ROVER OBSERVATIONS AND ORBITAL PREDICTIONS OF AN ANCIENT LACUSTRINE SEQUENCE ON MARS.

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Introduction: The large-scale climatic evolution of Mars may be recorded in its rock record as a mineralogical transition from clay, to sulfate, to oxide dominated assemblages [1]. The Curiosity rover's ascent and detailed observations of Mt. Sharp within Gale crater provide a means to examine this hypothesis *in situ*, in part because orbital data indicate the mountain may contain a microcosm of these mineral transitions [2]. Prior to Curiosity's arrival, the mineralogical and morphological variability of the strata in Mt. Sharp led to the belief that Gale crater may have hosted numerous depositional settings and forms of water-rock interaction. Rover data collected over the past 7+ years have revealed a complicated picture for lower Mt. Sharp, but these data provide important insight into an ancient lake system on Mars and how we may (or may not) be able to recognize and characterize such systems using orbital data.

In this study we integrate rover-based chemical, mineralogical and textural attributes of bedrock within Mt. Sharp and compare these results with pre- and post-landing predictions made from orbital data. Which interpretations were verified, which were proven to be incorrect? Which minerals do we not see in orbital data of Gale and why? What implications does this have for planning the Mars 2020 rover exploration of the Jezero delta?

Datasets: This analysis focuses on the chemistry and mineralogy of a >300 m section of ancient lacustrine mudstones collectively named the Murray fm. [3-4]. Elemental abundances for Si, Al, Mg, Fe, Ca, Na, and K from the ChemCam (CCAM) and APXS instrument teams were evaluated for all bedrock targets from Sols 755-2372. Veins, concretions, and other measurements that are clearly associated with diagenetic features are identified and evaluated separately, allowing us to assess how bedrock chemistry varies laterally and vertically. Mineralogical information for drilled bedrock targets is provided by the CheMin (XRD) instrument team [5-6]. Visible-near infrared spectral reflectance data from the MRO CRISM instrument are used to assess mineralogy from orbit [2,7].

Pre-Landing Predictions: Theories for the origin(s) of Mt. Sharp were diverse prior to landing, including eolian, lacustrine, volcanic, spring mound etc. [e.g., 8], but differentiating between these required a landed mission. Different mineral assemblages (e.g., clay, sulfate, hematite, anhydrous) were also observed from orbit, but the depositional conditions and detrital vs. authigenic origin of these phases were not constrained [2]. Curiosity is currently exploring the clay-bearing unit in the Glen Torridon region, which orbital data indicated was enriched in Fe-smectite (nontronite), possibly occurring as fine-grained sediment (mudstone) or as a cement in sandstones. The overlying sulfate-bearing unit that will be encountered in the future has been interpreted to be sulfate-cemented basaltic sandstones in some locations [9].

The bulk of the Murray fm. explored by Curiosity is to the north of and stratigraphically beneath the clay-bearing unit and a topographic ridge (the Vera Rubin Ridge, VRR) that exhibits enhanced hematite signatures from orbit [10]. However, the hematite signatures are not restricted to the ridge and are also seen from orbit in lower portions of the Murray fm. in conjunction with spectral evidence of hydrous phases of unknown type [2].

Post-Landing Perspectives: The bulk of the Murray fm. is now recognized to be of lacustrine origin and is dominated by fine-grained materials (e.g., mudstones) [11]. Though not identified from orbit, mudstones of the lower portions of the Murray fm. (below the VRR) contain a range in clay minerals [6] that are likely the origin of the weak H_2O/OH features seen from orbit. This suggests that clay minerals may be hard to uniquely identify from orbit in certain circumstances, thus our understanding of the true distribution of clay minerals in martian sedimentary systems is likely quite limited.

Significant amounts of Ca-sulfate are also observed in the Murray fm, and though some is in the form of anhydrite (not detectable at CRISM wavelengths), much is also in the form of gypsum/bassanite. This sulfate is often associated with mineralized veins that are too small to be resolved in orbital CRISM data. However, some stratigraphic sections exhibit enhanced Ca-sulfate that likely occurs as a cement, and other regions exhibit enhanced Mg abundances that likely corresponds to Mg-sulfate (Fig. 1; [12]). Interestingly, there is no clear indication of Ca-sulfate anywhere in Mt. Sharp when viewed from orbit, and it is possible (and likely) that Ca-sulfate is present in Jezero crater as well given its low solubility.

CRISM data indicate the presence of hematite in parts of the Murray fm. and the VRR in particular. Though one sample in the VRR exhibits a notable increase in hematite, the ridge as a whole is not uniquely enriched compared with the immediately underlying sections of the Murray fm [13]. In support of orbital predictions, recent CheMin XRD analyses have confirmed the clay-bearing unit seen from orbit is enriched in Fe-bearing clays compared with other portions of the Murray fm. [14].

Discussion: Some of the minerals detected in Gale prior to landing have been verified by rover data, but Curiosity has also shown that hydrous minerals are present in many regions that appear spectrally 'bland' in orbital data. A combination of dust/regolith cover and particle size effects (e.g., particulates vs. intact bedrock) may best explain these discrepancies, but it also highlights that. relative differences in CRISM absorption strength must be interpreted cautiously, particularly when used for strategic planning of a rover traverse path.

Overall variations in the absolute values of major elements are relatively subtle in Murray fm. bedrock targets (Fig. 1), even though CheMin data indicate a range in mineral assemblages. Some of the largest stratigraphic variations in chemistry and/or mineralogy include an interval enriched in Si, variations in hematite abundance, elevated Mg, etc., but these all appear to be primarily or at least partly associated with early or late diagenetic processes. In light of this, it is possible variations in mineral assemblages observed form orbit in Mt. Sharp may reflect spatial and temporal differences in diagenetic processes/fluids rather than inherent changes in sediment source regions or surface weathering associated with climatic evolution and near-surface water availability.

The Murray fm. does exhibit some evidence for enhanced chemical weathering compared with older mudstones in the Yellowknife Bay fm. [15], but it has also been affected by diagenetic processes, including potential clay authigenesis [6]. Indeed, the mud-sized sediment entering the lake may have been largely unaltered, consistent with minimal chemical weathering in the source region and moderate transport distances. The apparent enhanced weathering signature in CCAM and APXS data may instead reflect a combination of early and late diagenetic processes in which fluids interacted with the sediment in an open system, thus allowing for elemental mobility [e.g., 6,15].

To date only one clear example of subaerial exposure of a mudstone has been documented (mudcracks of [16]), and though the presence of a thick sequence of mudstones does not require very deep lake level, there is currently no diagnostic indication within the Murray fm., either textural or chemical, for sustained periods of subaerial exposure or long-lived evaporative conditions induced by very shallow lake level. The upcoming exploration of the overlying "sulfate unit" will thus provide a critical step forward in assessing if the mineralogical transitions observed from orbit do indeed represent the drying out of the Gale crater lake and implications for other martian paleolakes.

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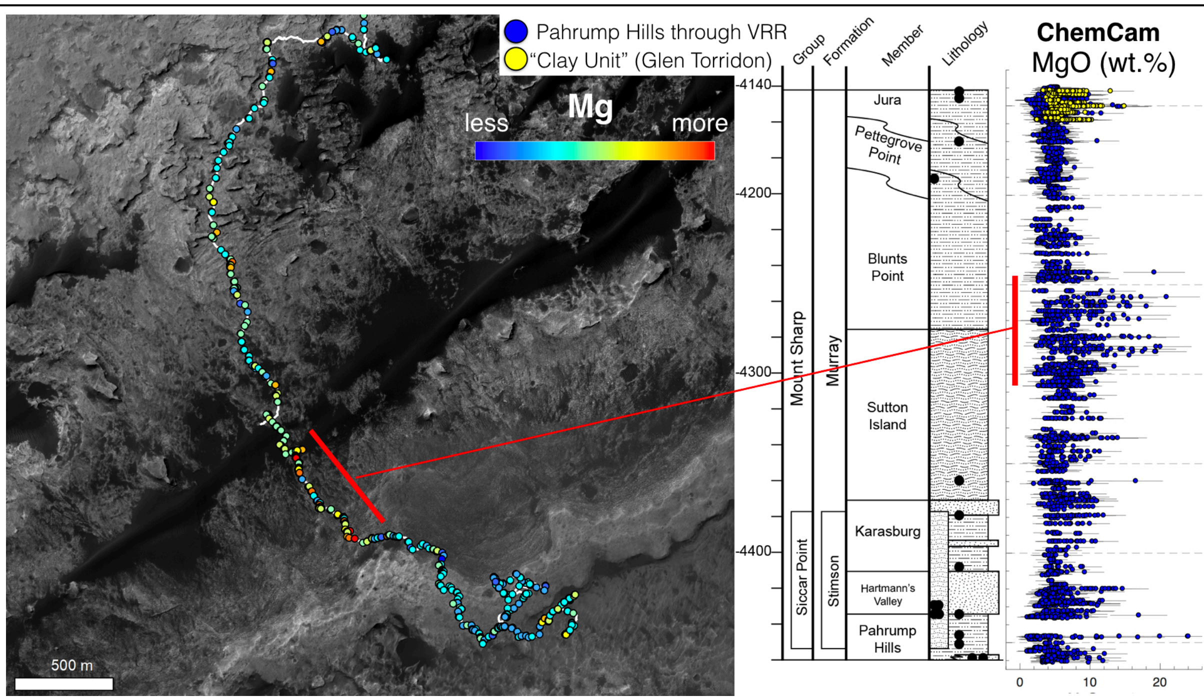

Fig. 1. Major elements do not vary much within the Murray fm. mudstones, though a section below the "hematite" Vera Rubin Ridge (VRR) exhibits enhanced Mg associated with sulfate (not in fractures/veins) [12]. An additional increase in Mg is observed in some portions of the "clay unit" in the Glen Torridon region that may be associated with Mg-bearing clays or indicate the presence of minor amounts of Mg sulfate, perhaps as an X-ray amorphous form.