UPDATED ORBITAL PERSPECTIVE OF THE MT. SHARP UPPER SULFATE BEARING STRATA IN PREPARATION FOR IN SITU EXPLORATION. Rachel Y. Sheppard[1*], William Rapin[2], Valerie Tu[3], Lucy Lim[4], Travis S. J. Gabriel[5], Madison Hughes[6], Abigail Fraeman[7], David Vaniman[1]. [1]Planetary Science Institute, [2]IRAP/UPS/CNRS, [3]NASA Johnson Space Center, [4]NASA Goddard Space Flight Center, [5]USGS, [6]Washington University in St. Louis, [7]Jet Propulsion Laboratory/Caltech *rsheppard@psi.edu

Introduction: Mg sulfates (MGS) are some of the most common secondary minerals on Mars [1], with orbital detections spread across the planet [2-3] and multiple occurrences at different elevations within Gale crater [4-6]. The mineralogy of MGS (including their crystallinity and hydration state) and their geologic setting can be used to understand aqueous conditions during formation and diagenesis. The high solubility of sulfates, particularly Mg-sulfates, means that, wherever they are present, those strata were likely exposed to minimal water after their formation. For example, monohydrated MGS (i.e., kieserite) cannot have been exposed to liquid water or protracted frost. Such a process would have hydrated the monohydrated MGS to form polyhydrated MGS in an irreversible way, i.e., subsequent dehydration forms amorphous or less-hydrated crystalline polyhydrated MGS, not the original monohydrated form.

Both monohydrated Mg-sulfate and polyhydrated Mg-sulfate have been observed in Gale crater from orbit [4-6]. Adding or removing structural waters from MGS causes bond restructuring that is reflected in visible-near infrared (VNIR) spectra, especially the shape, depth, and width of vibrational absorptions ~1.4 - 1.7 and 1.9 - 2.2 µm [2-10] (Fig. 1). Lab work has shown that monohydrated MGS may be stable under current martian surface conditions, while polyhydrated MGS is likely to dehydrate to an X-ray amorphous form [7-10]. Polyhydrated MGS is more widespread, both laterally and stratigraphically, and has a lighter toned coloration. Monohydrated MGS in Gale is darker-toned and almost entirely restricted to a small stratigraphic region that is visible around Mt. Sharp. The monohydrated MGS strata are obscured by erosion and talus in many areas, especially near the traverse route, but overall appear to be throughgoing in the sedimentary mound of Mt. Sharp. The MSL mission is within the area where MGS-rich strata are identified from orbit, presenting an opportunity to examine these common martian minerals *in situ*.

Methods: We conduct high-resolution orbital mapping of MGS using processed CRISM and HiRISE data, creating a geologic map of the variation in MGS hydration state in the upper strata around Mt. Sharp. We focus on a restricted stratigraphic range to develop a map that is at a higher resolution than [6] to aid in guiding upcoming and longer-term rover operations.

We map hydrous phases in a stratigraphic range relevant to upcoming *in situ* exploration by the Curiosity rover. To do so, we look at changes in VNIR spectral absorptions related to H_2O. In places where clay minerals are present, which is much of lower Mt. Sharp in Gale crater, the spectral features of the clay minerals can effectively mask the presence of small amounts of amorphous Mg sulfate [6-7]. We also map both orbital occurrences of clay minerals in these upper strata in addition to mapping MGS. Our geologic map of the variation in MGS hydration state in the upper strata around Mt. Sharp is generated based on associated spectral, textural, and albedo observations.

Results: We map MGS-rich outcrops using novel orbital data analysis techniques and we use results of these analyses to target further *in situ* observations with Curiosity. Our focus on a restricted stratigraphic range allows us to examine <100 m scale features, such as thin individual strata that may be putative monohydrated MGS layers.

Along the planned rover path, Extended Mission 4 (EM4), distinct spectral classes include monohydrated MGS, polyhydrated MGS, clay minerals, and mafic sands. Outcrops of alternating light-dark layers with changes in the 1.9 um absorptions consistent with changing MGS hydration state are found in multiple areas around Mt. Sharp. In the southeast where the topographical slopes are lower and thin strata take up more pixel space, there are areas with intercalated dark monohydrated MGS and light polyhydrated MGS (Fig. 2a-b). Mt. Sharp's slope is steeper along EM4 but there are a few dark bands that have spectra that may be consistent with monohydrated MGS (Fig. 2c-d, Fig. 3). These dark layers along EM4 are spectrally distinct from areas that have accumulated mafic-rich sand, e.g., where

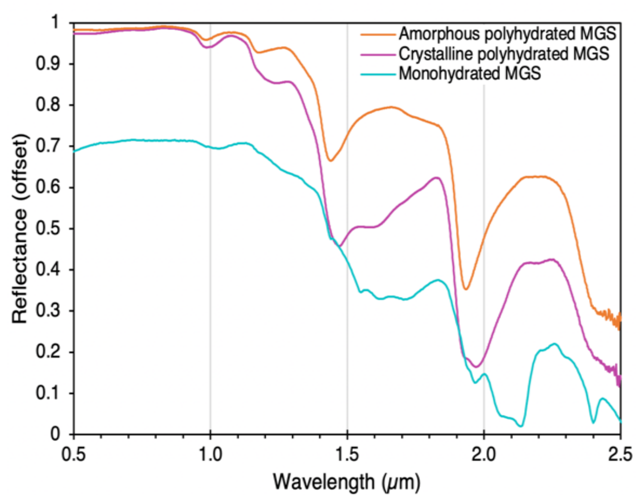

Fig. 1. *Laboratory spectra of monohydrated (teal), crystalline polyhydrated (pink), and amorphous polyhydrated (orange) MGS.*

sand ripples are visible, or along a dark marker bed that will be analyzed soon.

Discussion & conclusions: A whole-crater comparison of closely co-located layers where MGS hydration state appears to change in orbital VNIR data allows us to develop formation hypotheses which can be tested with high-resolution *in situ* textural observations by the rover. Sulfates formed in an evaporative lacustrine setting would likely have formed in surface or near-surface pore space water which could vary within the crater and reflect a changing lake environment; post-lacustrine sulfate emplacement by groundwater flow would be largely driven by porosity and permeability and reflect strata with different exposure histories to diagenetic fluids and/or erosion and subsequent exposure to the atmosphere. Finally, the nature of the alternating tonal and spectral changes (Figs. 2-3) could be related to preferential dehydration, erosion, or mass wasting processes (Fig. 4). Direct in situ observations throughout the coming months-years will allow for testing of these hypotheses.

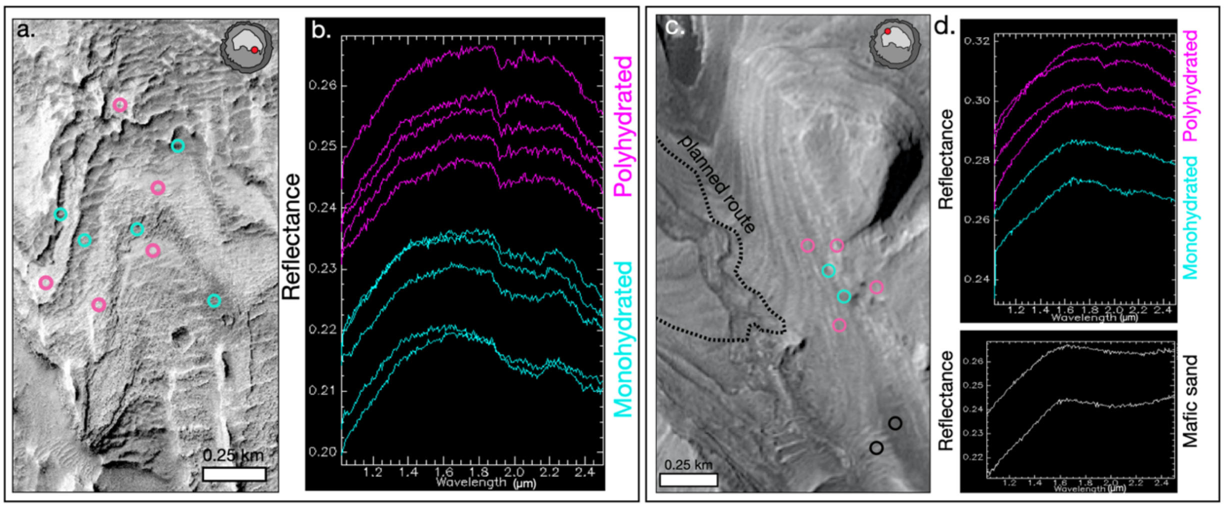

Fig. 2. (a-b) Intercalated monohydrated (dark-toned) and polyhydrated (light-toned) MGS bands in southeastern Mt. Sharp [6]. Dark bands are monohydrated MGS (teal circles/spectra); light bands are polyhydrated MGS (pink circles/spectra). (c-d) Light-dark layering along the planned rover traverse route. Steeper topography results in spectra less resolved, as the strata take up fewer pixels, but they have spectral evidence consistent with monohydrated (teal circles/spectra) and polyhydrated (pink circles/spectra) MGS. Spectra of mafic sands (black) are also shown in (d.) as well, to demonstrate that the dark strata have spectra distinct from sand.

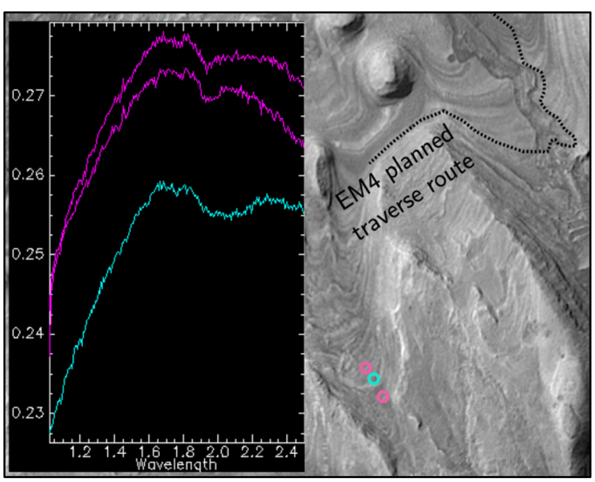

Fig. 3. Upper Mt. Sharp near the planned EM4 rover traverse route (black line). Another example of small-scale changes in the 1.9-2.1 um absorption shape that may be linked to changing MGS hydration state (teal is possible monohydrated, pink polyhydrated MGS).

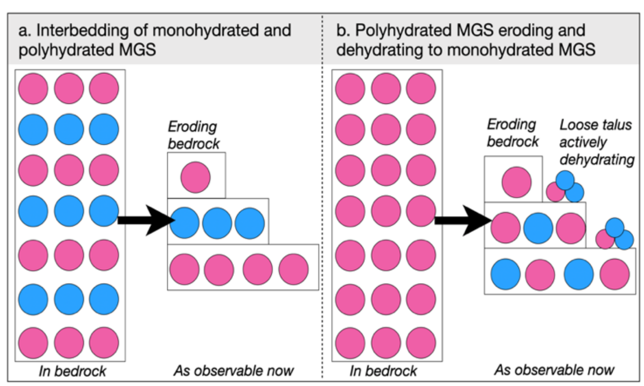

Fig. 4: *Formation hypotheses for coexisting monohydrated (teal) and polyhydrated (pink) MGS strata. (a) Interbedded monohydrated + polyhydrated MGS. (b) Polyhydrated MGS is eroding and dehydrating, with monohydrated MGS talus accumulating on low slopes. Note that dehyrdration to monohydrated MGS in modern Mars conditions is not generally supported by laboratory experiments [11].*

References: [1] Bibring et al., 2006 [2] Roach et al., 2009 [3] Murchie et al., 2009 [4] Milliken et al., 2010 [5] Fraeman et al., 2016 [6] Sheppard et al., 2020 [7] Sheppard et al., 2022 [8] Vaniman et al., 2004 [9] Vaniman and Chipera 2006 [10] Chipera and Vaniman 2007 [11] Wang *et al.,* 2009.