UNTANGLING SOURCE-TO-SINK GEOCHEMICAL SIGNALS IN A ~3.5 GA MARTIAN LAKE: SEDIMENTOLOGY AND GEOCHEMISTRY OF THE MURRAY FORMATION.

K.L. Siebach[1], C.M. Fedo[2], E.B. Rampe[3], J.P. Grotzinger[4], L.M. Thompson[5], C. O'Connell-Cooper[5], L. E. Edgar[6], and A. A. Fraeman[7] [1]Dept. Earth, Environmental, and Planetary Sciences, Rice University, Houston, TX (ksiebach@rice.edu), [2]Dept Earth & Planetary Sciences, University of Tennessee, Knoxville, TN, [3]NASA Johnson Space Center, Houston, TX [4]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, [5]University of New Brunswick, Fredericton, NB, Canada, [6]USGS Astrogeology Science Center, Flagstaff, AZ, [7]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Introduction: Sedimentary rocks are historical archives of planetary surface processes; their grains, textures, and chemistry integrate the effects of source terrains, paleoclimatic conditions, weathering and transport processes, authigenic mineral precipitation, and diagenesis, which records groundwater chemistry through time. "Source to Sink" basin analysis seeks to constrain the influence of each of these different signals through sedimentary and geochemical analyses. Here, we use Mars Science Laboratory (MSL) Curiosity rover images and geochemical and mineralogical data from a traverse across a portion of the Murray formation—the lowermost unit exposed in the Gale crater central mound—to begin to constrain the aspects of the source to sink system that formed this Martian mudstone between 3.7 and 3.2 Ga.

Geologic Context: Gale crater is a ~3.7 Ga complex crater with a ~5 km tall central peak surrounded by a crescent-shaped mound of layered sediments called Mount Sharp (formally Aeolis Mons), which is interpreted to be an erosional remnant of more extensive crater-filling deposits [1]. Curiosity has traversed >20 km, gained >375 m in elevation, and collected 21 drilled samples (14 in the Murray fm). A composite stratigraphic column depicting the facies encountered by Curiosity along its traverse, divided by elevation because layers are approximately flat-lying, is shown in Figure 1. The observed strata have been divided into 3 groups: the Bradbury group consists of fluvio-deltaic mudstones to conglomerates; the Murray fm, the lowermost exposed strata in the Mount Sharp gp, consists of laminated mudstones with occasional cross-stratified sandstones; and the unconformably overlying Stimson fm of the Siccar Point gp, a much younger deposit of mafic eolian sandstones. Here we focus on the Murray formation, where members have been defined by the MSL Sed-Strat Working Group through comparison of rover and orbiter images and identification of significant boundaries.

Sedimentology: The dominant facies in the Murray fm is a laminated lacustrine mudstone with laminations on the order of a few mm thick, ranging up to ~cm thickness [2]. Note that Curiosity cannot distinguish grain sizes below very fine sand, and even with larger grains, grain boundaries are often difficult to discern [2]. The second facies is a heterolithic assemblage of mudstone, siltstone, and sandstone. This facies includes laminated mudstones, cm-scale ripple cross-stratification, and dm-scale cross-stratified sandstones. The third facies, mostly present in the Hartmann's Valley mbr, shows meter-scale trough cross-bedding with steep foresets [3]. Clear geochemical differences between these facies have not been identified.

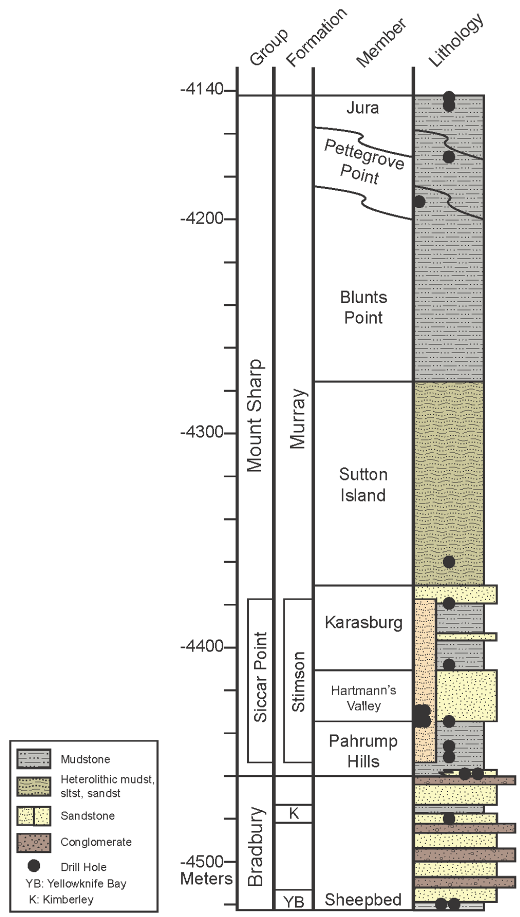

Figure 1. *Composite stratigraphic column showing facies observed by Curiosity by elevation and member divisions.*

Provenance and Transport Processes: It is difficult to constrain provenance from fine grained sediments, but a few parameters can be constrained. The Murray is interfingered with the Bradbury group, which is dominantly sourced from an Al-rich basalt with plagioclase phenocrysts and has elevated potassium relative to average Mars due to variable input of an alkali basalt [4, 5]. Having been deposited in a crater lake, the Murray formation likely also received detrital input from other watersheds around the crater along with eolian and groundwater inputs. The detrital input has been weathered, but all drilled samples in the Murray formation still contain an average of ~32% igneous minerals, ranging from 18% to ~50%. All samples in the Murray fm contain elevated potassium, perhaps due to contributions from the same alkali basalt as contributed to the Bradbury grp. This potassic source is thought to no longer be exposed as neither the eolian Stimson fm nor modern eolian sediments show elevated potassium.

One other distinctive source contributed to the Murray fm. In the Pahrump Hills member, an 1+ m thick layer identified by ChemCam and DAN to contain significant hydrated amorphous silica [6, 7] was found to contain opaline silica, cristobalite, and tridymite, a high-T low-P SiO_2 polymorph consistent with explosive felsic volcanism [8]. The lack of abundant crystalline SiO_2 in other layers indicates that this distinctive source was only contributing to lake sediments for a short duration.

Paleoclimate: The Chemical Index of Alteration (CIA) is a proxy for paleoclimatic conditions based on the weathering of feldspar minerals; it is a molar ratio of the labile elements in feldspar Ca, Na, and K to Al, which is immobile in weathering solutions [9, 10]. Comparisons of CIA values in the Bradbury fluvio-deltaic sediments to terrestrial rivers indicates that paleoclimatic conditions at the base of the Murray were similar to or colder than conditions in Iceland today [11]. Mangold et al. showed that CIA values increase with elevation for the first four members of the Murray formation [12], and Bristow et al. showed that the phyllosilicates transition from tri-octahedral to di-octahedral forms, consistent with increasing warming and chemical weathering upsection [13].

Authigenic Mineral Production: Minerals that formed through precipitation of dissolved components in the lake contribute to the geochemical and mineralogical trends observed. However, it is difficult to differentiate between authigenic minerals from the lake waters and diagenetic minerals from later groundwater. Amorphous silica, which is particularly abundant in and near the tridymite layer, may have precipitated out of lake waters, but it is also present in diagenetic fracture-associated halos. Iron oxides including magnetite, hematite, and akaganeite may have been detrital, may have precipitated from lake waters, or may have been diagenetic—or some combination thereof.

Some textural observations in the Murray show poikilotropic crystal shapes, which are consistent with gypsum crystallization in a stress field similar to near-surface conditions [14], but the lack of displacive textures precludes an authigenic interpretation. The Sutton Island and Blunts Point members of the Murray formation show sub-horizontal calcium sulfate enrichments that are variably mixed with the bedrock composition. These are also not interpreted as syn-depositional because the sulfate enrichments are discordant to primary laminations.

Diagenesis: Diagenesis includes all processes that affect the rocks between deposition and modern exposure and weathering—this includes cementation, lithification, fracturing, mineral alteration, and groundwater precipitation. All of the exposed facies in the Murray formation are lithified and show evidence for post-depositional fluid interactions; concretions of different shapes, sizes, and chemistries are frequently observed, as are late (post-lithification) typically sub-vertical calcium sulfate-filled fractures [15]. Some portions of the Murray, as mentioned, show sub-horizontal calcium sulfate enrichments that include admixtures of sulfate and bedrock, indicating that they may have formed earlier relative to lithification.

Diagenetic mineral alteration and cation mobility continued for extended time after deposition; the Mojave drill hole, for example, contains jarosite radiometrically dated to ~2.1 Ga [16]. Diagenetic iron mobility likely had a significant effect in the formation of the prominent Vera Rubin Ridge topographic feature [17]. Small localized concentrations of elements including Fe, Mn, P, and K, among others, sometimes associated with color changes, are likely related to diagenetic element mobility because they do not follow primary bedding [15].

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