The Murray formation, Gale crater, Mars: APXS compositional analysis reveals element gains and losses and multiple diagenetic events. L. M. Thompson[1] (lthompso@unb.ca), J. A. Berger[2], N. I. Boyd[3], R. Gellert[3], M. A. McCraig[3], C. O'Connell-Cooper[1], M. E. Schmidt[4], J. G. Spray[1], S. J. VanBommel[5] and A. S. Yen[6] [1]Planetary and Space Science Centre, University of New Brunswick, Canada, [2]NASA Johnson Space Center, USA, [3]University of Guelph, Canada, [4]Brock University, Canada, [5]Washington University, USA, [6]Jet Propulsion Laboratory, California Institute of Technology, USA

Introduction: *Curiosity* has been exploring Gale crater, Mars for 7.5 years, having traversed >22 km and climbed >400 m of elevation (Fig. 1). The Alpha Particle X-ray spectrometer (APXS) has acquired >850 analyses on solid rock, powdered drill samples, soil, sand and regolith targets, recording a diversity of compositions.

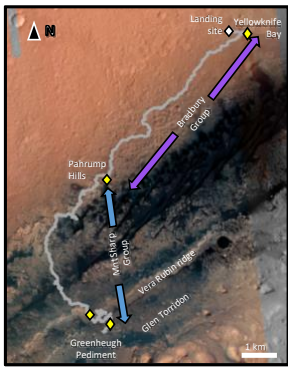

Figure 1. HiRISE map with Curiosity's traverse, points/areas of interest and the division of the Bradbury and Mnt Sharp grps (credit:NASA/JPL-Caltech/ASU/UA).

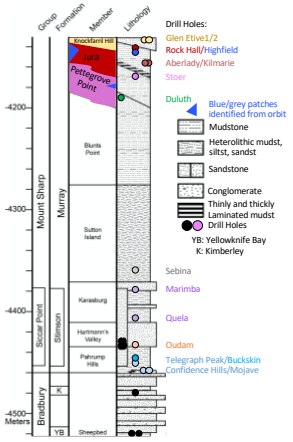

Figure 2. Stratigraphic column for Gale crater (credit: MSL Sedimentology and Stratigraphy Working Group).

The Murray fm is the lower-most sedimentary unit of the Mount Sharp grp, first encountered at Pahrump Hills (Fig. 1 & 2), and is interpreted to represent a primarily lacustrine and lacustrine margin depositional environment [1,2,3,4]. The APXS has measured the chemistry of >500 targets as *Curiosity* has climbed in elevation (>360 m) through the Murray fm. This work describes the results of that compositional analysis.

Composition of the Murray formation: The chemistry of the Murray fm is relatively uniform, in contrast to the Bradbury grp (Fig. 3). Murray fm rocks are generally depleted in Ca, Mg, Mn, K and Na, and enriched in Si, Al, Ge, with higher FeO/MnO than Bradbury grp strata [5,6]. Specifically, the Murray fm mudstones have a distinct composition from the Bradbury grp, basaltic Yellowknife Bay fm mudstones, trending to higher Si and Al, and to lower Mg and Ca concentrations (Fig. 3). The Murray fm is also characterized by higher K and Si concentrations than the basaltic composition Stimson fm sandstones [6] (Fig. 3), as well as low Mn, and high FeO/MnO (~100) relative

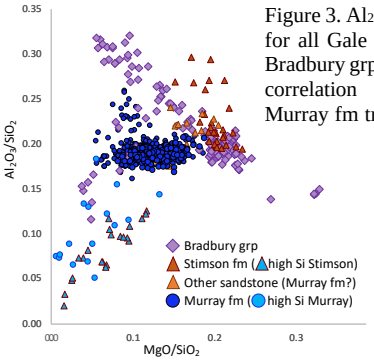

Figure 3. Al_2O_3/SiO_2 versus MgO/SiO_2 for all Gale bedrock. The majority of Bradbury grp targets plot on a negative correlation trend line, while the Murray fm trends to <Mg and >Si and to average basaltic martian soil/sand (~50) [7], and other Gale bedrock.

Despite the relative homogeneity of the Murray fm, variations in composition with elevation are observed. In general, Si, Al and Ti concentrations decrease, and Fe content increases with elevation to the base of the Blunts Point mbr, above which, trends reverse. Up to the base of Vera Rubin ridge (VRR), Si, Al and Ti positively correlate with one another and negatively correlate with Fe. On the ridge, particularly within distinct blue/grey bedrock patches, the Ti is negatively correlated with Al and Si for a number of targets, indicating addition of Al and Si.

Tau calculations (relative to average Murray bedrock, with Ti as the immobile element) highlight concentrations and depletions in specific elements associated with certain stratigraphic horizons (Fig. 4).

Pahrump Hills, the lowermost member of the Murray fm, generally shows gains in Mn, Al, Si, P and Zn and losses in Fe, Na, Mg and K. In particular, Al falls off the Si-Al trend exhibited by the rest of Murray. High Si (up to 74 wt% SiO_2) Pahrump Hills mbr, does not show Si gains, but instead losses in the majority of elements analyzed by APXS except P, indicating passive enrichment of Si.

The Karasberg through Sutton Island mbrs mostly reveal minor gains in Fe, and losses in Mn and Zn compared to average Murray fm. However, at the Sutton Island/Blunt's Point mbr contact, significant gains in Mn, Zn, P, Mg and Fe, and losses in K with minor losses in Si and Al are observed. The same trends in gains and losses continue through to the top of the Blunts Point mbr. The Blunts Point mbr is the most enriched in Fe of all the Murray fm encountered to date.

Significant losses in Mn and Mg mark the transition on to VRR, and the Pettegrove Point mbr. Above the base of VRR, Pettegrove Point bedrock shows mostly gains in Mn and K and variable Mg. All Pettegrove

Point mbr targets reveal minor gains in Fe and losses in Zn.

The overlying Jura mbr of VRR shows minor Si and Al gains, gains in K and Na, losses in Zn and P, and variable Mn and Fe. Distinctive grey/blue bedrock patches within VRR Jura, with contacts discordant to bedding, reveal significant Si and Al gains compared to average Murray. Si gains are the most pronounced of all Murray bedrock, and Al gains are similar to those observed within the Pahrump Hills mbr. K, Na, Mg and Ni gains are also evident, with consistent losses in Mn, some Zn losses and variable Fe.

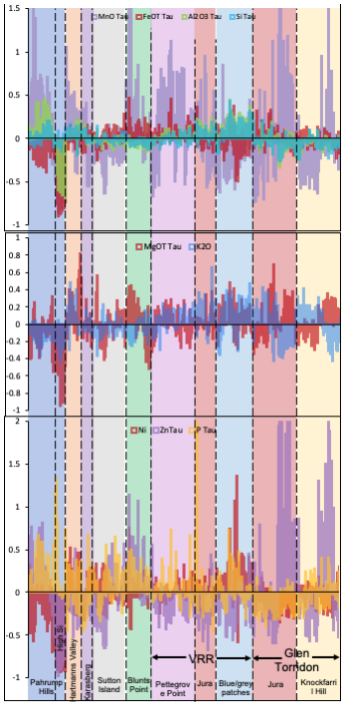

Figure 4. Tau histograms showing gains and losses for SiO_2, Al_2O_3, FeO, MnO, MgO, K_2O, Ni, Zn and P_2O_5 for the Murray fm members relative to average Murray bedrock (not including targets with obvious veins or diagenetic/alteration features and coarser sandstones). Note: width of each member/subdivision is not proportional to the thickness of the unit, but instead represents the

Bedrock encountered within the Glen Torridon, clay-bearing unit, reveals two distinct patterns in gains and losses: 1) rubbly bedrock with K gains and Mg losses, and 2) more coherent bedrock with K losses and Mg gains. The higher Mg bedrock typically also has Mn and Zn gains, with the highest relative gains in Zn of all Murray bedrock. The

exceptions are high Mg targets encountered immediately beneath the Greenheugh pediment, which do not exhibit associated Zn and Mn gains. In contrast, higher K bedrock shows losses in Zn and Mn.

Interpretation: Compositional differences between the Murray fm and other units within Gale crater are interpreted to be the result of distinct provenances. Specifically, the contrasting composition of the Sheepbed mbr, Yellowknife Bay fm mudstones, and the Murray fm probably reflect differences in provenance for the two mudstones; either 1) Differences in igneous protolith source rocks [8], or 2) Varying degrees of alteration of similar basaltic protoliths at source. The higher degree of alteration indicated for the Murray formation could also be in situ; either within the lacustrine setting [9], or post depositional [10].

The relatively uniform composition of the Murray fm over a significant elevation range (compared to the Bradbury grp) suggests a similar provenance for most of the sediment, and that significant open system alteration has not taken place..

Variations in composition (and mineralogy) with elevation within the Murray fm as a whole could be reflecting slight changes in the source sediment input. However, compositional trends observed within the bedrock are also reflected in the chemistry of diagenetic features at the same stratigraphic level (e.g., the Sutton Island/Blunts Point contact). Thus, an alternative explanation is that compositional variation is primarily the result of changes in post-depositional processes. The distinct chemistry of diagenetic features at different stratigraphic levels, and patterns in elemental gains and losses are therefore reflecting changing fluid chemistry and multiple diagenetic/alteration events throughout the Murray fm.

Diagenetic/alteration events appear to be concentrated at certain stratigraphic horizons within the Murray fm and include (no implied chronology): (1) leaching and passive enrichment of SiO_2 within the Pahrump Hills mbr, adjacent to the contact with the overlying Stimson fm, and possible mobilization and deposition of Al (and Mn) lower down the section (2) addition of Mn, Fe, Mg, P and Zn in the vicinity of the Sutton Island/Blunts Point mbr contact and within Blunts Point; also manifest as resistant nodular, patches and veins at this stratigraphic level (3) addition of Si and Al to VRR Jura mbr and specifically blue/grey patches (4) addition of K to, and removal of Mg from, Glen Torridon Jura and Knockfarril Hill (5) addition of Mg, Zn and Mn to, and removal of K from, Glen Torridon Jura and Knockfarril Hill.

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