Jon ZALOUMIS Report rcvd. 2.26.21
Lewis and Clark Fund for Exploration and Field Research in Astrobiology
Title: Microbial Biosignature Preservation in Mars-Analog Evaporative Lake Precipitates from the Atacama Desert, Chile

Project Report

Project Title: **Microbial Biosignature Preservation in Mars-Analog Evaporative Lake Precipitates from the Atacama Desert, Chile**

A primary focus of NASA missions to Mars has been the search for past habitable environments that could have supported an ancient biosphere. With the recent launch and successful landing of NASA's Perseverance rover, there has been growing interest in clarifying our understanding of how evidence of microbial life may get preserved in rocks from a variety of Mars analog environments. As outlined in the Mars 2020 (Perseverance Rover) Science Definition Team Final Report (2013), two major objectives of the mission are to "explore an astrobiologically relevant ancient environment on Mars…" and to "assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures".

One type of environment found on Earth today that is widespread and was likely present on Mars during its early history are continental evaporative lakes, also known as "sabkhas". These aqueous environments are characterized by high rates of solar evaporation that produce hypersaline water bodies that precipitate gypsum, anhydrite and other salty mineral phases. These minerals have been shown to be abundant on Mars via orbital and *in situ* rover observations (Bibring et al., 2006; Langevin et al., 2005; Nachon et al., 2014; Wray et al., 2010) and are characteristic of areas that once harbored liquid water. This project, funded in part by the American Philosophical Society Lewis and Clark Fund for Exploration and Field Research in Astrobiology, sought to explore whether microbial life living alongside evaporative lakes become fossilized and preserved within associated salt mineral deposits, and whether such signatures are detectable in ancient evaporative rocks.

Fieldwork and sampling took place in the Atacama Desert in Chile near the town of San Pedro de Atacama (22°54'41.8"S 68°12'04.1"W). With the highest UV fluxes reported on Earth (Cordero et al., 2014) and an average mean precipitation of 45 mm/yr, the Atacama Desert is among the driest environments on the planet and provides an opportunity to examine ancient evaporative lake deposits in a Mars-analog setting. Near San Pedro de Atacama are the Cordillera de la Sal, or "Salt Mountains", which as the name suggests is mountain range composed predominantly of evaporative salt minerals deposited originally in an ancient lake approximately ~25 million years ago (Martinez et al., 2017). An adjacent mountain range called the Cordillera de Domeyko contains a 1000+ m thick sedimentary sequence of even older evaporative salt rocks deposited in a similar evaporative lake environment approximately ~125 million years ago (Mpodozis et al., 2005). Using funding from our APS grant, we collected numerous samples from these two locations and brought them to the NASA Jet Propulsion Laboratory for analysis in the AstroBiogeoChemistry Lab (ABC Lab).

Fieldwork consisted of exploring these two mountain ranges to search for varieties of evaporative minerals such as gypsum and anhydrite. These minerals form a range of textures and crystallographic habits that reveal details about the lake environment in which they formed. Among our primary sampling goals was to collect as many varieties of these evaporative sulfate minerals as possible for detailed laboratory analysis. We sought to test the following hypothesis: as sulfate minerals precipitate in a drying lake bed, components of the microbial life present within the lake become trapped within the intracrystalline sulfate matrix, thus preserving evidence of lake-dwelling microbial life for geological timescales. By collecting a variety of different mineral types and textures, we sought to evaluate which sample types may best preserve microbial biosignatures.

Samples returned to the lab were initially treated by two approaches: first we sought to determine whether any *molecular* evidence of life was preserved in the ancient rocks. We developed a method to extract soluble organic matter from the rock matrix, first by an initial solvent cleaning to remove surface contaminants including modern microbes that may have inhabited the mineral surfaces and fracture spaces. After cleaning, we dissolved mineral samples in acid and isolated any soluble organic content that may have been released from the mineral matrix. Due to the extreme environment of the Atacama Desert, we expected little organic molecular remains to be preserved, however in almost every sample analyzed we detected organic molecules which we interpret as derived from the ancient microbial community that inhabited the original lake environment. These molecules were typically detected in the form of fatty acids, which are the main phospholipid-constituents of cell membranes of prokaryotic and eukaryotic organisms (Bowden & Parnell, 2007).

The second approach was to generate thin sections (i.e. extremely thin, 40 µm-thick slices of our mineral samples), which enabled us to look under the microscope and search for evidence of fossilized biological material. Structures such as individual cellular fossils and biologically induced sedimentary structures can be seen in thin sections of many ancient rocks worldwide, but few studies have investigated fossil preservation within ancient evaporative sulfate deposits such as those collected here. The initial molecular analyses showed that evidence of life was being trapped *somewhere* in these minerals, thus our goal was to identify structures that may represent the source of that organic signal. We generated a suite of approximately 50 thin sections and systematically searched for signs of preserved cellular life.

Through our search, we identified numerous spherical and filamentous structures that were preserved within the mineral matrix, which we interpret as fossilized cellular remains.

Intriguingly, we recognized that most of these putative biosignature structures occur within specific zones within the mineral matrix. While evaporite minerals like gypsum grow in an increasing saline evaporative lake, the accreting minerals can incorporate some of the surrounding lake sediment material including fine grained clays. We found that the structures resembling microbial fossil remains are most typically found within these clay inclusions in the gypsum matrix. Because of the relatively high solubility of calcium sulfate minerals (i.e. gypsum, anhydrite, etc.), these minerals readily alter by dissolving and reprecipitating into various crystallographic varieties including anhydrite and bassanite. Fossils caught within this recrystallizing matrix may become destroyed, thus creating a preservation bias within evaporative sulfate minerals. We hypothesize that this mechanism may be responsible for the overall lack of microfossils found within the pure gypsum matrix, however the clay inclusions can remain relatively unaffected by these recrystallization processes.

Through this work, we have discovered that minerals derived from evaporative lakes have the potential to preserve evidence of microbial life for hundreds of millions of years. We also identified a specific preservational window within these minerals, specifically among clay-rich inclusions where morphological cellular fossils can become preserved. Given the high prevalence of evaporative minerals on Mars, we hope that these results can be applied to the exploration of Mars and other astrobiologically-relevant targets where the evaporation of water bodies has occurred. Given the goal of the NASA Preserverance Rover to select samples for a future sample return mission to Earth, we suggest that evaporative lake samples containing clay-rich inclusions may be prime targets to search for evidence of life beyond Earth.

References Cited:

Bibring, J.-P., Langevin, Y., Mustard, J. F., Poulet, F., Arvidson, R., Gendrin, A., et al. (2006). Global mineralogical and aqueous mars history derived from OMEGA/Mars Express data. *Science (New York, N.Y.)*, *312*(5772), 400–4. https://doi.org/10.1126/science.1122659

Bowden, S. A., & Parnell, J. (2007). Intracrystalline lipids within sulfates from the Haughton Impact Structure-Implications for survival of lipids on Mars. *Icarus*, *187*(2), 422–429. https://doi.org/10.1016/j.icarus.2006.10.013

Cordero, R. R., Seckmeyer, G., Damiani, A., Riechelmann, S., Rayas, J., Labbe, F., & Laroze, D. (2014). The world's highest levels of surface UV. *Photochemical & Photobiological Sciences : Official Journal of the European Photochemistry Association and the European Society for Photobiology*, *13*(1), 70–81. https://doi.org/10.1039/c3pp50221j

Langevin, Y., Poulet, F., Bibring, J.-P., & Gondet, B. (2005). Sulfates in the north polar region of Mars detected by OMEGA/Mars Express. *Science (New York, N.Y.)*, *307*(5715), 1584–6. https://doi.org/10.1126/science.1109091

Martinez, F., Arriagada, C., Augusto Becerra, J., Bascuñán, S., Rubilar, J., Martínez, F., et al. (2017). Structure of the Cordillera de la Sal: A key tectonic element for the Oligocene-Neogene evolution of the Salar de Atacama basin Effects of hydrothermal alteration on the magnetic properties of rocks View project Structure of the Cordillera de la Sal: A key tectonic element for the Oligocene-Neogene evolution of the Salar de Atacama basin, Central Andes, northern Chile. *Journal of South American Earth Sciences*. https://doi.org/10.1016/j.jsames.2017.11.013

Mpodozis, C., Arriagada, C., Basso, M., Roperch, P., Cobbold, P., & Reich, M. (2005). Late Mesozoic to Paleogene stratigraphy of the Salar de Atacama Basin, Antofagasta, Northern Chile: Implications for the tectonic evolution of the Central Andes. *Tectonophysics*, *399*(1-4 SPEC. ISS.), 125–154. https://doi.org/10.1016/j.tecto.2004.12.019

Nachon, M., Clegg, S. M., Mangold, N., Schröder, S., Kah, L. C., Dromart, G., et al. (2014). Calcium sulfate veins characterized by ChemCam/Curiosity at Gale crater, Mars. *Journal of Geophysical Research: Planets*, *119*(9), 1991–2016. https://doi.org/10.1002/2013JE004588

Wray, J. J., Squyres, S. W., Roach, L. H., Bishop, J. L., Mustard, J. F., & Noe Dobrea, E. Z. (2010). Identification of the Ca-sulfate bassanite in Mawrth Vallis, Mars. *Icarus*, *209*(2), 416–421. https://doi.org/10.1016/J.ICARUS.2010.06.001

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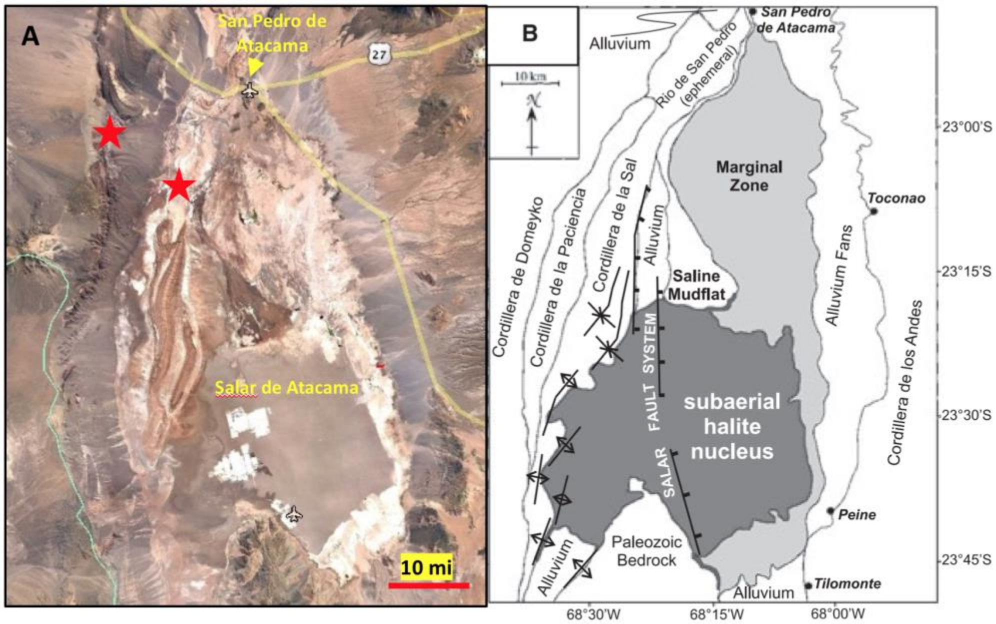

Figure 1: A) Aerial view of region near San Pedro de Atacama, Chile showing sampling localities represented by red stars. B) generalized geologic map of same region from Boscetti et al. 2007 showing the locations of the Cordillera de la Sal and Cordillera de Domeyko.

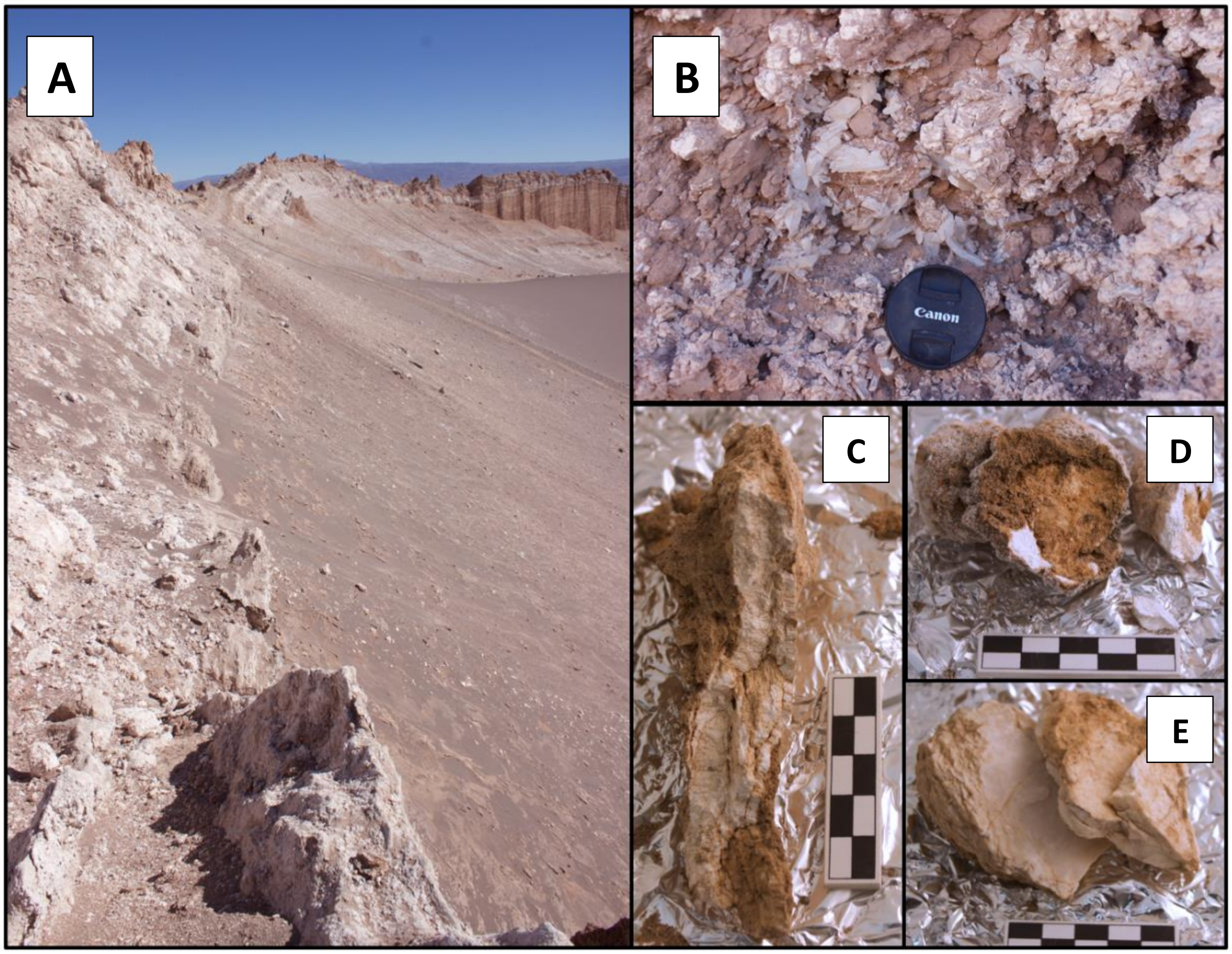

Figure 2: Select outcrop views of the Cordillera de la Sal. A) White resistant cliffs are composed of calcium sulfate minerals derived from an ancient evaporative lake environment. B) Outcrop containing large gypsum crystals partially altered into nodular anhydrite via recrystallization. C-D) Various textural varieties of sulfate minerals sampled including C) laminated pelagic gypsum, D) nodular anhydrite, and E) water-column nucleated sulfate.

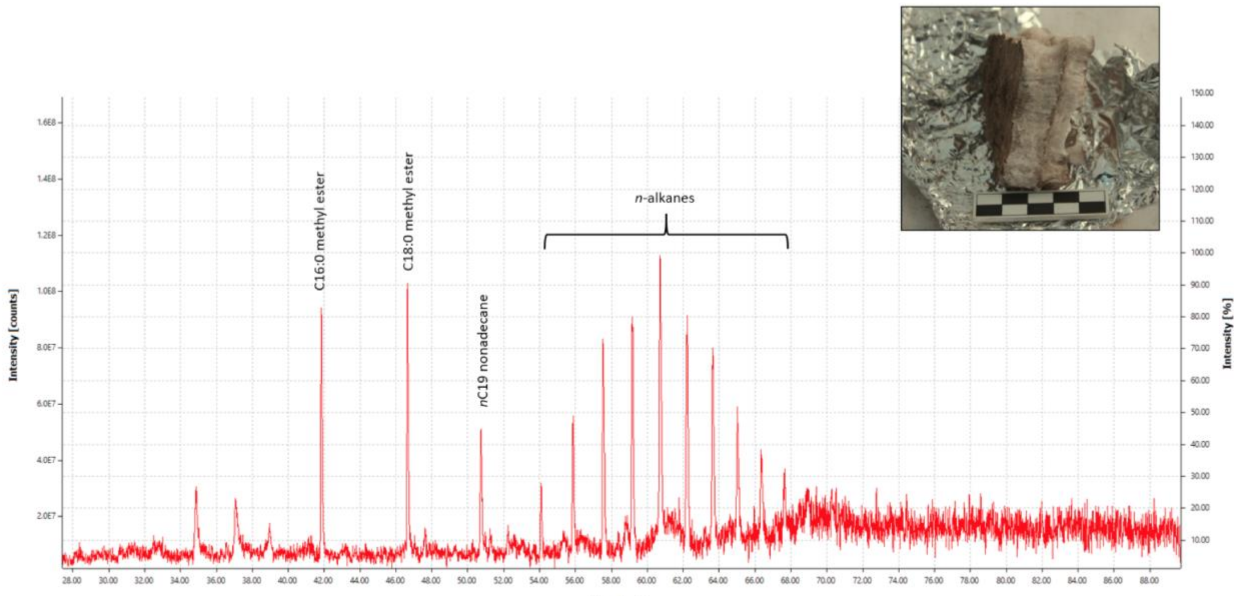

Figure 3: Sample chromatogram showing organics preserved within a calcium sulfate vein sample. The chromatogram shows the prevalence of C16:0, C18:0, and C19:0 Fatty Acid Methyl Esters as well as several higher chain n-alkane lipids, interpreted to be derived from a microbial population inhabiting the ancient lake environment.

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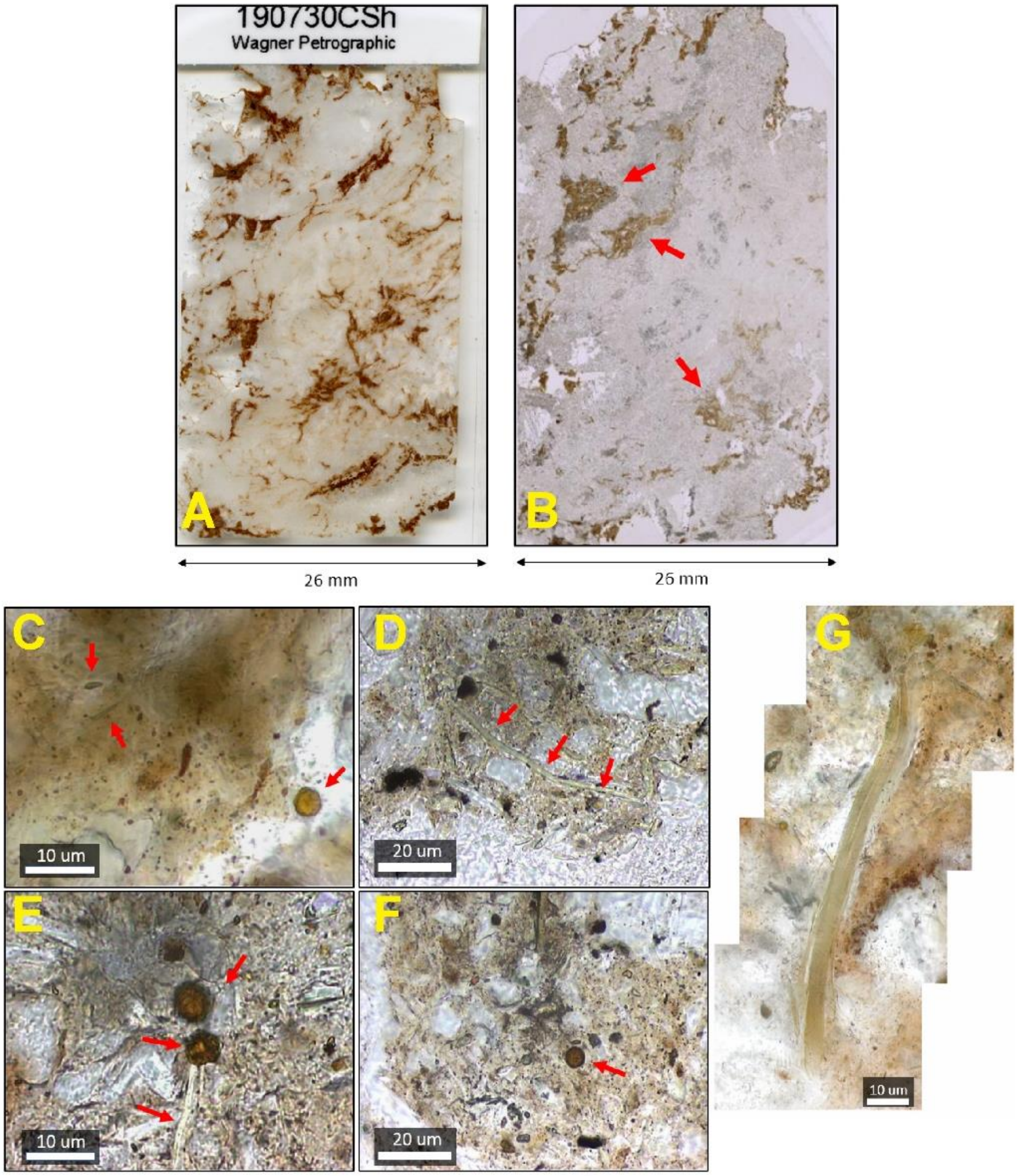

Figure 4: Thin section photomicrographs of putative fossil structures preserved in the collected sulfate samples. A-B) Thin sections showing gypsum (white material) along with brown clay-rich inclusions highlighted with red arrows. C-G) morphological structures interpreted as cellular remains. C, E, and F show amber-colored spherical structures resembling coccoidal microbial cells. D and G show the presence of structures resembling cyanobacterial filamentous cells. All structures occur within a brown clay-rich matrix.