A MARS EXPLORATION STRATEGY FOCUSED ON THE ORIGIN OF LIFE. J. R. Michalski[1], T. C. Onstott[2], S. J. Mojzsis[3-4], J. Mustard[5], Q. H. S. Chan[6], P. B. Niles[6], and S. Stewart Johnson[7]. [1]Dept. of Earth Sciences & Laboratory for Space Research, University of Hong Kong, Pokfulam Road, Hong Kong. [2] Department of Geosciences, Princeton University, [3]University of Colorado, Boulder. [4]Hungarian Academy of Sciences, Budapest, Hungary. [5]Brown University, [6]NASA Johnson Space Center, Houston, USA.

Introduction: Few traces of Earth's geologic record are preserved from the time of life's emergence, over 3800 million years ago. Consequently, what little we understand about abiogenesis—the origin of life on Earth—is based primarily on laboratory experiments and theory. The best geological lens for understanding the early Earth might actually come from Mars, a planet with a crust that's overall far more ancient than our own. On Earth, surface sedimentary environments are thought to best preserve evidence of ancient life, but this is mostly because our planet has been dominated by high photosynthetic biomass production for the last ~2500 million years or more. By the time *oxygenic* photosynthesis evolved on Earth, Mars had been a hyper-arid, frozen desert with a surface bombarded by high-energy solar and cosmic radiation for more than a billion years. Surface life may never have occurred on Mars. Therefore, one must question whether searching for evidence of life in martian surface sediments is the best strategy. We argue that the abundant hydrothermal environments on Mars provide more valuable insights into life's origins [1].

Exploration Strategies: Mars, a planet without plate tectonics and with much lower weathering rates through most of its history, contains a much older and better-preserved geologic record than the Earth [2]. The Martian geologic record presents a unique opportunity to search for clues to the origin of life because the crust contains deposits of similar origin and age to those containing the most ancient records of life on Earth (Figure 1).

Much of the thinking about candidate landing sites for future landed missions has been aimed at maximizing taphonomic potential by targeting sedimentary environments such as lacustrine delta deposits [3]. While this Mars exploration strategy is understandable, such an approach suffers a major epistemological problem: Mars is not Earth. We must recognize that our entire perspective on how life has evolved and how evidence of life is preserved is colored by the fact that we live on a planet where photosynthesis evolved. Even if photosynthesis did emerge on Mars, questions remain as to how successful surface life would have been, and whether evidence of that life was captured in the sedimentary record.

An emerging picture of Mars suggests that the planet was cold, arid, oxidizing and generally inhospitable at the surface for much of its history, but hydrothermal conditions in the near surface or subsurface were considerably more clement [4]. Considering that some of the most ancient analogue habitats on Earth, hydrothermal and subsurface environments, are mirrored on Mars, it is logical to search for the signs of primitive life there in settings analogous to where it may have emerged here. We thereby not only maximize our chances of finding chemotrophic life, but also of finding the evidence of prebiotic chemistry that might have led to the formation of life in a sustained habitable setting (Figure 2).

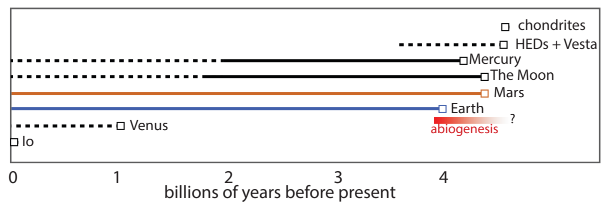

Figure 1: A comparison of the age of planetary crust. Lines represent the best estimate limits of oldest preserved crust. Dashed lines represent significant uncertainties. The crust of Mars might provide the best window into the time when abiogenesis occurred on Earth.

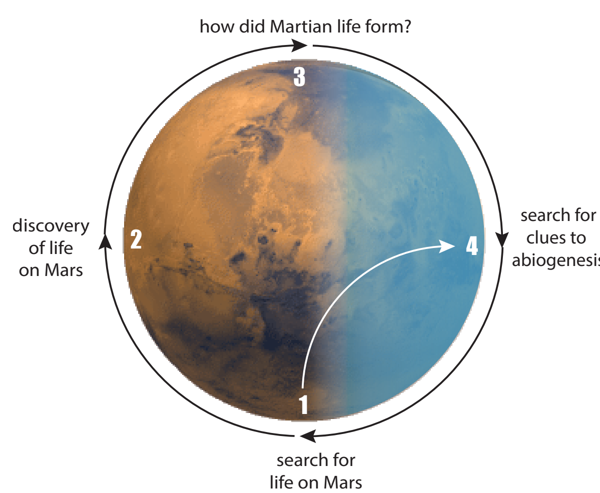

Figure 2: The ultimate goal is to understand how life originates. Even if life is discovered on Mars, the goal will be to understand its origins. We can search for the origin of life as the first objective.

Targeting hydrothermal and subsurface environments: Given how little we understand about the origin of life on Earth, it makes sense to adopt a broader plan to seek signs of life. In other words, it is perhaps more logical to seek evidence of prebiotic chemistry that might have led to the formation of life in sustained habitable settings rather than searching directly for substantially more evolved forms of surface life in ephemeral environments. We could search for the signs of early life on Mars in settings analogous to where it may have formed on Earth (Figure 3).

While concerns about the preservation potential of biosignatures in rocks from hydrothermal and subsurface martian environments are important to consider, it is clear that preservation issues do not present an ultimate stumbling block. Biomarker preservation in subsurface environments is a field that has hardly been explored, but biomarkers from Cretaceous subsurface environments clearly demonstrate that preservation is possible [5].

Potential biosignatures in exhumed deep crustal rocks include the following: 1) isotopic signatures of gasses (e.g. CH_4) trapped in fluid inclusions, 2) isotopic signatures of minerals, fluids and organic matter trapped in veins and diagenetic replacements [5], 3) metal or carbonate accumulations at redox gradients—especially indicating disequilibrium conditions, 4) biotextures in fractures and pores, 5) microfossils preserved in mineralized veins or diagenetic cements and concretions, and 6) important organic molecules such as nucleic acids, lipids, and amino acids in fractures, fluid inclusions, and within mineral aggregates [5-6]. The detection of disequilibrium chemistry implicating life may perhaps be less satisfying than the detection of fossilized microbial mats in lacustrine sediments, but such an approach might actually teach us more about the origin of life. Because the chemical signatures from the dawn of life have been entirely obliterated on Earth, finding these clues on Mars, a unique site within the Solar System, would provide an invaluable window into our own history.

By focusing our search on non-photosynthetic life, we not only maximize our chances of finding biosignatures on Mars but also uncovering clues to abiogenesis, an aspect that should be a key part of our exploration strategy. The quest to understand life's origins could be described as "Follow the energy sources [7]: sulphur, iron and H_2." That mantra would lead us to Mars, an iron and sulphur-rich planetary crust with abundant evidence for ancient hydrothermal activity and H_2 production that could have fueled an early chemosynthetic biosphere.

Figure 3: A false color image from the HiRISE instrument aboard NASA's Mars Reconnaissance Orbiter shows amazing diversity of rocks exhumed from the Martian subsurface a meteor impact in the Nili Fossae area. The image is 1 km across. This site and others like it contain rocks that were altered by fluids in the Martian crust billions of years ago, at the time when life first emerged on Earth. These rocks represent exploration targets that could teach us about the origin of life. HiRISE image ESP_044161_2005.

References: [1] Michalski, J. R. et al. (2017), *Nature Geo*. 11, 21–26. [2] Golombek, M. P. et al. (2006), *JGR Planets*, 111, 1–14. [3] Grotzinger, J. (2009), *Nature Geo*. 2, 231–233. [4] Ehlmann, B. L. et al. (2011), *Nature* 479, 53–60. [5] Klein, F. et al. (2015), *Proc. Natl Acad. Sci.*, 112, 12036–4. [6] Ringelberg, D. B., et al. (1997). *FEMS Microbiol. Rev*. 20, 371–377. [7] Parnell, J. et al. (2010). *Int. J. Astrobiol* 9, 193–200 (2010).