HABITABILITY OF NOACHIAN HYDROTHERMAL SYSTEMS AS CONSTRAINED BY ALTERATION OF A MAFIC DIKE. Justin Filiberto[1], Lacey J. Costello[2], Jake R. Crandall[3], Sally L. Potter-McIntyre[2], Susanne P. Schwenzer[4], Daniel R. Hummer[2], Karen Olsson-Francis[4], Scott Perl[5], Michael A. Miller[6], and Nicholas Castle[1,7]. [1]Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston, TX 77058, USA. jfiliberto@lpi.usra.edu, [2]Southern Illinois University, Department of Geology, 1259 Lincoln Drive, Carbondale, IL 62901, USA, [3]Eastern Illinois University, Department of Geology & Geography, 600 Lincoln Ave., Charleston, IL 61920, USA, [4]AstrobiologyOU. EEES, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK, [5]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, USA. [6]Materials Engineering Department, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238-5166, USA. [7]Planetary Science Institute, Tucson, Arizona, USA.

Introduction: High temperature hydrothermal systems associated with both volcanic activity and impact processes should have been abundant during the Noachian [1, 2]. Any potential biological activity would have had to deal with these conditions and could have used the energy and nutrients in a similar manner as organisms inhabiting hydrothermal systems on Earth [3]. As an analog for these processes on the Martian crust, we have investigated a mafic dike that was hydrothermally altered from contact with ground water as it was emplaced.

The Martian crust is largely basaltic [4], with a wide range of alteration minerals observed in a wide diversity of settings (sedimentary, post-magmatic, volcanic-hydrothermal and impact generated hydrothermal). Secondary minerals have been observed from orbit, by ground-based missions, and in Martian meteorites [5, 6]. However, finding evidence of high-temperature systems either from orbit or *in situ* has only been met with limited success [6]. Therefore, here we report the mineralogy, geochemistry, and S, C, and O isotopic systematics of an analogy system: an altered mafic dike and the surrounding metamorphic contact zone. Our results will be used to constrain the potential alteration mineralogy present in the Early Mars' crust from high-temperature hydrothermal systems, the habitability potential of such systems, and the remote detectability of their products.

Field Site: Our field site is located in the Entrada formation on the Colorado Plateau. The investigation focuses on the 22 Ma Robbers Roost dike [7]. The dike intruded though the Jurassic Entrada Sandstone, an iron-cemented red silty-sandstone deposited in an eolian to tidal environment [8]. The dike can be separated into four visually distinct zones based on differences in colors and textures correlated to different degrees of alteration. Samples of each zone were collected and analyzed (**Figure 1**). Further, samples of the surrounding 'baked contact zone' of the Entrada sandstone (**Figure 1**), as well as bleached fractures distal to the dike (**Figure 2**) were collected to constrain the chemistry of the fluid.

Analytical Methods: Each sample was measured for bulk chemistry at either Southwest Research Institute in San Antonio or Act Labs. Mineralogy was determined by X-Ray Diffraction, optical microscopy, and Visible-Near Infrared Spectroscopy at either LPI, SIU, or NASA JSC. Oxygen, Sulfur, and Carbon isotopic measurements are ongoing at Act Labs.

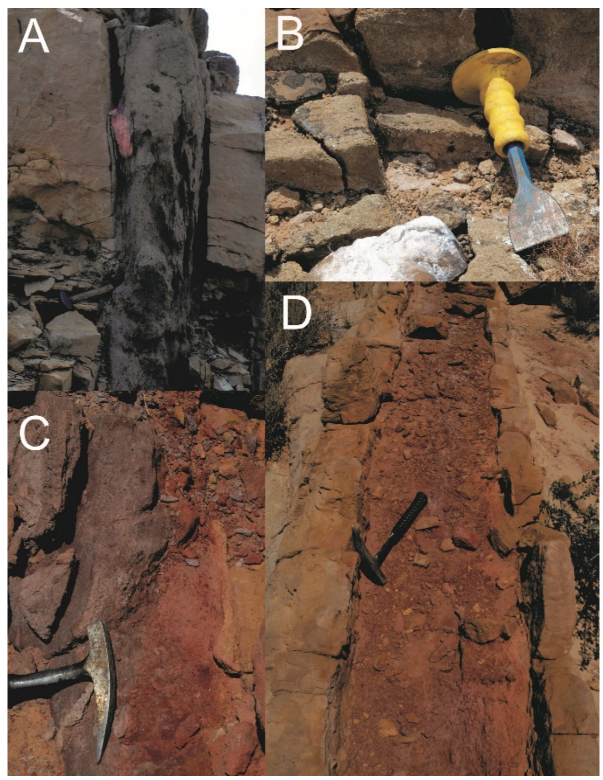

Figure 1. Field site showing each of the four visually distinct alteration zones of the dike. The alteration and oxidation of the dike changes from the 'darkest' zone (A), the 'green' zone (B), the 'purple' zone (C), and the 'red' zone (D).

Results: The dike can be divided in the field into four zones: dark, green, purple and red (**Figure 1**). Samples contain calcite, hematite, and kaolinite, with minor goethite, gypsum, and halite. The mineralogy shows an increase in sulfate and iron-oxide minerals with increasing alteration. Interestingly, even the least altered mafic dike sample contains alteration minerals. The bulk chemistry of these four zones is consistent with fluid mobility removing Si and K but adding S, Fe, Ca, and possibly Mg as alteration progresses.

Mineralogically, the metamorphosed contact zone is dominated by quartz, sanidine, albite, and calcite. Away from the dike, the bleached zone (**Figure 2**) is dominated by hydrothermal minerals: celestine, scapolite (marialite), and calcite. Bulk chemical and isotopic measurements of these samples are ongoing.

Figure 2. Bleached zone along a fracture - parallel, but distal, to the dike in Figure 1.

Conditions of Alteration: Thermochemical models from [9] were used to constrain the alteration conditions. Based on the dominance of carbonates in the mineral assemblage, the fluid was near-neutral in pH [10]. In order for Si to be mobile in a near-neutral pH, high temperatures (>200 °C) would be required. As the system cooled (≥150 °C) carbonates, kaolinite, and hematite precipitated. Goethite would have been produced at lower temperatures. Finally, gypsum and halite would have precipitated from the fluid after formation of a more concentrated brine. Based on the mineralogy of the bleached zones, the fluid would have been a near-neutral pH fluid with high CO_2, S, and Cl activity. Isotopic measurements will further constrain the conditions of alteration and fluid movement.

Implications for Habitability and Application to Mars: If the requirements for life on Earth are reasonable constraints for potential life on Mars [11], the hydrothermal system that formed during interaction of the magma and ground water would have been a habitable environment once the system cooled below ~120 °C [12]. The fluid within the system would have contained key elements used by microbial life (C, S, and Fe), which could have been utilized as an energy source for chemolithotophic microorganisms [13].

Similar alteration mineralogy has been analyzed at multiple landing sites and from orbit: carbonates with olivine, sulfates, and kaolinite and/or other clay minerals [5, 6]. Interestingly, scapolite has also been found in one Martian meteorite [14]. Therefore, this site is an ideal analog location for informing about alteration of the Martian crust and it is paramount that future missions, such as Mars 2020 and ExoMars [15, 16], look at the interface of sediments with magmas or impact melts where microbial life, if present, could have taken advantage of a selection of favorable conditions.

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