WINDOWS INTO THE HABITABLE SUBSURFACE: TERRESTRIAL EXAMPLES OF EXPOSED SUBSURFACE MINERALIZATION AS ANALOGS FOR MARS. S. L. Potter-McIntyre[1], R.Thomas[2], M. Osterloo[2] and B. M. Hynek[2], [1]Southern Illinois University, Geology Department, Parkinson Lab Mailcode 4324, Carbondale, Illinois, pottermcintyre@siu.edu, [2]Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder, Colorado.

Introduction: The subsurface of Earth is a habitable environment that contains a large portion of the total biomass on this planet [e.g., 1, 2, 3]. Similarly, the subsurface of Mars may represent a past or even present habitable environment [e.g., 4, 5, 6, 7]. Accessibility of the subsurface is challenging on both planets, but nevertheless, understanding the variability of subsurface fluids and water/rock/biota interactions occurring in these environments is crucial because this understanding informs both present conditions for habitability as well as the evolution of these environments over geologic time. Most terrestrial subsurface research focuses on drill cores [e.g., 8], deep sea drilling [e.g., 2], or cave or mine research [e.g., 9]; however, drilling and cave research are not likely to occur on Mars in the near future, so it is imperative that we are able to glean clues about the martian subsurface from surficial evidence [6, 7].

The subsurface also represents an environment where surface microbiota sought refuge from harsh surface conditions such as impacts on Earth [e.g., 10, 11] and a host of inclement conditions on Mars. This role as a refuge means that the subsurface of Mars is the planet's longest-lived, possibly even current, potentially habitable environment [e.g., 6, 7]. Taking refuge in the subsurface would require adaptations by microbiota to the subsurface and to changing conditions as geochemical regimes shifted throughout geologic time [12]. Therefore, it is crucial to understand the capacity for habitability that is recorded in surface minerals precipitated from subsurface fluids.

Geologic Interpretation and Comparison: A valuable method for investigating the composition of subsurface fluids and the history of evolving fluid chemistries is to examine mineralization along fractures that have provided conduits for fluids to move from the subsurface upwards through the overlying strata and, in some cases, to flow out onto the surface. Many examples of fracture-controlled fluid flow are present in southern Utah. For this study, we will focus on two specific field sites with a variety of mineralogies and physical processes of mineral precipitation represented within them. One is a modern cold spring system in Ten Mile Graben in southern Utah (Fig. 1D). The other is a series of joints that formed in the subsurface during the Miocene, also located in southern Utah (Fig. 1C).

Ten Mile Graben hosts a modern cold spring system that has been emanating along bounding faults for the past 400ka, forming calcium carbonate and iron (oxyhydr)oxide tufa terraces on modern and paleo-land surfaces. These terraces range in age from modern to Pleistocene [13]. The abundant carbonate minerals likely precipitate because of degassing when pressurized, CO_2-bearing fluids reach the surface environment; however, microbial involvement occurs in some capacity [e.g., 13,14]. Minor iron (oxyhydr)oxide minerals form owing to either rapid oxidation or metabolisms of microbes present at the land surface [13]. Erosion via down-cutting of the Green River has exposed some subsurface precipitates in the area and allows for observations in three dimensions. Denudation in the region has also exposed a sandstone with zones of cement depletion ("bleaching") where the reducing fluid (reducing because of the presence of CO_2 and hydrocarbons in the spring water) moved vertically along fractures in the subsurface and dissolved iron (oxyhydr)oxide cements leaving a white selvage along the fractures that results in a "bleached' look. This depletion of cement would be discernible on Earth in airborne hyperspectral data as a zone of silica enrichment compared to the surrounding host rock similar to features in the Stimson formation at Marias Pass, Gale crater.

The second site is located in the Grand Staircase Escalante National Monument in southern Utah where the Jurassic Navajo Sandstone is well-exposed. Miocene NE-striking joints are present in the Spencer Flat area, and these have abundant iron (oxyhydr)oxide mineralization along the joint faces and extending from the joints in flow lines to the southeast [15]. These joints were mineralized in the subsurface and are now exposed and resistant to erosion relative to the surrounding host rock owing to their degree of induration.

Evidence for chemical alteration and mineralization by fracture-controlled fluid flow has been observed at numerous sites on Mars. Within the graben system of Valles Marineris, ridges along fault traces are hypothesized to result from subsurface groundwater deposition of resistant minerals [16]. Within Candor Chasma, both cementation and bleaching have been attributed to this groundwater flow [Fig 1B; 17]; bleaching has also been observed at a rover scale by Curiosity in Gale crater. Furthermore, layered deposits within Valles

Marineris and within craters like Gale have been proposed to have been deposited at the surface by springs controlled by subsurface structure [18], while ridges on the floors of several impact craters in Margaritifer Terra are consistent variously with subsurface cementation and surface deposition from fluids controlled by crater floor fractures [Fig. 1A; 19]. This ongoing research provides crucial information for future surface missions of potentially habitable subsurface environments recorded in the surface fea-tures. Petrographic microscopy and scanning electron microscopy (SEM) are used to determine mineral paragenesis where multiple diagenetic precipitation events are documented. Bulk geochemistry (whole rock analysis) and mineralogy (from field and lab x-ray diffraction) provide parameters for geochemical modeling performed with Geochemists Workbench. Modeled fluid chemistries are used to constrain subsurface conditions and infer habitability. Airborne and field spectroscopy will provide parameters to identify similar environments on Mars.

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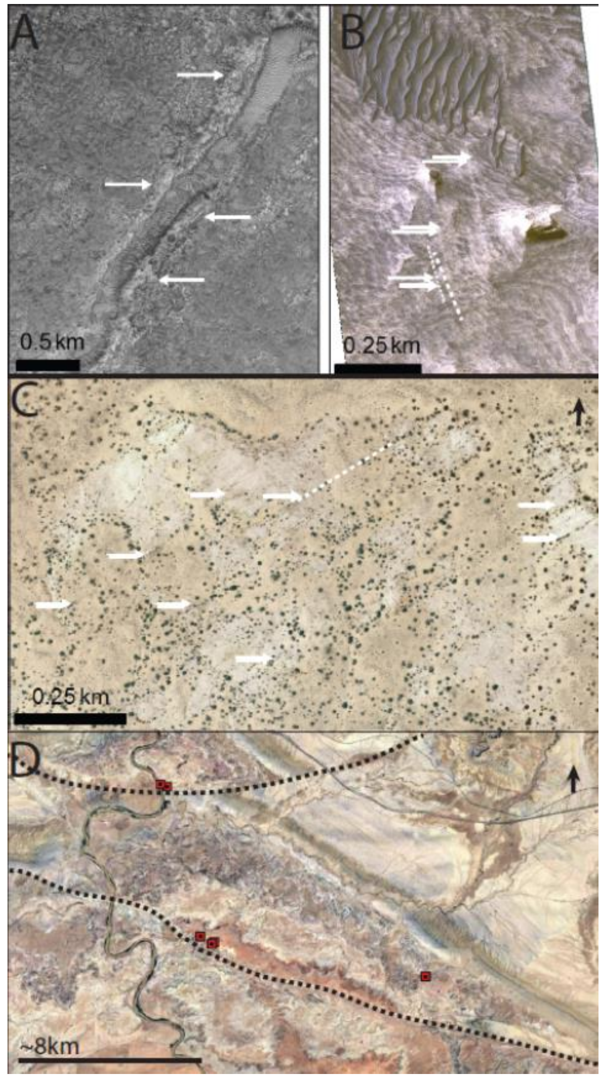

Fig. 1. Mineralized fractures on Mars and Earth. A. Positive relief ridges (indicated by white arrows) at the margins of fractures in an impact crater floor, Margaritifer Terra, Mars (5.6°S, -16.4°E; HiRISE ESP_024833_1745). B. HiRISE color image showing linear en echelon fractures with surrounding bleaching. White arrows point to fractures, and the dotted line delineates one example to orient reader. C. En echelon joints in the eolian Navajo Sandstone at Spencer Flat in southern Utah (white arrows). These joints extend for >100 m and are mineralized with iron (oxyhydr)oxide cements. The white dotted line delineates an example to orient reader. Note the similar scale in View B. and C. D. Ten Mile Graben. Dotted lines delineate graben-bounding faults. Red dots indicate both modern spring sites and tufa terraces ranging in age from 400-0ka.