USING GEOCHEMICAL KINETICS TO INTERPRET POTENTIAL HABITABILITY. E.M. Hausrath[1], C.T. Adcock[1], M.E. Elwood Madden[2], S.R. Gainey[1], A.A. Olsen[3], and M.H. Steiner[1], [1]Department of Geoscience, University of Nevada, Las Vegas, 4505 S. Maryland Pkwy, Las Vegas, NV 89154 Elisabeth.Hausrath@unlv.edu, [2]School of Geology and Geophysics University of Oklahoma 100 East Boyd Street, Suite 710 Norman, OK 73019 [3]School of Earth and Climate Sciences University of Maine 5790 Bryand Global Sciences Center Orono, ME 04469-5790

Introduction: In the search for evidence of life on Mars, past or present, the identification of habitable environments is an essential step. Interpreting the habitability of an environment involves a number of different factors, including the long term persistence of water, the presence of adequate raw materials, energy, and favorable conditions such as pH, ionic strength, and temperature [1, 2]. Observing and interpreting evidence of these conditions in rocks, soils or sediments can help interpret the potential presence of habitable conditions.

Mineral dissolution, which occurs in the presence of liquid water, involves both the properties of the mineral surface and the characteristics of the dissolving solution. The characteristics of mineral dissolution can therefore help shed light on conditions affecting past habitability, including persistence of water, release of nutrients, redox conditions, and favorable conditions for life such as pH, temperature and ionic strength. Mineral dissolution kinetics may also be able to be used in combination with thermodynamics to interpret metastable or apparently dis-equilibrium mineral assemblages that might reflect changing environmental conditions or localized sub-environments. Here we outline how geochemical kinetics can be used to help interpret potential habitability (Figure 1).

Persistence of liquid water: Liquid water is considered a necessary condition for life, and abundant evidence suggests the past presence of liquid water on Mars. In weathering profiles, interaction with liquid water is recorded in the dissolution and persistence of different minerals. For example, in a terrestrial weathering profile of a soil formed on a diabase of basaltic composition in Pennsylvania, the primary minerals augite and plagioclase present in the parent material dissolve to form smectite deep in the soil profile. The smectite then dissolves at shallower depths in the profile [3]. Similar profiles are observed on Mars, such as at Mawrth Vallis, where Fe- and Mg-rich smectite is overlain by a mixture of kaolinite and Al-rich smectite [4-8]. In order to interpret weathering profiles such as those observed at Mawrth Vallis, we have recently measured the dissolution rate of the ferric smectite nontronite, and compared it to the dissolution rates of the Al-rich smectite montmorillonite and kaolinite [9]. Results suggest that a mixture of nontronite, montmorillonite and kaolinite would, after chemical weathering over geological timescales under conditions similar to these experiments, be enriched in montmorillonite and kaolinite [9]. We are also currently conducting reactive transport modeling to further quantify these time frames. Reactive transport modeling allows quantitative interpretation of mineral dissolution kinetics in natural environments incorporating important factors such as distance from equilibrium, flow rates, changes in surface area, and other factors important in natural environments. Other minerals have also been used to infer presence or absence of persistent liquid water on Mars, including olivine [10-13] and jarosite [14, 15]. Mineral lifetime diagrams, such as those proposed by [11 and 15] can be quickly applied to observations of new mineral assemblages and place initial constraints on duration of habitability.

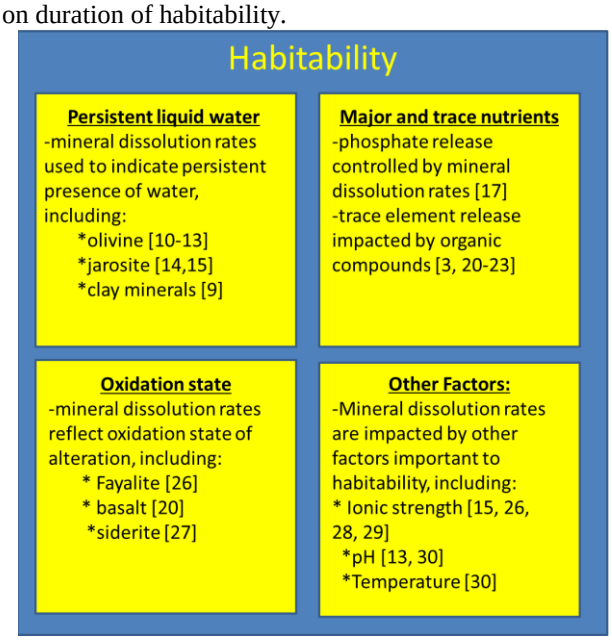

Figure 1. Schematic showing mineral dissolution kinetics that may record conditions of habitability, based on [1, 2].

Release of nutrients: In addition to liquid water, life also requires the major nutrients C, H, N, O, P, S, as well as trace elements. Phosphate, an essential nutrient for life, is largely bound up in solid minerals, and it is therefore a limiting nutrient in many terrestrial environments [16]. We have recently measured dissolution rates of various Mars-relevant phosphate-containing minerals [17]. The results of these experi-

ments indicate that phosphate release from Mars-relevant minerals such as merrillite and Cl-bearing apatite may be significantly higher than phosphate release from fluorapatite, with important implications for habitability on Mars [17]. We are also using reactive transport modeling to further quantify these effects under Mars-relevant conditions [18, 19]. Organic compounds can also increase release rates of trace elements from minerals, leaving leached signatures of their presence [20-23, 3]. Interaction of microorganisms with minerals can also increase release rates, leaving signatures of interaction [24, 25].

Characteristics of liquid water including oxidation state, pH, temperature, and ionic strength: The characteristics of liquid water can also be recorded in the dissolution rates of minerals. For example, changes in dissolution rates under differing oxidation conditions have been recorded for dissolution of Fe-rich olivine [26], basalt [20], and carbonates [27]. Dissolution experiments involving high ionic strength solutions have been performed on a number of minerals, including jarosite [15], olivine [28, 26], basaltic glass [26] and nontronite [29]. Results indicate that dissolution rates are much slower in the presence of brines than dilute solutions, suggesting that alteration signatures resulting from brines might result from much longer contact times than alteration by dilute solutions. Alteration by brines may also result in distinct leaching or precipitation signatures [26, 15]. The acidity and temperature of the dissolving fluid can also be recorded in the relative dissolution rates of minerals [13, 30].

Conclusions: Determining the presence of habitable environments is an important step in seeking signs of life. Geochemical kinetics can help shed light on characteristics of habitable environments. In particular, mineral dissolution kinetics can help interpret the duration of liquid water, oxidation conditions, release of nutrients, and characteristics of the liquid water including pH, temperature, and ionic strength.

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