

REACTION PATH RECONSTRUCTION OF A MAGMATIC INTRUSION INTO SULFATE-RICH SEDIMENTS TO CONSTRAIN HABITABILITY POTENTIAL ON EARLY EARTH AND MARS. B.

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Introduction: Magmatic induced hydrothermal systems are crucial in the search for life beyond our planet, and they could have provided habitable environments for microbial life on Early Earth [1-3]. As a magmatic body interacts with the surface and subsurface of a rocky planet, mineral bound fluids and different elemental species are released. Magmatism is a critical process through Earth and Mars history; however, unlike the Earth, the surface of Mars is dominated by sulfur-rich, basaltic soils [4-8].

At Jezero Crater, the landing site of the NASA Perseverance Rover, units containing sulfate minerals are capped by a volcanic unit, and their interactions may have formed a sulfur-rich hydrothermal environment [9-10]. This environment may have hosted elemental species that could support chemolithoautotrophic microorganisms [11], acting as nutrient and/or energetic sources for life. Therefore, researching sulfur-rich hydrothermal habitats on Earth is key to understanding habitable environments on ancient Mars. Here the interaction between Jurassic sulfate-rich sediments and magmatic dikes from the San Rafael Swell has been investigated as an Earth analog for the potential habitability of such an environment on ancient Mars [12].

Geologic Setting: During the middle Jurassic (~160 Ma), the Carmel Formation was deposited at desert latitudes when the Sundance sea covered large parts of what is today Utah [12]. The sea's cyclic behavior of inundation and withdrawal created an arid coastline depositing red siltstone formed under oxidizing conditions and deposition of an alabaster gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) sabkha sequence [12]. The sulfate-rich Jurassic sediment was intruded by a swarm of dikes during the Neogene, creating a localized heat source which putatively formed a sulfur-rich hydrothermal environment. Previous work reported that heat and fluids persisted meters away from the dike, indicated by temperature dehydration and recrystallization observed by mineral alteration [13].

Methods: During a field investigation, samples were collected from Awesome dike (AD; N3834.252 W11108.351) and the intruded country rocky of the Carmel Formation along a traverse from the most

unaltered sediment to the direct contact with the dike to constrain the geochemical alteration due to the intrusion. Fine-grained samples (clay scale) were polished and made into epoxy blocks. Moreover, igneous and sulfate-bearing samples were made into thin sections.

Samples were mapped using a scanning electron microscope and electron microprobe for general chemical distribution (Cameca SX100). Geochemical data was modelled using Geochemist workbench to reconstruct the fluid composition by titrating the magmatic bulk rock oxide composition [14] into a fluid representing the Sundance sea.

Modeling: To arrive at the model fluid composition contemporary sea water was used as the initial composition and Ca (22 mmol/kg H_2O) was added and SO_4 (5 mmol/kg H_2O) and Mg (30 mmol/kg H_2O) were reduced to simulate the composition of Jurassic sea water [15]. Preliminary temperature ranged from 300 °C to 100 °C. The reaction was completed to equilibrium and a water-rock ratio of one (Fig. 1).

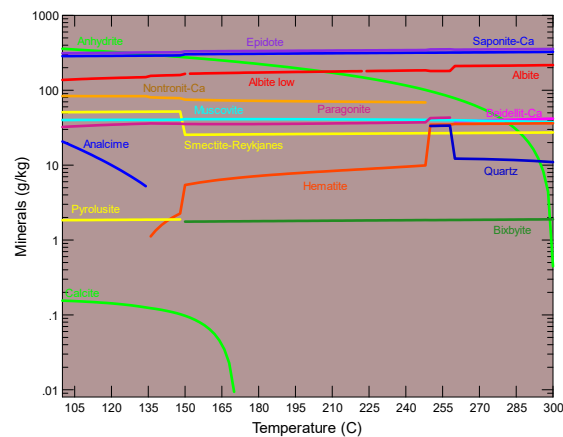


Figure 1. Preliminary model results showing temperatures along the X axis and mineral precipitation in g/kg is along the Y axis.

Model Results: Hydrothermal alteration produces Ca, Mg and Fe smectites, hematite, anhydrite, epidote, bixbyite (Mn-oxide), albite and quartz at 300 °C with an initial pH of 5.22. At 250 °C, hematite as Fe bearing phase decreases and is gradually replaced by nontronite.

By 130 °C hematite is no longer stable. In contrast, calcite starts precipitating at 170 °C and does not inhibit Ca smectite formation. Through the reaction path, the pH and temperature are in a linear relationship, reaching a pH of 7.15 at 100 °C with a water-rock ratio of one.

Sample Results: Calcite, albite, apatite and mica are persistently observed through the alteration path, including the unaltered and dike samples (Fig. 2). The minerals associated solely with the hydrothermal activity are $\text{CaSO}_4 \cdot n\text{H}_2\text{O}$ and Mg-rich clays, as they are both limited to the baked zone and as secondary veinlets within the dike. The baked zone has a sub-centimeter morphological change from amorphous homogenized clay directly in contact with the dike to a grain size of $\geq 10 \mu\text{m}$ which are semi rounded and elongated a few cm away coupled with a color shifts from green to light brown.

Discussion: From these preliminary results, the mineralogy of the system is consistent with the modeled lower temperature regime ($\leq 170 \text{ }^\circ\text{C}$) and higher water rock ratios, as Fe-oxides are absent within the baked zone, yet, CaCO_3 is persistent throughout the samples. If this is the case, the fluids had a circumneutral pH by the time temperatures cooled to habitable conditions ($< 122 \text{ }^\circ\text{C}$ [16]), though there were less fluids in the system. However, this reaction path is not yet complete as it excludes the unaltered sediment composition, which may change the reaction path. Ongoing work will investigate the changes to the sediments, how this affects the reaction path, and the potential for habitability.

Conclusion: The geochemical alteration occurs on the sub-cm scale, suggesting the baked zones may have formed isolated habitable fringes in a complex hydrothermal environment. The fluids potentially reached circumneutral pH, which reached habitable temperatures at low water-rock ratio. Although the Sundance sea is low in Mg, the reaction with the sea composition alone formed Mg rich smectite seen in both the model and detected in the baked zone, hence, an additional source of Mg is not needed. This is also consistent with surface clays detected globally on the surface of Mars and the suggested pH regime [18-22] making this site a good Mars analog site. Further, Raman analysis of the same samples surface will clarify the clay mineralogy and secondary chemistries associated with clay formation. This will allow the samples to be compared with future Raman data from Mars 2020 Perseverance as it explores Jezero Crater. Furthermore, these comparisons can be used to show potential Mars Sample Return properties when those samples are analysed when returned to Earth.

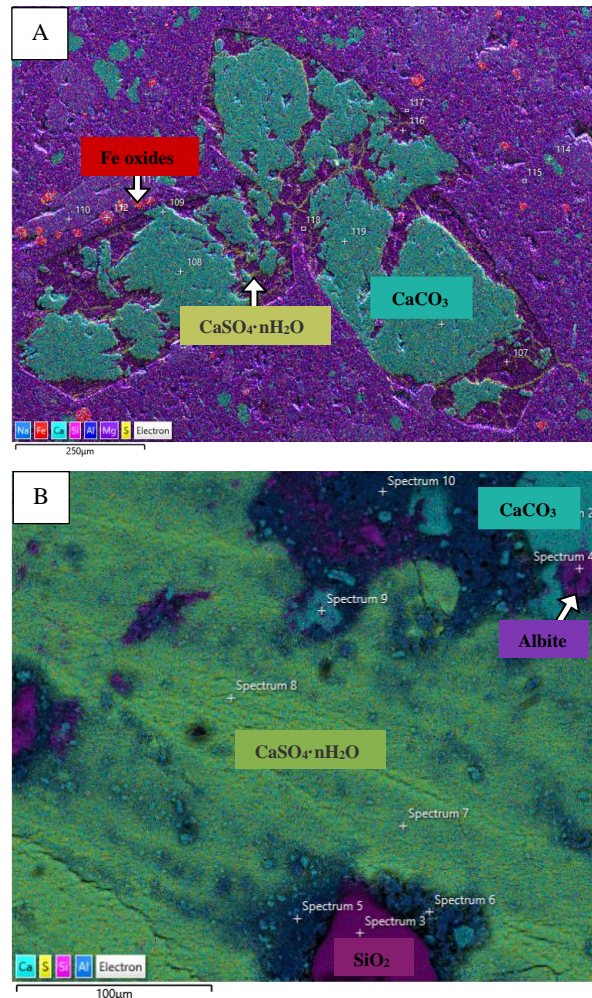


Figure 2. A) SEM image of Awesome dike. B) SEM image of the baked margins a few cm away from the dike.

- References:** [1] Pirajno F. (1992) *Geol. Mag.*, 130, 409-409. [2] Van Kranendonk M. et al. (2018) *LPSC 49 abstr.* #2535 [3] Farmer J. D. (2000) *GSA Today*, 10, 1-9. [4] Carr M.H. and Head J.W. (2010) *EPSL*, 294, 185-203 [5] Gellert R. et al. (2006) *JGR*, 111, E02S05 [6] Gaillard F. and Scaillet B. (2009) *EPSL*, 279, 34-43 [7] Gendrin A. et al. (2005) *Science*, 307, 1587-1591. [8] Franz, H.B. et al. (2019) *Sulfur on Mars from the Atmosphere to the Core*, in *Volatiles in the Martian Crust*, 119–183, Elsevier. [9] Ehlmann B.L. and Mustard J.F. (2012) *GRL*, 39, L11202 [10] Goudge T. et al. (2015) [https://marsnext.jpl.nasa.gov/workshops/2015_08/20Goudge Jezero Mars 2020 2nd Workshop for Web.pdf](https://marsnext.jpl.nasa.gov/workshops/2015_08/20Goudge%20Jezero%20Mars%202nd%20Workshop%20for%20Web.pdf) [11] Nixon S.L. et al. (2013) *News Rev. Astron. Geophys.*, 54, 13-16 [12] Crandall J.R. et al. (in review) *Astrobiology*. [13] Richards H.G. (1958) *J Sed. Res.*, 28, 40-45 [14] Crandall J.R. et al. (2018) *LPSC abstr.* #2083, 2220 [15] Diez M. (2009) *Lithosphere*, 6, 328-336. [16] Horita J. et al. (2002) *GCA*, 66, 3733-3756 [17] Takai K. et al. (2008) *Proc. Nat. Acad. Sci.*, 31, 10949-10954 [18] Bibring J. P. et al. (2006) *Science*, 312, 400-404 [19] Ehlmann B. L. et al. (2013) *Space Sci. Rev.*, 174, 329-364 [20] Ehlmann, B.L. et al. (2011) *Nature*, 7371, 53-60 [21] Carter J. et al. (2013) *JGR*, 118, 831–858 [22] Murchie S. L. et al. (2009) *JGR*, 114, E00D06.