COMPOSITIONAL TRENDS WITHIN THE MURRAY FORMATION, FROM THE BASE OF THE PAHRUMP HILLS TO THE END OF THE VRR CAMPAIGN, AS DETERMINED BY APXS.

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Introduction: Since landing in August 2012, the *Curiosity* (MSL) rover has traversed ~20 km within Gale Crater, across the crater floor and up onto the slopes of Mount Sharp (Aeolis Mons), to facilitate the investigation of a sequence of layered sedimentary rocks (Murray formation, Mount Sharp Group). The Canadian built Alpha Particle X-ray Spectrometer (APXS), which combines PIXE and XRF techniques [***1***], to determine whole-rock geochemical compositions, has been instrumental in defining geochemical trends, and helping to refine mineralogical compositions of drilled samples, via CheMin [***2***]. This work relates APXS geochemical analyses to the stratigraphic column, proposed by the Curiosity-MSL Sedimentary-Stratigraphy Working Group.

Stratigraphic context: Heterolithic fluvio-deltaic deposits (mudstones to conglomerates) of the Bradbury group, were encountered from the landing site to the base of Mount Sharp [***3***]. Since reaching the base of Mount Sharp, *Curiosity* has been investigating fluvio-lacustrine mudstones to sandstones of the Murray fm [***3-6***], and the eolian sandstones of the Stimson fm (the unconformable Siccar Point gp) [***7***].

Murray fm: The >315 m thick Murray fm has been divided into seven distinct members [***4, 8***] (Table 1), across a lateral distance of ~10 km, from Pahrump Hills and onto the Vera Rubin Ridge (VRR). Strata within the Murray fm are divided by elevation, as layers are approximately flat-lying; morphologic boundaries on the VRR do not follow elevation [e.g., ***10***]. Lithofacies changes with elevation suggest changing depositional environments [***3-6***]; fine-grained VRR bedrock provides additional evidence for a long-lived, low-energy lacustrine environment [***4***].

Discussion: Three broad zones are identified, based on geochemical trends observed by APXS (Fig. 1; Table 1).

(1) *Lowermost Murray:* (Pahrump Hills [*PH*]; Hartmann's Valley [*HV*]): mbrs exhibits broad ranges in concentrations. High Si, Ti, Al, Mn, Na, P, Cr, Zn in *PH*, decreasing with elevation in *HV*; low Fe, Mg, increasing with elevation in *HV*; variable K, Ni.

(2) *Pre-VRR (middle) Murray*: (Karabsurg [*KB*], Sutton Island [*SI*], Blunts Point [*BP*]): typically less varied, with concentrations similar to median Murray. P-, Mn- and/or Fe-rich diagenetic features are present, primarily in *SI*, to a lesser degree in *BP*. Abundant $CaSO_4$ veins found in *BP*, to a lesser degree in *SI*.

(3) *VRR Murray*: (Pettegrove Point [*PP*], Jura ["*Grey*" & "*Red*", based on tonal differences identified in HiRISE, confirmed by in situ analyses [***8-10***]]): Very variable, trends to high Si, Al, K, Mn, Na, low Ti, Fe, P, Cr, Zn. Both K and Mn are highly variable on the VRR, but Mn trends to low concentrations with increasing elevation, whilst K trends to high concentrations. Similarities to lowermost Murray mbrs (*PH* & *HV*) are identified. In particular, *Grey* Jura is similar to *PH* (high Si, Al, Na; low Fe, K), and *HV* (high Si, K; low Cr). The *PP* mbr is similar to median Murray, and pre-VRR mbrs, but marks the beginning of trends to increasing Si and Al, and decreasing Fe with elevation.

Conclusion: Si, Al, Na and K generally trend to decreasing concentrations with elevation below the VRR, then increase on the VRR; Ti, Fe, Mg, P, Zn broadly increase up to the VRR, decreasing on the VRR. Mn, Cl, Br, Zn, are highly variable for most mbrs, with broad ranges in values. All seven mbrs across the Murray fm (> 315 m) analyzed thus far by APXS are in family, but with broad geochemical variations, supporting the sedimentological interpretation of a long period of deposition, with fluctuating depositional environments [***4, 7***].

References: **1.** Gellert, R. et al. (2015) *Elements* (11). **2.** Rampe, E. et al. (2017) *EPSL*, 471. **3**. Grotzinger, J.P et al. (2015) *Science*, 350(6257). **4**. Edgar, L.A. et al., *LPS* XLIX, abs. #1704. **5**. Stack, K.M. et al. (2018), *Sedimentology*, in press. **6**. Fedo, C.M. et al. (2018) LPS XLIX, abs. #2078. **7**. Banham, S.G. et al. (2018) *Sedimentology*, 65(4). **8**. Fraeman, A.A. et al., 2013. **9**. Thompson, L.M. et al. (2019) this conference. **10.** Thompson, L.M. et al. (2018), LPS XLIV, abs. #2826. **11.** Siebach, K.L., (2019), this conference. **12**. Stein, N. et al. (2018) *Geology*, 46(6). **13**. Bristow, T.F. et al. (2018) *Sci. Adv.* 4(6).

Acknowledgements: The MSL APXS is managed and financed by the Canadian Space Agency. We appreciate and acknowledge the support of engineers at JPL during operations.

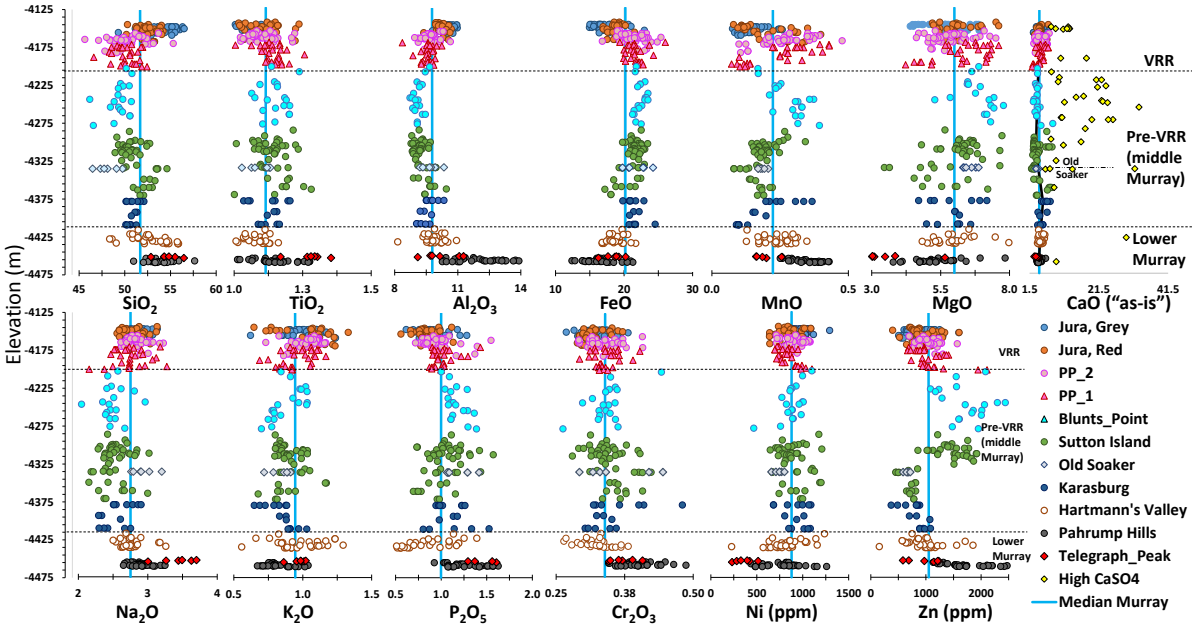

Figure 1. Elevation (m) (proxy for stratigraphic position) versus elemental concentrations for Murray samples, sols 720-2258, excl. obvious diagenetic features (e.g., $CaSO_4$ veins), high SiO_2 >60 wt. %). All data in wt. %, except Ni and Zn (ppm). All data adjusted to $CaSO_4$-free, except Ni, Zn, CaO ("as is" data). Pettegrove Point is divided into PP-1 (first traverse) and PP-2 (second).

Member	Depositional environment	Compositional Trend
Jura subdivided into "*Red*" and "*Grey*"	Lacustrine deposition. Variable: fine-grained, parallel, thinly laminated, to larger, inclined strata [***4***]	-High (> median Murray) Si, Al, K (*Grey* trends to highest values Si, Al) -Low (< median) Fe, P, Cr (*Grey* trends to lowest values) -*Grey*: low Mn; variable P, Mg, Ni (some high Ni values) -*Red*: lower Ni, Mg & Cr; variable Ti & Mn
Pettegrove Point	Fine-grained, thinly laminated, parallel stratified bedrock, consistent with lacustrine sedimentation. [***4***].	-Si, Al, K, Na, Ni increase up column; Fe, Mg, Ti, P, Zn decrease -Mn highly variable in PP, but general trend of increase up column -PP#2 variable Si, Ti, Al, Fe, P, Cr, Mg; PP#1 broader range in Na -Fewer veins than Blunts Point; some concretions/nodules
Blunts Point	Fine-grained, extensive thin planar laminations, possibly fallout from suspension in a lacustrine setting [***4***].	-Si, Al, K low (< median), increasing up column; Mn, Mg, decreasing; Zn high (> median), but with a sharp decrease up column; variable Si, Ti -Fe, Ti, Cr, P high (> median); Na low – little change with elevation -Abundant fine fractures and $CaSO_4$ veins, occasionally obscuring primary sedimentary structures; Fe-, Mn-, P-rich concretions/features continue
Sutton Island Includes *Old Soaker* ("*OS*") locale	Heterolithic, ranging from mudstone to sandstone [***6***]. Dessication cracks at *OS* suggest dryer conditions, warmer temperatures [***12,13***]	-Broad variations in most elements; some changes near "*Old Soaker*" -Si high (> median), increasing up to OS, decreasing above OS. -Al, K, Na, Fe, Mg low (< median), Al decreases with elevation -Mn variable, lowest near *OS* – marked increase -4300 m; abundant concretions, nodules etc (Fe-, Mn-, P-rich) start here -Cr, Ni high values near *OS*; Zn, Mn lowest values near *OS* -Zn < median below *OS*, sharp increase, highest values seen just above *OS* -***OS****:* low Si, Ti, K, Al, Mn, Ni, Zn; high Na, Mg, P, Fe; varied Cr -Abundant fine fractures and $CaSO_4$ veins, from *OS* upwards
Karasburg	Mudstones & interbedded sandstones; lake deposits & interbedded lake-margin facies [***6***]	-Relatively homogeneous; similar to median Murray, for all elements -Si, Al, Mn, Mg, Na, K, Cr, Zn low (< median); Fe, P, Ni high (<median) -Most variation within Quela (drill) data-set (-4379 m) (very high Cr, Mn; high Al, Mg, Na; very low K, Zn)
Hartmann's Valley	Large scale x-stratified; eolian or fluvial reworking of fine sediment [***5, 11***]	-Most variable unit below the VRR, esp. Si, Mn, Mg, K, P, Cr, Ni, Zn, Br -Little variation in Na, Al, Fe – close to median Murray. -Si, Mg, K trend to high (>median); Ti, Al, Cr, P trend to low (<median).
Pahrump Hills - *Telegraph Peak* (*"TP"*) locale	Lake env., proximal to prograding delta system [***5***]	-Very high Al, Mn, Cr; Si, Ti, Na, P, Zn; low K; -Variable Ti, Mn, Ni -***TP***: high Ti, Al, Na, P; low Fe, Ni; higher K, lower Mn than Pahrump Hills

Table 1. Geochemical composition of Murray formation members, as determined by APXS, excluding obvious diagenetic features or altered material (see Figure 1 for further details).