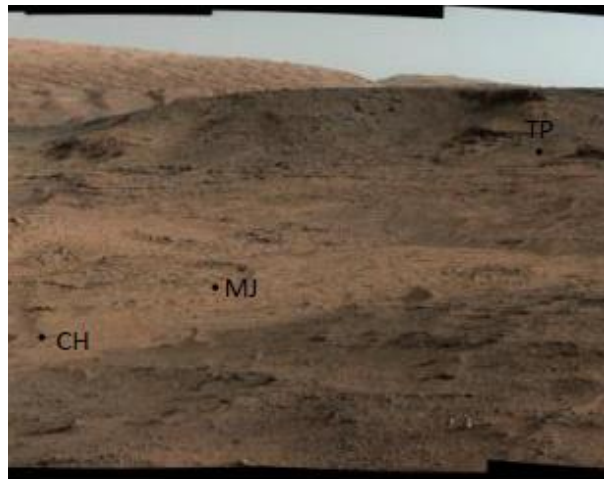


**INTERPRETING AQUEOUS ALTERATION IN THE MURRAY FORMATION USING REACTIVE TRANSPORT MODELING** E.M. Hausrath<sup>1</sup>, D.W. Ming<sup>2</sup>, E.B. Rampe<sup>2</sup>, and T. Peretyazhko<sup>3</sup> <sup>1</sup>UNLV, Las Vegas, NV 89154 [Elisabeth.Hausrath@unlv.edu](mailto:Elisabeth.Hausrath@unlv.edu), <sup>2</sup>NASA Johnson Space Center, Houston, TX 77058 <sup>3</sup>Jacobs, NASA Johnson Space Center, Houston TX 77058

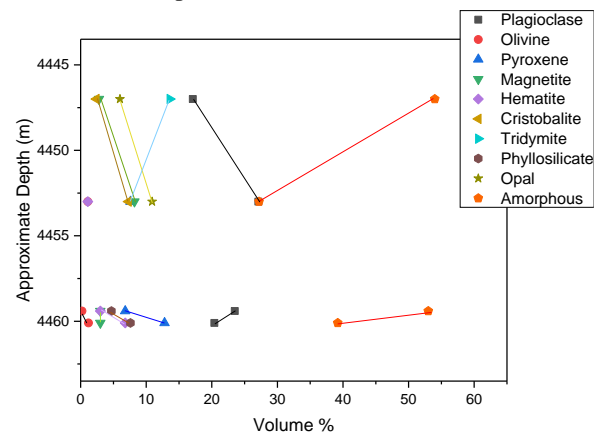
**Introduction:** Abundant evidence for liquid water exists at Gale crater, Mars [e.g. 1]. However, the characteristics of past water remain an area of active research. The first exposures of the Murray formation in Gale crater, Mars (Fig. 1) were studied with four samples analyzed using CheMin: Buckskin, Telegraph Peak, Mojave, and Confidence Hills [2]. Analyses indicate differences in mineralogy and chemistry between the samples which have been attributed to changes in pH and oxidation state of depositional and diagenetic environments [2-6]. Recent work also suggests that hydrothermal fluids may have been present based on the presence of Se, Zn, Pb, and other elements [7, 8].



**Fig. 1.** Panoramic view of the Pahrump Hills outcrop of the Murray formation, with the locations of Confidence Hills (CH), Mojave (MJ) and Telegraph Peak (TP) marked. The sample Buckskin is approximately 6 m higher in elevation than Telegraph Peak. Image Credit: NASA/JPL-Caltech/MSSS.

One way of testing the effect of changes in environmental conditions such as pH, oxidation state and temperature is to use reactive transport modeling. The reactive transport code CrunchFlow has been used to examine terrestrial soil chronosequences [9], ocean floor sediments [10], weathering on Costa Rica basalts [11-13], a range of terrestrial settings [14], and Svalbard basalts [13]. CrunchFlow has also been previously used to interpret weathering on Mars [13, 15-17]. Here we test the effect of pH, oxidation state, and temperature on water-rock interactions in the Murray formation using the reactive transport code CrunchFlow.

**Methods:** Mineralogy was input into CrunchFlow as two layers of different compositions. The bottom layer was based on CheMin measurements of Mojave and Confidence Hills samples, and the top layer on CheMin measurements of Buckskin and Telegraph Peak samples, including proposed past dissolution [2]. Both layers contained plagioclase, pyroxene, olivine, magnetite, fluorapatite, glass, and hisingerite; the top layer also contained cristobalite and tridymite, and the lower layer nontronite. In addition to the minerals input, the secondary phases amorphous silica, hematite, ferrihydrite, jarosite, gypsum, and clinocllore were included based on measurements by CheMin and evidence of incipient chloritization [18, 19].



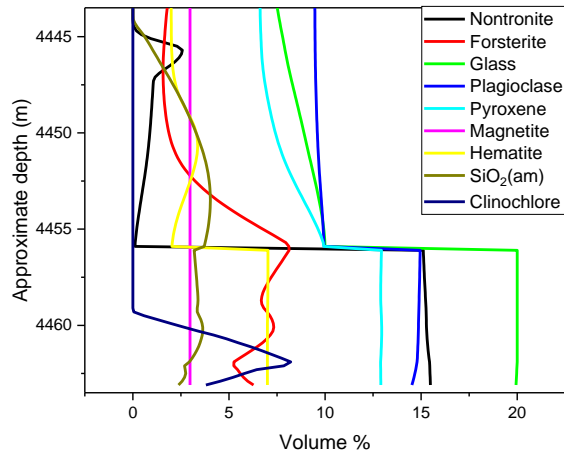
**Fig. 2.** Mineralogy measured by CheMin in the Murray formation from [2].

Solution was modeled as flowing from top to bottom, with pH ranging from 2-6 based on [2]. Both high oxidation and low oxidation state conditions were modeled. Low oxidation states consisted of zero oxygen or equilibrium with current atmospheric O<sub>2</sub> conditions, and oxidized conditions consisted of oxidants in both the reacting fluid and the top layer based on [3], using oxidant concentrations from [17] based on measurements from the Phoenix lander [21].

In order to test the effect of temperature, models were run with fixed temperatures of 1, 25, and 75 °C, as well as both increasing and decreasing temperature with depth, including based on scenarios from [20].

**Results and Discussion:** As has previously been proposed by [2], lower solution pH values result in modeled dissolution that is consistent with observations of increasing plagioclase, pyroxene, and olivine between Buckskin and Telegraph Peak, as well as formation of secondary amorphous silica (Fig. 2 and

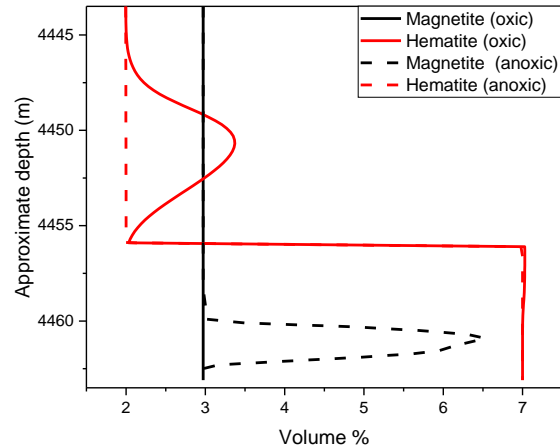
3). At higher pH values, less dissolution and precipitation of amorphous silica occurs, and therefore results are less similar to observations from Murray fm.



**Fig. 3.** Modeled mineral volumes with temperature increasing with depth, 1-10°C in the top layer, and 10-40°C in the bottom layer and pH = 2.

Comparing model results to measurements from Mars, we also observe that the temperature conditions that were most consistent with observations from Mars consisted of alteration under low temperature conditions in the upper layer, and alteration at higher temperatures in the lower layer (Fig. 3). Under these conditions (at low pH as discussed above), dissolution occurred that was consistent with increasing plagioclase, pyroxene, and olivine with depth in the upper layer, and formation of clay minerals in the lower layer. With higher temperature alteration in the upper layer, olivine, plagioclase, and pyroxene did not show the increase in depth that is present in the observations from Mars (Fig. 2 and 3), and with lower temperature alteration in the lower layer, the increase in phyllosilicates was not observed. Lower temperatures near the surface and higher temperatures at depth therefore better match measurements from Mars.

However, modeled conditions explored so far do not replicate all observations from Mars. For example, little dissolution of cristobalite or tridymite is observed in modeled results so far. In addition, changes in oxidation state in the models impact the modeling results, with low oxidation state conditions resulting in precipitation of magnetite, and oxidizing conditions resulting in formation of hematite (Fig. 4). However, the magnetite and hematite precipitation modeled under the conditions described above (low pH, and lower temperatures near the surface and higher temperatures at depth), do not replicate the magnetite and hematite measured by CheMin (Fig. 2). Higher temperatures, higher pH values, or variations in concentrations of detrital minerals may help explain results from Mars.



**Fig. 4.** Modeled mineral volumes of hematite and magnetite under anoxic and oxic conditions with temperature = 1-10°C in the top layer, and 10-40 °C in the bottom layer.

#### Conclusions and Future Work:

Results of ongoing modeling indicate that the pH most consistent with Mars observations is a highly acidic pH. Comparison of modeling results varying temperatures with observations from Mars indicate alteration in the top layer is most consistent with low temperature conditions, and that mineral precipitation observed in the lower levels is more consistent with higher temperature precipitation. Tests of oxidation state indicate that magnetite precipitates under low oxidation state conditions, and hematite under high oxidation state conditions. More work is needed to explore interactions between pH, oxidation state and temperature, as well as the role of detrital minerals.

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**References:** 1.Grotzinger, J.P., et al. (2014) *Sci.* 343: 1242777. 2.Rampe, E.B., et al. (2017) *EPSL* 471: 172-185. 3. Hurowitz, J.A., et al. (2017) *Sci.* 356: 6341. 4. Yen, A.S., et al. (2017) *EPSL* 471: 186-198. 5. Frydenvang, J., et al. (2017) *GRL* 44: 4716-4724 6. Hausrath, E.M., et al. (2018) *EPSL* 491: 1-10. 7. Yen, A.S., et al. (2018) *LPSC Abs.* #2690. 8. Gellert, R., et al. (2018) *LPSC Abs.* #2259. 9.Maher, K., et al. (2009) *GCA* 73: 2804-2831. 10. Maher, K., et al. (2006) *GCA* 70: 337-363. 11. Navarre-Sitchler, A., et al. (2009) *JGR* 114: 10.1029/2008JF001060. 12.Navarre-Sitchler, A., et al., (2011) *GCA* 75: 7644-7667. 13.Hausrath, E.M., et al. (2008) *Geology* 36:67-70. 14. Maher, K. (2010) *EPSL* 294: 101-110. 15. Gainey, S.R., E.M. Hausrath, and J.A. Hurowitz (in revision) *JGR* 16. Adcock, C.T. and E.M. Hausrath (2015) *Astrobiology* 15: 1060-1075. 17.Hausrath, E.M. and A.A. Olsen (2013) *Am. Min.* 98: 897-906. 18. Vaniman, D.T., et al. (2014) *Sci.* 343:6169. 19. Bristow, T.F., et al. (2015) *Am. Min.* 100:824-836. 20. Borlina, C.S. et al. (2015) *JGR* 120: 1396-1414. 21. Quinn, R.C., et al. (2011) *GRL* 38 : L14202.