in your hotel in Granada. Please bring adequate foot wear (8 km walking) and sun protection, and a picnic in case you cannot have early breakfast in your hotel. Hiking poles may be useful. Lunch at a restaurant, and water and field guides will be provided.

Meeting and drop-off point: Bus stop "Neptuno" (opposite to the commercial center) (https://maps.app.goo.gl/3rcDMMF34XxsBJHu9)
Field trip leaders: Carlos J. Garrido, Manuel D. Menzel

Field trip 2: 26 – 27 September 2024

During two days we visit the Almirez massif (Sierra Nevada, Spain), the world's unique exposure of the high-pressure serpentine dehydration front to prograde harzburgite. This is the perfect place to learn and discuss about the role of serpentinites in subduction zones.
max. 30 participants, registration required (fully booked)

Thursday 26, 8:00	Departure from Granada with cars and Mini-buses
Thursday 26, all day	Field trip first part
Thursday 26, 20:00	Dinner and overnight stay in "Hotel Almirez", Laujar de Andarax
Friday 27, all day	Field trip second part
Friday 27, evening	Return to Granada (train station)

Both days involve hiking in easy/moderate alpine terrain at 2000 – 2500 m altitude. Weather conditions are difficult to predict, it can be very windy and much colder than in Granada. Please bring personal equipment accordingly (mountain foot wear, rain coat, warm clothes / wind-breaker, but also sun protection and hat).
All of the Almirez outcrops are located within the Sierra Nevada National Park. The National Park administration did not grant permission for sampling during this trip.
We have limited space for luggage. Please arrange to deposit larger items in your hotel in Granada if possible; luggage lockers may also be found close to the train station.

Meeting and drop-off point: Granada train station, main square in front (https://maps.app.goo.gl/4nNx4UKQCyNvUzZw7)
Field trip leaders: José Alberto Padrón Navarta, Vicente López Sánchez-Vizcaíno, Carlos J. Garrido, Manuel D. Menzel, Michał Bukała

Scientific program

Sunday, 22 September

19:45 - 22:00 ICEBREAKER (Carmen de la Victoria; buffet + drinks)

Monday, 23 September

8:00 - 8:45 REGISTRATION & NAME BADGES

8:50 - 9:00 WELCOME

Oral 1: Serpentinization at the ocean floor. Chairs: Manuel Menzel; Carlos Garrido

9:00 - 9:15	Baptiste	Debret	Abyssal serpentinite geochemistry and geodynamics
9:15 - 9:30	Coralie	Vesin	Geochemical discrimination of serpentinisation conditions at mid-ocean ridge and continental passive margin
9:30 - 9:45	Muriel	Andreani	Diversity and dynamics of ultramafic-hosted hydrothermal activity at the Rainbow Massif, 36°14'N Mid-Atlantic Ridge.
9:45 - 10:00	Rémi	Coltat	Spatio-temporal variability of mineralized hydrothermal systems in exhumed abyssal serpentinites (Rainbow Massif, 36°N, Mid-Atlantic Ridge)
10:00 - 10:15	Marguerite	Godard	Serpentinization, carbonation and H_2 production at Atlantis Massif (MAR 30°N): Preliminary geochemical results from IODP Expedition 399
10:15 - 10:30	Andrew	McCaig	Macroscopic reaction porosity in the Atlantis Massif: potential for enhanced hydrothermal circulation, fluid access for serpentinisation and the subsurface biosphere

10:30 - 10:45 Flashtalks Posters P1 - P6

P1	Will	Osborne	Tracking Fluid-Rock Interaction Using B Isotopes in Abyssal Serpentinites: Insights from Recent Deep Drilling at the Atlantis Massif (IODP Exp. 399)
P2	Rebecca	Kuehn	Foliation by deformation in low-grade serpentinites from the Atlantis Massif
P3	Lisa	Eberhard	Stress makes it faster: Rapid serpentinization due to deformation-induced permeability increase
P4	Leonardo	Salvadori	Frictional strength, healing behaviour and deformation mechanism of low-grade serpentinites at hydrothermal conditions
P5	Chang	Zhang	Multiple stages of serpentinization identified by boron isotopes of ultramafic rocks from the Xigaze ophiolite, Yarlung-Tsangpo Suture Zone, southern Tibet
P6	Paula	Dörfler	In-situ oxidation of Fe-brucite under hydrothermal conditions: A synchrotron XANES study

10:45 - 11:30 COFFEE BREAK

Oral 2: Serpentinization processes and hydrogen formation. Chairs: Marguerite Godard; Remi Coltat

11:30 - 12:15	Frieder	Klein	KEYNOTE: Reaction Pathways of Serpentinization in Oceanic Settings
12:15 - 12:30	Ruifang	Huang	The influence of fluid compositions on hydrogen (H_2) production during serpentinization
12:30 - 12:45	Benjamin	Malvoisin	New thermodynamic and kinetic constraints on H_2 production during ferroan brucite reaction at low temperature

12:45 - 13:00 Flashtalks Posters P7 - P12

P7	Clément	Herviou	Serpentinization, a key process for the abiotic formation of varied carbonaceous material in the oceanic lithosphere
P8	Lisa	Tagliacollo	Revived interest in historically dismissed Volcanogenic Massive Sulfide (VMS) deposit of the Emilia Romagna region (Italy): Critical Raw Materials (CRMs) petrological and geochemical study
P9	Olivier	Alard	S-C-H relationships in metamorphic serpentines
P10	Yin	Zhuangzhuang	Serpentinization and deserpentinization of the mantle wedge at a convergent plate margin
P11	María	Ramón-Fernández	Hydrogen in orthopyroxene records oxidation during hydration of the cold mantle wedge
P12	Guillaume	Bonnet	Post-peak formation of diopside-bearing calcsilicate rocks within subducted mantle rocks at Cima di Gagnone (Central Alps)

13:00 - 15:00 LUNCH

Oral 3: Serpentinization and life. Chairs: Carlos Garrido & Marguerite Godard

15:00 - 15:45	Barbara	Sherwood Lollar	KEYNOTE: Serpentinization's links to subsurface life constrained by new insights into the Hidden Hydrogeosphere
15:45 - 16:00	Alexis	Templeton	Detecting life-activity within actively serpentinizing peridotite rocks and fluids
16:00 - 16:15	William	Brazelton	Unusual metabolic strategies shared by microbial communities fueled by serpentinization
16:15 - 16:30	Palash	Kumawat	Unraveling Mariana's Microbial Marvels – A Lipidomic Journey into the Serpentinite Biosphere
16:30 - 16:45	Agustín	Solano Arguedas	Biogeochemical cycling of metals in serpentine soils of Costa Rica; linking microbial ecology to the fate of trace elements

17:00 - 19:00 POSTER SESSION I: coffee, drinks and snacks

Tuesday, 24 September

Oral 4: Volatiles and metals during serpentinization and serpentinite alteration. Chairs: Remi Coltat; Lisa Eberhard

9:00 - 9:15	Maureen	Feineman	Sulfur Isotope Variation in Partially Serpentinized Harzburgite from the ~2.05 Ga Layered Mafic Suite of the Molopo Farms Complex, Botswana
9:15 - 9:30	Julien	Fort	Pseudomorphosis and brucite silicification during serpentinization
9:30 - 9:45	Long	Zhang	Formation of kuliginite during serpentinization by saline fluids: reappraisal and new findings
9:45 - 10:00	Katy	Evans	The characteristics and origin of platinum group minerals from Macquarie Island, Australia
10:00 - 10:15	Bastien	Audran	Metals mobility during serpentinization: new insights from the Ronda Massif, Spain
10:15 - 10:30	Thierry	Decrausaz	Mobility of metals during the carbonation of peridotites (Semail Ophiolite, Fanjah, Oman): clues from stable isotopes

10:30 - 10:45 Flashtalks Posters P13 - P18

P13	Guilherme	Ínsua-Pereira	Major and trace element geochemistry of serpentinized ultramafic rocks from the Bragança Complex, NE Portugal
P14	Israel David	Garduño Torres	Structural and geochemical analysis of the Tehuitzingo and Allende serpentinite bodies in Southern Mexico
P15	Tomas	Magna	Serpentinites and serpentinized garnet and spinel peridotites from various lithotectonic units of western margin of the Bohemian Massif – Considerations of mineralogy, geochemistry and non-traditional stable isotope systematics
P16	Takayuki	Nakatani	Experimental study on the formation of spinifex-like textured olivine during antigorite dehydration at 200-700 MPa
P17	Laurie	Besognet	Experimental insight into the abiotic organic synthesis during subduction
P18	Shunya	Okino	Talc formation enhanced by CO_2-metasomatism at crust-mantle boundary in subduction zone

10:45 - 11:30 COFFEE BREAK

Oral 5. CO_2 sequestration and natural hydrogen production. Chairs: Manuel Menzel; Carlos Garrido

11:30 - 12:15	Greg	Dipple	KEYNOTE: Carbon dioxide removal using serpentine-rich mine residues
12:15 - 12:30	Alicja	Lacinska	Serpentinites and ultramafic systems – their role in decarbonisation and resource management
12:30 - 12:45	Eric	Gaucher	Serpentinization, a new proxy for industrial exploration of natural hydrogen

12:45 - 13:00 Flashtalks Posters P19 - P23

P19	Emma	Legros	Serpentine dehydration in subduction zones: characterization of metamorphic olivine veins from the Zermatt ophiolite (Swiss Alps)
P20	Sebastian	Stumpf	Antigorite dehydration fluid element concentrations and fluid/mineral element distribution coefficients
P21	Julia	Dietrich	Ferric iron systematics of hydrated metaperidotites beyond antigorite dehydration
P22	Luis Samuel	Cristóbal Díaz	Unravelling the Redox Conditions during Deserpentinization through Sulphide Mineral Assemblages
P23	Serena	Cacciari	Fluid-rock interaction in eclogite-facies meta-peridotite (Erro-Tobbio, Ligurian Alps)

13:00 - 15:00 LUNCH

Oral 6: Physics of serpentinization, deformation and dehydration. Chairs: Lisa Eberhard; Jose Alberto Padrón Navarta

15:00 - 15:15	Javier	García-Pintado	Tectonics, Hydrothermal Circulation and Serpentinization in Magma-poor Rifting and start of Oceanic Spreading
15:15 - 15:30	Jeremy	Deans	Petrophysical properties of a 1.2 km section of the Atlantis Massif oceanic core complex: IODP Expedition 399
15:30 - 15:45	Wolf-Achim	Kahl	Low-temperature alteration of ultramafic seafloor: Imaging reaction-induced porosity as precursor for microbial habitat development and carbonation
15:45 - 16:00	Juan Carlos	de Obeso	Geochemistry and petrology of the Vizcaino Ophiolite serpentinites
16:00 - 16:15	Manuel	Menzel	Changing deformation style during serpentinite carbonation to talc-magnesite and quartz-magnesite along a plate-scale fault zone
16:15 - 16:30	Jesús	Muñoz	Fluid-Driven Shear Instabilities in the Subducted Oceanic Mantle at Intermediate Depths: Insights from Western Alps meta-ophiolites
16:30 - 16:45	Austin	Arias	Pre-encoded Permeability: An evaluation of the fluid flow properties and growth drivers of serpentinite dehydration vein networks
16:45 - 17:00	Timm	John	Pulsed fluid release from subducting slabs caused by a scale-invariant dehydration process

17:00 - 19:00 POSTER SESSION II: coffee, drinks and snacks

18:30 - 19:00 Organization meeting Future SerpentineDays

Wednesday, 25 September

Oral 7: Fluid-rock interactions in (meta)serpentinites at the subduction interface. Chairs: Jose Alberto Padrón Navarta; Manuel Menzel			
9:00 - 9:45	Atsushi	Okamoto	KEYNOTE: Dynamic interplay of fluid-rock reactions, mass transport and fracturing at shallow mantle wedge
9:45 - 10:00	Vicente	López Sánchez-Vizcaíno	High-pressure metasomatism and carbonation of metaserpentinites during deformation at the subduction interface
10:00 - 10:15	Samuel	Angiboust	Deciphering fluid-rock interaction events in fractured mantle wedge jadeitites
10:15 - 10:30	Clothilde	Minnaert	Omphacitite formation and deep fluid-rock interaction processes in an intra-slab serpentinite-bearing shear zone
10:30 - 10:45	Kevin	Wong	Numerical modelling of dynamic fluid-rock reactions in subduction settings
10:45 - 11:30	COFFEE BREAK		
Oral 8: High-pressure (de)serpentinization and redox processes. Chairs: Vicente López Sánchez-Vizcaíno; Lisa Eberhard			
11:30 - 11:45	Alberto	Vitale Brovarone	The deepest roots of serpentinization: implications on deep energy, geophysics, and deep life at convergent plate margins
11:45 - 12:00	Isabelle	Daniel	Serpentine triggers the formation of Condensed Carbon Matter
12:00 - 12:15	Orlando Sébastien	Olivieri	Production and migration of metamorphic CH_4 driven by fluid infiltration and serpentinization of subducted ultramafic/mafic rocks
12:15 - 12:30	José Alberto	Padrón-Navarta	Redox-modulated deserpentinization in subduction zones
12:30 - 12:45	Michał	Bukała	Metaserpentinites sequester sediment-derived methane and CO_2 in subduction zones via redox-driven carbonate precipitation
12:45 - 13:00	Thomas	Pettke	Sulphide geochemistry and sulfur isotope systematics of subducted hydrous ultramafic rocks from Cerro del Almirez, Spain
13:00 - 15:00	LUNCH		
Oral 9: Serpentinite dehydration and consequences for geochemical cycling. Chairs: Carlos Garrido; Marguerite Godard			
15:00 - 15:15	Yi-Xiang	Chen	The role of serpentinite in crust-mantle interaction and arc magma formation
15:15 - 15:30	Jo Hannah	Asetre	Fluid mobile elements and volatile behaviour during serpentinite dehydration
15:30 - 15:45	Michelle	Ulrich	Serpentine dehydration in the subducted lithosphere produces no B isotopic fractionation
15:45 - 16:00	Enrico	Cannaò	Variable δ11B signatures reflect dynamic evolution of the Mariana serpentinite forearc
16:00 - 16:15	Francesco	Ressico	Coupling bulk and in-situ boron isotopes from a subduction related serpentinization front (Monte Maggiore, Alpine Corsica)
16:15 - 16:30	Ivan	Savov	Storage and fate of volatiles in the shallow mantle: Insights from fluid mobile elements and B and Li isotopes in serpentinites
16:30 - 17:30	DISCUSSION & OUTLOOK		
19:45	CONFERENCE DINNER (La Chumbera Restaurant)		

S-C-H relationships in metamorphic serpentines

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Different types of serpentine (i.e., Chrysotile, Lizardite) have been characterized by XRD and Raman in term of proportion of chrysotile, lizardite and antigorite. Theirs devolatilization and breakdown behaviour along with their H, C and S contents have been investigated using simultaneous thermal analysis and elemental analysis. Thermogravimetry (TG) and differential TG (DTG) show that the main devolatilization occur at temperature characteristics of the serpentine type, with a reproducibility ca. 10ºC. Differential Scanning Calorimetry (DSC) show a sharp exothermic peak at T ca. 815±10ºC for all serpentine types corresponding to the formation of Olivine (±pyroxene). This peak can be used to detect trace amount of serpentinisation, not detected through petrographic inspection.
The thermograms show that most of the degassing is accounted by water up to ≈90%, yet C release can be significant (up to ≈13%) for specific temperature ranges. While the massive release of water follows the endothermic peaks, C does not, leading to extremely variable C/H ratio as temperature increases. This C release occur at temperature not typical of carbonates, which have not been detected during XRD and Raman characterisation. S degassing pattern is variable but show multiple peaks corresponding or not to serpentine breakdown. The contrasted degassing behaviours of C and S suggest that they are hosted in different structural site than water. However, overall bulk analyses of serpentinite and variably serpentinised rocks, using elemental analyser, show broad positive correlations between H, C and S.

Diversity of ultramafic-hosted hydrothermal activity at the Rainbow Massif, 36°14'N Mid-Atlantic Ridge.

Andreani Muriel[1,2]
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Last decades of ocean bottom exploration along mid-ocean ridges (MORs) have revealed an increasing variety of fluid-rock interactions within the oceanic lithosphere, and of hydrothermal systems forming diverse types of localised vents and pervasive diffuse outflows through the seafloor. These different systems are ubiquitous in mantle-dominated substrates uplifted by long-lasting detachment faults that may represent up to 25% of the seafloor, while being neglected so far in evaluations of ocean-lithosphere chemical exchanges. Dredged and drilled serpentinized mantle rocks in present-day oceanic lithosphere show that the main stage of mantle rock aqueous alteration (serpentinization) occurs at 250-350°C during rock exhumation and affects the first 4 to 5 km of the lithosphere while microseismicity indicates fracturing down to 8-15 km-depth. Various chemical changes are attributed to this reaction that is also characterized by the generation of H2. The syntectonic background serpentinization can be overprinted by focused flow driven by magma emplacement at depth at any time near the ridge axis, leading to ephemeral hydrothermal sites on the footwall of detachment faults. Recent observations at the Rainbow Massif located 36°14'N along the Mid-Atlantic Ridges during the Arc-en-sub cruise[1] in 2022 revealed a complex spatio-temporal dynamics of fluid flow, resulting in a far more widespread hydrothermal activity of varied style, than expected on ultramafic-hosted environments. The AUV microbathymetry[2] shows a complex tectonic history of oblique high-angle normal faulting, small-scale detachment faulting, and late strike-slip deformation yet to be related with hydrothermal outflows. ROV observations[3] and sampling confirmed the dominance of ultramafic rocks in the massif substrate, and revealed previously unknown hydrothermal sites, both active and fossil. First, in addition to Rainbow, we have identified several active sites of a new type, with LT fluids venting at temperatures from a few degrees above ambient seawater, and up to 70°C. This discovery significantly extends the style and areal exposures of present-day activity well beyond the HT Rainbow hydrothermal field (> 10 km2). Second, we have identified numerous fossil carbonate and sulfide hydrothermal chimneys at various locations on the massif that are sometimes in close spatial association, suggesting a temporal evolution of local hydrothermal style. Third, fossil bivalve communities are found over much broader areas than previously described (hundreds of m2), extending along the summit of the Massif and its western flank, demonstrating an extensive, and pervasive diffuse flow in the past. Dating of these sites within a detailed structural framework help constraining the timing and duration of these different hydrothermal events to better evaluate their relationships and their links to the magmatic and structural evolution of the massif. These results reinforce consideration of the impact of ultramafic-hosted hydrothermal systems on global chemical exchanges at the mantle-(sediment)-ocean interface and integration to global models.

References:

[1] Andreani Muriel, Escartin Javier, and Scientific Party (2022), Arc-En-Sub cruise, RV Pourquoi pas ?, https://doi.org/10.17600/18000663

[2] Avoustin Marianne, Gini Caroline, Andreani Muriel, Escartin Javier (2022). Rainbow massif (Middle Atlantic Ridge 36 14'N): AUV IdefX Microbathymetry and Acoustic Backscatter. https://doi.org/10.17882/89445

[3] Andreani Muriel, Escartin Javier (2022). Arc-en-Sub 2022 cruise ROV VICTOR Navigation. https://doi.org/10.17882/89985

Deciphering fluid-rock interaction events in fractured mantle wedge jadeitites

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Seismological studies report transient seismicity clusters in the mantle wedge several kilometers above the subduction interface and relate them to a possible evidence for active fluid drains [1]. Jadeitites are known to form and/or be associated with mantle wedge serpentinites in the c. 40-70 km depth range, and thus may yield information on fluid-rock interaction physical processes in this region of deep subduction environments [2]. We herein showcase natural occurrences of fault zone textures from jadeitites, including tectonic breccias, hydraulic breccias and foliated cataclasites [3]. We document extensive evidence for dissolution-precipitation, metasomatism and multiple cross-cutting relationships between viscous and brittle deformation mechanisms. New geochemical investigations on brecciated jadeitites indicate approach to isotopic and trace element equilibrium between the external infiltrating fluid and the clasts upon fracturing and cementation. In some cases, externally-sourced (Cr- or K-bearing) fluid infiltration is documented during the fracturing process, pointing to either mantle-derived or sediment-derived origin (or a combination of both). These high permeability drains likely (i) contribute to the transfer of highly pressurized plate-interface metamorphic fluids into the mantle wedge; and (ii) trigger seismic instabilities recorded in the basal part of active mantle wedge sections. These findings provide new insights into the current understanding of the rheology (e.g., serpentinization ratio) and stress state in the mantle wedge, with implications for subduction interface seismogenesis.

References:

[1] Halpaap, F., Rondenay, S., Perrin, A., Goes, S., Ottemöller, L., Austrheim, H., ... & Eeken, T. (2019). Earthquakes track subduction fluids from slab source to mantle wedge sink. *Science Advances*, *5*(4), eaav7369.

[2] Harlow, G. E., Tsujimori, T., & Sorensen, S. S. (2015). Jadeitites and plate tectonics. *Annual Review of Earth and Planetary Sciences*, *43*, 105-138.
[3] Angiboust, S., Muñoz-Montecinos, J., Cambeses, A., Raimondo, T., Deldicque, D., & Garcia-Casco, A. (2021). Jolts in the Jade factory: A route for subduction fluids and their implications for mantle wedge seismicity. *Earth-Science Reviews*, *220*, 103720.

Pre-encoded Permeability: An evaluation of the fluid flow properties and growth drivers of serpentinite dehydration vein networks

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In subduction zones, as the slab descends, serpentinite undergoes dehydration, a process that significantly influences global volatile cycling, volcanism, and earthquake genesis. During serpentinite dehydration, changes in mineralogy are coupled with structural alterations, leading to changes in the effective properties of the rock. To determine the impact of these structural changes on the fluid flow properties of the rock, we applied a novel workflow that couples petrology, equilibrium thermodynamics, and generative machine-learning models to generate accurate graph representations of dehydration vein networks. Specifically, the workflow was applied to the Erro-Tobbio meta-serpentinites (ET-MS) in Italy. These rocks preserve a highly connected network of olivine veins that fossilize the original fluid flow pathways that emerged during the serpentinite dehydration [1]. These networks exist within representative volumes on scales ranging from cm^3 - m^3 and, therefore, are challenging to analyze with traditional sampling methods. Utilizing drone surveying of outcrops, we trained the machine-learning models to generate 3D digital samples at different length scales. Then we assessed the fluid flow properties at different stages of network evolution by extracting graphs from the generated volumes and performing volumetric filtrations on the graphs. Petrographic and geochemical observations suggest the vein network structure developed according to the initial distribution of brucite and bulk iron in the rock. These observations combined with predictions from equilibrium thermodynamics suggest that a volumetric graph filtration can be representative of the vein network evolution. The extracted graphs of the vein networks show that at the time of dehydration, the dehydration vein networks may support an upper bound permeability increase of three orders of magnitude above background values, indicating that dehydrating serpentinites acted as high-permeability zones within subducting slabs.

References:
[1] Plümper, O., et al. (2017). *Nature Geoscience* 10, 2, 150-156.

Fluid mobile elements and volatile behaviour during serpentinite dehydration

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Geochemical exchanges occurring along subduction zones regulate the mobility and long-term cycle of life-essential elements (e.g. C, H, O, S, F, Cl) between the exospheres and the deep earth. The capture, transfer, and eventual release of volatiles from the seafloor to subduction depths are a product of key metamorphic reactions, as initiated by the dehydration of the plunging slab. In particular, the prograde metamorphism and dehydration journey of serpentinites ($Mg_3Si_2O_5(OH)_4$) acts as a filter to either release volatiles and fluid-mobile elements (FME's) back to the mantle wedge and/or the surface, or sequester them further down to the deep mantle contributing to the evolution of the Earth's mantle composition. The composition and volatile contents of the fluids liberated by serpentine breakdown reactions have thus critical implications on the secular equilibrium of Earth's reservoirs, the emplacement of critical elements, and the oxidation of the mantle wedge. However, the specific systematics and relative contribution of serpentinites in the global geochemical cycle remains to be fully understood. The nature, composition, and abundances of volatiles within the fluids released during deserpentinization reactions remain largely unconstrained. How efficient are these reactions in releasing fluids? Do these reactions produce oxidized or reduced fluids? Is S significantly extracted from the slab components, and if so, at which stage/depth does this occur? Do water and halogens enhance element transfer? All these questions remain highly debated in the literature (Benard et al., 2018; Evans and Frost, 2021; Kendrick et al., 2018; Marchesi et al., 2013; Pettke and Bretscher, 2022; Piccoli et al., 2019).

By employing *in-situ* mineral trace element analyses on high-pressure serpentinites and metaperidotites recording unique subduction histories, we have investigated the geochemical signatures associated with serpentine dehydration at various depths. Enrichments in key FME's reinforce the importance of surviving hydrous phases (i.e. chlorite, humites) as a carrier of these elements down to 150 km depth. Preliminary results from high-pressure experiments also highlight the volatile-halogen transfer mechanisms at key temperatures and pressures where serpentine breakdown occurs. Volatile release and retention in the subducting slab is a complex and protracted process that merits further investigation. Ultimately, our study solidifies the significance of serpentinites towards the larger geochemical "diet" of subduction zones that govern the crossroads between the surface reservoirs and the deep mantle.

References:
[1] Benard, A et al. (2017) Geochimica et Cosmochimica Acta 199:324-350
[2] Evans, KA & Frost, BR (2020) Journal of Petrology 62(1):1-32
[3] Kendrick, MA et al. (2018) Geochimica et Cosmochimica Acta 235:285-304
[4] Marchesi C et al. (2013) Lithos 178:128-142
[5] Pettke, T and Bretscher, A (2022) Earth Science Reviews 225:103896
[6] Piccoli, F et al. (2019) Sci Rep 9:19573

Metals mobility during serpentinization: new insights from the Ronda Massif, Spain

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The Ronda peridotite represents the largest exposure of the subcontinental lithospheric mantle at the Earth surface. This makes it an exceptional site to investigate the process of serpentinization which accompanies exhumation from mantle depths. In particular the mobility of metals associated with serpentinization reactions remains to be characterized at various scales. This study first examines the structural, petrologic and geochemical aspects of serpentinization in the Ronda Massif. We have identified three successive stages of serpentinization. Stage 1 is characterized by pervasive lizardite with a highly variable proportion of serpentine. Stage 2 indicates fluid focusing, resulting in fully serpentinized planar structures ("corridors") with a high content of magnetite. Stage 3 is marked by syn-tectonic veins with varying amounts of magnetite. Deformation analysis of the stage 3 shear veins suggests extensional deformation associated with exhumation of the Ronda Massif, most likely during the early Miocene. Oxygen isotope systematics on stage 3 serpentine-magnetite pairs yield temperatures of 170 ± 50°C. The O-H isotope composition of Ronda serpentinite shares a similar signature between all stages, suggesting i) serpentinization evolved in a continuum from stage 1 to stage 3 of the Ronda Massif and ii) no evidence for

influx of different fluids during stage 2 and 3 relative to stage 1. The origin of the serpentinizing fluids during stage 1 can be attributed to deep-seated magmatic-metamorphic fluids with a possible small meteoric water contribution. Bulk rock geochemistry, micro-XRF elemental mapping and mineral analysis by in situ LA-ICP-MS were then conducted on variably serpentinized peridotite rocks for the different serpentinization stages. The principal outcome of this study is that Ca, Fe, Cu and even Al, to some extent, were mobilized during serpentinization of the Ronda Massif. These elements were subsequently trapped through nearby chloritization and during rodingitization of syn-serpentinization felsic magmas emplaced in the Ronda Massif. This study provides new insights into the source of elements associated with Fe-Ca metasomatism and mineralization in ultramafic-hosted systems.

Funding: This work was made possible thanks to CNRS-Tellus-Syster and “Défi Scientifique de l’Université de Rennes” grants to PB and BA.

Linking the nanostructures of serpentine minerals to large scale processes *(withdrawn)* *Will be postponed to SerpentineDays webinar (https://serpentinedays.org/webinars/)*

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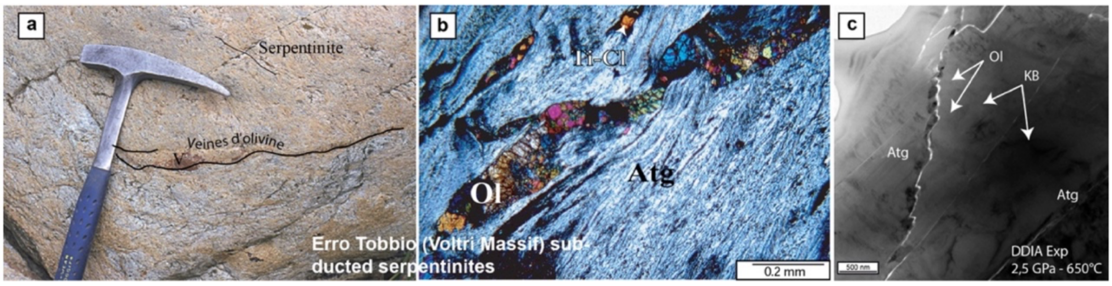
Serpentine minerals produce a wide range of sublime crystalline structures, from the classic flat TO lizardite to the modulated antigorite, from the coils of chrysotile to the ball-shaped polyhedral serpentine. Such variety leads to contrasted behaviors in terms of geochemistry, physical properties, rheology (e.g., [1]) that generate an amazing diversity of microstructures (veining, cracking, recrystallizing, twinning, kinking...) This is probably why there is this “serpentine seduction” to explain so many geodynamical processes [2].
What governs the microstructural richness observed in serpentinites is still matter of debate. Thus, the significance of these micro/nano-structures and how we can use them to better understand large scale processes is not straightforward and necessitate meticulous examination. While some structures can be almost fractal and are observed at different scales (Figure: metamorphic olivine veins linked to serpentinite dehydration in subduction conditions), others are not that obvious at all scales (significant microcracking in a mesoscopically ductile sheared serpentinite [3]). As serpentine minerals are mostly nanonoscopic phases, their investigation is greatly helped with high resolution techniques such as Transmission Electron Microscopy, though we need to remain aware of the low statistics that represent one observation at such scale and that numerous observations are required to access the complexity of serpentinite rocks. How to extrapolate these nanoscopic observations to multi-kilometric objects and long duration processes is also a tricky issue but a step-by-step approach can help performing such scaling.
Here, we will discuss serpentine growth during olivine hydration, serpentine stability, seismic wave velocities, serpentine deformation and breakdown using their microstructures and trying to extrapolate to larger scale processes, such as oceanic serpentinization or serpentinite role(s) in subduction settings.



a) and b) Serpentinites recording subduction-related dehydration (Erro-Tobbio, Massif de Voltri) *[4]* and c) initiation of antigorite dehydration during a D-DIA experiment *[3]*

References:
[1] Guillot et al (2015) Tectonophysics, DOI : 10.1016/j.tecto.2015.01.020
[2] Kerrick (2002) Geology, DOI: 10.1126/science.298.5597.13
[3] Auzende et al (2015) EPSL. DOI : 10.1016/j.epsl.2014.11.053
[4] Auzende et al (2006) Eur. J. Mineral. DOI 10.1127/0935-1221/2006/0018-0021

Investigating hyperalkaline fluids and associated carbonates for isotopic and elemental abundances to resolve mineralization kinetics (*withdrawn)*

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Serpentinization is a widespread phenomenon resulting from the hydration of ultramafic rocks. The occurring reactions transform olivine and pyroxene into serpentinite minerals. Moreover, they modify meteoric fluids by producing hyperalkaline waters, that eventually resurface through springs. Such hyperalkaline spring waters are characterized by light (meteoric) $\delta^{18}O$ and $\delta^{2}H$ values, pH ranges between 10 and 12.5, and very limited DIC. Absorption of atmospheric CO_2 drives mineralization, producing crystalline crusts on the air-water interface or more extensive formations like travertines. Additionally, mixing with DIC-rich surface water initiates carbonate precipitation and sedimentation. The structure of alkaline spring tufa deposits produces a natural gradient from these two sources of carbon, and presents a natural laboratory for studying the reaction kinetics of CO_2 hydration and mineral formation. The contributions of these two end-members can be unambiguously identified in modern and ancient tufa deposits using the novel dual clumped isotope method [1]. This method combines two independent temperature calibrations for Δ_{47} and Δ_{48}, both have been empirically calibrated against carbonates, which are meant to have precipitated from isotopically equilibrated fluids of controlled temperature [2]. Quantification of departures from this Δ_{47}/Δ_{48} equilibrium relationship can be used to resolve mineralization kinetics [2,3]. Recent efforts in optimization of analytical methods and data processing schemes led to improved repeatabilities, which are now matching the theoretically predicted shot-noise limits for isotope ratio mass spectrometers [4].

For this project, we collected river and spring waters, atmospheric air and carbonate samples at hyperalkaline spring sites within the Ronda Peridotite massif. By generating a dataset that includes analyses of all potential reactants (i.e., $\delta^{2}H$, $\delta^{18}O$, Element/Ca ratios of waters and $\delta^{13}C$, $\delta^{18}O$ of the atmosphere), as well as carbonate minerals (i.e., $\delta^{13}C$, $\delta^{18}O$, Δ_{47}, Δ_{48}, Element/Ca ratios) we aim to identify and quantify kinetic isotope effects associated with carbonate formation using numerical models.

References:
[1] Fiebig, J. et al. (2019). *Chem. Geol.* **522**, 186–191. doi.org/10.1016/j.chemgeo.2019.05.019
[2] Fiebig, J. et al. (2021). *Geochim. Cosmochim. Acta* **312**, 235–256. doi.org/10.1016/j.gca.2021.07.012
[3] Guo, W. (2020). *Geochim. Cosmochim. Acta* **268**, 230–257. doi.org/10.1016/j.gca.2019.07.055
[4] Bernecker, M. et al. (2023). *Chem. Geol.* **642**, 121803. doi.org/10.1016/j.chemgeo.2023.121803

Experimental insight into the abiotic organic synthesis during subduction

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Thermodynamic, experimental and field studies have suggested that organic compounds could be stable within subduction zones under high pressure (HP; 0.5-6 GPa) and high temperature (HT; 600-1000°C) conditions and in some cases predominate over inorganic carbon species [1, 2, 3]. Beyond sedimentary organic matter of biological origin, slab-derived organics can be abiotically formed either in hydrothermal conditions at mid-ocean ridges or subduction through metamorphic reactions. To better constrain the nature and diversity of organic compounds at high pressure, we examine natural samples from blueschist and eclogitic terrains (Queyras, Zermatt Saas, Monviso; Western Alps) and compare those with piston cylinder subduction experiments. Results show the presence of different organic compounds, such as disordered carbonaceous matter, graphite and organic minerals, which can be observed in both natural and experimental samples. The nature of solid organic compounds depends mainly on its origin (biotic versus abiotic) and on the P-T conditions and redox state (i.e., oxygen fugacity). Our results highlight the wide variety of solid organic compounds which can be stabilized at HP-HT and therefore recycled into the deep mantle during subduction.

References:
[1] Galvez ME, Beyssac O, Martinez I, et al (2013). *Nature Geosci* 6:473–477. doi.org/10.1038/ngeo1827
[2] Sverjensky DA, Stagno V, Huang F (2014). *Nature Geosci* 7:909–913. doi.org/10.1038/ngeo2291
[3] Tao R, Zhang L, Tian M, et al (2018). *Geochimica et Cosmochimica Acta* 239:390–408. doi.org/10.1016/j.gca.2018.08.008

Post-peak formation of diopside-bearing calcsilicate rocks within subducted mantle rocks at Cima di Gagnone (Central Alps)

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Decarbonation reactions during the metamorphism of carbonated lithologies have direct impact on CO_2 cycling. Carbonate-bearing ultramafic rocks ("ophicarbonates") may be subject to decarbonation associated to the large fluid volumes liberated during the main dehydration reactions (brucite-out, antigorite-out and chlorite-out). Ophicarbonates affected by high temperature low pressure metamorphism in contact aureoles suffer intense decarbonation, and transform to diopside- and tremolite-rich rocks [1]. To the contrary, thermodynamic and field studies show a limited mobilization of carbon due to the low XCO_2 of fluids in equilibrium with carbonates along high-pressure-low-temperature gradients in subduction settings (e.g., [2, 3]).
Here, we studied diopside-bearing calcsilicate rocks from Cima di Gagnone (Cima-Lunga unit, Central Alps), that have been proposed to be relicts of oceanic ophicarbonates, affected by partial decarbonation during subduction [4]. These rocks are enclosed within ultramafic remnants of the Piemont-Liguria ocean. Constraints on associated lithologies suggest that these rocks were metamorphosed at conditions of ~800°C, 2.7 GPa (i.e. past antigorite dehydration) during Alpine subduction and exhumed within the Lepontine Dome down to conditions of ~600°C, 1.0 GPa [5].
A reevaluation of the structural setting and petrology of these rocks show: (1) almost undeformed fabrics, (2) occurrence as meter-thick dikes discordant to the prograde-to-peak Chl-harzburgite foliation, and (3) occurrence of low-pressure mineral assemblages in equilibrium with calcite and diopside, notably plagioclase. These observations are incompatible with a formation by decarbonation associated to antigorite breakdown during prograde metamorphism. We hence propose an alternative scenario for the formation of these rocks involving fluid/melt infiltration during exhumation, and propose that ultramafic rocks could locally behave as carbon traps.

References:
[1] Eberhard, L. and Pettke, T. (2021). *Geochemica et Cosmochemica Acta 300*, 192-214. doi.org/10.1016/j.gca.2021.02.030
[2] Kerrick, D.M. and Connolly, J.A.D. (1998). *Geology 26*, 4, 375-378.
[3] Menzel, M.D., et al. (2019). *J. of Metam. Geol. 37*, 618-715. doi.org/10.1111/jmg.12481

[4] Pfiffner, M., Trommsdorff, V. (1998). *Schweiz. mineral. petrogr. Mitt. 78*, 337-354.
[5] Piccoli, F., et al. (2019). *Scient. Reports 9*, 19573. doi.org/10.1038/s41598-019-55944-8.

Unusual metabolic strategies shared by microbial communities fueled by serpentinization

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Seafloor chimneys of the Lost City hydrothermal field are windows into a potentially vast microbial habitat within the oceanic crust where energy and organic molecules are provided by geochemical reactions. Hydrogen, formate, and methane generated by serpentinization-associated reactions may be the only available sources of energy for biological activity in these settings. By integrating metagenomic approaches with biogeochemical measurements, we have revealed a few key species of archaea and bacteria that are likely to play critical roles in this subseafloor microbial ecosystem. The key species in the Lost City subseafloor share novel enzymes that may be unique to hydrothermal and subsurface alkaline environments where hydrogen and formate are much more abundant than carbon dioxide. These shared enzymes point to metabolic strategies that must be advantageous in hydrothermal and subsurface environments where energy and carbon are provided by geochemical reactions. I will present a summary and synthesis of our recent work on metagenomic analyses of fluids venting from Lost City chimneys, which we sampled during the 2018 Lost City expedition with R/V Atlantis and ROV Jason.

Acknowledgements: This presentation is a summary of a large team-based project including all members of the 2018 Lost City expedition scientific party, including the crews of R/V Atlantis and ROV Jason, as well as multiple students working in the Brazelton lab at the University of Utah. Funding was provided by NSF awards to W. J. Brazelton and S.Q. Lang (OCE-1536702/1536405) and by the NASA Astrobiology Institute Rock-Powered Life team.

References:

[1] Brazelton WJ, et al. (2022). *Applied and Environmental Microbiology*: e00929-22. DOI: 10.1128/aem.00929-22.
[2] Lang, SQ, et al. (2021). *Geology.* doi: https://doi.org/10.1130/G48322.1.
[3] McGonigle, JM, et al. (2020). *Applied and Environmental Microbiology* 86 (8). DOI: https://doi.org/10.1128/AEM.02583-19.
[4] Lang, SQ and Brazelton, WJ (2020) *Philosophical Transactions of the Royal Society A* 378 (2165). DOI: https://doi.org/10.1098/rsta.2018.0429.

Metaserpentinites sequester sediment-derived methane and CO_2 in subduction zones via redox-driven carbonate precipitation

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High-pressure interactions between aqueous fluids and different rock types at the subduction interface modify the deep volatile recycling and redox capacity of fluids migrating towards the overlying mantle wedge. Although serpentinites generate the largest volumetric fluid fluxes, the estimated $fO2$ of deserpentinization fluids varies widely, encompassing both reducing and oxidizing fluid capacities. Recent findings [1] show that interaction between serpentinites and reduced fluids derived from graphite-bearing metasediments may promote deserpentinization and modify the intrinsic redox capacity of the released fluid.
We tested this hypothesis through fieldwork, microstructural analysis, and thermodynamic modelling of a newly discovered deserpentinization front at Cerro Pingano (Betic Cordillera, Spain), located 20 km north of the type locality of Cerro del Almirez. This ultramafic body, hosted within a sequence of graphite-bearing metasediments and marbles, records the influx of C-bearing fluids at high-pressure conditions. A transition from antigorite (Atg-) serpentinite to Chl-harzburgite through an Atg-Chl-Opx-Ol rock can be traced across a ~50 cm wide redox reaction front.
The oblique orientation of the transition zone relative to the serpentinite foliation indicates the lateral propagation of the redox reaction front. The consistency of planar structure orientations and microstructural observations suggests that the Atg-Chl-Opx-Ol rock and Chl-harzburgite formed at the expense of the serpentinite precursor. This transition is also marked by the bulk reduction of the $Fe^{3+}/\Sigma Fe$ ratio and the enrichment in carbon, associated with the appearance of magnesite (up to 6 vol.%) in the Chl-harzburgite.
Thermodynamic modelling confirms that the graphite-bearing metasediments could have served as a source of highly reducing CH_4, $H_2S_{,(aq)}$, and CO_2-rich fluids, under P-T conditions coinciding with those of serpentinite dehydration at ~16 kbar and ~660°C. Open-system infiltration models show the transformation of CH_4 and $H_2S_{,(aq)}$ to more oxidized CO_2 and $HSO_4^-{}_{,(aq)}$ species upon contact with serpentinite. This reaction effectively reduces the serpentinite redox budget and explains the observed $Fe^{3+}/\Sigma Fe$ decrease between serpentinites and Chl-harzburgites. Consequently, models show that the cumulative CO_2 content in the fluid

exceeds that in equilibrium with reduced serpentinite. This, in turn, allows for the precipitation of excess CO_2 in the form of magnesite carbonate explaining its high content in Chl-harzburgites and its absence in serpentinites.

Therefore, we propose a new reduction-carbonation model showing that serpentinite can capture carbon from CH_4 and CO_2 via redox-driven carbonate precipitation at high-pressure conditions along a hot subduction geotherm. Importantly, the redox contrast between the metasediments' reduced fluids and those of the prograde dehydrating serpentinites represents a new mechanism for precipitating carbonates that can be further subducted. Additionally, we confirm that serpentinites may act as a reactive lithology in the subduction zone, effectively buffering the composition and redox capacity of metasediment-derived fluids.

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References:

[1] Padrón-Navarta, J.A. et al. (2023) *Nat. Geosci.*

Fluid-rock interaction in eclogite-facies meta-peridotite (Erro-Tobbio, Ligurian Alps)

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In subduction zones, fluids released by dehydration reactions strongly influence rock rheology and seismicity. In particular, the occurrence of deep Episodic Tremor and Slow Slip events (ETS) along the subduction interface, at 25-60 km depth [1], is likely fostered by the simultaneous presence of fluctuating fluid pressure and rheological heterogeneities, that allow for strain partitioning into low-strain domains radiating tremor, and high-strain domains accommodating slow slip events.

The Erro-Tobbio meta-peridotite (Ligurian Alps) records fluid-rock interactions and associated deformation that occurred within the deep ETS depth range. Heterogeneous serpentinization of the original mantle peridotite resulted in partitioning of the eclogite-facies deformation into high-strain domains of antigorite mylonites and low-strain domains of undeformed meta-peridotites. Both mylonites and meta-peridotites contain veins and reaction bands of metamorphic olivine (Ol_2) and Ti-clinohumite (Ti-chu), formed by breakdown of brucite (Brc) and antigorite (Atg) at 1.5 GPa and 500 °C [2]. The reaction bands are arranged into two main sets, mutually oriented at ~50°: (i) Set_1, steeply-dipping around 320°, (ii) Set_2, trending N-S parallel to the mylonites. A strain gradient is outlined by a decrease in spacing between Set_2 reaction bands from the core of undeformed meta-peridotite towards the mylonites.

Within the undeformed domains, hydration and dehydration events occurred statically. In such domains, Al-rich Atg (Atg_1) epitaxially replaced mantle olivine (Ol_1), and was in turn epitaxially overgrown by Ol_2, that crystallized in radial aggregates and along Set_1-Set_2 reaction bands. Along the mylonitic horizons, Atg_1 is affected by ductile deformation, and Set_2 reaction bands mark a planar foliation parallel to that of Atg_1. In this case, Ol_2 is rarely crystallographically related to Atg_1 and is mostly oriented with a-axis parallel to the reaction bands, suggesting oriented growth of Ol_2. Atg_1 and Brc relics are preserved along Set_1 - Set_2 and the paucity of Brc in the host rock indicates that Brc distribution reflected chemical heterogeneities at the bulk-rock scale, that preferentially drove the Atg+Brc breakdown to Ol_2+fluid along Brc-rich layers [3].

Later stage, Al-free serpentine (Atg_2 + chrysotile/lizardite) replaces Ol_2 (locally up to 70% volume) along a pervasive network of microcracks exploiting the reactive sites of Set_1-Set_2 structures.
The integration of field and petrographic observations highlights the occurrence of localized Brc ± Atg_1 dehydration to Ol_2 along specific planes, likely related to the initial Brc distribution and Atg deformation, and subsequent Ol_2 hydration localized along serpentine-bearing microcracks.
In-situ LA-ICP-MS reveals an enrichment in fluid-mobile elements (As, Sb, Ba, Li, B) in prograde Ol_2 and retrograde Al-free serpentine compared to Atg_1. This information provides evidence of infiltration of external fluids, indicating open system conditions during eclogite-facies deformation, in agreement with the literature [4,5], and during retrogression.

References:
[1] Behr, W. M., Bürgmann, R., (2021). *Phil. Trans. R. Soc.* A 379: 20200218. https://doi.org/10.1098/rsta.2020.0218.
[2] Hermann, J., et al. (2000). *Tectonophysics* 327, 225-238. https://doi.org/10.1016/S0040-1951(00)00171-2
[3] Plümper, O., et al. (2017). *Nat. Geoscience* 10, 150-156. doi: 10.1038/NGEO2865
[4] Clarke, E., et al. (2020). *Geochemical Perspective Letters* 16, 25-29. doi : 10.7185/geochemlet.2039
[5] Scambelluri, M., et al. (2012). *Geology* 40, 10, 907-910. doi:10.1130/G33233.1

Variable δ^{11}B signatures reflect dynamic evolution of the Mariana serpentinite forearc

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The development of hydrated forearc mantle regions is considered one of the major outcomes of chemical recycling in convergent margins, influencing the geochemical signatures of volcanic arcs [1] and sustaining the deep microbial ecosystems [2]. We focus our attention on the serpentinite clasts from the Asùt Tesoru mud volcano (18.06°N and 147.06°E in the Mariana forearc, IODP Exp 366) as a proxy to unravel the active geochemical exchanges between the upper mantle and slab-derived fluids at shallow depths. We provide new *in-situ* trace element concentrations and boron (B) isotope compositions (δ^{11}B) employing a laser ablation system coupled with an ICP-MS and a multi-collector ICP-MS, respectively, for a suite of well-studied samples [3-4]. The Asùt Tesoru mud volcano is located about 70 km from the Mariana trench and 18 km above the slab, where temperatures at the slab-mantle interface are estimated at 250°C. The analyzed serpentine polymorph in the serpentinite clasts span from lizardite- to antigorite-end members. Trace element results document enrichments in B (from 10 to 150 ppm) and other fluid-mobile and redox-sensitive elements (e.g., Ba, Sr, As, W, Mo). Boron isotope composition range between -5 and +21‰ and shows a positive correlation with the B concentrations. Our findings document a progressive ^{11}B-depletion from lizardite- to antigorite-bearing serpentinites, accompanied by a reduction in incompatible element inventory. This pattern aligns with either a chemical evolution linked to phase transitions along the slab interface of shallow forearc serpentinites dragged down to depth, or interaction with shallow *vs.* deep slab fluids. Our results support the scenario of complex fluid and mechanical mixing along the plate interface in the Mariana subduction system, with major implication on the B recycling in convergent margins [5].

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References:
[1] Savov, I.P., et al. (2005). *Geochem Geophys* 6. https://doi.org/10.1029/2004GC000777
[2] Plümper, O., et al. (2017). *Proc Natl Acad Sci USA* 114, 4324–4329. https://doi.org/10.1073/pnas.1612147114
[3] Debret, B., et al. (2019). *Lithos* 326–327, 230–245. https://doi.org/10.1016/j.lithos.2018.10.038

[4] Debret, B., et al. (2020). *Geochem Perspect Lett* 12, 46–51. https://doi.org/10.7185/geochemlet.2003
[5] Cannaò, E. and Debret, B. (2024). *Geochem Perspect Lett* 30, 13–19. https://doi.org/10.7185/geochemlet.2416

The role of serpentinite in crust-mantle interaction and arc magma formation

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Serpentinites play an important role in crust-mantle interaction and arc magma formation in subduction zones. However, it is usually difficult to trace the serpentinite signature in deeply subducted crustal rocks and in arc magmas. Therefore, we need to develop effective geochemical tracers to address this issue.

Boron and Mg isotope compositions have been increasingly used to track the effect of serpentinite derived fluids in crust-mantle interaction. This is because serpentinite derived fluids have been documented to show high Mg-B contents and heavy Mg-B isotope compositions even at subarc depths, which are distinct from fluids released from altered oceanic crust (AOC) and sediments. In addition, B and Mg are trace and major elements in most rocks, respectively. Therefore, combined B and Mg isotope compositions can give unique constraints on the contribution of serpentinites in crust-mantle interaction and arc magma formation.

In this talk, I will introduce our work on Mg-B isotope studies of fluid-metasomatized rocks from the western and eastern Alps, as well as the South Sandwich island arc magmas. We show that the greatly elevated Mg and B isotope compositions in the fluid-metasomatized rocks formed at forearc to subarc depths of Alps can be unambiguously ascribed to the infiltration of fluids derived from serpentinites. In addition, by integrated Mg-B isotope analyses of South Sandwich island arc magmas, we find that they show the heaviest Mg and B isotope compositions among worldwide arc magmas. This unique signature can be attributed to a serpentinite component. However, by combined Mg-B isotope compositions, we propose that the traditional model, i.e., fluid-flux melting of mantle wedge cannot explain simultaneously the Mg and B isotope composition of the arc magma. Instead, the origin of the unique geochemical composition of the arc magma can be well explained by partial melting of serpentinite mélange in subduction zones.

Serpentinization, a key process for the abiotic formation of varied carbonaceous material in the oceanic lithosphere

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Understanding how simple abiotic organics evolve toward more complex molecules is vital to investigate processes that may have controlled life emergence. Until recently, the limited variety and concentration of organic compounds identified in hydrothermal fluids had challenged the hydrothermal theory for abiogenesis. However, multiphase inclusions containing key gases, polyaromatic carbonaceous materials and minerals have been recently found [1] in olivine hosted in magmatic rocks drilled within the oceanic lithosphere (Atlantis Massif 30°N MAR, IODP Exp 304-305). These inclusions highlight that serpentinization reactions promote the drying of degassed COSHN magmatic fluids, leading to the formation of complex organic compounds under such hydrothermal conditions. We herein report the extended study of fluid inclusions hosted in olivine from the different rock types (troctolite, gabbro, peridotite) of the same mid-ocean ridge sequence. In the three rock types, fluid inclusions contain various minerals (serpentines + Fe-oxide + brucite ± Fe-Ni sulphides ± carbonates), gaseous species such as CH_4, H_2 and N_2, and a carbonaceous material that can harbor different characteristics. Our results suggest that the identified reactions are ubiquitous in hydrothermal environments and that they can lead to the abiotic formation of diverse organic compounds possibly sensitive to the local environment in the inclusion.

References:
[1] Andreani, M., Montagnac, G., Fellah, C., Hao, J., Vandier, F., Daniel, I., Pisapia, C., Galipaud, J., Lilley, M. D., Früh Green, G. L., Borensztajn, S., & Ménez, B. (2023). The rocky road to organics needs drying. *Nature Communications*, 14(1), 347.

Spatio-temporal variability of mineralized hydrothermal systems in exhumed abyssal serpentinites (Rainbow Massif, 36°N, Mid-Atlantic Ridge)

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At slow to ultraslow-spreading ridges, tectonic mantle exhumation drives deep hydrothermal circulation, controlling chemical and thermal exchange between the lithosphere and the oceans. As the mantle exhumes towards the surface, the percolation of asthenospheric melts generates significant lithological heterogeneity in the lithosphere, leading to considerable variability in hydrothermal alteration and fluid venting at the seafloor. High Temperature (HT, >350°C) fluid-rock interaction may produce metal-rich, reduced, and acidic fluids that precipitate metals in seafloor massive sulfide deposits when mixing with ambient seawater. Such hydrothermal systems have been reported in serpentinites exhumed at the Rainbow Massif (36°N, Mid-Atlantic Ridge).
During the recent Arc-en-Sub oceanographic cruise (May 2022, PIs: M. Andréani and J. Escartín), we seized the opportunity to unravel the spatio-temporal variability of HT hydrothermal activity at an unprecedented scale across the massif. We combined detailed petrographic investigations, geochemical tracers (namely S-Se-Fe-Cu-Zn isotopes), and geochronological analyses of seafloor massive sulfides hosted in ultramafic rocks. Mineralizations next to the main Rainbow active field consist of Cu-sulfides ± sphalerite ± magnetite ± pyrite. The content of Cu-sulfides increases from shallow mineralization in the basement (e.g., stockwork) to sulfide mounds and hydrothermal chimneys. In contrast, massive sulfides away from the main Rainbow active field are enriched in pyrite ± sphalerite ± barite ± marcasite and minor Cu-sulfides. As a result, mineralizations next to the main Rainbow active field are enriched in Cu, Co, and Se compared to other inactive sites,

suggesting a potential remobilization of these elements during the waning of hydrothermal activity and further seafloor maturity. Isotope compositions (S, Se, Fe, Cu, and Zn) of hand-picked sulfides reveal significant heterogeneity at the scale of the massif. Pyrite shows a broad range of isotope compositions ($\delta 34S$ = -10.19 to 19.49‰; $\delta 56Fe$ = -1.24 to 0.46‰; $\delta 65Cu$ = -1.10 to 0.76‰; $\delta 66Zn$ = -0.08 to 1.03‰; $\delta 82Se$ = -2.33 to 1.01‰) compared to Cu-sulfides of the main active site ($\delta 34S$ = 0.72 to 6.37‰; $\delta 56Fe$ = -0.11 to 0.17‰; $\delta 65Cu$ = -0.16 to 0.05‰; $\delta 66Zn$ = -0.24 to 0.31‰; $\delta 82Se$ = -0.04 to 0.69‰). This indicates different sulfur sources and both biotic and abiotic processes at the origin of this isotopic heterogeneity. Additionally, this suggests non-uniform hydrothermal activity and preservation of mineralized systems throughout the massif. We discuss our findings and their implications in this presentation.

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Unravelling the Redox Conditions during Deserpentinization through Sulphide Mineral Assemblages

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Are serpentine dehydration fluids capable of oxidising the overlying mantle wedge? The oxidising potential of deserpentinization fluids is still debated as thermodynamic models predict elevated oxygen fugacity (fO_2), which is not consistently observed in nature and experiments [1, 2]. To further constrain sulphur mobility and oxygen fugacity during deserpentinization, we have investigated sulphide mineral assemblages in serpentinites and metaperidotites from the Val Malenco massif in the Alps. Malenco serpentinites provide a potential study case to evaluate differences arising from a subduction-related regional metamorphism overprinted by contact metamorphism triggered by the Bergell granodiorite intrusion [3]. Under this working hypothesis, we tested Val Malenco as a natural case to investigate the effects of both intrinsic and extrinsic deserpentinization [4]. To investigate the influence of a near-isobaric increase in temperature on sulphur mineral assemblages and sulphide compositions, we have studied samples across a 1.5-kilometre transect perpendicular to the Bergell intrusion (Alpe Zocca). Based on their primary silicate mineral assemblage, samples can be classified as Antigorite serpentinite (Atg-S) and Antigorite serpentinite with dusty Clinopyroxene (Cpx-S). The increase in temperature results in the formation of Antigorite serpentinite with Tremolite and Olivine (Tr-S), through the consumption of diopside and antigorite. At higher temperatures, antigorite starts to transform into Olivine and Talc, resulting first in partially reacted serpentinite (PR-S), and later in Olivine-Talc metaperidotite (Ol-Tlc).

As shown in previous studies [5], our Cpx-S, and some Atg-S, exhibit a distinctive assemblage of oxides and sulphides, including magnetite (Mag), pentlandite (Pn), heazlewoodite (Hzl), and awaruite (Awr), equilibrated at an oxygen fugacity of ca. 4 log units below the FMQ buffer. Tr-S and Atg-S record a relative increase in temperature, which is accompanied by the presence of Mag, Pn, and pyrrhotite (Pyh) as the predominant sulphide-oxide assemblage. PR-S and Ol-Tlc-F show a progressive decrease in antigorite content, with sulphides evolving from Mag+Pn+Pyh, where Pn predominates, to Mag+Pn+Pyh, with predominance of Pyh. Importantly, the sulphide and oxide assemblages included in crystals of metamorphic olivine were equilibrated at higher fO_2, particularly, Mag, Pn and millerite (Mlr), reaching a maximum of approximately 1.5 log units above the FMQ buffer. Sulphur content measured in whole rock remains relatively constant along the transect (140 - 630 ppm in serpentinites, and 120

- 620 ppm in metaperidotites), locally increasing significantly (up to 1790 ppm, similar to the values obtained in previous studies for the contact metamorphism [5]). These observations suggest that during contact metamorphism, there is a progressive modification in serpentinite sulphide mineral assemblages, resulting in a gradual increase in both the oxygen fugacity (fO_2) and sulphur fugacity (fS_2) [6].

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References:
[1] Evans, Earth-Science Reviews, 113(1-2), 11-32 (2012).
[2] Iacovino et al., Contributions to Mineralogy and Petrology, 175,1-21 (2020).
[3] Trommsdorff and Connolly, Schweizerische Mineralogische und Petrographische Mitteilungen, 76,537-547, (1996).
[4] Padrón-Navarta et al., Nature Geoscience, 16 (3), 268-275 (2023).
[5] Peretti, PhD Thesis, Swiss Federal Institute of Technology, Zurich, Switzerland. 8740 (1988)
[6] Evans et al., Lithos, 278, 26-42, (2017).

Serpentine triggers the formation of Condensed Carbon Matter

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This study focuses on the forms and cycling of deep carbon in the context of subduction zones, where large amount of reactive fluids shape the nature of degassing fluids on the shorter time scale and eventually the co-evolution of the biosphere and the geosphere on the longer one. Although most studies of subduction-zone fluids have focused on oxidized carbon species, there are more and more evidences in nature and experiments that deep reducing fluids are generated during serpentinization at upper mantle conditions.

In this study, experimental serpentinization of olivine (different Mg#, Fe(II) only) by a C-O-H fluid was conducted at high-pressure (~ 3 GPa) and moderate temperature (~ 340 ^{o}C) in the diamond anvil cell. Changes in both mineral and fluid were monitored *in situ* by Raman spectroscopy as a function of time. The initial C-O-H fluid consisted in an aqueous acetate solution (bulk C(0); 1 mol.kg^{-1}), for which the evolution is well-known under similar *P*,*T* conditions without olivine [1,2]. Additional post-mortem infrared, SEM and TEM measurements were used to characterized CCM.

The results are highly dependent on the Mg# of the reacting olivine, whether natural or synthetic. Serpentinization of forsterite and Mg-rich olivine at forearc mantle conditions leads to the disproportionation of the C-O-H fluid into C(IV) carbonate mineral or aqueous ions and carbonaceous condensed matter intimately associated with the phyllosilicate phase. In contrast, Fe(II)-rich olivine and fayalite reacted in the same conditions formed iron oxides and most of the C was transferred into carbonate mineral or aqueous ions and immiscible hydrocarbons, along with minute amount of carbonaceous matter. FTIR spectroscopy on the decompressed samples showed that CCM contains both aromatic and aliphatic molecules.

In short, serpentinization is mandatory to the formation of the abiotic condensed carbonaceous matter. Fe(II)-rich olivine, which might have been expected to produce more reduced forms of C potentially in the form of CCM, as Fe oxidizes, dissolves quickly and leads to immiscible fluid hydrocarbons. Implications for subduction zones is that serpentines *s.l.* may host a large amount of carbon, not only in the form of carbonates, but also CCM.

References:
[1] Huang, F., et al. (2017). *Nature Communications 8, 15798. doi.org/10.1038/ncomms15798*
[2] Huang, J. et al. (2024). *Lithos 468-469, 107498. doi.org/10.1016/j.lithos.2024.107498*

Petrophysical properties of a 1.2 km section of the Atlantis Massif oceanic core complex: IODP Expedition 399

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IODP Expedition 399, Building Blocks of Life, drilled the currently longest section of uplifted mantle providing an unprecedented opportunity to study oceanic mantle and serpentinization processes [1]. Variations in petrophysical properties such as density, porosity, magnetic susceptibility, and sonic velocity are used here to characterize changes in the nature of serpentinization with depth. Bulk density measured on discrete samples of serpentinized peridotites ranges from 2.34 g/cm^3 to 2.72 g/cm^3, averages 2.55 g/cm^3 and has a standard deviation of 0.08. Grain density measured on discrete samples ranges from 2.52 g/cm^3 to 2.97 g/cm^3, averages 2.66 g/cm^3 and has a standard deviation of 0.05. Bulk and grain densities both increase slightly downhole. Effective porosity measured on discrete samples of serpentinized peridotites ranges from 1.7% to 20.4%, averages 7.0% and has a standard deviation of 3.7. Magnetic susceptibility measured on discrete samples ranges from 0.01 to 0.11 IU. The average velocity of serpentinized ultramafic rocks is 4480 m/s, and ranges from 3442 m/s in serpentinized harzburgite to 5960 m/s in serpentinized dunite. Values for the majority of petrophysical properties reported here overlap with those for previously drilled mantle sections, for example, Leg 147, 149, 153, 209, and Expedition 357. Porosity, grain density, P-wave velocity, and magnetic susceptibility are relatively constant in the uppermost 50 m, which is structurally above a peak in porosity and natural gamma ray that may indicate a zone of increased seawater ingress and reaction. Using published linear regressions to relate grain density to serpentinization [2] indicates serpentinization levels near 82% for the entire section, with a slight decrease with depth. However, the trend varies locally, with the degree of serpentinization varying by as much as 10% over 10 m. Additionally, some of the lowest calculated serpentinization values are relatively deeper in the hole (e.g., 700-750 mbsf). Serpentinization values were also calculated using P-wave velocity from published linear regressions [2], averaging 110% and were nearly always higher than those calculated using grain density for the same sample. Future work will attempt to relate P-wave velocity, grain density, and porosity with independently derived values for percent serpentinization.

Results suggest serpentinization is not linear nor regular downhole, indicating the availability of fluids was not consistent with depth.

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References:

[1] McCaig et al., 2024, Preliminary Report Expedition 399, https://doi.org/10.14379/iodp.pr. 399.2024

[2] Miller, J. D., and Christensen, N. I., 1997, Proceedings Leg 153, chapter 25, 437-454.

Abyssal serpentinite geochemistry and geodynamics

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The formation of abyssal serpentinites leads to deep changes of the oceanic lithosphere rheology and geochemistry, hence playing a key role on geodynamic and geochemical cycles. However, most abyssal peridotite studies have assessed the role of pre-existing mantle composition, partial melting and/or melt-rock interaction processes affecting peridotite composition prior to their exhumation and serpentinization, and geochemical studies of abyssal serpentinites are limited to regional observations. Hence, there was a significant knowledge gap regarding the role of the serpentinization processes on the geochemical budget of abyssal peridotites worldwide.
In this study, we review the geochemical characteristics of serpentinites collected on abyssal floors (i.e., abyssal serpentinites) by dredging, submersible and drilling during oceanographic expeditions in different geodynamical settings, namely passive margin, forearc and oceanic spreading ridges. The oceanic ridge setting was further divided according to the tectonic context in which the serpentinites were sampled, i.e., slow-spreading centres, ultra-slow spreading centres, fast spreading axis and large transform faults (all spreading rates). This classification allows to better decipher the influence of the geodynamical setting (e.g., structures, tectonic and magmatic activities, thermal regime) on fluid geochemistry and serpentinite composition. On the basis of a comprehensive review of the data available in the literature and of new geochemical data on the serpentinites of the Mid-Atlantic Ridge valley near Kane transform fault (MARK), the Romanche area (Mid-Atlantic Ridge) and the Mariana forearc, we compare the major, volatile, trace and stable isotope (S, C, Fe, Zn and Cu) signatures of abyssal serpentinites. We discuss the role of serpentinization processes in the distribution of volatile and redox sensitive elements within the oceanic mantle lithosphere and highlight the main geochemical heterogeneities between in the different geodynamical settings and tectonic contexts.

Mobility of metals during the carbonation of peridotites (Semail Ophiolite, Fanjah, Oman): clues from stable isotopes

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Pervasive carbonation of peridotites is triggered by fluxing of CO_2-bearing fluids. This reaction can result in a wealth of metasomatized products, the most extreme being the formation of listvenites (quartz–Mg-carbonate). In the course of ICDP Oman Drilling Project (2017-2018), drilling the basal section of the Semail ophiolite mantle and its sole allowed the continuous sampling of carbonated serpentinites (serpentine, Mg-carbonate) and listvenites which have been thoroughly investigated to understand carbonation processes. In this contribution we present a dataset of multiple stable isotopes tracers (C, Fe, Zn, S) measured on samples of peridotite protoliths and carbonated products to quantify the remobilization and transport of chalcophile elements during CO_2 metasomatism at low temperatures (50-250°C).

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Ferric iron systematics of hydrated metaperidotites beyond antigorite dehydration

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Fluid-mediated mass recycling in subduction zones enables geochemical cycling in the crust – mantle system, refertilization of mantle domains, and ultimately triggers arc magmatism. Serpentinite subduction is a key factor in this recycling process by conveying large amounts of mineral-lattice bound water to depths exceeding ~ 50 km [1]. Our study focuses on the controversy surrounding fluid-mediated redox budget cycling. Subduction of serpentinites is thought to carry prominent redox budget down subduction zones, which is then transferred via dehydration fluids to the source of arc magmas, explaining their comparatively oxidized nature (e.g., [2]). However, recent studies challenge this paradigm, stating that the mobilisation of redox budget is more complex (e.g., [3 – 5]) and that the oxidation state of subducted hydrated metaperidotites is commonly too low for prominent fluid-mediated redox budget transport [6, 7].
To address this controversy, we aim to investigate several ultramafic lenses in the central European Alps which represent antigorite dehydration product rocks. Quantitative compositional mapping using EPMA reveals that the major constituents olivine, chlorite, and orthopyroxene are homogeneous in Fe, allowing the application of ^{57}Fe Mössbauer spectroscopy to determine the Fe^{3+} and Fe^{2+} concentrations of bulk rock and mineral separates. Chl-metaperidotites of different oxidation degrees and their respective mineral separates will be analyzed for $Fe^{3+}/\Sigma Fe$ to quantify the redox budget fixed in bulk rock and minerals beyond Atg-dehydration and potentially beyond Chl-dehydration.
Our data set obtained for variably oxidized metaperidotites will shed light on how much redox budget might have been lost at antigorite and chlorite dehydration and how much can be recycled to the deeper mantle, with important implications for possible causes of the comparatively oxidized nature of arc magmas.

References:
[1] Ulmer, P., & Trommsdorff, V. (1995). *Science, 268(5212),* 858–861. doi.org/10.1126/science.268.5212.858
[2] Kelley, K. A., & Cottrell, E. (2009). *Science*, *325(5940)*, 605–607. doi.org/10.1126/science.1174156
[3] Piccoli, F., et al. (2019). *Scientific Reports*, *9,* 19573. doi.org/10.1038/s41598-019-55944-8
[4] Lazar, C. (2020). *Journal of Petrology*, *61(11–12)*. doi.org/10.1093/petrology/egaa101
[5] Evans, K. A., & Frost, B. R. (2021). *Journal of Petrology*, *62(3)*. https://doi.org/10.1093/petrology/egab016
[6] Vieira Duarte, J. F., et al. (2023). *Contributions to Mineralogy and Petrology*, *178*, 60. doi.org/10.1007/s00410-023-02032-w
[7] Eberhard, L., et al. (2023). *Journal of Petrology*, 64(10). doi.org/10.1093/petrology/egad069

Carbon dioxide removal using serpentine-rich mine residues

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The greenhouse gas carbon dioxide reacts spontaneously with serpentine-rich mine tailings to permanently store carbon in minerals through the process of carbon mineralization, a form of accelerated chemical weathering. In carbon mineral mineralization, carbon dioxide is captured from the air above mine tailings and stored in hydrated Mg-carbonate minerals where it is isolated from the atmosphere over geological time scales. The total carbon sequestration capacity of ultramafic mine tailings greatly exceeds that of conventional mining and mineral processing, however background rates of reaction are much smaller and are controlled by gangue mineral content which in turn reflect serpentinization processes. For some mine sites, passive rates of carbon mineralization approach about 10% of total mine greenhouse gas emissions with conventional mining methods. For these sites, optimization of mine tailings storage can increase rates of carbon mineralization to offset the hard to abate greenhouse gas emissions that remain after deployment of renewable electricity generation and decarbonation of motive power, thus providing pathways to carbon-neutral mining. To achieve carbon sequestration at a scale meaningful for global greenhouse gas emissions, the reactivity of ultramafic minerals must be increased. One pathway to increasing the capacity and rate of carbon mineralization is activation of serpentine. This also expands the application of carbon mineralization to more mine sites with different gangue mineral content to further increase the global impact of mineral carbon. Projections from bench top scale tests indicate that with activation large individual mines have the capacity to sequester carbon dioxide at a rate of $1E^5$ to $1E^6$ tonnes of CO_2 per year. This creates a future scenario in which carbon mineralization in mine waste enables carbon negative mining of the critical metals needed for the energy transition in electricity generation and in transportation. Metal mines of the future may not only supply the resources we need for the energy transition, but they may also play a significant role in achieving global climate goals through net reduction in the greenhouse gas content of Earth's atmosphere.

In-situ oxidation of Fe-brucite under hydrothermal conditions: A synchrotron XANES study

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Serpentinisation, the hydration and oxidation of peridotite in contact with crustal and atmospheric waters, leads to the formation of three main mineral products: serpentine, brucite and magnetite. Another product of serpentinisation is H_2, an important energy source for microorganisms and pillar for life on earth. Although hydrogen production is widely observed in nature and in experiments, there is no in-depth understanding of the processes that lead to its formation.

Hydrogen forms mainly due to the oxidation of Fe-containing serpentinisation products. The most reactive of them appears to be brucite, which contains up to 30 % Fe^{2+} replacing Mg on the octahedral sites (ferroan brucite). Ferroan brucite oxidation has been shown to proceed in several days at 378 K, since the brucite structure allows for isostructural Fe^{3+} incorporation. However, Fe^{3+}-brucite (ferrian brucite) is not commonly observed in nature, suggesting that it could be a reaction intermediate during ferroan brucite oxidation. Possible reaction pathways of ferroan brucite include magnetite precipitation or the formation of layered double hydroxides (LDH) by the uptake of anions, i.e. carbonate, sulphate or chlorine. Analysis of Fe^{2+} brucite is challenging as it reacts rapidly under ambient conditions. Samples must be sealed from oxygen which requires special care during preparation and analysis.

Our experimental setup was designed to in-situ constrain the oxidation pathway and the phase relationships of ferroan/ferrian brucite, magnetite and LDH. We carried out an in-situ heating stage XAS study (Fe-Kα edge) of synthetic brucite with two different Fe compositions. The heating experiments were performed in a diamond anvil cell at beamline BM23 of the ESRF. The study was complemented by XRD-analysis at the same beamline. Raman heating stage analyses were performed to obtain direct information of the H2 production.

Both pre-edge peak analysis and XANES linear combination fitting allow to distinguish brucite oxidation and magnetite formation. Beam damage effects lead to formation of ferrian brucite at T < 120 °C. Magnetite formation was observed above 140 °C.
Our results can be directly applied to natural systems, since the initial grain size of the synthetic brucite is similar to that of natural samples. So far, the presence of anions has not been considered in this study. However, LDH formation from a ferrian brucite precursor could also have implications for the carbon, sulfur- and chlorine-cycles and further research constraints in this direction could provide valuable insights for understanding global element cycles.

References:
[1] Templeton, A. S., & Ellison, E. T. (2020). Formation and loss of metastable brucite: does Fe (II)-bearing brucite support microbial activity in serpentinizing ecosystems?. Philosophical Transactions of the Royal Society A, 378(2165), 20180423.
[2] Carlin, W. et al. (2023). FeIII-substituted brucite: Hydrothermal synthesis from (Mg0.8 FeII0.2)-brucite, crystal chemistry and relevance to the alteration of ultramafic rocks. Applied Clay Science, 234, 106845.

Stress makes it faster: Rapid serpentinization due to deformation-induced permeability increase

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Serpentine is the major alteration product of ultramafic rocks and forms by extensive fluid-rock interaction at the ocean floor as well as in ophiolites. The hydration reaction requires infiltration of water into the solid rocks through interconnected pore space and/or tectonic fractures. However, the reaction is volume increasing and thus self-limiting. Fluid pathways progressively close and the reaction eventually ceases. The fact that heavily hydrated rocks exist, may indicate that dynamic processes, able to renew pore space, play a crucial role.
We performed hydration experiments to study the effect of serpentinization reaction progress on bulk sample permeability. Experiments were performed in the TARGET apparatus, a gas medium triaxial apparatus that allows to measure permeability in large samples at high pressure and temperature conditions [1]. The apparatus is equipped with a hydraulic force unit to apply a differential stress during the experiments. We reacted Twin Sisters (Mount Baker, Washington, USA) dunite samples at conditions of 300 °C, 125 MP confining pressure and 25 MPa pore pressure. The permeability was continuously measured in hydrostatic and differentially stressed experiments. Our results show that the permeability decreases within hours. Applying a differential stress results in a temporary permeability increase, which decreases again when the deformation is halted. Ex-situ analyses of microstructures and mineralogy reveal the formation of Mg-rich sheet silicates along fractures and within fault gouges that formed upon deformation.
In line with various studies on experimental olivine alteration, we show that serpentinization is a fast process and the nucleation of secondary sheet silicates takes place within a few hours. Secondary phases forming on reactive surfaces, however, shield fresh olivine and the reaction front dries out. Our results on stressed samples show that rock deformation is capable to overcome these limitations. In a dynamic system in which olivine grains are in movement, such as in fault gouges, new pore space and fluid pathways are created and fresh olivine surfaces become exposed.
These results are important in the light of reaction-induced permeability modifications and have implications not only for natural fluid-rock interaction systems but also for CO_2 injection schemes in ultramafic rocks to mitigate the effects of greenhouse gas emissions. The storage of carbon in the form of solid carbonates is discussed as a possibility to reduce atmospheric

CO_2. Similar to serpentinization, carbonation is a volume increasing reaction and fluid pathways close upon continuous alteration. Alkalinity enhancement through silicate weathering is another process capable of binding CO_2 from the atmosphere [2]. However, the fast formation of secondary minerals on silicate surfaces can result in slower reactivity and therefore decrease the effectiveness of the process.

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References:
[1] Meyer, G.G., et al. (2023). Rev.Sci.Instrum. 94, 043903.
https://doi.org/10.1063/5.0135947
[2] Fuhr et al. (2022). Front.Clim. 4, 831587. https://doi.org/10.3389/fclim.2022.831587

The characteristics and origin of platinum group minerals from Macquarie Island, Australia

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The highly siderophile elements (HSEs), which include Re and Os, are valuable geochemical tracers and geochronometers that have been used to constrain the formation and evolution of Earth's crust and mantle. Rocks from Earth's mantle found on the surface of Earth are commonly serpentinized, but the effect of serpentinization on the distribution of HSEs is poorly understood, partly because a large proportion of the HSE budget is hosted by rare, micrometer- to sub-micrometer-scale grains of platinum group minerals (PGMs). These grains are difficult to find, characterise, and interpret. Atom probe tomography (APT) provides the necessary nanometer-scale spatial resolution to characterize complex PGMs and was applied to two spatially close PGM grains hosted by a partially serpentinized harzburgite from Macquarie Island, Australia.
The APT data reveal an extraordinary level of complexity that has been used to derive insights into the origin of a complex Cu–Pt alloy grain (average composition ~ Cu_4Pt). The grain hosts Fe-, Ni-, and Pt-rich sub-grains that are associated with Rh, variably overlapping Pd- and Cd-enriched networks, and OH-rich volumes that are interpreted as fluid inclusions. An idioblastic laurite (RuS_2) grain hosts Os and Ru. The compositions and textures of the alloy grains, combined with phase diagram constraints, indicate that the PGMs formed prior to serpentinization but were modified by serpentinizing fluids. These results are discussed in the context of biological utilisation of serpentinites and the potential for PGMs to act as catalysts.

Sulfur Isotope Variation in Partially Serpentinized Harzburgite from the ~2.05 Ga Layered Mafic Suite of the Molopo Farms Complex, Botswana

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A massive pulse of magmatism occurring at ~2.05 Ga is recorded by intrusive and extrusive igneous bodies across southern Africa. Among these is the Molopo Farms Complex (MFC), a layered mafic intrusive suite ~200 km west of the Far Western Limb of the Bushveld Igneous Complex, straddling the border between southeastern Botswana and northern South Africa. The base of the MFC is an ultramafic zone made up of harzburgites, olivine orthopyroxenites, and orthopyroxenites; olivine content increases with depth. The harzburgites are pervasively (though incompletely) serpentinized, preserving olivine and pyroxene cores in a matrix of fine-grained serpentine, oxides, and rare sulfides. The serpentinized harzburgites are characterized by negative $\delta^{34}S$ (-4.95 +/- 0.14‰), distinguishing them from the rest of the layered mafic suite which has positive $\delta^{34}S$ ~0-3‰. These same serpentinized harzburgites have slightly elevated initial $^{87}Sr/^{86}Sr$ (0.7111-0.7158) compared to the mafic and unserpentinized ultramafic units, which potentially suggests a sediment-derived fluid as the serpentinizing agent. The $\Delta^{33}S$ (0.034 +/- 0.015‰) of the serpentinized harzburgites overlaps the range observed in the unserpentinized units. Microbial fractionation of sulfur in the Transvaal sediments underlying the base of the MFC may be indicated as the source of negative $\delta^{34}S$ and slightly positive $\Delta^{33}S$ in the serpentinized zone, but local sediment is unlikely to be the primary source of sulfur for the vast intrusive suites in this region. The $\delta^{34}S$ - $\Delta^{33}S$ range of the drilled MFC (*excluding* the serpentinized zone) forms an array between that of the Bushveld Igneous Complex and normal MORB. Although nickel sulfides and scattered occurrences of PGE sulfides have been observed in the MFC, a continuous PGE-enriched layer comparable to that at the Bushveld complex has yet to be found. Exploration is ongoing, and recent geophysical surveys suggest the presence of an as-yet unencountered conductive zone. The intermediate array of $\delta^{34}S$ vs. $\Delta^{33}S$ between Bushveld and MORB suggests that, at least in the parts of the MFC that have been studied to date, the exotic sulfur contribution to the Bushveld parental magma is attenuated in the MFC by mixing with normal upper mantle.

Pseudomorphosis and brucite silicification during serpentinization

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Serpentinization is a fundamental mechanism in Earth Sciences playing a major role in energy and mass exchanges between the ocean, the crust, and the upper mantle as well as in the biogeochemical cycling of volatiles. Moreover, these reactions also modify in depth the rheologic, magnetic, geochemical, and thermal structure of the lithosphere. While the general mechanisms of serpentinization are well known and well constrained from a geochemical perspective, there are still major unknowns in the physicochemical processes transforming a fresh and anhydrous peridotite into a fully hydrated serpentinite. Rates of reaction, volume changes and reaction front propagation are intimately related to the local scale mass transfers during the hydration reaction. These local mass transfers are in turn related to the coupling between the geochemical reaction and the hydrodynamics of the system. We present batch short duration serpentinization experiments of a fresh natural dunite in artificial seawater at 280°C and 450 bar. Experiments lasted 28 and 45 days, allowing to observe the incipient serpentinization of the olivine, orthopyroxene and clinopyroxene grains. Results show that the general geochemical behavior is controlled by local equilibria and short length mass transfers, leading to characteristic features such as pseudomorphic replacement, but also to out-of-equilibrium features. These features exhibit for example contacts between brucite $Mg(OH)_2$ and talc $Mg_3Si_4O_{10}(OH)_2$ demonstrating the importance of silica mobility during serpentinization, and in turn its importance on the transient volume changes, permeability evolution and surface passivation of a peridotite subjected to on-going serpentinization. These results highlight the importance of taking into account metastable and relative kinetics of the different species involved in the serpentinization reaction, in particular in terms of geochemical cycles and hydrogen production as well as for the numerical modelling of the reaction from either a reactive transport modelling or a batch geochemical reaction.

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Tectonics, Hydrothermal Circulation and Serpentinization in Magma-poor Rifting and start of Oceanic Spreading

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Serpentinisation of ultramafic rocks results from relatively low-temperature metamorphic reactions. Ultraslow and slow passive margins and oceanic spreading generally result in magma-poor conditions that provide a suitable environment for exhumation of mantle rocks where serpentinisation can occur. The opening of the oceans at magma-poor rifted margins occurs under relatively cold conditions and provides a window of opportunity for mantle exhumation and serpentinisation at the continent-ocean transition (COT) before oceanic spreading is established. The domain at which this exhumation occurs is substantial; the interpretation of seismic data indicates that a band of varying width around 100 km of exhumed mantle is persistent along both conjugate margins of the southern North Atlantic [1]. In addition, the dynamics of formation of oceanic core complexes (OCC) in magma-poor margins are likely similar to those in OCCs occurring in on mid-ocean ridges (MOR) in ultraslow and slow spreading (USSR). In general, asymmetric oceanic accretion represents 50% of oceanic accretion in USSR, which itself represent 50-60% of the global MOR.
In this asymmetric spreading context, the sequence of mantle upwelling in the magma-poor COT, and how it is related to the deposition of sedimentary layers is of key importance, as it provides a blanket of low-permeability that profoundly affects the patterns of hydrothermal circulation and so the temperature field, which modulates the thermodynamics of serpentinization, as well as the 120ºC isotherm, relevant for the limits of life. Isotopic alteration of fault rocks in USSRs has demonstrated that oceanic detachment faults can focus large volumes of hydrothermal fluids, both in discharge and recharge zones [3], with the intrusion of gabbro bodies below the detachment being key in generated the thermal energy source to feed the hydrothermal system. Here we present a model-based analysis of extensional tectonics coupled to hydrothermal circulation applied to ultraslow to slow rifting and initial oceanic spreading. We show how advective heat transfer via hydrothermal circulation leads to a high spatio-temporal variability of the thermal field, with feedbacks on tectonics. Dynamic permeabilities play a fundamental role, and we discuss the time dynamics of tectonics, hydrothermal circulation, the temperature fields patterns, and the generation of serpentinization. As an example, we focus on a 20 mm.yr-1 simulation and describe the tectonic and hydrothermal system from the initial stages of serpentinization occurrence, which is previous to continental breakup, to the COT. Systematically, major faults and fractures focus fluid flow away of the spreading axis, and deep penetrating faults alternate in flip-flop mode, sometimes with the brittle-ductile transitions reaching ~9km. Under some

conditions, a previously established focused flow, fed by repeated magma intrusions in the highs of a massif, is maintained for a few tens of kiloyears even after its detachment has been abandoned in favor of the new detachment fault in opposite direction taking over of the main spreading. Eventually, after a transitional situation, a definitive switching into the new detachment where focused venting occurs, with a subsequent reconfiguration of the temperature water-to-rock ratio fields.

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References:

[1] Liu, Z., et al. (2023). *Geology 51*, 3, 284-289. *doi:10.1130/G50722.1*
[2] Escartín, J., et al. (2008). *Nature 455*, 7214, 790-794. *doi: 10.1038/nature07333*
[3] McCaig, A.M., et al. (2007). *Geology 35*, 10, 935-938. *doi: 10.1130/G23657A.1*

Structural and geochemical analysis of the Tehuitzingo and Allende serpentinite bodies in Southern Mexico

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Tehuitzingo and Allende serpentinite bodies represent the largest outcrops of serpentinized ultramafic rocks within the high-pressure units of the Acatlán Complex (south Mexico); however, their serpentinization and deformation processes are still under debate. Thus, we present here a detailed structural, petrological and geochemical study of these serpentinite bodies to compare and understand better their origin and deformation histories.

Serpentinites from Tehuitzingo and Allende exhibit three petro-structural domains: 1) massive or rigid blocks, with pseudomorphic (eg., mesh and bastite textures) and non-pseudomorphic textures (eg., interpenetrating and interlocking textures) composed of lizardite, chrysotile, lizardite/antigorite, and antigorite; 2) foliated, enclosing the rigid blocks, mainly composed of antigorite which define three and two superimposed foliations in Tehuitzingo (S1= NNE-SSW, S2= NW-SE, S3= NNW-SSE) and Allende (S1= N-S, S2= NE-SW) respectively; 3) cataclastic, which display brittle/ductile deformation associated with shear zones.

The compositional analysis of the Tehuitzingo and Allende serpentinites shows similar high concentrations of MgO (35.98-39.57 wt.%), SiO_2 (39.14–42.99 wt.%), and low to moderate of CaO (0.02–0.8 wt.%), Al_2O_3 (0.53–2.54 wt.%), and FeO (6.06-9.34 wt.%). Analysis using the MgO-CaO-Al_2O_3 ternary diagram suggests that the protolith of both serpentinites is likely harzburgite. Also, in the Al_2O_3/SiO_2 versus MgO/SiO_2 diagram the serpentinites display geochemical signatures overlapping with those of abyssal and subduction-related serpentinites. Additionally, the chondrite-normalized rare earth element (REE) reveals two distinct patterns: i) a slightly concave pattern in both Tehuitzingo and Allende serpentinites, indicative of a relative enrichment in both heavy (HREE) and light (LREE) rare earth elements compared to medium rare earth elements (MREE); ii) a pattern with a slightly negative slope, reflecting depletion in HREE relative to LREE, only observed in Tehuitzingo serpentinites. These REE patterns are consistent with those observed in mantle wedge and subduction zone serpentinites (Deschamps et al., 2013).

The observed structural, mineralogical and compositional data suggest that both serpentinite bodies preserve four deformation/serpentinization processes: 1) oceanic serpentinization from a harzburgitic protolith at <300 °C with lizardite/chrysotile formation; 2) Deformation/serpentinization at maximum temperatures of 390-500 °C and 300-390 °C in Tehuitzingo and Allende serpentinite bodies, respectively, and formation of S1 foliation composed of antigorite in a subduction zone; 3) retrograde deformation/serpentinization at greenschist facies (200-400 °C) with the development of conjugate crenulation S2 and S3; 4) brittle/ductile deformation that produced cataclastic texture in both serpentinites.

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References:

[1] Galaz, E.G., et al. (2013). *Gondwana Research, 23*, 2, 641-660.
doi.org/10.1016/j.gr.2012.04.011
[2] Deschamps, F., et al. (2013). *Lithos, 178*, 15, 96-127.
doi.org/10.1016/j.lithos.2013.05.019
[3] Ortega-Gutiérrez, F., et al. (2018). *Earth-Science Reviews, 183*, 2-37.
doi.org/10.1016/j.earscirev.2018.03.006

Serpentinization, a new proxy for industrial exploration of natural hydrogen

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The industrial exploration of natural hydrogen has been launched at an international level [1,2], with funds now exceeding 500 million euros [3]. Of all the ways our planet can produce hydrogen (primordial hydrogen, radiolysis, reduction by organic matter, etc.), reduction of water by Fe(II) is undoubtedly the most prolific [4]. Among the potential reactions, serpentinization is a must. With industrial exploration underway, the challenge now is to find places where olivine and pyroxene are destabilized in a geological context where water can be supplied to the geochemical system in unrestricted quantities. The hydrogen kitchen can be found where pressure, temperature and access to water are optimal for accelerating reactions. Considering the available mass of ferrous iron, the quantities of produced hydrogen could be enormous. In the evaluation of exploration prospects, the method consists in the identification of kitchens, of migration pathways, of potential reservoirs and caprocks.

If mid-oceanic ridges have been the historical places where natural H_2 have been first discovered, they are not the first targets for industrial exploration because of deep water depths and remoteness from coasts. Iceland is an exception, because economic quantities of H_2 have been detected [5]. Serpentinization in subduction systems has not shown significant discoveries for the moment [6]. Collisional systems appear really promising because of the abnormally high position of large mantle bodies in the mountain ranges that allows active serpentinization, as in the Pyrenees [7] or in the Dinaride ranges [8], where exploration licenses have been accepted by the local governments. Obduction systems have also given interesting systems in New Caledonia [9], or Oman [10]. Ambiguous origin of H_2 exists in old cratons. But the H_2 discoveries of Mali [11] and Kansas [12] could be linked to current serpentinization processes, as olivine and serpentine-clays are described there. The presence of green rocks in old cratons could be a valuable driver for exploration, as serpentinization appears to be still active, but further research efforts are needed for a proper understanding. Finally, the technological approach to H_2 production can also be developed by injecting brines and catalysts to induce artificial serpentinization of rocks [10, 13] via deep boreholes.

References:
[1] Gaucher, E. C. (2020). *Elements*, *16*(1), 8-9. doi.org/10.2138/gselements.16.1.8
[2] Hand, E. (2022 *Science*, *379*(6633). doi.org/doi:10.1126/science.adh1460
[3] Gaucher, E.C., et al,. (2023). European Geologist, 55. doi: 10.5281/zenodo.8108239
[4] Klein, F., et al., (2020). *Elements*, *16*(1), 19-24. doi:10.2138/gselements.16.1.19
[5] Combaudon, V., et al., (2022). *IJHE*, *47*(18), 10217-10227. doi.org/10.1016/j.ijhydene.2022.01.101
[6] Moretti, I., et al., (2023). *Geosciences*, *13*(4), 109. doi.org/doi.org/10.3390/geosciences13040109
[7] Lefeuvre, N., et al., (2022). *Applied Geochemistry*, 105396. doi.org/10.1016/j.apgeochem.2022.105396
[8] Truche, L., et al., et al., (2024). *Science*, *383*(6683), 618-621. doi:10.1126/science.adk9099
[9] Monnin, C., et al., (2014). *Biogeosciences*, *11*(20), 5687-5706. doi.org/10.5194/bg-11-5687-2014
[10] Templeton A.S., et al., (2024) *Front. Geochem*. 2:1366268. doi: 10.3389/fgeoc.2024.1366268
[11] Maiga, O., et al., (2023). *Scientific Reports*, 13(1), 11876. doi.org/10.1038/s41598-023-38977-y
[12] Coveney, J., et al., (1987). *Am. Assoc. Pet. Geol., Bull.; (US)*, 71:1, 39-48.
[13] Barbier S., (2022). *PhD Thesis*. UCBL Lyon, France. www.theses.fr/2022LYSE1099/document

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Serpentinization, carbonation and H_2 production at Atlantis Massif (MAR 30°N): Preliminary geochemical results from IODP Expedition 399

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IODP Expedition 399 (IODP – International Ocean Discovery Program) has, for the first time, allowed drilling into the feeding system of an active hydrogen-rich hydrothermal site, the Lost City Hydrothermal Field (LCHF, Atlantis Massif) on the Mid-Atlantic Ridge (30°N MAR). The LCHF is an exceptional site producing hydrogen-rich alkaline fluids that harbor unique chemolithoautotrophic microorganisms. These fluids are interpreted as derivatives of the serpentinization of underlying mantle peridotites.
Hole U1601C is the deepest hole ever drilled into mantle rocks (1267.8 m deep) with an exceptional recovery rate (up to 100% at certain levels). The recovered cores are primarily composed of more or less serpentinized harzburgites intersected with gabbros, especially beyond depth of 950 m. These rocks are locally fractured, forming serpentinite-rich zones ± carbonates, which have been sampled for microbiological studies. The fluids from the cores and along the borehole have been collected for analyses.
Here, we present preliminary results on the bulk major and trace element geochemistry of the rocks recovered from Site U1601, and discuss the new insights they provide about the conditions and mechanisms driving carbon mineralization and hydrogen-rich hydrothermal systems during serpentinization.

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The influence of fluid compositions on hydrogen (H_2) production during serpentinization

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Serpentinization greatly influences the physical and chemical properties of the oceanic lithosphere [2, 3], and it also affects microbial habitability at hydrothermal vent fields (Schrenk et al., 2013). Serpentinization greatly decreases the strength, density and seismic velocity of olivine [2, 3], possibly resulting in an increase in volume [5]. Serpentine, a hydrous mineral with H_2O contents up to 13.5 wt%, remains stable at depths of even greater than 150 km [8]. Therefore, serpentinization plays an important role for the recycling of H_2O in subduction zones. Serpentinization produces molecular hydrogen (H_2) that may influence microbial habitability at hydrothermal vent fields [7].

Previous experiments were performed mostly with olivine and pure H_2O as the starting reactant, and hydrogen production is greatly inhibited due to slow reaction rates. Our experimental results suggest that hydrogen production increases greatly during peridotite serpentinization. The presence of pyroxene and spinel, pH and chlorine contents of starting fluids greatly influence hydrogen formation during olivine serpentinization [4]. Hydrogen production is directly linked to the kinetics of olivine and pyroxene serpentinization. An increase in the rates of olivine serpentinization results in an increase in hydrogen production. In contrast, faster rates of pyroxene serpentinization during peridotite serpentinization impede hydrogen formation [4]. In the presence of N_2 gas, serpentinization forms abundant ammonia [6], which is the key towards the formation of amino acids.

References:

[1] Ripple, W.J., et al. (2017).*BioScience 67*, 12, 1026-1028.*doi.org/10.1093/biosci/bix125*
[2] Escartín, J., et al. (1997). Earth and Planetary Science Letters 151, 3-4, 181-189. *doi.org/10.1016/S0012-821X(97)81847-X*
[3] Escartín, J., et al. (2001) Geology 29, 11, 1023-1026.
[4] Huang, R. F., et al. (2023) Journal of Geophysical Research: Solid Earth, doi.org/10.1029/2022JB025218.
[5] Malvoisin, B., et al. (2020) Journal of Geophysical Research: Solid Earth, 125, doi.org/10.1029/2019JB018877
[6] Shang, X.Q., et al. (2023) Science Bulletin, doi.org/10.1016/j.scib.2023.04.038
[7] Schrenk, M.O., et al. (2013) Reviews in Mineralogy & Geochemistry 75, 575-606.
[8] Ulmer, P. and Trommsdorff, V. (1995) Science 268, 858-861.

Major and trace element geochemistry of serpentinized ultramafic rocks from the Bragança Complex, NE Portugal

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The Bragança Complex (NE Portugal) preserves an arc-derived unit (Upper Allochthon, UA), exhumed along with an early-variscan accretionary wedge (ca. 410-400 Ma), and emplaced over the Iberian massif during the Variscan collision [1]. The UA encompasses a set of mafic-ultramafic igneous rocks (i.e., gabbro, peridotite, pyroxenite, hornblendite) attributed to magma chambers emplaced in the lower crust to upper mantle levels [2]. Al_2O_3/SiO_2 and MgO/SiO_2 ratios show a transition from more refractory dunite and harzburgite rocks to more fertile lherzolitic rocks. Rock samples plot slightly below the terrestrial mantle array [3], pointing to a slight elemental loss during fluid-rock interactions.
Primitive mantle (PM)-normalized trace element patterns show a moderate to strong enrichment in fluid-mobile elements (FME; e.g., W, Sb, As, Cs and Pb). FME enrichments are usually associated with melt hydration in abyssal and/or subduction environments, with a possible contribution of external fluids. A strong enrichment in W (over 2000 x PM) and Sb (over 3500 x PM) may suggest a mixing of fluids from both sedimentary and igneous sources. The ultramafic rocks show a general depletion in high-field-strengths elements (HFSE) relative to the PM (e.g., Hf ≈ 0.177–1.06 x PM; Zr ≈ 0.095–1.14 x PM; Nb ≈ 0.146–0.292 x PM; Ta ≈ 0.135–3.51 x PM), showing only exceptional values >1 x PM. These values, however, do not always correspond to a negative anomaly relative to neighboring rare earth elements (REE). The Nb/Ta and Zr/Hf ratios vary between 2-20 and 20-60, confirming a HFSE fractionation. Furthermore, variable REE enrichments (∑REE ≈ 1.86–78.4 x C1-chondrite (Ch) values) are well observed. These rocks are enriched in light REE relative to middle REE [$(La/Sm)_N$ ≈ 1.30–20.61] and to heavy REE [$(La/Yb)_N$ ≈ 1.08–42.129].

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References:
[1] Martínez Catalán, J.R., et al. (2019). *Springer*, 99-130. https://doi.org/10.1007/978-3-030-10519-8_4
[2] Bridges, J.C., et al. (1995). *Geol. Mag. 132*, 1, 39-49. https://doi.org/10.1017/S0016756800011419
[3] Jagoutz, E., et al. (1979). *Proc. Lunar. Planet. Sci. Conf. 10th*, 2031–2050.

Pulsed fluid release from subducting slabs caused by a scale-invariant dehydration process

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The chemical composition of a rock has a first-order effect on the onset and duration of rock dehydration. We present a multiscale dataset of chemical heterogeneities found in a low-temperature serpentinite from the Mirdita ophiolite in Albania, and we explore the effects of such heterogeneities on slab dehydration during subduction. The dataset consists of chemical and geological mappings from the micrometer to the meter scale, spanning five orders of magnitude. At each scale, we investigate the interplay of metamorphic reactions as well as porosity and fluid production through thermodynamic modeling along a slab Moho P-T path typical for subducting plates. Notably, our results show that chemical heterogeneities are preserved, regardless of the observation scale, even in the case of local homogenization by events such as the lizardite-antigorite transition. Consequently, scale-invariant patterns of porosity evolution and fluid production along the P-T path emerge, with characteristic peaks for each dehydration reaction. As such, the dehydration behavior on the slab scale seems to be controlled by the processes on the millimeter scale, whereby resulting peaks correspond to pulsed slab fluid release localized in space and time at each scale, along strike and along dip of the subducting plate. These pulses of fluid release reflect the time available for the specific mineral reactions, i.e. for given parameters of the subduction zone, the brucite-out and antigorite-out reactions can take about 0.4 and 0.8 Ma, respectively. The more oxidised the serpentinite is, the shorter and spike-like the corresponding pulses are. We conclude that previously developed predictive continuum models of serpentinite dehydration based on small-scale observations can be applied up to the meter scale and likely also at the scale of a subduction zone.

Low-temperature alteration of ultramafic seafloor: Imaging reaction-induced porosity as precursor for microbial habitat development and carbonation

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This communication demonstrates how quantitative digital image analysis of 3D X-ray tomography data can contribute to the understanding of low-temperature seawater alteration (LTSA) reaction pathways.
Mantle rocks are commonly exhumed to the seafloor at mid-ocean ridges, rifted margins, and transform faults. Both pristine and serpentinized domains are subject to LTSA, reacting with seawater at temperatures below the main "serpentinization window" over long timespans [1,2]. Olivine and pyroxenes, for instance, are unstable in the presence of seawater and slowly dissolve, serpentine may undergo weathering [3], and brucite dissolves when exposed to seawater [4].
LTSA-induced dissolution of olivine and/or brucite is recognizable as voids or void fillings in the rock's microfabric ([5,2,6], and our own reconnaissance observations, unpublished). Cavities originating from brucite dissolution, for instance, may be filled with aragonite [5], suggesting that brucite dissolution and aragonite precipitation are causally linked. Similarly, Andreani et al. [7] reported direct replacement of olivine by Ca carbonate, and conducted carbonation experiments to demonstrate that carbonate precipitation is more effective under stagnant fluid conditions. Thus, carbonation can become the dominant process when flow is minor and the dissolution of olivine and brucite is retarded. The competition between permeability-increasing processes with permeability-decreasing processes (e.g., serpentine or carbonate precipitation) puts tight controls on processes such as environmental availability of microbial habitats in the oceanic crust [8,9]. Likewise, existence or absence of ferroan brucite can have profound impact on microbial activity [10].
LTSA likely depends on the rock's bulk composition and its primary and alteration phase assemblage. To understand the role of LTSA for global mass budgets, it is important to understand in which lithologies and under what conditions olivine and/or brucite dissolution takes place. Moreover, the requirements for fluid access to domains where LTSA occurs need to be clarified: is LTSA restricted to the seafloor or can major fault zones, commonly considered fluid pathways, also facilitate LTSA deep within the seafloor? Our approach of

quantitative digital 3D image analyses contributes true spatial fabric analyses and volume-based calculations of the proportions of the reactive minerals on the pore scale to unravel the underlying weathering relations and reaction pathways. Correlated with detailed petrologic investigations and with composition-based data from other spectroscopic methods (SEM/EDX, EMPA, Raman), our results will provide the basis for a detailed understanding of LTSA processes.

References:
[1] Bach et al. (2011) EPSL, 311, 242–252. doi:10.1016/j.epsl.2011.09.021
[2] Albers et al.(2021) Front.EarthSci. 9:673063. doi:10.3389/feart.2021.673063
[3] Bach et al. (2013) LectureNotesinEarthSystemSciences, Springer, 253–288, doi:10.1007/978-3-642-28394-9_8
[4] Klein et al. (2020) Geochem.Persp. Let. 16, 1–5. doi:10.7185/geochemlet.2035
[5] Jöns et al. (2017) Lithos 268-271, 274–284. doi:10.1016/j.lithos.2016.11.014
[6] Pujatti et al. (2023) EPSL, Volume 604. doi:10.1016/j.epsl.2023.118006.
[7] Andreani et al. (2009) Environ.Sci.Technol., 43, 1226–1231. doi:10.1021/es8018429
[8] Orcutt et al. (2011) ISME J. 5:692–703. doi:10.1038/ismej.2010.157
[9] Edwards et al. (2012) Annu.Rev.EarthPlanet.Sci. 40, 551–568. doi:10.1146/annurev-earth-042711-105500
[10] Templeton & Ellison (2020) Phil.Trans.R.Soc.A 378: 20180423. doi:10.1098/rsta.2018.0423

Reaction Pathways of Serpentinization in Oceanic Settings

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From hydrogen production and abiotic organic synthesis to plate tectonics, serpentinization plays key roles in several planetary processes. Yet, the underlying mechanisms that control reaction pathways during serpentinization remain poorly constrained. Understanding the mechanisms that control the sequences of secondary mineral formation is imperative to recognizing why and how physical rock properties and compositions of hydrothermal fluids evolve through time. This is important to adequately assess the temporal effects of serpentinization on tectonic processes and the architecture of the oceanic lithosphere, the transfer of mass between the oceanic lithosphere and the ocean, and the habitability and physiological challenges in subseafloor serpentinization systems.
The chemical and physical effects of serpentinization are fundamentally rooted in the dissolution of primary and precipitation of secondary minerals, the sequence and timing of which are highly variable. While thermodynamic modeling studies suggest that protolith composition and temperature, as well as $Fe^{2+}Mg_{-1}$ exchange potential and silica activity affect the stability of secondary minerals and their composition, recent hydrothermal laboratory experiments suggested that the sequence of secondary mineral formation is also influenced by disparate reaction rates of primary minerals [1–5]. The impact of such disparate dissolution rates on the timing and amounts of secondary minerals that are formed during serpentinization can be evaluated with simple reaction path models. If olivine and orthopyroxene (Opx) react at the same rate during serpentinization of harzburgite, the simplified succession of dominant mineral assemblages is as follows: talc–serpentine (represented by chrysotile)–olivine–Opx → serpentine–olivine–Opx → serpentine–magnetite–olivine–Opx → serpentine–magnetite–brucite–olivine–Opx until primary minerals are consumed. The predicted successions of mineral assemblages and mineral abundances differ if olivine reacts faster or slower than Opx (even though in a closed system reaction pathways would ultimately converge on the same final equilibrium mineral assemblage). As a result, the timing of the onset of magnetite and brucite precipitation and the amounts of these minerals present at different points in the overall process differ depending on the relative rate of reaction of primary minerals, as do the relative proportions of as-yet unreacted primary minerals. This has implications for temporal variations in the composition of serpentinization fluids, including pH, silica activity, and H_2 concentrations. Because the production of magnetite and ferric iron in serpentine correlate with increased H_2 generation, the flux of H_2 over time will vary as the relative contributions from olivine and Opx evolve

with reaction progress. We conclude that reaction pathways of serpentinization affect the physicochemical rock properties of partially serpentinized peridotite as well as the chemistry of serpentinization fluids in oceanic settings.

References:
[1] Klein, F. et al. American Mineralogist 100, 991–1002 (2015).
[2] Grozeva et al. GCA 199, 264–286 (2017).
[3] Klein, F. & Le Roux, V. Geology 48, 552–556 (2020).
[4] McCollom, T. M. et al. GCA 282, 55–75 (2020).
[5] Portella, Y. de M et al. Geoscience Frontiers 15, 101763 (2024).

Foliation by deformation in low-grade serpentinites from the Atlantis Massif

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Foliated serpentinites are a common feature in a variety of tectonic settings, ranging from orogenic serpentinites to spreading oceanic ridges. Whether this foliation is a primary feature, like veining, which results directly from serpentinization or a secondary feature, resulting from deformation is not always clear. To understand the mechanisms of foliation formation in low-grade serpentinites, we analysed a set of samples ranging from non-foliated to strongly foliated fabrics.
The samples originate from the Atlantis Massif, an Oceanic Core Complex located at 30°N, Mid-Atlantic Ridge. During IODP Expedition 357, oceanic serpentinites were recovered from shallow drill cores along the southern wall of the Massif. Microstructural analysis was based on optical and electron microscopy as well as large area µXRF mapping. For CPO analysis synchrotron high energy X-ray diffraction was applied.
Foliation in these serpentinites is clearly evident by the aligned distribution pattern of magnetite. Serpentinites with a microstructure of intact regular mesh cells show a close to uniform CPO. Samples with an increased foliation of vein-like magnetite aggregates show a single c-axis-maximum and increased CPO strength of serpentine as well as magnetite.
This correlation between foliation strength and serpentine as well as magnetite CPO indicates that the growth and spatial distribution of both minerals is a result of deformation. The most likely deformation mechanism to form the foliated fabric of serpentinite is dissolution-precipitation.

Serpentinites and ultramafic systems – their role in decarbonisation and resource management

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Ultramafic systems, including partially serpentinised peridotites, serpentinites and nickel laterites exhibit geochemical properties that are important for decarbonisation technologies. As the primary source of nickel globally (sulphide or oxide/silicate ore), these rocks have been mined and processed on a large scale for nearly two centuries now [1]. The use of nickel in rechargeable batteries for electric vehicles drives the global demand for nickel, providing further incentive for the expansion of mining and processing of primary ores. However, those industrial operations can adversely affect the environment, for example through the release of CO_2 and potentially hazardous elements (PHE), such as hexavalent chromium, or minerals, e.g. chrysotile asbestos. Through our better understanding of the social and environmental impacts of mining operations and the availability of technologies that can potentially mitigate adverse impact, it is paramount to aim for more responsible mining and metal recovery operations globally.

At the British Geological Survey, we focus on full system, multi-scale understanding of ore to provide insights into the potential of improved ore utilisation (maximum metal output and minimum waste). To that extent, we investigate the metallogenic models for the concentration of metals in serpentinites and the overlain laterites, focusing on the metal deportment across the deposit's profile or the role of manganese oxides in the concentration of nickel and cobalt, more specifically. Secondly, we explore the potential of ultramafic systems (including serpentinites and laterites) to sequester CO_2 through the formation of carbonate minerals (mineral carbonation) [2 - 5], and the potential of carbonates to crystallographically immobilise chromium alongside the CO_2 [6].

Ultramafic systems offer a plethora of natural resources needed for transition to greener technologies, including metals used in rechargeable batteries or fuel cells (Ni, Co, PGE), metals needed for CO_2 sequestration (Mg, Fe) or indeed natural hydrogen. It must be stressed that these rocks also contain minerals that can pose serious health risks to the communities around mining and ore processing operations, and that this resource must be understood thoroughly and managed carefully.

References:

[1] Mudd, G.M. (2010). Ore Geology Reviews, 38.
https://doi.org/10.1016/j.oregeorev.2010.05.003
[2] Lacinska, A. M., et al. (2017). Frontiers in Earth Science, 5.
https://doi.org:10.3389/feart.2017.00037

[3] Lacinska, A. M., et al. (2016). Chemical Geology, 437.
https://doi.org:10.1016/j.chemgeo.2016.05.015
[4] Styles, M. T., et al. (2014). Greenhouse gases science and technology 4.
https://doi.org:DOI:10.1002/ghg
[5] Lacinska, A., et al. (2024). UK Government, the Department of Energy Security and Net Zero.
[6] Lacinska, A. M., et al. (2024). Mineralogical Magazine 1-8.
https://doi.org:doi:10.1180/mgm.2023.91

Serpentine dehydration in subduction zones: characterization of metamorphic olivine veins from the Zermatt ophiolite (Swiss Alps)

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The subducted oceanic lithosphere contains hydrated minerals such as serpentine and brucite formed by the chemical interaction of seawater with mantellic rocks. Along a subduction geotherm, P-T conditions are met for these minerals to dehydrate, releasing aqueous fluids. Water and other chemical components incorporated into the subducted oceanic lithosphere as a result of shallow serpentinization reactions are then remobilized. Some of these elements can be taken up by the fluids produced by the dehydration reaction while a portion can be recycled into the deep mantle. One of the main solid products of serpentine dehydration is olivine, called metamorphic olivine to differentiate it from its magmatic counterpart. Metamorphic olivines can be found in serpentinized ophiolites that underwent subduction down to eclogitic facies. In the Zermatt ophiolite (Swiss Alps), metamorphic olivines can be preserved in veins that illustrate the dehydration process of the oceanic lithosphere.

The first results obtained were acquired on serpentinites from Zermatt, originally lherzolites-harzburgites-dunites serpentinized during the opening of the Tethys ocean and subducted to eclogitic facies during the Alpine collision [1]. These rocks reached pressure-temperature conditions leading to (partial) dehydration that can be attributed to the following reaction:

$$\text{Antigorite + Fe-Brucite = Olivine + } H_2O \qquad (1)$$

This reaction is often mentioned as an important dehydration reaction but is still poorly investigated as brucite is rarely found in HT serpentinites.
Two olivine vein types are identified by petrological observations:
- i) Small veins, made of small olivine grains (<50 micrometers), underline the C/S structures. Preliminary electron microprobe results on these metamorphic olivines show a un enrichment in magnesium Mg# of 93-95, in contrast to mantle olivine whose average Mg# is 90.
- ii) Large crosscutting veins consisting of large olivine (>500 micrometers). Microprobe results on this type show higher magnesium enrichment, with Mg# of 95-99%.

Two types of serpentines can be distinguished based on their chemical signatures. First, the sheared serpentines that constitute the major part of rock, are crosscuted by the olivine veins and have high aluminum and iron content (>1wt%) and are identified by Raman spectroscopy as antigorite. The second type of serpentine is within the veins and seems to grow at the expense of the metamorphic olivines. Its composition is closer to pure Mg-end member with low Al and Fe concentration (<1wt%) and is identified as lizardite. They can traduce retromorphic fluids during exhumation of the Zermatt units. All serpentines analyzed have Mg# ranging of 95-98.

So far, antigorite + brucite intergrowths were not detected either by electron microprobe or micro-Raman, and will be searched by transmission electron microscopy. Thermodynamic modelling, using Perple_X software, will enable us to constrain a dehydration P-T field in relation to our rock geochemistry and thus constrain the mechanisms of deserpentinization.

References:

[1] Kempf *et al. (2020) Swiss J Geosci, DOI : 10.1186/s00015-020-00368-0*

Formation of kuliginite during serpentinization by saline fluids: reappraisal and new findings

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Serpentinization on Earth and beyond generally occurs in the presence of Cl-bearing fluids, but the formation of chloride minerals and their role in serpentinization are poorly understood. Kuliginite, a recently discovered hydroxychloride mineral with the ideal formula of $Fe_3Mg(OH)_6Cl_2$, was shown to form during internal serpentinization within olivine-hosted fluid inclusions in ultramafic rocks from New Caledonia, southwest Pacific[1]. It was suggested kuliginite may form during serpentinization by Cl-rich saline fluids under certain conditions on Earth and beyond, which can play an important role in iron transfer and hydrogen generation during serpentinization. Kuliginite is a mineral extremely enriched in ferrous iron, therefore its formation retards iron oxidation and related hydrogen production; but its further hydration represents a new pathway of iron oxidation and related hydrogen generation.
Recently, kuliginite was found within serpentinized fluid inclusions in peridotite from other localities, e.g., the Xigaze ophiolite from Tibet that represents an analog of ultraslow-spreading oceanic lithosphere. This indicates that the occurrence of kuliginite in more diverse serpentinized rocks are expected. However, a reappraisal of kuliginite from New Caledonia shows that only rare grains have Raman spectra strictly similar to standard kuliginite, and most grains have Raman spectra slightly different from those of kuliginite, which may be a

variant of kuliginite. More works are needed to characterize these phases, and verify its relationship with kuliginite and its role in serpentinization.

References:
[1] Zhang, L., et al. (2022). J. Geophys. Res. Solid Earth 127, e2022JB024508. doi.org/ 10.1029/2022JB024508

High-pressure metasomatism and carbonation of metaserpentinites during deformation at the subduction interface

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The study of exposed paleosubduction metamorphic suites is revealing an increasing number of cases where carbonation of metaserpentinites and formation of magnesite-bearing rocks along the slab interface has occurred as the result of fluid-rock interactions under high-pressure conditions concurrent with tectonic mixing, deformation and recrystallisation. Subsequently, these hybrid metasomatic lithologies may undergo decarbonation reactions under further prograde or retrograde conditions, potentially influencing the fluxes and cycling of carbon and other volatiles at convergent margins.
Here we study the Cerro Blanco ultramafic massif (Nevado-Filábride Complex, Betic Cordillera, southern Spain), which records high-pressure alpine subduction metamorphism as evidenced by the transition from antigorite-serpentinite to chlorite-harzburgite due to high-pressure deserpentinisation. In this massif, boudins of coarse magnesite-amphibole-chlorite-magnetite aggregates, several metres long and decimetres thick, are evidence of chlorite-harzburgite carbonation reactions. Such carbonation can be explained by thermodynamic models, in which the infiltration of external CO_2 fluids derived from meta-sediments reproduces the formation of magnesite at high-pressure conditions. However, modelling based on current high-pressure aqueous geochemistry databases predicts insufficient Ca solubility under these conditions, suggesting that the high amounts of amphibole observed may be due to locally Ca-enriched chlorite-harzburgite compositions.
Subsequent tectonic detachment and exhumation of the massif is recorded across a 60 m thick, very heterogeneous mylonite zone that includes strongly deformed marble layers, chlorite-harzburgite lenses (in some cases completely transformed into retrograde serpentinite) and transposed magnesite-bearing boudins. Combined field, EDS-SEM and EPMA data from a detailed sampling of a cross-section of this mylonite zone show that the rocks resulting from the tectonic mixing of the magnesite veins with other lithologies were intensely reworked and re-equilibrated during deformation. Thermodynamic modelling of these changes suggests that mineralogical and chemical re-equilibration for the resulting differently mixed hybrid bulk compositions occurred at temperatures between 550 and 600

°C. Simultaneous isothermal decompression and infiltration of H_2O-rich fluids induced a magnesite breakdown reaction (magnesite + amphibole + H_2O-rich fluid = dolomite + antigorite + CO_2-bearing fluid). Our results demonstrate that carbonated serpentinites are sensitive archives of fluid flow during prograde metamorphism and exhumation processes. They act as a trap-and-release mechanism, modulating carbon fluxes in subduction zones.

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Serpentinites and serpentinized garnet and spinel peridotites from various lithotectonic units of western margin of the Bohemian Massif – Considerations of mineralogy, geochemistry and non-traditional stable isotope systematics

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Abundant bodies of variously serpentinized peridotites crop out in western part of the Bohemian Massif, along the tectonic contact of the underlying Saxothuringian (ST) block with the Teplá–Barrandian Block (TBB). These bodies were derived from various levels of the Earth's mantle, exhumed during Devonian to Carboniferous stages of Variscan collision, thus linked to the closure of the Saxothuringian ocean between ST and TBB. The peridotites and serpentinites can be distinguished on the basis of the assumed initial protolith, metamorphic evolution and lithotectonic relationships:
(i) Serpentinized garnet peridotites associated with (U)HP granulites of the Saxonian Granulite Mts., U(HP) serpentinized garnet peridotites forming lenses and boudins in the gneiss-eclogite unit of the Krušné Hory Mts. and seprentinized garnet peridotite xenoliths in Cenozoic volcanic rocks in the Ohře rift; (ii) strongly serpentinized peridotites ± spinel serpentinites at the base of the Mariánské Lázně Complex and in tectonic klippen resting on the Kladská unit of ST; (iii) serpentinites, which are a part of the Neoproterozoic to Lower Cambrian accretionary wedge forming TBB upper crust (Blovice accretionary complex); (iv) serpentinites

and serpentinized peridotites, exhumed during the Devonian at the base of a tectonic stack of uppermost allochthonous units derived from the ST ocean (Prasinite-Phyllite Unit of the Münchberg Massif, base of the Erbendorf–Vohenstrauss Zone and small tectonic slices in gneisses and cordierite bearing migmatites of the Oberpfalz area.

To address the fate of volatile components of serpentinites, we will combine elemental and stable isotope systematics of Li, K, Cl, Fe and U. These elements cover a wide range of volatility, redox conditions and (in)compatibility under fluid mobility regimes, which will aid in deconvolving variability in pressure, temperature and chemistry, recorded by serpentinites across western Bohemian Massif. Some of these systems may be responsive to seawater, which may be considered the ultimate source of volatiles in the oceanic crust, although fluids released from dehydration of lower oceanic crust and underlying lithosphere at various stages of subduction may also impart specific elemental and isotope signature. These new stable isotope data will be combined with detailed petrography and mineralogy of serpentinites, which may be critical for our understanding of partitioning and variable extent of isotope fractionation of some of these elements. Raman spectroscopy and XRD analyses indicate lizardite and/or polygonal serpentine as major phases in the studied samples. Antigorite was also detected in a few cases. Minor phases include chlorite, spinel, magnetite, dolomite, talc and amphibole. We will link these data with non-traditional stable isotope systematics to gain further understanding of serpentinization process and possible differences in protoliths of serpentinites from various groups.

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New thermodynamic and kinetic constraints on H_2 production during ferroan brucite reaction at low temperature

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The alteration of ferroan brucite, a common by-product of serpentinization, has been proposed as a H_2 source at low temperature. Here, synthetic ferroan brucite with Fe/(Fe+Mg) = 0.2 was reacted with pure water at temperatures ranging from 348 to 573 K in 29 experiments either conducted in gold capsules or Ti-based reactors. H_2 production monitoring with time and characterization of the reaction products revealed the occurrence of the following reaction: 3 $Fe(OH)_2$ brucite = Fe_3O_4 + H_2 + 2 H_2O. This reaction proceeds completely in ~ 2 months at 378 K and is thermally activated. The small grain size of the synthetic brucite (40-100 nm) is similar to observations in natural samples, and is probably responsible for the high reaction rate measured. H_2 production reached a plateau and Fe-bearing brucite also precipitated as a reaction product, suggesting the achievement of equilibrium. The thermodynamic properties of $Fe(OH)_2$ were refined based on the experimental dataset and differ by less than 5 % from previous estimates. However, ferroan brucite is predicted to be stable at an hydrogen activity one order of magnitude lower than previously calculated. As a result, significant H_2 production during ferroan brucite alteration at low temperature requires efficient fluid renewal. Such a mechanism strongly differs from olivine serpentinization which can occur even at high activity in H_2 and thus with limited water renewal.

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Temperature and pH Effects on Serpentinization of a Natural Harzburgite *(withdrawn)*

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Two pairs of laboratory serpentinization experiments were performed using a natural harzburgite at 170°C and 230°C, with one experiment at each temperature conducted at strongly alkaline pH and the other at circumneutral pH. The experiments utilized a harzburgitic xenolith from San Carlos, Arizona, powdered to 53-212 microns for the 230°C experiment and 38-53 microns for the 170°C experiment. The initial fluid was an NaCl solution, with NaOH used to raise the pH for the alkaline experiments. Experiments were all conducted at 35 MPa. Although a greater degree of reaction occurred at the higher temperature (~17% after 260 days at 230°C vs. ~5% after 340 days at 170°C), mineral products from all of the experiments were very similar. The primary secondary product in all experiments was serpentine (lizardite and/or chrysotile), along with small amounts of talc and trace Fe-oxides. Trace amounts of Ti-rich andradite was also present in the higher pH experiments, while brucite and magnetite were absent from all experiments. Whereas previous studies have found that olivine and synthetic olivine-orthopyroxene mixtures reacted more rapidly at higher pH, very little difference in reaction rates was observed between harzburgite experiments conducted at circumneutral and alkaline pH. In addition, although other experimental studies have suggested that spinel may significantly accelerate the reaction rate of olivine, the natural abundances of spinel present in the harzburgite had no discernible impact on reaction rates. Furthermore, whereas other serpentinization experiments conducted under similar conditions have generated substantial amounts of H_2, only very small amounts of H_2 were generated in any of these experiments, suggesting that the early stages of serpentinization in natural systems may produce only small amounts of H_2. In serpentine-hosted hydrothermal systems and alkaline springs, the high pH (>11) is commonly accompanied by elevated Ca concentrations, and dissolution of Ca from pyroxenes coupled to high solubility of Ca-hydroxide minerals is typically invoked to explain the elevated pH values. Yet, the circumneutral harzburgite experiments resulted in millimolal Ca concentrations with no change in pH. Overall, the fluids produced by the harzburgite experiments more closely resembled deep-sea hydrothermal vent fluids that are typically ascribed to basalt-hosted systems than to ultramafic-hosted systems, suggesting that the source rock for some hydrothermal vents may need to be re-evaluated.

Macroscopic reaction porosity in the Atlantis Massif: potential for enhanced hydrothermal circulation, fluid access for serpentinisation and the subsurface biosphere.

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We define ***macroscopic*** reaction porosity as dissolution of minerals leaving pores at a mm+ scale which may subsequently be partially or completely filled by secondary minerals. Typical textures are rosettes of secondary minerals partially surrounded by relict porosity, interlocking grains of minerals such as amphibole with faceted pores, and interlocking acicular grains. Reaction porosity has been documented in Troodos epidosites [1], and suggested to be a significant permeability enhancement mechanism in the upflow zone of black smoker fluids. Here we present SEM, EPMA, and XCT data from both the detachment fault zone of the Atlantis Massif oceanic core complex, and deep in the massif in IODP Holes U1601A and C, and U1309D. Porosity generation takes different forms in different lithologies, and three main vectors can be identified.

1. In gabbroic and diabasic rocks at IODP Site U1309, the first mineral to dissolve is pyroxene, although plagioclase can be completely dissolved in extreme cases creating fluid conduits up to 10 cm in diameter. Minerals filling the porosity are mainly actinolitic amphibole and albitic plagioclase, but new samples from a newly discovered fault zone at 1500 mbsf in Hole U1309D include fill by edenitic hornblende suggesting dissolution temperatures in excess of 650 °C.
2. In gabbroic layers within serpentinised ultramafic rocks sampled in IODP Exp. 357, plagioclase is first to dissolve, with porosity fill dominated by chlorite, and extensive replacement chloritization of pyroxene. Chlorite geothermometry suggests that porosity fill began at temperature ~ 400 °C and extended to temperatures < 80 °C.
3. Samples from IODP Expedition 399 Hole U1601C include dissolution of plagioclase with porosity fill including prehnite, chlorite and saponite. Core description in hand

specimen suggests dozens of examples of reaction porosity in a gabbro net vein complex cutting serpentinized harzburgites and dunites. A close relationship between gabbro dissolution, prehnite growth and serpentinization is hypothesized, similar to microrodingites in troctolites described in Hole U1309D [2]. Gabbros may form important pathways for serpentinizing fluids

XCT data has been collected on 5 samples and estimates of current porosity, and the progressive evolution of porosity and permeability will be provided, together with preliminary modelling of the fluids responsible for the very different reaction paths.

In samples from Exp. 357, cell counts were generally low, but highest in samples taken close to reaction porosity zones. We hypothesise that the physical and chemical environment of porosity fill was favourable to growth of extremophile microbes, possibly exploiting fluids rich in H_2, CH_4 and more complex organic species, such as those seen in the nearby Lost City vent field.

References:

[1] Cann et al. (2015). *Geofluids 67*, 15, 179-192. doi.org/10.1111/gfl.12117
[2] Frost et al. (2008). *J. Petrology, 49, 1579-1588.* doi.org/10.1093/petrology/egn038

Changing deformation style during serpentinite carbonation to talc-magnesite and quartz-magnesite along a plate-scale fault zone

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Serpentinization and carbonation of ultramafic rocks are key processes influencing volatile transfer and fluid pathways along the shallow slab-wedge interface of subduction zones. Both processes are related to open-system fluid flux but also precipitation and volume expansion, which can clog porosity. To explore if volume changes and sustained permeability can be accommodated by deformation, here we investigate (micro)structures of serpentinized harzburgite of the Advocate complex, Newfoundland, which was progressively carbonated at > 300 °C to brucite-magnesite bearing serpentinite, magnesite-talc rock and listvenite along a major fault zone [1].

The serpentinites show the metamorphic transition from lizardite to antigorite + brucite (± magnetite). Conjugate vein sets of brucite rimmed by antigorite, and local transposition of antitaxial antigorite veins by a newly developed antigorite foliation show that this transition was related to brittle to semi-ductile deformation. SEM analysis on broad-ion-beam polished samples show that brucite veins have higher micro- and nano-porosity than the serpentine matrix, thus facilitating the initial infiltration of CO_2-bearing fluids. Remnant lizardite reacted first to antigorite + brucite, followed by replacement of brucite by magnesite. Subsequently, reaction of antigorite with CO_2 to magnesite–talc led to increasing talc proportions and ductile deformation. These talc-rich rocks show a penetrative foliation, with deformation fully accommodated by talc while zoned magnesite porphyroblasts continued to grow with euhedral facets.

In contrast, the carbonation reaction talc + CO_2 to quartz–magnesite increased the rock strength, causing brittle deformation. This is manifested by sub-parallel sets of quartz extension veins mostly arranged in echelon arrays oblique to the foliation of talc-poor listvenite, consistent with syn-reaction shearing. At the outcrop scale, these veins cut listvenite layers and boudins, without continuation into talc-magnesite rock. At the microscale, similar quartz veins transect elongated magnesite porphyroblasts in magnesite-talc-quartz rock and foliated listvenite. Their termination at the porphyroblast rims together with co-precipitated magnesite along the vein-walls suggest that they formed during carbonation reaction. Strongly foliated transitions from Tlc-rich lithologies to listvenites further show apparent mylonitic fabrics with local grain size reduction and weak–moderate crystallographic preferred orientations ($[001]_{Mgs}$ normal and $[001]_{Qtz}$ parallel to foliation). We propose that this fabric was likely caused by oriented growth during a transient state of reaction-enhanced ductile deformation, similar as in foliated low-temperature listvenites [2]. Fuchsite-filled stylolites in quartz-depleted listvenite further attest for prolonged deformation by pressure solution. Our results indicate that listvenite formation is related to a changing deformation style with increasing carbonation extent, from brittle brucite/magnesite veining, to ductile creep in talc, and semi-brittle fracturing and dissolution-precipitation creep in listvenite. Thus, deformation is a key factor controlling permeability and accommodating volume changes during carbonation. In turn, CO_2-fluid-rock interactions substantially change the rheology of deforming serpentinites.

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References:
[1] Menzel, M.D., et al. (2018). *Lithos*, 323, 238-261. *doi.org/10.1016/j.lithos.2018.06.001*
[2] Menzel, M.D., et al. (2022). *Nature Communications*, 13, 3478. *doi.org/10.1038/s41467-022-31049-1*

Omphacitite formation and deep fluid-rock interaction processes in an intra-slab serpentinite-bearing shear zone

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We document the formation of omphacitites in the Monviso Lago Superiore Unit (W. Alps) where eclogite-facies, serpentinite-bearing shear zones host ample evidence for intense intra-slab fluid flow. In the first locality studied, a serpentinite-hosted jadeitite block is rimmed by strained omphacitite (with lawsonite pseudomorphs and minor phengite). U-Th-Pb zircon dating yields a protolith age of c.150 Ma, thus pointing to a burial-related replacement of a former Tethyan seafloor material, and revealed a lack of alpine rims. Multi-mineral Rb-Sr dating of the minerals forming this omphacitite rind yields an isochron age of 41.6 ± 0.7 Ma, corresponding to the early exhumation path still within the eclogite-facies. In this case, omphacitization led to the nearly complete replacement of the former prograde jadeitite through solution-precipitation and was followed by crystal-plastic deformation processes.
In various Monviso localities, Fe-Ti metagabbro blocks (commonly exhibiting brecciated garnetite fragments) display evidence for intense fluid-rock interaction leading to the formation of decimeter-thick, weakly strained omphacite-dominated rinds (with minor amounts of lawsonite, clinochlore and talc) around the blocks at the contact with the surrounding serpentinite. Partly dissolved zircon crystals separated from omphacitite rimming an eclogitic Fe-Ti metagabbro block only yielded middle-Jurassic protolith ages. This indicates that omphacitite rinds did not overgrow the eclogite blocks but rather replaced metasomatically the garnet-rich eclogitic assemblage. The omphacitization overprint occurred independently of the nature of the protolith (namely, forming after a jadeitite or after an Fe-Ti eclogite) as a consequence of infiltration of externally-derived fluids and subsequent element sequestration from the incoming fluid phase. These observations

highlight the extraordinary ability of eclogite-facies metasomatic fluids to nearly totally overprint rocks as resistant and impermeable as Monviso eclogite breccias or jadeitites.

Fluid-Driven Shear Instabilities in the Subducted Oceanic Mantle at Intermediate Depths: Insights from Western Alps meta-ophiolites

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Serpentinites are major carriers of volatiles in deep subduction zones, releasing most fluids in the 500-650°C range [1, 2]. Despite fundamental implications for mass transfer and intermediate-depth seismicity, the mechanical role of these fluids is unclear. To characterize the mechanical role of fluids at (ultra)high-pressure conditions, we perform a petro-structural analysis on olivine-rich veins from the Western Alps meta-ophiolite. Some veins formed through dilational and mixed dilational-shear fracturing without significant shear-related deformation. However, field and microstructural observations, including: (i) foliated sheared veins; (ii) newly formed olivine and Ti-clinohumite within mineral lineations coating sheared veins and shear bands; (iii) Olivine and Ti-clinohumite mineral fibers sealing porphyroclasts; (iv) mutual crosscutting relationships among dilational and shear features, indicate transient shearing and dilational fracturing at high pore fluid pressures. Dilational veins prevail in low-strain areas, while sheared veins and shear bands dominate within high-strain zones towards the ultramafic sliver boundaries. These strain variations underscore the role of local stress regimes during serpentinite dehydration. Consequently, areas experiencing stronger shear stresses or mechanical weakening during fluid circulation are prone to develop interface-parallel, fracture-controlled pathways for draining overpressurized fluids from the dehydrating downgoing slab. Transient events of dilational fracturing and brittle-ductile shearing, along with strain localization in highly comminuted olivine-bearing sheared veins, may have resulted from strain rate bursts potentially related to seismic or sub-seismic deformation. These observations are in line with geophysical data indicating high pore fluid pressures within the intermediate-depth seismicity region [3, 4].

References:

[1] Schmidt, M., and Poli, S. (2013). Devolatilization during subduction. In Treatise on geochemistry: vol. 4: The Crust (Vol. 4, pp. 669-701). Elsevier.
[2] Klein, F., Humphris, S. E., and Bach, W. (2020). Brucite formation and dissolution in oceanic serpentinite. Geochemical Perspectives Letters, 16, 1-5.
[3] Bloch, W., John, T., Kummerow, J., Salazar, P., Krüger, O. S., and Shapiro, S. A. (2018). Watching dehydration: Seismic indication for transient fluid pathways in the oceanic mantle of the subducting Nazca slab. Geochemistry, Geophysics, Geosystems, 19(9), 3189-3207.
[4] Delbridge, B. G., Houston, H., Bürgmann, R., Kita, S., & Asano, Y. (2024). A weak subducting slab at intermediate depths below northeast Japan. Science Advances, 10(9), eadh2106.

Experimental study on the formation of spinifex-like textured olivine during antigorite dehydration at 200-700 MPa

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Spinifex-like textured olivine with an elongated tabular shape has been reported in antigorite serpentinites dehydrated both at low pressures [1] and high pressures (above the invariant point at ~1.6 GPa) [2]. This texture is thought to be formed by antigorite dehydration at far-from-equilibrium conditions possibly caused by sudden fluid pressure drop. However, the detailed conditions and mechanism of spinifex-like textured olivine formation are poorly understood due to the lack of systematic experimental studies.

We performed dehydration experiments on an isotropic natural antigorite aggregate by using internally heated pressure vessels with an argon gas pressure medium at the Geological Survey of Japan. Water-saturated experiments (initial fluid-rock ratio of 0.2 in weight) were conducted for ~210 hours at a constant temperature of 630°C and different pressures of 200, 400, 600, and 700 MPa to examine the effect of reaction affinity caused by fluid pressure drop on reaction textures. Olivine and talc were mainly grown inward from the rim part of the prism-shaped starting antigorite. Olivine at 600 and 700 MPa shows a granular shape, while olivine at 200 MPa and 400 MPa often shows an acicular elongated shape on cross-sections. Olivine aspect ratio defined by the long-axis length/short-axis length becomes larger at lower pressures and its maximum value exceeds 15 at 200 MPa. Electron backscattered diffraction analysis reveals that the short axis of elongated olivine is mainly directed toward the a-axis, while the long axis is distributed between the c- and b-axes. At 600 and 700 MPa, adjacent olivine grains dominantly show twinned grain boundaries (60° rotation about the a-axis), whereas the twinning becomes less evident with decreasing pressure especially at 200 MPa where most of the adjacent elongated grains are randomly oriented each other.

Our experiments demonstrated that antigorite dehydration at high reaction affinity can lead to the formation of spinifex-like textured olivine. These olivine grains are shortened along the a-axis and elongated along the c- and b-axes. Dilissen et al. [3] proposed that surface-active molecules supplied from the external fluid plays a role to suppress the growth on {100} faces of tabular olivine in dehydrated antigorite serpentinite. Our data showed that such surfactants may not be required for the inhibited growth on {100}. Acosta and Baumgartner [4] proposed the twin-mediated growth of tabular forsterite crystals during the contact metamorphism of quartz-bearing dolomite. However, it could not be the case for the formation of tabular olivine in dehydrated serpentinite because the twinning rather becomes inconspicuous when olivine crystals show a tabular shape in our experiments.

References:
[1] Clément, M., et al. (2019). Journal of Petrology, 60(10), 1935-1962.
[2] Trommsdorff, V., et al. (1998). Contributions to Mineralogy and Petrology, 132, 139-148.
[3] Dilissen, N., et al. (2021). Lithos, 382, 105949.
[4] Acosta, M. D., & Baumgartner, L. P. (2024). Contributions to Mineralogy and Petrology, 179(3), 1-16.

Geochemistry and petrology of the Vizcaino Ophiolite serpentinites

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The Vizcaino ophiolite, in Baja California, Mexico, is a dismembered and tectonically thinned slab of oceanic crust and upper mantle that has barely been studied. Initial interpretations associate it with the Coast Range ophiolite in California, though existing geochronology is ambiguous at best. Original studies describing the area have focused on the subduction mélange containing high pressure metamorphic rocks that underlie the ophiolite. Evidence of multiple generations of serpentine involving high pressure from occurrences of antigorite to modern serpentinization as evidenced by hyperalkaline springs within the mélange serpentinite matrix will be presented together with initial bulk rock geochemistry and petrography of the serpentinites.

Dynamic interplay of fluid-rock reactions, mass transport and fracturing at shallow mantle wedge

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The mantle wedge is a unique location where the subducting plate interacts with the overlying mantle, leading to a wide range of fluid-rock interactions and the transfer of H_2O-CO_2 fluids and elements. In particular, serpentinization and metasomatic reactions play a significant role in influencing fluid pressure and mechanical properties at subduction zone interfaces. However, the relationship among fluid-rock reactions, mass transfer and fracturing is still poorly understood. In this talk, we present several geological records of fluid flow and fluid-rock interactions found near the mantle wedge corner and discuss the potential influence on mechanical properties at the subduction zone interface.
The first example is the antigorite vein networks that developed in hydrated ultramafic rocks in the Oman ophiolite [1]. The Oman ophiolite was formed at the mid-ocean ridge and suffered from extensive low-temperature serpentinization, but they also recorded fluid processes at the later stage of subduction zone setting. We analyzed the samples of the crust-mantle transition zones recovered by the Oman Drilling Project. In the samples, antigorite veins that cut the completely serpentinized dunite (lizardite+brucite+magnetite) have brucite-rich reaction zone, indicating the leaching of silica from the host rocks. By using the coupled thermodynamic and diffusion model, we revealed that the channelized fluid flow was short-lived (several months to years) and had a high fluid flow velocity (2.7×10^{-3} to 4.9×10^{-2} meters second^{-1}). This timescale and fluid flow velocity are similar to the propagation of seismic events in subduction zones related to slow earthquakes. Episodic fluid drainage can result in a decrease in poor fluid pressure, which influences seismicity at the plate boundaries.
The second example is metasomatized serpentinite bodies from the Sanbagawa metamorphic belt in Japan. At the contact serpentinite and metasediments, clear reaction zones developed: actinolite + chlorite schists close to the serpentinite and chlorite rocks close to the pelitic schists. Talc schists or thin talc vein networks developed within the serpentinite. This suggests that Si transport from the crust to the mantle and Mg transport from the mantle to the crust occur simultaneously [2]. Thermodynamic calculations along the subduction zones indicate that the fluid compositions, relative mobility of Si and Mg, and abundances of the sheet silicates (talc versus chlorite) change between the subduction zone geotherms. In

addition, the infiltration of CO_2-bearing fluids, if present, effectively causes significant talc formation with the carbonation and dehydration of serpentinites [3]. Our recent experiments on metasomatic reactions at analog crust-mantle boundaries (serpentine/metapelite and peridotite/metapelite) at 500 °C and 1 GPa also indicated the strong effect of CO_2 rather than Si (over 10 times) on talc formation during metasomatism, resulting in the reduction in the mechanical strength at the plate interface. These examples and other recent studies have suggested that fluid-mediated metamorphic or metasomatic reactions may be fast relevant to slow earthquakes.

References:

[1] Yoshida K et al. (2023). Science Advances, 9, eade6674. doi:10.1126/sciadv.ade6674
[2] Okamoto A, Oyanagi R, 2023. Progress in Earth and Planetary Science, 10, no. 39. doi.org/10.1186/s40645-023-00568-w
[3] Okamoto A et al. 2021. Communications Earth & Environment, 2, 151. DOI:10.1038/s43247-021-00224-5

Talc formation enhanced by CO_2-metasomatism at crust-mantle boundary in subduction zone

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Geophysical observations have revealed that mantle wedge is extensively serpentinized due to the fluid contained in subducting slab. Talc is one of the weakest minerals, and the relationship between the formation of talc layer and slow slip event is proposed[1]. It is widely believed that talc is formed by Si-metasomatism of mantle at the slab-mantle interface. In contrast, serpentinite bodies with carbonate + talc veins are commonly observed in the high-pressure metamorphic belts[2], suggesting the influences of CO_2-fluids on the formation of talc. However, relative importance of silica and CO_2 in fluids on the formation of talc, and on the influences on the mechanical properties are poorly understood. In this study, we used Griggs-type deformation apparatus to investigate the metasomatic reactions at the interface between crustal rocks (pelitic schist or quartzite) and mantle rock (harzburgite or serpentinite) at 500 ˚C and 1 GPa.
In the experiments under hydrostatic conditions, we prepared the three layers of core samples; pelitic schist (the Sanbagawa belt) or Brazilian quartzite was sandwiched between harzburgite (Horoman peridotite, dry mantle) and serpentinite (Mikabu belt, wet mantle). Two types of fluids were introduced: pure H_2O fluid and H_2O-CO_2 fluid. The latter produced by the decomposition of Oxalic Acid Dihydrate (OAD). We maintained 4 wt% H_2O and set the $XCO_2 = 0.2$ for the H_2O-CO_2 experiments.
In all conditions, the alteration more proceeded in the mantle rocks than on the crust side. In the experiment with H_2O, talc was formed both in harzburgite and serpentinite at the contact with crustal rocks. In the pelitic schist at the contact with ultramafic rocks, albite was selectively replaced by Mg smectite, whereas in the quartzite, a small amount of talc was formed, indicating that counter diffusion of Si from crust to mantle, and Mg from mantle to crust. In the experiments with H_2O-CO_2 fluids, talc was formed with magnesite both in harzburgite and serpentinite with intense fracturing. In an experiment with short duration time revealed that quartz+magnesite is formed at the boundary, which decomposes to talc because of high silica activity due to crustal rock. The preliminary mass balance calculations

reveal that the amount of talc in the ultramafic rocks can be explained solely by the reaction with CO_2-fluid, even if quartz-bearing rocks existed at the contact.

References:

[1] Lindquist et al. (2023). *Geochemistry,Geophysics,Geosystems* 24, e2023GC010981. doi:10.1029/2023GC010981
[2] Okamoto et al. (2021). *Communications Earth & Environment* 2, 151. doi:10.1038/s43247- 021-00224-5.

Production and migration of metamorphic CH_4 driven by fluid infiltration and serpentinization of subducted ultramafic/mafic rocks

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Emerging evidence suggests that high pressure serpentinization in subduction zones bears the potential to produce reduced fluid species such as abiotic CH_4 [1,2,3,4,5]. This may change the perspective on deep energy availability for microbial life in the deep subsurface biosphere at convergent margins [2]. Nevertheless, the scarcity of fluid inclusion isotope studies hampers our understanding of CH_4 formation/transformation and migration in metamorphic settings.
The mafic/ultramafic Belvidere Mountain Complex (BMC), Northern Vermont (USA), hosts CH_4 + minor N_2, NH_3, H_2 and S-H compounds fluid inclusions (FIs) [3,4]. The BMC experienced multiple high-pressure fluid-rock interactions and serpentinization events beginning in the Taconic orogeny (505-473 Ma) [3,4]. A large isotopic diversity of fluid inclusion-hosted CH_4, previously observed in 9 samples, ranging from thermogenic to abiotic, was suggested to document the complexity of metamorphic CH_4 generation and transformation [4].
In this study we applied a new approach to study fluid-rock interaction processes, using the BMC as a natural case study for large-scale fluid inclusion isotope mapping. We mapped FIs bulk $\delta^{13}C$-CH_4 across the BMC through mechanical extraction combined with Cavity Rind-Down Spectroscopy (CRDS) and Gas Chromatography Isotope Ratio Mass Spectrometry (GC-IRMS) in more than 70 samples distributed over 0.7 km^2. We coupled bulk FIs analyses with quantitative in-situ Micro-Raman spectroscopy and petrographic observations. We performed

$\delta^{13}C$ measurements in organic carbon and carbonates to investigate their relationship with FIs-hosted CH_4.

This approach allowed to depict spatial changes in $\delta^{13}C$-CH_4 across the BMC that are, mostly but not systematically, closely linked to the host-rock mineralogy. This correlation could be the result of diverse events of CH_4 production, migration and transformation and/or post-entrapment modification of CH_4 within the fluid inclusions. During fluid-rock interaction, the alteration of minerals hosting FIs favoured the migration of CH_4 with specific ranges of isotopic compositions during the BMC tectono-metamorphic history.

References:
[1] Vitale Brovarone et al., 2017 - *https://doi.org/10.1038/ncomms14134*
[2] Vitale Brovarone et al., 2020 - *https://doi.org/10.1038/s41467-020-17342-x*
[3] Boutier et al., 2021 - *https://doi.org/10.1016/j.lithos.2021.106190*
[4] Boutier et al., 2024 - *https://doi.org/10.1016/j.gca.2023.10.028*
[5] Giuntoli et al., 2024 - *https://doi.org/10.1038/s41467-023-44641-w*

Tracking Fluid-Rock Interaction Using B Isotopes in Abyssal Serpentinites: Insights from Recent Deep Drilling at the Atlantis Massif (IODP Exp. 399).

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Using B isotopes to track fluid-mediated subduction zone processes requires an accurate estimate of the B abundance and isotopic makeup of the subducting slab. Numerous drill cores penetrate the upper oceanic crust and provide relatively robust constraints on the B systematics of sedimentary and volcanic crustal components. However, very few drill cores sample the lower gabbroic and lithospheric mantle crustal domains, which are rich in hydrous minerals (serpentine, brucite, amphibole, chlorite, prehnite, talc, zeolites, etc.) and represent the largest potential source of fluid mobile element input to subduction zones. Ophiolites present a valuable analogue, but their fluid mobile element systematics record the integrated effect of interaction with seawater, subduction related and/or meteoric fluids, and as such can be hard to interpret.

Lower crustal rocks are exposed by domal detachment faulting at the Atlantis Massif (30°N; Mid-Atlantic Ridge). We will present preliminary data from IODP Exp. 399, which recovered 1268m of serpentinized mantle peridotite and subordinate gabbroic rocks from the southern wall of the massif, proximal to the famous Lost City Hydrothermal Field.

We report whole rock major and trace element data, including [B], $\delta^{11}B$, [Sr] and $^{87/86}Sr$ measurements on serpentinites and variably altered (olv-bearing) gabbroic rocks recovered during drilling operations. We report for the first-time downhole trends in these isotopic and elemental signatures and speculate as to how these patterns might result from changing T, pH, water-rock ratio and/or fluid composition during the serpentinization process. We will also present plans for forthcoming in situ B and O isotope work (LA-MC-ICP-MS/SIMS) on various serpentine microtextures and vein filling minerals (chrysotile, calcite, talc etc.)

which record the progressive influx and compositional evolution of fluids driving alteration in the actively metamorphosing basement of the Lost City Hydrothermal Field.

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Redox-modulated deserpentinization in subduction zones

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Seafloor serpentinization of the oceanic lithosphere leads to a substantial increase in both the water content and the ratio of ferric iron to total iron ($Fe^{3+}/\Sigma Fe$) compared to the dry mantle ("seafloor hydration-oxidation"). Although the subduction of serpentinites is crucial for the recycling of volatiles, their role as oxidizing agents in the deep redox cycle, particularly in relation to primitive arc basalts, remains a subject of debate [1]. A critical factor to address is not only the oxygen fugacity (fO_2) of the released fluids but also their content of oxidized species of multivalent elements. Due to the variable intake of redox-sensitive elements such as sulphur during seafloor serpentinization, intrinsic deserpentinization fluids —despite equilibrating at high fO_2— possess a low oxidation capacity, insufficient to explain by their own, the production rate of oxidized primary magmas.
We propose that deserpentinization fluids can achieve a strong oxidation capacity only if their intrinsically high fO_2 values are modulated by an external sulfur intake from crustal-derived fluids at the slab surface [2]. For instance, the following general unbalanced reaction,

H_2S [sediment-fluid] + Fe^{3+}[serpentinite] => HSO_4^-,aq [deserpentinization fluid] + Fe^{2+}[Ol/Opx in Chl-harzburgite]

would result in an oxidation of the sulphur into sulfates in solution while partially reducing the dehydration products. An exemplary case of modulated redox-dehydration is observed at Cerro del Almirez (Spain), the type locality for serpentinite high-pressure dehydration, where the infiltration of external reduced fluids resulted in a significant "dehydration-reduction trend" that partially reverses the "seafloor hydration-oxidation". The infiltration of small amounts of reduced fluids (in the order of 10 mol fluid/kg rock) results in the breakdown of antigorite at temperatures up to 10-20 ºC lower than for the intrinsic case, a process described as "redox dehydration" [3]. This process can be further corroborated through the investigation of other components of the external fluids, notably carbon, involving the oxidation of CH_4 to CO_2 and concomitant reduction of the dehydration products [4].

Interaction during deserpentinization with sulfur-bearing, oxidized, GLOSS-derived fluids does not modify the fO_2 of the dehydration products in the slab, but it will considerably increase the oxidation capacity of deserpentinization fluid because of the higher solubility of sulfate relative to that of the intrinsic case. Importantly, there is no correlation between the fO_2 of sediment-derived infiltrated fluid and its capacity to boost the oxidation capacity during deserpentinization. Oxidized metasediments devoid of sulfur—such as cherts and quartzites equilibrated at very high fO_2—have the reverse effect of reducing the oxidation capacity of deserpentinization fluids. This result emphasizes that the redox state of subducted metasediments alone is not an adequate proxy for the redox capacity of deserpentinization fluids.
In this context, the redox-modulated deserpentinization model could be extended to other dehydration reactions and involve fluids from other sources, such as the Altered Oceanic Crust, thus opening avenues for further research from both natural and experimental perspectives.

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References:
[1] Evans and Frost, B.R., (2021). *Journal of Petrology* 62, 1–32. https://doi.org/10.1093/petrology/egab016
[2] Padrón-Navarta, J.A. et al. (2023) *Nat. Geosci. 16,* 268–275 https://doi.org/10.1038/s41561-023-01127-0
[3] Eberhard et al., (2023). *Journal of Petrology* 64, 1-18. https://doi.org/10.1093/petrology/egad069
[4] Bukala et al., (2024). *EGU24-12237*, https://doi.org/10.5194/egusphere-egu24-12237

Unraveling Mariana's Microbial Marvels – A Lipidomic Journey into the Serpentinite Biosphere

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Serpentinization of the mantle wedge by slab-derived fluids is widespread in the Mariana Forearc. Upon serpentinization, the fluids become enriched in *geofuels* such as molecular hydrogen (H_2), methane (CH_4), and other reduced chemical compounds. They are transported to the forearc seafloor through mud volcanism and can sustain a low-temperature serpentinite-hosted chemosynthetic biosphere at and below the seafloor. The role and the survival mechanisms of these extremophilic microbial communities remain enigmatic. Despite the presence of life-sustaining *geofuels*, the endurance of the microbial communities in an environment marked by an elevated pH, limited metabolic substrates, and low availability of nutrients renders the serpentinite biosphere an exceptionally challenging habitat that potentially favors the growth of hydrogenotrophic and methanotrophic alkaliphiles. To discern the nature of the microbial communities and the geochemical environment they survive in, we combined thorough petrologic–geochemical work with lipid biomarker analyses on gravity cores obtained during R/V Sonne expedition SO292/2 in 2022. The cores exhibit hemipelagic mud with seawater-like porewaters in shallow depths, transitioning to green – dark blue serpentinite mud, comprising brucite and iowaite in deeper core sections where porewaters are highly alkaline serpentinization fluids. Our High-Performance Liquid Chromatography-Mass Spectrometry (HPLC-MS) analyses show distinctive trends in archaeal and bacterial membrane lipid patterns from typical marine sediment biomarkers in the hemipelagic muds to a clear dominance of Lost City-type methanogenic and methanotrophic biomarker distribution in the serpentinite muds. We also detected various intact as well as core diether (DEG) bacterial-origin lipids in the serpentinite horizons, which have previously been detected in sulfate reducers belonging to the consortium with anaerobic methanotrophic archaea (ANME) that are involved in the Anaerobic Oxidation of Methane (AOM). Moreover, our compound-specific isotope analyses of distinct lipid biomarkers suggest an accumulation of methanogenic and methanotrophic community signals in the serpentinite lithologies. Our study sheds light on the low-temperature chemosynthetic biosphere at the forearc of Mariana, where the hydrated forearc mantle of the Mariana subduction system may represent one of Earth's deepest and perhaps least studied microbial ecosystems.

Sulphide geochemistry and sulfur isotope systematics of subducted hydrous ultramafic rocks from Cerro del Almirez, Spain

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Serpentinite dehydration has been claimed to be a major player in oxidising the source of partial mantle melting atop subduction zones, via redox budget liberation into the dehydration fluid upon antigorite decomposition. One model proposes that sulphide sulphur in the Atg-serpentinites is oxidised to, and mobilised as, sulphate sulphur in the antigorite dehydration fluid, thus eventually oxidising the source of arc magmas. Another model proposes that externally derived S2- is advected by fluid to the site of antigorite dehydration, where it gets oxidised to fluid-dissolved sulphate and leaves the system. Yet another model proposes that antigorite dehydration fluids are commonly not oxidised enough to allow for redox budget transfer as fluid-dissolved sulphate.
To elucidate the fate of S upon antigorite dehydration in Almirez metaperidotites, we combine in-situ data on δ34S and S mineral compositions determined by SIMS and LA-ICP-MS. Pentlandite ± pyrrhotite + magnetite (+ chromite ± hemo-ilmenite - but not hematite) is the stable peak metamorphic paragenesis across the different lithologies. This is indicative of moderate fS2 and fO2 conditions at Δlog10fO2,QFM of +1 to +2, where H2S rather than SO2 is predicted to be the main sulphur species in the fluid. In pentlandite of Atg-serpentinites and Chl-peridotites, increasing S contents correlate with decreasing Se contents, indicating dilution of mantle Se during sulfur addition upon oceanic hydration - metasomatism. Uniform sulfide δ34S signatures (1.5 to 3.2 ‰) are found in Chl-peridotites when compared to the Atg-serpentinites (3.0 to +8.7), suggesting that the antigorite-dehydration fluid had a homogenous δ34S of ca. 0 to +1.5‰ when present as H2S species in the fluid. Homogenous sulphide compositions far away from sediment S isotope signatures, S-Se compositional trends, and the absence of key trace elements (e.g., Cs, Rb, As, Pb) all indicate that the Chl-peridotite S inventory originates from within the hydrous metaperidotites, still preserving in part a memory of its oceanic metasomatism. Our data do not support infiltration of externally derived fluids during prograde to peak subduction metamorphism for Almirez metaperidotites.

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Hydrogen in orthopyroxene records oxidation during hydration of the cold mantle wedge

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The mechanisms influencing the oxidation state of arc magmas and their correlation with high volatile content remain highly debated. It has been suggested that the incorporation of hydrogen into Nominally Anhydrous Minerals (NAMs), particularly pyroxenes, in the mantle wedge may play a significant role in the oxidation of arc magmas in subduction zones [1]. To assess this potential link, samples from two contrasting settings were analyzed using infrared spectroscopy (FTIR): [i] ultramafic xenoliths from the Colorado Plateau (CP, USA), representing a unique direct sampling of the cold part of the mantle wedge (< 800ºC), and [ii] reference samples from the Kilbourne Hole (New Mexico), and San Quintín volcanic field (Mexico) which were not directly affected by the fluids responsible for the hydration of xenoliths from CP.

CP samples exhibit significant lithological variability, ranging from Opx-poor harzburgites to lherzolites and pyroxenites, with hydration levels varying from incipient hydrated bearing amphibole to chlorite-rich samples (occasionally antigorite), and to a lesser extent, bearing Ti-clinohumite. The extent of hydration nicely correlates with the transition from spinel to ferrit-chromite. Hydrogen content hosted in NAMs is higher and more variable in samples from the CP cold hydrated mantle wedge (Ol: 4-32 and Opx: 146-685 ppm wt% H_2O) compared to other localities (Ol: 0-4 and Opx: 24-209 ppm wt% H_2O). Notably, absorption bands exhibit distinct signatures for the two sample groups. Olivines from other localities display bands related to Tidefect complexes, while CP olivines also present bands related to Si- and Mg-vacancies. Interestingly, CP orthopyroxene shows distinctive bands (3544, 3520, 3325, and 3060 cm^{-1}) previously observed at relatively high oxygen fugacities [1] consistent with the presence of magnetite in these samples. These bands are absent in samples outside CP.

These observations suggest that NAMs can serve as sensors of redox processes occurring during the hydration of the cold mantle wedge and that fluids derived from the slabs have sufficiently oxidizing capacity to significantly alter its redox budget [2].

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References:
[1] Tollan & Hermann (2019). Nature Geoscience 12, 667-671. *doi.org/10.1038/s41561-019-0411-x*
[2] Evans (2006). Geology 34, 489–492. *doi.org/10.1130/G22390.1*

Coupling bulk and in-situ boron isotopes from a subduction related serpentinization front (Monte Maggiore, Alpine Corsica)

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Examples of exhumed portions of oceanic lithosphere are widespread in orogenic belts and are usually interpreted to have undergone serpentinization in an oceanic context prior to convergence and orogenesis [1]. The presence of fresh abyssal peridotite bodies in these domains, however, indicates the potential for the subducting oceanic lithosphere to interact with metamorphic fluids at depth, thereby recording multiple serpentinization events during subduction that may release reduced fluids (H_2) over a broad range of pressures and temperatures [2]. Discriminating between the contributions of high-pressure serpentinization and shallow serpentinization may be challenging, due to similarities in the mineralogy and trace element concentrations of serpentines. Boron isotopes are considered as an important tracer of the serpentinization environment (oceanic *vs.* subduction) [3] and for understanding the evolution of the fluid/rock system during peridotite hydration.In this study we present the case of Monte Maggiore, Alpine Corsica, an example of subducted oceanic lithosphere recording multiple serpentinization events [4], some of which occurred at high- temperature through metamorphic fluid interaction along an Alpine tectonic contact. We adopted a high-density sampling approach (68 variably serpentinized samples on an area of ~ 2km^2) to characterize bulk (MC-ICP-MS) and *in-situ* (LA-MC-ICP-MS) boron isotopic values ($\delta^{11}B$) for multiple serpentine generations and across the entire massif. Average bulk $\delta^{11}B$ values from serpentinites ($\delta^{11}B_{bulk}$) are intermediate between the signature characteristic of oceanic and subduction zone serpentinization ($\delta^{11}B_{bulk}$: +3.5 to +20.8‰, mean +11.8‰, ± 7.5‰ 2 S.D., n = 30). *In-situ* $\delta^{11}B$ results ($\delta^{11}B_{in\text{-}situ}$) on serpentine minerals mostly overlap the bulk results

($\delta^{11}B_{in\text{-}situ}$: -0.2 to +30.1‰, mean +10.5‰, ±6.7‰ 2 S.D., n = 145) showing no significant correlation between $\delta^{11}B_{in\text{-}situ}$ in Liz and Atg. This evidence rules out fractionation of B isotopes due to no B loss at the Liz/Atg transition suggesting that several Atg generations formed during serpentinization events mediated by metamorphic fluids. Heavier $\delta^{11}B$ may record either oceanic serpentinization events –a hypothesis assumed by other geochemical tracers and geochronological data–, or the interaction with prograde slab-derived fluids with a seawater-like imprint. Both *in-situ* and bulk results –the latter normalized for serpentinization degree– indicate a decrease in $\delta^{11}B$ with increasing serpentinization degree towards the underlying tectonic contact.

These findings contribute to the understanding of B isotope behavior throughout the serpentinization cycle from the ocean floor to subduction. Moreover, this study highlights the role of B isotopes as key tracer for discerning serpentinization settings in exhumed metamorphic terranes, thereby improving the understanding of the environments in which H_2-rich fluids may be released through serpentinization.

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References:

[1] Deschamps et al., 2013, https://doi.org/10.1016/j.lithos.2013.05.019
[2] Vitale Brovarone et al., 2020, https://doi.org/10.1038/s41467-020-17342-x
[3] Martin et al., 2020, https://doi.org/10.1016/j.chemgeo.2020.119637
[4] Debret et al., 2014, https://doi.org/10.1016/j.epsl.2014.05.038

Frictional strength, healing behaviour and deformation mechanism of low-grade serpentinites at hydrothermal conditions

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Serpentinites, common in mid-ocean ridges, transform faults and subduction zones, are “weak” rocks that play a critical role in the nucleation and propagation of slow slip events, tremors and earthquakes due to their unique rheological properties.
The studied serpentinites pertain to the exhumed Monte Fico shear zone (Elba Island, Italy) that reached greenschist facies conditions, where they were most likely deformed. The shear zone is made of 0.01-1.0 m scale lenses of massive serpentines wrapped by foliated serpentinites and cut by brittle faults. Bulk deformation was accommodated by anastomosing and pervasive S/C foliations. Brittle faults are covered with slickenfibers composed of chrysotile and polygonal serpentine.
To determine the frictional and healing properties of these serpentinite-bearing faults we performed experiments on powders obtained from the lenses and from the slickenfibers with a rotary shear apparatus and a hydrothermal vessel (ROSA-HYDROS). We conducted slide-hold-slide experiments at effective normal stress σ'_n=20 MPa, pore fluid pressure P_f=6 MPa and slip rate V_{shear}= 10 µm/s at temperatures ranging from 20°C to 400°C. Experiments at 300°C fall along the liquid-vapour transition of water; to keep the fluid liquid, we performed some experiments at 300°C and σ'_n=18 MPa and P_f=12 MPa. Powders from the lenses show an increase of friction coefficient with temperature when water is liquid (from 0.3 to 0.5), and a stronger increase (from 0.6 to ≈0.9) at higher temperatures (300°C and 400°C) when water is in vapour conditions. Moreover, we observe stick-slip behaviour at 400°C. Instead, powders from the slickenfibers show similar friction coefficient for temperatures up to 200°C (0.23), an increase at 300°C (0.34) with water in liquid conditions and a further increase (0.47 to 0.57) when water is in vapour conditions (300°C and 400°C). Contrary to the case for powders from the lenses, in “slickenfibers” sheared at 400°C (vapour conditions) no stick-slip behavior is observed.
The frictional healing properties document how the strength of these heterogeneous brittle-ductile shear zones evolves during the interseismic period. Powders from the “lenses” show a continuous increase toward positive healing with increasing temperature while showing a maximum at 200°C. Instead, powders from the “slickenfibers” show negative healing for all temperature but not at 200°C, where a marked positive healing maximum is observed.
Our experimental observations highlight a strong rheological difference between massive lenses and bounding faults (slickenfibers) at hydrothermal conditions which impact on strain

localization processes. For instance, in a subducting slab, with increasing temperature, the lenses will become stronger while slickenfibers will remain weak and localize deformation.

Storage and fate of volatiles in the shallow mantle: Insights from fluid mobile elements and B and Li isotopes in serpentinites

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We will present whole rock and mineral chemistry insights (inc. ToF SIMS multi-element imaging) into the systematics of light elements (B, Li) and their isotopes during the serpentinization processes at both divergent and convergent plate margins. For the divergent plate case we have selected Site U1309D and some from the recently drilled (IODP Expedition 399, Atlantis Massif, Mid-Atlantic Ridge 30N) Site U1601C as the deepest in situ gabbro-peridotite drill cores ever recovered from the ocean floor. The downcore variation in fluid mobile elements and the vast Sr and light element isotope fractionations highlight the important role of seawater infiltration and seawater-crust interactions taking place at depth. However, it appears that the role of seawater is gradually diminishing with depth, where rather unaltered lithologies may still be involved in active metamorphic (hydration) reactions. For the convergent plate margin serpentinization we have selected to present the fascinating case of the Mariana serpentinite mud “volcanism” in the W. Pacific. Several key cores were recovered during ODP Legs 125 and 195, as well as during the IODP Expedition 366. The rocks and fluids at these forearc sites also show very large downcore elemental and isotope fractionations. In contrast to the oceanic intraplate sites, these are associated with fluids

produced by metamorphic dehydration reactions occurring at blueschist and amphibolite facies conditions as a consequence of subduction of old and cold Pacific slabs. We will attempt to contrast the different tectonic settings and speculate on the importance of variously hydrated ocean crust as a volumetrically important carrier of volatiles from the surface to the deep mantle and back. Serpentinites may be important to kick-start subduction initiation.

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Serpentinization's links to subsurface life constrained by new insights into the Hidden Hydrogeosphere

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The canonical water cycle assumes that all water entering the subsurface to form groundwater eventually re-enters the surface water cycle by discharge to lakes, streams and oceans. Recent discoveries in groundwater dating have challenged that understanding however, revealing that between 30-46% of the planet's groundwater makes up an immense "Hidden Hydrogeosphere", that is not yet incorporated in traditional water cycle conceptual models [1]. Tellingly, it has been overlooked to date largely because it is stored deeper in the crust, on long timescales ranging from thousands or years, to millions, and in rare places, more than a billion years. This conceptual gap is particularly problematic for investigation of subsurface microbiology, as this part of the crust is the biome for a deep subsurface biosphere estimated to account for a significant proportion of the Earth's biomass [2].

Over the past 40 years the discovery of the role of water-rock reactions producing electron donors and acceptors that support a deep biosphere has revolutionized our understanding of habitability and the range of metabolic strategies for life. But major questions remain concerning the production rates of critical electron donors and acceptors required to sustain deep subsurface communities. While radiolytic production of hydrogen (as well as sulfate and potentially small organic compounds) has received a lot of recent attention, the arguably faster rates of serpentinization (and hydration of mafic and ultramafic minerals in general) continue to be a major focus for quantifying the habitability of the Earth's subsurface biosphere over both space and time. Better quantification of the rates of generation of products of water-rock reactions to sustain the deep biosphere are critical to resolving important questions including:

How do we best integrate time constraints on habitability reactions from the host rock, but also the most recent mobile phases (fluids and groundwaters) that have moved through any subsurface systems?

How long can microbial communities survive in the subsurface? And how much can we discern about their rates of transport and evolution compared to surface communities?

What do rates of electron donors and acceptors from radiolysis and serpentinization tell us about the potential habitability of other planets and moons such as Enceladus or Europa?

This presentation will integrate the links between an improved understanding of groundwater cycling and age, the production of electron donors and acceptors via serpentinization, and the constraints these new concepts provide for habitability of Earth, and elsewhere in the solar system.

References:
[1] Sherwood Lollar, B., et al. (2024). *Annual Reviews of Earth and Planetary Sciences 52*, 15.1-15.24. *doi.org/10.1146/annurev-earth-040722-102252*
[2] Magnabosco, C., et al. (2018) Nat*ure Comm. 11(10):*707-717.

Biogeochemical cycling of metals in serpentine soils of Costa Rica; linking microbial ecology to the fate of trace elements

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The Santa Elena Peninsula in the northwestern Pacific coast of Costa Rica is a site of geological interest, harbouring the Santa Elena ophiolite, an ultramafic unit mainly composed by peridotites: rocks rich in iron, magnesium and other metals. Due to its tropical location, the area is exposed to active weathering processes, where a pronounced dry-wet seasonality and warm annual temperatures deliver the climatic conditions required to develop serpentine soils. However, despite their well-studied geology, the indigenous microbial communities and biogeochemical cycles occurring in the resulting metal-rich soils have not been studied to date (1). This research aims to address this key knowledge gap, aiming to study the biogeochemical cycling of metals like cobalt and nickel in serpentine soils associated with the Santa Elena ophiolite, contributing to improvements in our understanding of natural serpentine ecosystems. To deliver a better understanding comprehension of the microbial processes that could potentially operate within serpentine soils, microcosm experiments were conducted using samples collected from across the ophiolite area, and reflecting seasonal changes expected (e.g. oxygen status, carbon inputs and local soil geochemistry). Results of microcosm experiments will be presented, focusing on variations that occurred both in the mineralogy of the soils and their aqueous geochemistry during anaerobic-aerobic incubations after stimulation with carbon sources. Additionally, those changes will be correlated with microbial community composition, identified using 16S rRNA gene profiling, highlighting microbial influences on the biogeochemistry of metals within the serpentine soils. The outcomes will be discussed considering the implications to the surrounding ecosystems.

References:
[1] Solano-Arguedas, A.F., et al. (2022). *Geochem. Trans. 23*, 2. doi.org/10.1186/s12932-022-00079-5

Antigorite dehydration fluid element concentrations and fluid/mineral element distribution coefficients

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Fluids released at dehydration reactions during progressive subduction of hydrated oceanic lithosphere govern significant control on element (re-)cycling, mass transport and ultimately the geodynamics of subduction zones. These fluids are liberated at different depths by successive breakdown of the H_2O-bearing minerals brucite, antigorite and chlorite. Antigorite dehydration is arguably the most relevant dehydration reaction releasing up to 13 wt% of crystal-bound water at fore-arc to sub arc depth. Fluid mobile elements in antigorite (e.g. S, Cl, B, U, As, Sb, LILE and halogens) are released upon breakdown, interact with residual magnetite and sulfides and may potentially transfer significant redox budget to crust and mantle reservoirs. Although antigorite dehydration is of major relevance on geochemical cycling within subduction zones, little compositional data of dehydration fluid element concentrations are available to date.
Relics of fluid released by antigorite dehydration can be found as polyphase, desiccated inclusions within product Chl-Harzburgite from Cerro del Almirez and the Central Alps. We aim to quantify fluid mobile and redox sensitive elements, most importantly S, Cl and Br in dehydration reaction product minerals and polyphase fluid inclusion relics via LA-ICP-MS. We calculate fluid-mineral element distribution coefficients to give insight into element and potential redox budget mobility during progressive subduction. Moreover, such compositional data are also important to better understand how far a slab dehydration fluid signal may survive upon percolation through ultramafic rocks and to reduce uncertainties and discrepancies inherent in modelling results.

Revived interest in historically dismissed Volcanogenic Massive Sulfide (VMS) deposit of the Emilia Romagna region (Italy): Critical Raw Materials (CRMs) petrological and geochemical study

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Italian Emilia Romagna Region has more than 100 dismissed mine sites, exploited in the last century as war Cu supply, many occurring in Volcanogenic Massive Sulfide Deposits (VMS), metal sulfide deposits occurring after underwater volcanic eruptions, associated with hydrothermal events in submarine environments and are divided based on ore composition (Cu, Cu-Zn, Cu-Zn-Pb group) and environmental formation (Cyprus, Kuroko, Besshi) [1].
In this region, VMS deposits occur as pods within small bodies of ophiolitic basalts cropping out as olistoliths in the Northern Apennine External Ligurian units and owe their origin to the metal-rich hydrothermal circulation which developed quartz-sulfide veins when mixed with seawater through a fissures network [2]. The area is characterized by sequences of pillow lavas associated with serpentinite and gabbro breccias, radiolarian cherts, limestones, and abundant serpentinized mantle peridotites [3].
A group of samples from the Boccassuolo ophiolite (Modena province) was geochemically analyzed for both major and trace elements: the results agree with those found in literature [*e.g.,* 1], classifying them as Cu and Cu-Zn deposits, with Cu up to 5818 ppm, 200 times Upper Continental Crust, UCC, and Zn up to 7941, 118*UCC, and as Cyprus-type in term of environment formation. The Pb content is very low, <1 ppm. All the veins observed at the macroscale are made of quartz, as revealed by calcimetry analyses.
Another group from Montecreto (Modena province) was collected and analyzed, although results are still under observation. These samples are sulfide-enriched, with sulfide minerals up to 8 mm in size, and they are made of both quartz and calcite veins, as tested on the field.
For both sites, radiogenic (Sr-Nd-Pb) and stable (S-C) isotopic analyses, as well as mineralogical and *in-situ* analyses area planned to provide additional information on the enrichment and distribution of VMS deposits in the Emilia Romagna Region.

References:

[1] Zaccarini, F. & Garuti, G. (2008). Min. and Pet., 94, 61-83, doi.org/10.1007/s00710-008-0010-9

[2] Saccani, E. (2015). Geos. Fron., 6, 4, 481-501, doi.org/10.1016/j.gsf.2014.03.006
[3] Kiss, G.B., et al. (2023). Minerals, 13, 1, 8, doi.org/10.3390/min13010008

Detecting life-activity within actively serpentinizing peridotite rocks and fluids

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In 2017-2018, the Oman Drilling Project multi-borehole observatory was established in rocks undergoing active serpentinization and carbonation in the Samail Ophiolite in Oman, and our geochemistry/microbiology team has continued to access these sites between 2020-2024. Through support from the NASA Astrobiology and Exobiology Programs, we have then been able to quantify the abundance and distribution of microbial life within the highly serpentinized rocks and fluids. We have specifically focused on contrasting the differences in microbial community structure and activity observed across the large geochemical gradients that persist within 400 meters of the surface. These investigations combine microbial community metagenomic data and isotope probing approaches in order to identify the dominant metabolisms and quantitatively assess the full spectrum of microbial activity rates and how they vary as a function of the in-situ pH, Eh and energy availability.

Within this framework, we will discuss how we have then integrated aqueous geochemical data from borehole fluids with detailed core-scale mineralogical data that includes hyperspectral Raman maps of mineral composition and synchrotron-based x-ray fluorescence mapping and x-ray absorption spectroscopy of S, P and Fe speciation, to identify unique habitats within the serpentinites. This microscale context is then used to frame investigations of single-cell activity that can be achieved using Raman-based stable isotope probing (Raman-SIP) using deuterated water ($^{2}H_2O$) to quantitatively estimate microbial activity and growth rates in serpentinites. In particular, we quantify methanogenic and sulfate reduction activity, observing cell-specific generation times that vary from a few days to years depending upon the local environmental conditions, such as pH and dissolved inorganic carbon availability. We have also probed the microbial carbon assimilation rates in the Oman serpentinites via incubation with carbon stable isotope probes including bicarbonate ($H^{13}CO3^{-}$), formate

($H^{13}COO^-$), and acetate ($^{13}C_2H_3O_2^-$), measuring biomass ^{13}C enrichment with nanoscale secondary ion mass spectrometry (nanoSIMS). This data enables us to calculate cell-specific carbon assimilation rates and rates of biomass turnover. We find that the microbial communities are highly adapted to low energy conditions >200 hundred meters depth, yet they are also poised to rapidly overcome carbon limitation. At the most extremely reducing and hyperalkaline conditions, we can identify a geochemical “edge of habitability” where microbial activity is severely limited. Our findings regarding the distribution and scale of microbial activity have important implications for detecting active microbial life and preserved biosignatures in serpentinites. In addition, they provide a framework for predicting the rates of microbial hydrogen and carbon utilization in actively serpentinizing rocks, which is critical for determining how microbial activity will affect processes such as hydrogen and carbon storage in actively-hydrating peridotite systems.

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Serpentine dehydration in the subducted lithosphere produces no B isotopic fractionation

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Ocean-floor serpentinites are typically enriched in the fluid-mobile element B due to oceanic alteration, and their B isotopic composition varies from +5 to +40 ‰ depending on serpentinization conditions [1]. During subduction, antigorite serpentinites remain enriched in B and generally maintain a high $\delta^{11}B$ > +10 ‰. In-situ $\delta^{11}B$ of antigorite from high-pressure serpentinites from the Western Alps (Zermatt-Saas Unit and Erro-Tobbio Massif) shows distinct isotopic compositions with low $\delta^{11}B$ of –5 to +15 ‰ and high $\delta^{11}B$ of +15 to +20 ‰ for Zermatt-Saas, and even higher $\delta^{11}B$ of up to +27 ‰ for Erro-Tobbio, reflecting serpentinization at different temperatures and fluid/rock ratios. Upon serpentinite dehydration during subduction, metamorphic olivine is produced whereby most of the metamorphic olivine in oxygen isotope equilibrated serpentinite samples [2] shows insignificant B isotopic fractionation compared to coexisting antigorite, having $\Delta^{11}B_{Ol\text{-}Atg}$ near zero (–0.7 ± 3.4 ‰). In contrast, olivine formed in shear bands, shear zones and veins, which act as fluid channels for $\delta^{11}B$ serpentinite-derived fluids, are in B isotopic disequilibrium with coexisting antigorite. This implies that there is little B isotopic fractionation during serpentinite dehydration. Non-zero B isotopic fractionation ($\Delta^{11}B_{Ol\text{-}Atg}$) on the other hand might indicate influx of external fluids.

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References:
[1] De Hoog, J. C. M. & Savov, I. P. (2018). Boron isotopes as a tracer of subduction zone processes. In: Marschall, H. & Foster, G. (eds) *Boron isotopes: The fifth element. Springer International Publishing*, 217–247.
[2] Ulrich, M., Rubatto, D., Hermann, J., Markmann, T. A., Bouvier, A. S. & Deloule, E. (2024). Olivine formation processes and fluid pathways in subducted serpentinites revealed by in-

situ oxygen isotope analysis (Zermatt-Saas, Switzerland). *Chemical Geology 649*, 121978. *doi.org/10.1016/j.chemgeo.2024.121978*.

Geochemical discrimination of serpentinisation conditions at mid-ocean ridge and continental passive margin

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Mid-ocean ridges (MOR) and passive continental margins (PaMa) are two main settings where mantle peridotites exposed near the seafloor are serpentinised. This hydration of ultramafic rocks leads to the crystallisation of serpentine in various textural domains, including mesh texture after olivine and bastite after orthopyroxene.
The interaction between seawater and ultramafic rocks occurs at different temperatures, pH and fluid compositions in successive stages, which are best recognised by *in situ* analysis of the serpentine in the distinct textural domains. We analysed the oxygen isotopic composition and the fluid-mobile elements, such as Cl, B, and Sr of serpentine to reconstruct temperature variations, water-rock ratios and fluid composition. The study of oceanic serpentinisation, using samples from IODP drill cores (MOR and PaMa) provides a comprehensive framework for peridotite serpentinisation to compare with serpentinites in obducted oceanic lithosphere, such as the Erro-Tobbio massif (Italy), the Ligurian Ophiolite (Italy), and the Oman Ophiolite.
The oxygen isotopic composition of serpentine indicates a temperature decrease from the early stage of serpentinisation (mesh rim) to the late stage (bastite), covering a temperature range of 300–120°C for MOR and 200–65°C for PaMa. Furthermore, there is a clear difference in the concentration of fluid-mobile elements in serpentine between the two settings, particularly in the Cl/B ratio and Sr content. PaMa serpentinites are typically enriched in B (up to 220 $\mu g\ g^{-1}$, resulting in a Cl/B < 25) and Sr (up to 40 $\mu g\ g^{-1}$) compared to the MOR serpentinites (B < 100 $\mu g\ g^{-1}$, Cl/B > 25 and Sr < 10 $\mu g\ g^{-1}$). Combining the boron and oxygen isotope composition of serpentine reveals the temperature variability and the extent of pH fluctuation during serpentinisation. This method suggests a more alkaline environment in PaMa setting compared to MOR, where the pH can fluctuate significantly during the serpentinisation. The relative chronology of olivine and orthopyroxene serpentinisation can be determined by analysing the transition metal composition (e.g., Ni, Cr, V) of serpentine in mesh and bastite domains. A redistribution of these elements between mesh serpentine and bastite serpentine may indicate simultaneous serpentinisation of the entire peridotite, whereas different compositions reflect sequential serpentinisation of the olivine and orthopyroxene.

The geochemical affinity of serpentinites from the Erro-Tobbio Massif (Western Alps) and the External Ligurian domain (Northern Apennine) are similar to that of the PaMa setting. The Internal Ligurian serpentinites show chemical features of both PaMa and MOR settings, whereas the serpentinites from the Oman Ophiolites are likely to have formed in a MOR setting.

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The deepest roots of serpentinization: implications on deep energy, geophysics, and deep life at convergent plate margins

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Serpentinization gathers scientists from a multitude of disciplines spanning geology, biology, planetary sciences, and environmental sciences. Rheology, natural H2, and abiotic light hydrocarbon production, microbial incubation, and search for life on other planets are some of the key aspects that make serpentinization special. One of the beauties of serpentinization is its possibility to take place under a vast range of conditions, from very low-pressure and temperature to high-pressure and temperature conditions. Despite that, most of our knowledge on serpentinization is limited to the shallowest part of the serpentine stability field, which is well represented at mid-ocean ridges, in ophiolites, and in the shallow part of the forearc mantle of subduction zones. Although the possibility for serpentinization to extend to much greater depths at convergent margins has been the subject of geophysical investigations, our understanding of the petrological and geochemical patterns of the deepest roots of this process is largely incomplete. This contribution centers on recent advances on the characterization of high-pressure, high-temperature serpentinization processes and their implications on deep energy production in subduction zones. Natural case studies from multiple localities and ages will be introduced, as well as results from thermodynamic and plate tectonics modeling, rocks magnetism, and deformation analysis.

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Limited role for serpentine in accommodating slip on oceanic transform faults *(withdrawn)*

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Understanding the brittle and ductile processes that lead to seismic slip versus aseismic creep on faults is a longstanding goal of tectonics. Oceanic transform faults, with their relatively uniform composition and predictable motion, are ideal laboratories for studying the relationship between mineralogy, fluid flow, deformation mechanisms, strain localization, and seismicity. These faults have an 80% seismic deficit and variable seismic behavior – sections that slip in large earthquakes separated by primarily aseismic sections [1]. Recent studies have suggested that seawater penetrates deep into transform faults, increasing porosity and changing the mineralogy and seismic behavior [e.g., 2]. Yet the specific role that fluids and the formation of rheologically weak minerals play in the accommodation of slip and formation of uplifted fault structures remain unknown.

Serpentine has been proposed as an explanation for the low seismic coupling of transform faults, with some models suggesting that transforms are zones of extensive serpentinization [e.g., 3]. In addition, intrusion of serpentine diapirs to form flower structures and median ridges has been proposed to explain the fault-parallel uplift observed within these dominantly strike-slip environments [e.g., 4]. Yet these interpretations are hindered by limited knowledge of fault-zone lithologies.

To assess the role of serpentinites in transform faults, we evaluated the mineralogical and textural characteristics of 40 ultramafic mylonites (i.e., rocks that have undergone intense ductile deformation) from the Shaka and Prince Edwards transform faults on the Southwest Indian Ridge. Both locations have exceptionally good recovery of deformed rocks by dredging, suggesting that the fault zone was sampled. While many samples have cross-cutting serpentine veins, only 6 mylonites – all from Shaka – contain syn-foliation serpentine that could have accommodated some of the ductile deformation.

The six serpentine mylonites are characterized by crystallization of abundant serpentine parallel to foliation, along with formation of serpentine in one orthogonal and two oblique conjugate fracture sets. Raman data indicates that foliation-parallel serpentine is predominantly antigorite or lizardite, while cross-cutting serpentine is predominantly chrysotile or lizardite. Analysis of two samples by a combination of electron backscatter diffraction and energy dispersive spectroscopy reveals that the samples are characterized by formation of tremolite, chlorite, and magnetite in addition to serpentine, whereas talc is limited to absent.

The textures of the serpentine mylonites indicate static growth of the secondary mineral assemblage, suggesting that serpentine and other minerals where not active in accommodating deformation. Combined with the overall limited abundance of serpentinites among rocks recovered from these fault zones, existing samples suggest that serpentinites do not provide an explanation for the seismic deficit on these faults. We cannot, however, rule out the possibility of a serpentine *mélange* within the transform fault, as softer materials may have been lost during dredge recovery from water depths of 3-5 km.

References:

[1] Boettcher, M.S. & Jordan, T.H. (2004). *JGR 109*, B12302. *doi.org/10.1029/2004JB003110*
[2] Kohli, A., et al. (2021). *Nat. Geosci. 14*, 8, 606–611. *doi.org/10.1038/s41561-021-00778-1*
[3] Roland, E., et al. (2010). *G-Cubed 11*, 7, Q07001. *doi.org/10.1029/2010GC003034*
[4] Bonatti, E. (1978). *EPSL 37*, 3, 369–379. *doi.org/10.1016/0012-821X(78)90052-3*

Numerical modelling of dynamic fluid-rock reactions in subduction settings

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At subduction zones, geophysical and petrological observations suggest that forearc mantle wedges may be serpentinised by fluids released from the devolatilization of subducting slabs [1]. This pervasive serpentinisation of the wedge may be a substantial source of abiotic hydrogen (H_2) and methane (CH_4): gases with the potential to feed extremophile microorganisms in the deepest parts of the continental lithosphere that overlie the wedge. Characterisation of mantle wedge serpentinisation is therefore paramount to constraining the limits within which this deep biosphere can exist. However, the geochemical and geodynamical controls on wedge serpentinisation remain a subject of immense uncertainty. The magnitude of H_2 and CH_4 concentrations and fluxes generated from wedge serpentinisation are therefore poorly constrained at present.

Owing to the inaccessibility of the mantle wedge, constraints on H_2 and CH_4 generation within the mantle wedge must be predicted through geochemical models. In this contribution we present the preliminary results of an ongoing modelling study into mantle wedge serpentinisation. Our approach utilises the Deep Earth Water model [2] to calculate fluid-rock reactions at relayed pressure-temperature conditions in the wedge, which are dictated by geodynamical models of subduction zone thermal structure [3]. The resultant fluids of prior reactions are used as reactant fluids for subsequent reactions at new pressures and temperatures; a chain of individual reactions therefore simulates the whole-scale serpentinisation of a column of mantle rock by slab fluid as the fluid migrates upwards through the wedge. By recording the composition of the overall mantle column at each pressure-temperature step, the introduction of new fluid to the resultant column provides a time element, which we use to track the evolution of bulk mantle mineralogy as subduction progresses.

Our preliminary results suggest that a heavily serpentinised layer forms rapidly at the slab-wedge interface, thereby consuming infiltrating fluid mass and strongly shielding the overlying mantle from significant alteration. Over more time steps, while bulk mantle density continues to decrease with time and increasing serpentinisation, our model suggests that new fluid does not significantly alter the mineralogical composition of the already-serpentinised bulk mantle. H_2 and CH_4 concentrations remain invariant throughout this portion of the column, and fluid speciation is principally controlled by the thermal conditions within the column. However, the rate (i.e., number of timesteps) at which this fluid equilibration is achieved is strongly dependent on the initial conditions applied to the model. Our approach therefore provides a means to test multiple different parameters on H_2 and CH_4 generation at subduction zones from a purely petrological viewpoint, with scope for investigating the impact of variable mass of input fluid, initial mantle wedge and slab fluid compositions, and mantle wedge thermal structures.

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References:
[1] Vitale Brovarone et al., 2020. *Nature Comms.* 11(1), 3880.
[2] Sverjensky et al., 2014. *Geochim. Cosmochim. Acta* 129, 125-145.
[3] Holt and Condit, 2021. *Geochem. Geophys. Geosyst.* 22(6), e2020GC009476.

Serpentinization and deserpentinization of the mantle wedge at a convergent plate margin

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Plate subduction is an important mechanism for energy and mass transfer between the mantle and the crust and is a key factor in maintaining the habitability of the Earth. The relationship between the genesis of serpentinite at convergent plate margins and the composition of metasomatic mantle wedge fluid represents the forefront of geochemical research on subduction zone fluids. Previous studies have made many assumptions and inferences about slab serpentinites but have ignored the geochemical effects of dehydration of mantle wedge serpentinite. An integrated study of petrography, whole-rock and mineral major-trace elements and oxygen isotopes as well as zircon U−Pb ages, trace elements and Hf-O isotopes was carried out on serpentinites from the Hong' an orogen to constrain the protolith nature, metamorphic evolution and multiple episodes of crustal metasomatism of the serpentinites. These serpentinites are mainly composed of Ol+Atg+Liz+Mag±Bru±Mgs and have high Mg# and MgO/SiO_2 ratios but low Al_2O_3/SiO_2 ratios as well as low Ti contents, resembling those from the mantle wedge rather than the subducting oceanic slab. The enrichments of Th, U, LREE and HFSE in the whole-rock and the finding of zircon indicate that these rocks formed through metasomatism of mantle wedge peridotites by subducted crust-derived fluids. The ca. 310 Ma zircon domains exhibit positive $\varepsilon_{Hf}(t)$ values of 4.5 to 19.1, variable $\delta^{18}O$ values and high Th/U ratios similar to those of oceanic eclogites in the Hong'an orogen but different trace element compositions, indicating their formation through metasomatism by fluids from the subducting Paleo-Tethyan oceanic crust. The ca. 430 Ma zircons exhibit U-Pb ages, trace elements and Hf-O isotopes similar to those of the protolith magmatic zircons in the oceanic-type eclogites. The older zircon domains also exhibit similar element and isotope compositions to those of inherited zircons from high- to ultrahigh-pressure metamorphic rocks in the Hong'an orogen. The ca. 220 Ma zircon domains show negative $\varepsilon_{Hf}(t)$ values of -16.0 to -2.7, indicating their formation through metasomatic overprinting by deeply subducting continental crust-derived fluids in the continental subduction channel during Triassic continental collision. In this context, mantle wedge peridotites were first metasomatized in the Carboniferous by subducted oceanic crust-derived fluids. Afterwards, part of the metasomatized peridotites were off-scrapped into the oceanic subduction channel, where they were hydrated by further subducting oceanic crust-derived fluids to form antigorite serpentinite at forearc depths. The antigorite serpentinite was carried to deeper depths during subsequent continental subduction and underwent dehydration there. This gave rise to metamorphic olivine with extremely high Fo values of

96.7 to 97.6 and higher MnO but lower NiO contents than common mantle olivine. Therefore, the present observations and interpretations of orogenic serpentinites provide insights into multistage fluid metasomatism at different depths during the tectonic transition from oceanic subduction to continental collision.

Multiple stages of serpentinization identified by boron isotopes of ultramafic rocks from the Xigaze ophiolite, Yarlung-Tsangpo Suture Zone, southern Tibet

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Clarifying specific serpentinization processes experienced by serpentinites is of the top priority to solve some key scientific problems, including elemental behaviors and isotopic fractionation during serpentinization. Ultramafic samples with different degrees of serpentinization were collected from the Xigaze (Luqu) ophiolite in southern Tibet. In addition, due to the fluid activity of element B and the fractionation characteristics of its isotope composition in fluids from different environments, the source and characteristics of fluids in different serpentinization processes can be clarified based on the relationships between element content changes and isotopic compositions. Through systematic sampling and geochemical analyses, the following preliminary understandings were obtained: 1) Petrographic observations indicate that serpentinites mainly have two textural characteristics. One is a network textures with remnants of primary minerals in the cores, which usually represents pervasive fluid-rock interaction. The other type is of penetrative serpentine veins. The serpentines in these veins are mostly lizardite or fibrous chrysotile formed under low temperature and low pressure. It is speculated that their formation may be related to direct contacting with seawater of previous serpentinites or peridotites exhumed by detachment fault in ultraslow-spreading ridges. 2) Fresh peridotites at the core of the Luqu section have the lowest contents of B elements (as low as 0.35 ppm), and their isotopic compositions ($\delta^{11}B$) are consistent with those of unaltered oceanic peridotites (-4.8‰ ~ -6.9‰ vs. -5 ‰ ± 2‰). 3) From the core to the north and south ends, the degrees of serpentinization become more intensive, and the B element contents show a gradually increasing trend. The matrix serpentinites of the southernmost mélange have the highest B contents (~20 ppm). 4) Inconsistent with the content trend, the $\delta^{11}B$ isotope compositions generally show a trend of decreasing first (minimum -22‰) and then increasing (maximum +7.7‰). This also implies that the Luqu serpentinites had experienced at least two stages of serpentinization. The fluids participating in the two stages of reaction had different B isotope

characteristics, which might correspond to different fluid sources or fractionation trends. 5) During the first stage of serpentinization, the B contents were almost unchanged, but the $\delta^{11}B$ isotope compositions continued to decrease (possibly ^{11}B was taken away by the open-system fluid); while the fluid participating in the second stage obviously continued to provide B contents and to transmit the enriched ^{11}B signals to the serpentinites or the fluid extracted the ^{10}B from serpentinites. Both processes were able to result the residual serpentinites with higher $\delta^{11}B$ isotopic compositions. The two phases of fluids may represent products derived from different settings. The first phase was likely to be supercritical fluids produced during detachment fault activity, while the second one may be related to the penetration of seawater along rock cracks or fissures at low temperature and low pressure.

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