OF ELEMENTS, MINERALS AND ROCKS: MT. SHARP AS A KEY REFERENCE SECTION IN ASSESSING THE CLIMATIC EVOLUTION OF MARS. R.E. Milliken[1], J.A. Hurowitz[2], J.P. Grotzinger[3], R.C. Wiens[4], R. Gellert[5], A. Vasavada[6] [1]Brown University, Providence, RI 02912, ralph_milliken@brown.edu, [2]SUNY Stonybrook, NY, [3]Caltech, Pasadena, CA, [4]Los Alamos Natl. Lab, Los Alamos, NM, [5]Univ. of Guelph, Guelph, ON, [6]JPL/Caltech, Pasadena, CA.

Introduction: The large-scale climatic evolution of Mars has been posited to be recorded in the rock record by the apparent transition from clay, to sulfate, to oxide dominated mineral assemblages at a global scale [1]. This hypothesis can be fully tested only by detailed reconstruction of a variety of geologic sections that include rocks similar in formation/depositional age as well as those that span a range in age in order to allow global-scale stratigraphic correlations. However, the Curiosity rover's exploration of Gale crater is a major advance in this quest given that orbital data of strata within Mt. Sharp suggest it may represent a microcosm of these mineral transitions and record the 'drying out' of Mars [2]. Here we discuss elemental, mineralogical, and textural attributes of rocks measured *in situ* along Curiosity's traverse that can be integrated with and used to refine orbital predictions over larger spatial scales, allowing for an improved understanding of how and where Gale fits into the geologic evolution of Mars.

Geologic Overview: Previous and ongoing observations by Curiosity indicate that lower strata of the Mt. Sharp group are dominated by lacustrine mudstones that interfinger to the north with coarser-grained fluvial and alluvial deposits of the Bradbury group, including sandstones and conglomerates [3,4]. Though not apparent from orbital data, mudstones rich in clay minerals were first encountered in the Yellowknife Bay (YKB) region [3,5], which represent the oldest and most deeply buried rocks that Curiosity will encounter [4]. Younger mudstones were encountered ~60m upsection in the Pahrump Hills region and continue to be encountered ~140m above that. Known as the Murray fm., these rocks exhibit orbital spectral signatures of hematite and unspecified hydrated phases [2,6]. These observations indicate ~200m or more of lower Mt. Sharp may be composed of muds deposited in an ancient martian lake, thus the chemistry and mineralogy of these rocks provide a means to assess aqueous chemistry, sediment-water interaction, and lake-atmosphere interactions during the Noahcian-Hesperian transition.

The Murray fm. is unconformaby overlain by eolian sandstones of unknown age (though likely Hesperian) of the Stimson fm. [7], consistent with transition to a drier environment. All units exhibit at least some evidence for post-depositional fracturing and/or diagenesis, and the morphological and chemical attributes of the latter are highly variable [3,8]. Within the mudstones as a group, variations in bulk chemistry and mineralogy may thus reflect variations in sediment provenance, lake chemistry (chemical precipitates), or the composition of diagenetic/pore fluids, and such data are best evaluated alongside textural information and geologic context.

Elemental Chenistry: Bulk chemisty (Si, Al, Fe, Mg, Ca, Na, K) of mudstones over a ~140m interval of the Murray fm. is largely homogeneous based on ChemCam and APXS elemental data (Fig. 1; diagenetic features excluded), with several important exceptions. A significant increase in Si and decrease in other elements was observed in the Marias Pass/Bridger Basin region, and similar Si enrichments were observed in nearby sandstones of the Stimson fm.

Excluding these Si-enriched zones, the lowest Fe and highest Al values were observed at the base of the section in the Pahrump Hills. In contrast, several recent analyses of mudstones beyond the Murray Buttes have yielded the highest Fe and lowest Si abundances (with no significant change in Al). Some analyses in this stratigraphically higher region also exhibit elevated Ca contents. Mg is variable throughout the section, but trends are difficult to establish due to differences in sampling density as a function of elevation.

The lowest ~20m of the Murray fm. (PH region) exhibits the largest variation in Mn, Ni, and Zn (Fig. 2), possibly indicating changes in oxidation state of lake waters [9], but values are less variable within the ~80m of section above the Si-enriched zones. Ni abundances are commonly above average crustal values for Mars, simiar to trends observed in rocks at Gusev by the Spirit rover that have been interpreted to represent recycling of oxidized crustal materials into the upper mantle [10]. Though not a unique interpretation, the high Ni values for rocks in Gale my similarly reflect igneous processes associated with sediment source regions instead of modifications by post-depositional processes.

In contrast to major elements, S, Cl, and Br are variable throughout the Murray fm. and particularly so for mudstones within and above the Murray Buttes region, where Ca is also more variable and B is present in some vein materials [11]. Increases in both Na and Cl are also observed for some ChemCam bedrock points, suggesting that the relative abundance of salts may increase upsection compared to what was observed in the Pahrump Hills and at YKB.

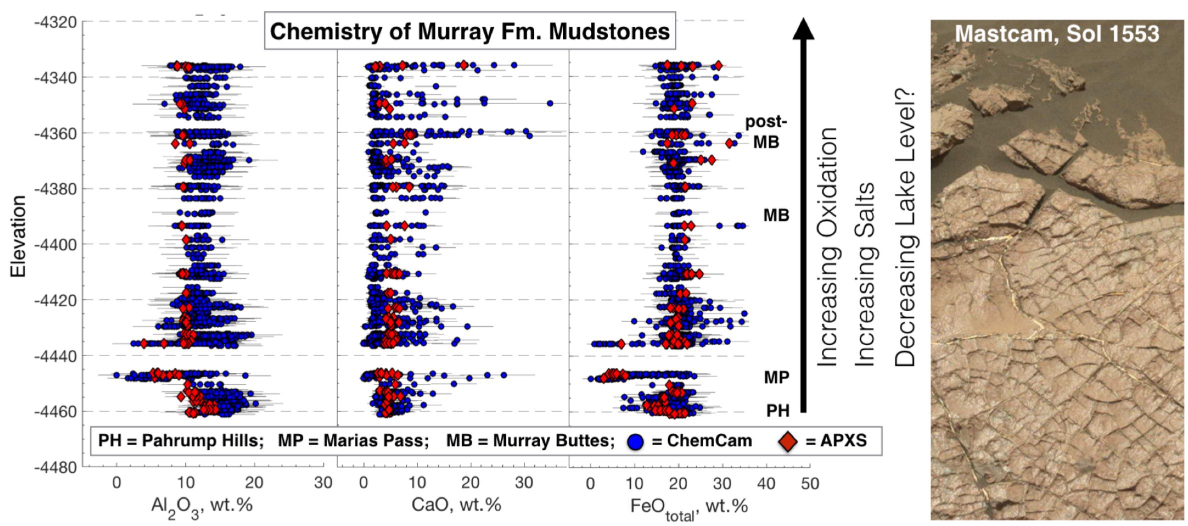

Fig. 1. Largest chemical variability is observed for mudstones near PH (high Al, low Fe) and above MB (increased Ca, Cl, S, Br), where the latter also show evidence for possible thin beds of Ca-sulfate and perhaps dessication cracks (see image).

Mineralogy: Mineralogy of Gale mudstones as determined from CheMin XRD data is quite variable given the overall limited chemcial variability discussed above. Those in the lower ~40m of the Murray fm. are particularly heterogeneous, including variable amounts of clay minerals, silica (including tridymite), hematite, magnetite, sulfate, and primary igneous phases [12,13]. In contrast, numerous drill samples in the overlying ~100 m are more homogeneous and are dominated by plagioclase, hematite, Ca-sulfates, and clay minerals [14]. All Murray fm. mudstones are distinct from the YKB mudstones, where crystalline phases in the latter were dominated by primary igneous phases, Fe-bearing clays, and magnetite, where the latter two may be authigenic [5].

Discussion: Gale mudstones may be broadly grouped into hematite-clay and silica-magnetite facies, a distinction that may reflect changes in the oxidation state of lake waters [9]. Those in the upper Murray fm. are generally consistent with more oxidizing conditions than those observed at YKB, and mudstones in between (e.g., Pahrump Hills, Marias Pass) may indicate fluctuations in oxidation state of lake waters. Paleo lake level is difficult to constrain, but these shifts in mineral assemblages may reflect changes in water depth and/or distance to shoreline in a redox stratified lake, which would also control the mineralogy of chemical precipitates [9]. Alternatively, the (lower) mudstones indicative of more reducing conditions may reflect deeper *in situ* alteration of lake sediments by pore waters not in contact with atmospheric oxidants or UV radiation in what was otherwise an oxidizing lake environment.

Elemental data indicate an upsection increase in salts within the mudstones, consistent with CheMin observations of increased Ca-sulfate. Though discrete evaporite beds have not yet been observed, the sulfate-rich upper mudstones may indicate dirty evaporites formed as water level was dropping. If correct, Curiosity's trek from YKB through Murray fm. mudstones may have traversed the drying out of lake Gale, reflected by an increase in oxidized minerals. Intriguingly, the Murray fm. mudstones also exhibit higher Chemical Index of Alteration (CIA) values compared with YKB, possibly due to enhanced weathering or mobility of cations during diagenesis.

There are no indicators that lake pH deviated significantly from circum-neutral conditions, but changes in mineral assemblages are clearly reflective of changes in redox conditions within Gale. In this context, mineral transitions observed in Gale may provide a window into the connectivity and oxidation capacity of groundwater, surface water, and the atmosphere through geologic time rather than pH conditions. Strata above the Murray fm. are predicted to be enriched in sulfate and poorer in clay minerals, in contrast to the underlying clay-bearing mudstones of YKB. If confirmed, then the Murray fm. may represent a critical stratigraphic section that records the transition from a wet, reducing(?), Si-dominated system to a drier, oxidizing, S-dominated environment.

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