Trip Report to the NASA Astrobiology Institute *3/9/2017*

Enhancing Participation in Serpentine Days 2016 Conference, Sète, France

Proponent: D. Cardace, University of Rhode Island, Department of Geosciences, Kingston, RI, cardace@uri.edu

Overview.

The Serpentine Days 2016 conference consisted of 4 conference days are organized around the five following themes: (1) serpentinization at plate boundaries, (2) serpentinization and global geochemical cycles, (3) serpentinites, carbon cycle and life, (4) extra-terrestrial serpentines, and (5) serpentinization, energy and mineral resources: economic, environmental and societal impacts. The Serpentine Days 2016 Organizing committee was composed of Marguerite Godard (Géosciences Montpellier, France), Bénédicte Ménez (IPG Paris, France), Bruno Reynard (LST ENS U. Lyon, France), José Alberto Padrón-Navarta (Géosciences Montpellier, France).

Two U.S. scientists (**Alexis Templeton and Bethany Ehlmann**), who drive ongoing science in astrobiological aspects of serpentinization, delivered strong and very well received keynote talks.

Elena Amador, Dawn Cardace, Eric Ellison, Mary Sabuda, Lauren Seyler, Sanjoy Som,and Kristin Woycheese attended the Serpentine Days 2016 workshop in Sète, France. 86 scientists from 13 countries were part of the official registrant list for the meeting; 37 of these 86 (43%) were women. The conference was deliberately a mix of early career and senior scientists, and there was good exchange of ideas and a supportive, community feeling at the conference.

NAI-funded, early career participants found that the experience was extraordinarily rewarding and inspiring, and, in some cases, of critical importance in a professional sense (e.g., landing a post-doc, structuring sabbatical plans, building mentorship links). Our group (5 women, 2 men) interacted with an international group of presenters in formal conference presentations and informal family-style meals, and grew in terms of exposure to new scientific findings and approaches, and also built new relationships with colleagues in cutting edge laboratories beyond the U.S.

In the following pages, each participant has provided comments on the importance of the experience, personally and professionally.

Full Name: Elena Sophia Amador

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Serpentine Days presentation:

The Lost City Hydrothermal Field as a Spectroscopic and Astrobiological Analog for Nili Fossae, Mars

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Serpentinization, Mars, Habitability

The Lost City Hydrothermal Field (LC) is a submarine site of serpentinization, west of the mid-Atlantic ridge near 30ºN (Kelley, 2001). The site presents a unique environment where the alteration of source rocks provides biologically viable energy. The LC serpentinites and associated alteration products are produced by the fluid interaction and hydration of ultramafic rocks. Fluid/rock interactions at temperatures <150ºC produce alkaline vent fluids enriched in CH_4 and H_2, sustaining microbes through an abiotic process (e.g., Brazelton, 2006). We have acquired a suite of variably altered serpentinites, meta-gabbros, talc-rich and amphibole-rich fault rocks, and carbonates from the LC to assess their spectral signatures in the near- and thermal-infrared wavelength regions (NIR and TIR). This has provided 1) a confirmation of the mineralogy of these rocks using a non-destructive method, 2) a detailed understanding of the spectral and mineralogical variability within a given rock type from a low-T serpentinizing setting, and 3) a spectral library with measurements similar to those acquired of the martian surface.

Bulk-rock compositions were determined for the LC samples, the non-carbonate rocks were dominated by serpentine (mostly lizardite and chrysotile), amphibole (mostly tremolite), and talc. NIR reflectance measurements uniquely identified the serpentinites and carbonates. Reflectance measurements for the talc-rich fault rock, the amphibole-rich fault rock, and the meta-gabbro were nearly indistinguishable, though their rock types can be confirmed from the TIR measurements, illuminating the sensitivities of the two wavelength regions. Our NIR measurements were then directly compared to similar measurements made of the martian surface using CRISM NIR instrument.

We have aggregated CRISM observations of phases associated with low-T serpentinization in the Nili Fossae region of Mars. Previous studies have shown the presence of olivine (Hamilton, 2005), carbonate (Ehlmann, 2008), serpentine and talc/saponite/amphibole (Ehlmann, 2009; Brown, 2010; Viviano, 2013). We have also added new observations of serpentine, talc/saponite, and Mg-carbonate from more recent CRISM data. Interestingly, we observe the same NIR spectral signatures in both the LC and Nili Fossae, with the exception of the major metal cation type of the carbonates. On Mars, the observed suite of minerals (olivine+serpentine+carbonate+talc/saponite/amphibole) are all within close regional proximity, sometimes within the same image. Additionally, this suite of minerals implies that H_2 was produced during the time of alteration, providing an energy source and a habitable environment for putative life in Nili Fossae's past. Though the geologic setting present in Nili Fossae was most certainly uniquely Martian and may have looked quite different from the LC, the geochemical environment implied by the observed spectral signatures is one that is known to support microbial life on Earth.

Brazelton W.J., et al., (2006). Methane- and sulfur-metabolizing microbial communities dominate the Lost City Hydrothermal Field Ecosystem, App. and Envi. Microbiology, doi:10.1128/AEM.00574-06.

Brown A.J. et al., (2010). Hydrothermal formation of clay-carbonate alteration assemblages in the Nili Fossae region of Mars, EPSL, 297, 1-2, 174-182.

Ehlmann, B.L. et al., (2008). Orbital identification of carbonate-bearing rocks on Mars, Science, 322, 1828 1832.

Ehlmann B.L. et al., (2010). Geologic setting of serpentine deposits on Mars, GRL, 37, 6, 1-5.

Kelley D.S. et al., (2001). An off-axis hydrothermal vent field near the Mid-Atlantic Ridge at 30 degrees N. Nature, 42, 145-149.

Hamilton, V.E. and Christensen P.R., (2005). Evidence for extensive, olivine-rich bedrock on Mars, Geology, 94, 433-436.

Viviano, C.E. et al., (2013). Implications for early hydrothermal environments on Mars through the spectral evidence for carbonation and chloritization reactions in the Nili Fossae region, JGR, 118, 1858-1872.

Conference themes of particular interest to you: I was particularly interested in the geochemical studies that provided mineralogical constraints on serpentinizing environments – These discussions are especially important for me as I try to assess the environments present on Mars strictly from mineralogical information. I was also very happy with the 2 day field trip, it provided grounded context for the information we had been exposed to all week.

Interest in being part of an NAI Serpentinizing Systems Science Working Group: Sure!

Summary of how your participation in Serp Days has impacted your plans for the future: Participation in this conference and two immediate effects on my future. First, the feedback I received from my presentation as well as new concepts I learned during the conference, were immediately incorporated into a manuscript that was submitted to Astrobiology 2 weeks after returning from the conference. Second, participation in this conference allowed me to make connections and finalize a post-doc position starting in the spring at the Jet Propulsion Laboratory.

Other comments for NAI: Thank you for the opportunity!

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Serpentine Days presentation:

Aqueous Geochemical Dynamics at the Coast Range Ophiolite Microbial Observatory (CROMO)

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Keywords: Serpentinization, water-rock reactions, Coast Range Ophiolite Microbial Observatory (CROMO)

Serpentinization is a water-rock reaction that drives the evolution of micro- to mega-scale habitability in ultramafic rocks, through the aqueous alteration of primary minerals in parent rocks, and concurrent production of H_2, CH_4, and (possibly) biologically useful organic compounds. This process pervades extensive areas of silicate planetary bodies, in geologic settings as diverse as cratered fracture zones and fault systems in ultramafic rocks, hydrothermal flow systems operating near crust/mantle interfaces, and deep subsurface groundwater flow systems. Serpentinization causes transformations in mineralogy, rock geochemistry, and co-occurring associated water chemistry, including redox-sensitive dissolved species, which together control the feasibilities of prominent microbial metabolisms. At CROMO, a NASA Astrobiology Institute-funded initiative, the existing groundwater well array allows monitoring of shallow, open-system groundwaters and deeply sourced, closed-system groundwaters in one geographic locale. In this report on the increasingly resolved geochemical patterns at CROMO, documented shifts in pH, conductivity, oxidation-reduction potential (ORP), dissolved oxygen (DO), and major ion geochemistry are discussed and contrasted with other terrestrial sites of serpentinization (marine and continent-hosted). The particular utility of CROMO wells as means of responding to pertinent hypotheses in geomicrobiology (e.g., how serpentinization-linked geochemical parameters influence habitability, how surface and subsurface mineral assemblages relate) in terrestrial and extraterrestrial settings is also considered.

Conference themes of particular interest to you: Methane production via serpentinization, Geomicrobiology of ultramafic rocks, fluid driven geochemistry.

Interest in being part of an NAI Serpentinizing Systems Science Working Group: Absolutely!

Summary of how your participation in Serp Days has impacted your plans for the future:

For the first time, I met Benedicte Menez, Marguerite Godard, and Muriel Andreani, and had the chance to discuss research at some length with Isabelle Daniel. These were the most important and immediately transformative interactions I had at the meeting. I have my first sabbatical leave upcoming (2018-2019 academic year, I hope) and am working on procuring funds to visit Montpelier during that time. Even if this doesn't pan out as I hope, the connection with these scientists will be a lasting legacy of the Serpentine Days meeting in 2016. I also made a number of new contacts that were not so germane to my research interests, but increased my understanding of petrological and experimental components to studies of serpentinization.

Participating in this meeting also widened the scope of my interests in serpentinization, as I followed the recurring theme of disordered/cryptic carbonaceous material lodged in reaction surfaces/at grain boundaries in serpentinites. I have encouraged my current M.S. students to consider the role that distributed carbon could play as a carbon resource in modeling work we are doing to understand astrobiological prospects in extraterrestrial serpentinites.

Other comments for NAI:

I can't thank you enough for making this trip possible for myself and this group of incredibly motivated and promising young scientists. I was very aware during this trip of how cloistered I have been, at my home university, and in my circle of scientist colleagues. Being at the Serpentine Days conference was an intense learning experience and a much-needed reminder to reach out beyond my existing network in the interest of innovative and promising new research.

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Serpentine Days presentation: **Co-registered Fe Redox and Raman Imaging to Trace Low-Temperature Serpentinization Reaction Pathways.**

Low temperature serpentinization reactions have the capacity to generate hydrogen that may support subsurface lithoautotrophic microbial ecosystems. Hydrogen is produced by the oxidation of Fe(II) to Fe(III) by reaction with water under highly reducing conditions. However, the reaction pathways that facilitate the release of Fe(II) to solution and sequester Fe(III) in mineral phases at low temperature are poorly understood. We employ several complementary and spatially co-registered microscale imaging techniques to quantify Fe oxidation state and elucidate iron mineral speciation in serpentinite rocks with complex alteration histories.

We have developed an approach to quantitatively image the Fe(III)/Fe(Total) ratio within rocks that contain multiple generations of minerals produced during water/rock interaction. Synchrotron-based micro X-ray Fluorescence multiple energy mapping (e.g. Mayhew *et al.* 2011) has been optimized for the pre-edge region of the Fe K-edge and carefully calibrated to a set of well-characterized standards (e.g. Andreani *et al.*, 2013) to estimate the Fe(III)/Fe(Total) ratio for every pixel. Iron element distribution maps derived from micro-XRF mapping reveal the mineral phases that contribute to the overall iron budget. Hyperspectral Raman imaging of the same region enables identification of distinct mineral phases even when minerals may be intimately intergrown. Minor spectral differences in the Raman maps reflect variation in chemical composition and crystallinity between distinct generations of serpentine and hydroxide minerals.

The sequential application of these techniques to a single region of interest generates spatially co-registered datasets that reveal the complex variation of Fe-oxidation with mineral speciation and composition. Fe(II)/Fe(III) ratio maps can be placed into the context of total Fe concentration and mineralogy to determine the key mineral sources of Fe(II) and sinks for Fe(III), facilitating interpretation of reactions that may be important at low temperature. This technique has been applied to studying serpentinite rocks from the Samail Ophiolite in Oman which contain abundant Fe(II)-bearing brucite, usually intimately intergrown with serpentine containing both Fe(II) and Fe(III). Microscale Fe-oxidation state mapping suggests that the oxidation of brucite may be recorded by the presence Fe(III)-bearing hydrotalcite-group minerals such as pyroaurite and iowaite, prior to conversion to magnetite and Fe(III)-bearing serpentine. Quantitative imaging therefore allows us to explore whether brucite may represent

an important reservoir for Fe(II), and whether brucite is destabilized at low temperatures by silica- and bicarbonate- bearing groundwater, potentially fueling hydrogen production.

Andreani, M., Muñoz, M., Marcaillou, C., & Delacour, A. (2013). μXANES study of iron redox state in serpentine during oceanic serpentinization. Lithos 178, 70–83.

Mayhew, L. E., Webb, S. M., & Templeton, A. S. (2011). Microscale imaging and identification of Fe speciation and distribution during fluid–mineral reactions under highly reducing conditions. Environmental Science & Technology 45, 4468–4474.

Conference themes of particular interest to you:

-Serpentinization, redox & carbon cycle

- Serpentinization & life

- Ophiolites as field laboratories

Interest in being part of an NAI Serpentinizing Systems Science Working Group: Yes.

Summary of how your participation in Serp Days has impacted your plans for the future:

In the near term, I received valuable feedback that I will incorporate into the preparation of a manuscript on the topic of my talk. I also interacted with and met for the first time numerous team members of the RPL NAI and other members of the serpentinization community. I discussed potential areas of collaboration with several people. I also was exposed to important in-person discussions of plans for the Oman Drilling Project which I intend to participate in.

Other comments for NAI:

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Serpentine Days presentation: **Investigations of Methane, Sulfur, and Iron in the Serpentinite Subsurface using Depth-Resolved Biogeochemical Analyses, Stable Isotope Geochemistry, and Microcosm Approaches**

Serpentinizing systems are considered to be an analogue for geologic processes throughout the Solar System, in locations such as Mars, Europa, and Enceladus. Characterizing the unique geomicrobiology and of these systems has potential to yield insight into the potential for life on those worlds. The more we can learn from accessible analogue sites on Earth, the more focused and streamlined searches can become in resource-limited extraterrestrial locations. Because methane is widespread within the serpentinite subsurface, understanding its origins and fate can provide essential information about carbon cycling, redox reactions, and microbial activity. To this end, we conducted a detailed investigation of biological methane oxidation within the serpentinite groundwater at the Coast Range Ophiolite Microbial Observatory (CROMO), to constrain how microbial community composition and activity is linked to methane, sulfur, and iron availability with depth.

Depth profiles of methane, methane stable isotopes, oxygen, iron, sulfur, pH, and microbial community composition (16S rRNA analysis) were determined in the water column occupying a purpose-drilled borehole (CSW1,1) at CROMO. Samples were collected at depths where dissolved oxygen concentrations were 100%, 50%, 15%, and 0% of air saturation. In parallel, microcosm incubations were conducted to quantify rates of methane consumption. From the 15% O_2 air saturation point and the anoxic well bottom, groundwater was pumped directly into bottles for laboratory incubation. All bottles were inoculated with 50cc of 20%$^{13}CH_4$: 80%$^{12}CH_4$ gas, with parallel experiments run following the addition of iron-hydroxide or thiosulfate respectively. Changes in fluid chemical composition were monitored by colorimetric methods (HS^-, ferrous and total iron), ICP-MS (total sulfur, iron), and gas chromatography (methane). The evolution of ^{13}C labeled CO_2 -- the presumable product of methane oxidation – was quantified using membrane-inlet mass spectrometry (MIMS) and, as an independent control, isotope ratio mass spectrometry (IRMS). The results of these in-progress microcosms and geochemical analyses will be presented.

Conference themes of particular interest to you: biogeochemistry, microbiology, Mars exploration

Interest in being part of an NAI Serpentinizing Systems Science Working Group: yes

Summary of how your participation in Serp Days has impacted your plans for the future:

Attending Serpentine Days was the ideal opportunity to not only present new research on the anaerobic oxidation of methane coupled to iron and sulfur reduction in serpentinizing systems, but it was a chance to summarize the findings thus far and discuss the best course of action to take for the next steps of this work with collaborators. It was a great chance to interact with colleagues in the field who have experience in this area and discuss the intriguing results. Because this AOM research took place at NASA Ames Research Center and was funded by the NAI Early Career Collaboration award, this study came full circle at Serpentine Days, where almost everyone involved had a chance to discuss what was happening.

Furthermore, a more personal outcome of this conference is that I’ve decided to apply for Ph.D. programs and hopefully continue research in an astrobiology related field (or something similar).

Other comments for NAI:

Thank you very much for this amazing opportunity to travel and share my research with extremely talented scientists!

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Serpentine Days presentation: **Global Metabolomics as a Means of Linking Microbial Activities and their Biogeochemical Consequences in Serpentinizing Systems**

Environmental metabolomics is an emerging approach used to study ecosystem properties, yet to date this technique has mostly been applied to soils and plant-associated habitats. Through bioinformatic comparisons to genomic and transcriptomic data sets, metabolomics can be used to study microbial adaptations and responses to varying environmental conditions. Since the techniques are highly parallel to organic geochemistry approaches, metabolomics can also provide insight into biogeochemical processes, such as carbon turnover. These analyses are a reflection of metabolic potential and intersection with other organisms and environmental components. Here, we use an untargeted metabolomics approach to characterize both intracellular and aqueous metabolites from environmental biomass samples obtained from an actively serpentinizing habitat, in order to describe overlapping biogenic and abiogenic processes impacting carbon cycling in serpentinizing rocks.

We applied untargeted metabolomics techniques to environmental biomass samples taken from the Coast Range Ophiolite Microbial Observatory (CROMO), a subsurface observatory consisting of a series of eight wells drilled into an actively serpentinizing ophiolite in the California Coast Range. Cellular biomass from groundwater (~4 L) was collected on combusted glass fiber filters using a peristaltic pump, and immediately frozen in liquid nitrogen. Metabolites were extracted from frozen cells using cold 40:40:20 acetonitrile:methanol:0.1 M formic acid. Total organic carbon in the filtrate was measured using a Shimadzu TOC-L analyzer. Dissolved organic carbon from the filtrate was trapped using Solid Phase Extraction (SPE) Bond Elut PPL (Agilent) cartridges and eluted in pure methanol. All extracts were dried down via vacuum centrifugation, resuspended in 95:5 water:acetonitrile, and analyzed via quadrupole time-of-flight liquid chromatography tandem mass spectrometry (QToF-LC/MS/MS) on a Waters Xevo G2-XS UPLC/MS/MS instrument. Sample splits were also analyzed using NMR and FT-ICR-MS through an ongoing collaboration with the Environmental Molecular Sciences Laboratory (EMSL) for analysis of continental serpentinites. Direct cell counts were obtained using DAPI staining.

Biomass was also collected (~2 L per well) using Sterivex filter units (EMD Millipore) and total RNA was extracted, reverse transcribed, and sequenced to produce a metatranscriptome of each well. Metabolomes and metatranscriptomes were imported into Progenesis QI software for statistical analysis and correlation, and metabolic networks constructed using the Genome-Linked Application for Metabolic Maps (GLAMM), a web interface tool. Further multivariate statistical analyses and quality control was performed using EZinfo. All metabolomics data is currently being combined into a boutique database that can be repeatedly mined as more data is obtained and metabolic networks are constructed from this environment.

Conference themes of particular interest to you: biogeochemistry, metabolism, carbon cycling, origin of life

Interest in being part of an NAI Serpentinizing Systems Science Working Group: yes

Summary of how your participation in Serp Days has impacted your plans for the future: Participating in serp days gave me the opportunity to connect with several other researchers studying biogeochemistry and carbon cycling in serpentine systems, and set up a few possible collaborations. I also learned a great deal about the geology and geochemistry of these systems, which was invaluable to me as someone with very little background in geology.

Other comments for NAI: Thank you so much for funding me to attend this conference. It was an incredible experience.

Full Name: **Sanjoy Som**

QUANTIFYING ENERGY YIELDS FOR METHANOGENS IN SERPENTINIZING SYSTEMS

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Bioenergy, Methanogenesis, Modeling

Geological settings dominated by water-to-rock reactions are natural targets for geobiological investigations decoupled from surface processes. The geochemical diversity that characterize such sites provides abundant energy to support subsurface microbial life. Hydrogen oxidizers are of particular interest because H2-based metabolisms are widespread and deeply rooted throughout the phylogenetic tree of life, implying they may have emerged extremely early in the evolution, and possibly even the origin of life on Earth and potentially any other rocky body bearing liquid water. Initial work on lithogenic H2 production has focused on ultramafic serpentinization, as it is occurring on Earth, is known to have occurred on Mars, and is likely occurring on icy satellites such as Europa.

Serpentinization is modeled using EQ3/6 with the thermodynamic databases of McCollom and Bach, 2009, whereby ultramafic harzburgite rocks are reacted with oxygen- and sulfate- depleted seawater. Reaction kinetics are not explicitly considered, but comparable effects of partial reaction are approximated by assuming post-reaction dilution of equilibrated fluids. The output of EQ3/6 serves as the input to a single-cell bioenergetic model, which calculates energy yields based on spherically-symmetrical diffusion of substrates to a cell followed by reaction at the diffusion-limited rate. Membrane selectivity for substrate transport is explicitly considered. Methanogenesis is the metabolism of focus.

Acknowledgments: Thomas McCollom (CU Boulder) & Marc Alperin (UNC Chapel Hill)

McCollom, T. & Bach, W. (2009). Thermodynamic constraints on hydrogen generation during serpentinization of ultramafic rocks. *Geochimica et Cosmochimica Acta* 73, 856-875.

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Affiliation: Massachusetts Institute of Technology (RPL-NAI)

Serpentine Days presentation:

CARBON CYCLING IN SERPENTINIZING SPRINGS OF THE ZAMBALES OPHIOLITE RANGE

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Metagenomics, Zambales ophiolite, methane cycling

Serpentinizing fluid springs originating in the Zambales Ophiolite Range (Luzon, the Philippines) were investigated to determine microbial community composition and putative function via metagenomic analysis. Assessment of taxonomic biodiversity and metabolic capacity was contextualized with regards to the fluid and solid geochemistry of these ecosystems. Field observations of pH, temperature, and dissolved oxygen indicated that spring fluids were highly alkaline (pH 10-11 at 33-34°C) and hypoxic. Fluids collected from the springs for dissolved organic and inorganic carbon yielded very low concentrations (less than 0.5 mM in both cases). The spring fluids were actively bubbling at the source pools; approximately 207.0 micromoles of hydrogen gas and 187.2 micromoles of methane (Cardace et al., 2015)

Amplicon sequencing of the small subunit rRNA gene indicated that microbial communities were dominated by heterotrophic and lithotrophic microorganisms. Shotgun metagenomic analysis of fluid and sediments provided evidence of the metabolic capacity for methanogenesis, suggesting that some of the methane present in these serpentinizing fluids may be microbial in origin. Archaea from the classes Methanobacteria and Methanomicrobia were detected in spring fluids and sediments. Key enzymes involved in methanogenesis, including methyl coenzyme M reductase (MRI, encoded by *mcrBDCGA*), and formylmethanofuran dehydrogenase (FWD, encoded by *fwdHFGDACB*) were detected. Relative abundance of these enzymes increased in pools near the spring source, where fluids approached anoxic conditions.

The phyla Firmicutes, Bacteroidetes, and Proteobacteria were dominant in both metagenome and amplicon sequence data. Anaerobic Firmicutes from the class Clostridia were abundant in the fluids and sediment of these source pools; the sulfate-reducing *Dethiobacter* and *Desulfotomaculum* comprised the majority of taxa from this lineage. A large percentage of taxa were associated with the phylum Proteobacteria, including: methanotrophic Alphaproteobacteria and Gammaproteobacteria, sulfate-reducing Deltaproteobacteria, and Betaproteobacterial hydrogen-oxidizing *Hydrogenophaga*. The carbon cycling regime at Manleluag is likely reliant on methanogenesis, acetogenesis, sulfate reduction, hydrogen oxidation, and methane oxidation.

Given the presence of key methanogenesis genes and taxa, it is possible that some of the dissolved methane in these seeps is microbial in origin. Disentangling the thermogenic/microbial and/or abiotic formation of methane in this system will require more sophisticated analytical techniques. A future field expedition will focus on the collection of methane gas from the Zambales system for clumped isotopologue analysis, to be carried out in the Ono lab at the Massachusetts Institute of Technology.

Cardace, D., Meyer-Dombard, D.R., Woycheese, K.M., Arcilla, C.A. (2015). Feasible metabolisms in high pH springs of the Philippines. *Front. Microbiol*. 6:10.

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Conference themes of particular interest to you:

Serpentinization, redox and carbon cycle
Serpentinization and life
Ophiolites as field laboratories
Serpentinization in extra-terrestrial systems

Interest in being part of an NAI Serpentinizing Systems Science Working Group:

Yes

Summary of how your participation in Serp Days has impacted your plans for the future:

My experience at Serpentine Days 2016 was highly rewarding, and has helped me to better understand my research and career goals. I came away from the conference with a fresh perspective on my own research topics, which has been extremely helpful with regards to manuscript preparation. Exposure to this worldwide community of researchers has also broadened my knowledge of what is possible in the field, and I am hopeful that some of the contacts I have made will develop into fruitful collaborations. In particular, RPL researcher Eric Ellison has invited me to come to the CU-Boulder campus to work on Raman spectroscopic imaging of my samples, which will provide a powerful new angle in microbe-mineral data interpretation. Active collaborations were also strengthened; Dr. Dawn Cardace, with whom I have collaborated with in the past, has taken on a more direct (if informal) mentoring role for which I am extremely grateful. During conference breaks and over lunch and dinner, we discussed in great detail our upcoming research excursion to the Philippines. Dr. Cardace also gave me invaluable advice about forging ahead with my next career goal: finding a tenure-track professor position in academia. I am thrilled to be a part of this vibrant community of scientists that actively encourages success through mentoring, collaboration, and healthy discourse.

Other comments for NAI:

I would like to express my gratitude for the support provided by the NAI to attend Serpentine Days 2016. Programs like these inspire cross-cultural communication and collaboration, which is integral to moving the science forward by promoting fresh perspectives and the dissemination of knowledge across borders.

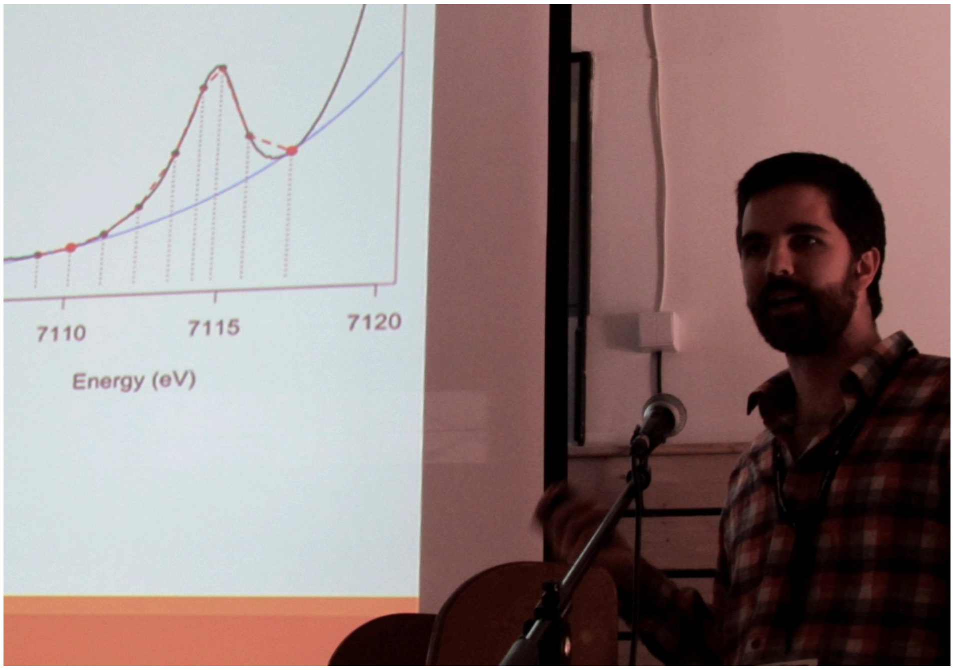

Figure 1: RPL Researcher Eric Ellison (University of Colorado-Boulder) presents his research on iron redox and Raman imaging of samples from Oman.

Figure 2: RPL co-investigator Dr. Lisa Mayhew (University of Colorado-Boulder) presents her research on iron and mineralogical transformations in serpentinites from Oman.

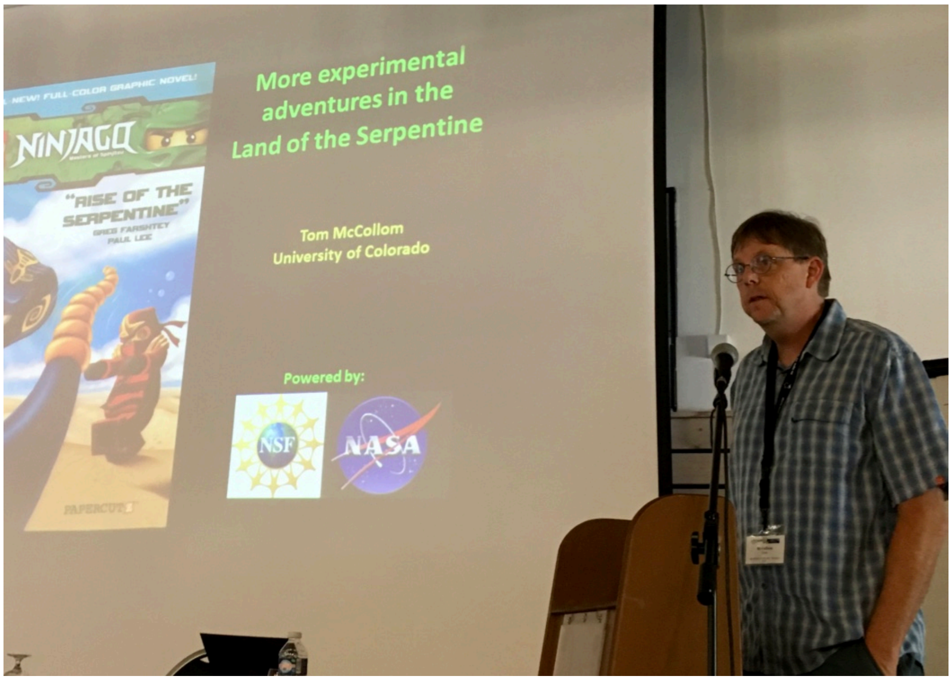

Figure 3: RPL co-investigator Dr. Tom McCollom (University of Colorado-Boulder) presents his research on experimental constraints of serpentinization reactions during olivine dissolution.

Figure 4: NAI Postdoctoral Fellow Dr. Kristin Woycheese (Massachusetts Institute of Technology) presents her research on metagenomic analysis of carbon cycling in the Philippines.

Figure 5: Postdoctoral researcher Dr. Lauren Seyler (Michigan State University) presents her research on metabolomics at the Coast Range Ophiolite Microbial Observatory (CROMO).

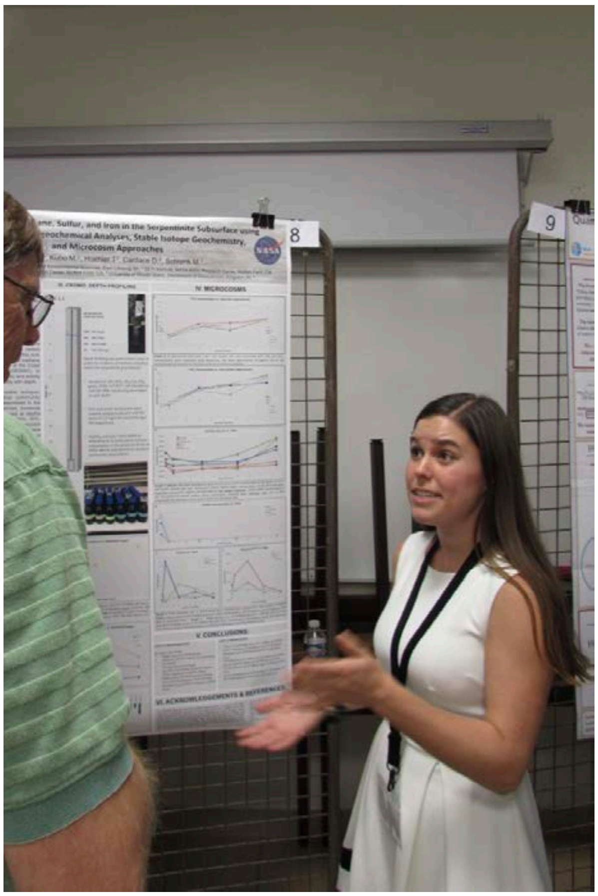

Figure 6: Graduate student Mary Sabuda (Michigan State University) explains her research on methane, sulfur, and iron cycling at CROMO to Dr. Tom McCollom (far left).

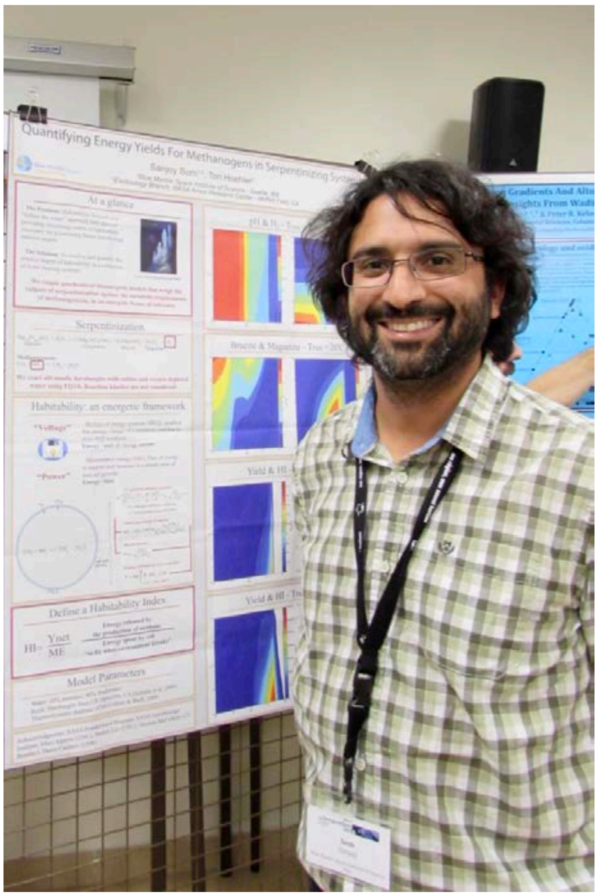

Figure 7: RPL research scientist Dr. Sanjoy Som presenting his poster on modelling energy yields of methanogenesis in serpentinizing systems.

Figure 8: RPL Principal Investigator Dr. Alexis Templeton (University of Colorado-Boulder) presents the keynote address for the "Ophiolites as Field Laboratories" session.

Figure 9: RPL co-investigator Dr. Dawn Cardace (University of Rhode Island) presents her research on aqueous geochemical dynamics at CROMO.

Figure 10: RPL co-investigator Dr. Tori Hoehler (NASA Ames) presents his research on metabolic potential and activity at CROMO.

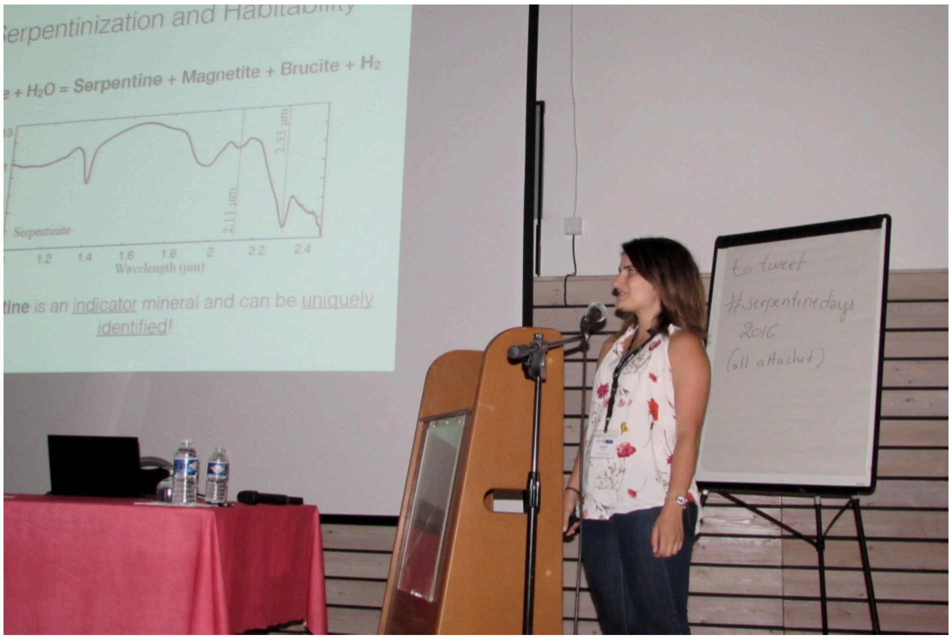

Figure 11: Graduate student Elena Amador (University of Washington) presents her research on spectroscopy of Mars analog systems in the Lost City Hydrothermal Field.

Figure 12: Dr. Dawn Cardace discussing research with Isabelle Daniel over lunch at Serpentine Days 2016.

Figure 13: (from left to right) Eric Ellison, Mary Sabuda, Elena Amador, and Dr. Sanjoy Som enjoy a sunny stop for lunch in the French Pyrenees on day 1 of the Serpentine Days 2016 field trip. Day one focused on mantle bodies in North Pyrenean Zone, with particular emphasis on the Lherz massif.

Figure 14: (from left to right) Eric Ellison, Mary Sabuda, Dr. Lauren Seyler, and Elena Amador at Col d'Agnes in the French Pyrenees, where the Lherz body outcrops in contact with brecciated marble and ultramafic-derived clasts.