

**GEOCHEMICAL ENDMEMBERS PRESERVED IN THE FLUVIOLACUSTRINE SEDIMENTS OF GALE CRATER.** C. C. Bedford<sup>1</sup>, J. C. Bridges<sup>2</sup>, S. P. Schwenzer<sup>3</sup>, R. C. Wiens<sup>4</sup>, E. B. Rampe<sup>5</sup>, J. Frydenvang<sup>6</sup>, P. J. Gasda<sup>4</sup>. <sup>1</sup>School of Physical Sciences, The Open University, Walton Hall, Milton Keynes, UK (candice.bedford@open.ac.uk), <sup>2</sup>Leicester Institute for Space and Earth Observation, University of Leicester, UK. <sup>3</sup>School of Environment, Earth and Ecosystem Sciences, The Open University, Milton Keynes, UK. <sup>4</sup>Los Alamos National Laboratory, Los Alamos, New Mexico, USA. <sup>5</sup>NASA Johnson Space Centre, Houston, TX, US. <sup>6</sup>Natural History Museum of Denmark, University of Copenhagen, Copenhagen, Denmark.

**Introduction:** Gale crater possesses a diverse stratigraphic record consisting of conglomerate, fine to coarse sandstone and mudstone units deposited after the crater's formation (~3.8 Ga) in an ancient fluvio-lacustrine system [1–3]. Since landing in August 2012, the NASA Mars Science Laboratory *Curiosity* rover has analysed the geochemistry and mineralogy of these sedimentary units using the Chemistry and Camera (ChemCam), Alpha Particle X-ray Spectrometer (APXS) and Chemistry and Mineralogy (CheMin XRD) onboard instrument suites. This has uncovered a largely unanticipated geochemical and mineralogical diversity across and within the Bradbury and Mt Sharp stratigraphic groups for sediments [4].

The Bradbury Group (sols 1–750) is dominantly fluvial conglomerate and sandstone with some lacustrine mudstone identified at Yellowknife Bay [1,2]. The Mt Sharp Group (Murray formation analysed from sols 750–1482, the latest sol used in this study) consists of well laminated mudstone deposited in a lake environment with some interstratified fine sandstone [2].

Previous studies of CheMin derived mineralogy conducted on two drilled samples of sedimentary outcrop (Windjana, sol 610 [5] in the Bradbury Group and Buckskin, sol 1061 [6] in the Murray formation) have identified primary minerals indicative of evolved potassic [5] and silicic [6] igneous source regions. APXS and ChemCam analyses of identified igneous float and conglomerate clasts with aphanitic, porphyritic and leucocratic textures have also shown a wide range of igneous compositions [7,8] probably resulting from the fractionation of olivine from a subalkaline basaltic parent melt [7]. This study uses the data obtained by ChemCam (over 1200 targets) for the stratigraphic record analysed from sols 1–1482 to determine the extent previously identified endmembers have contributed to Gale's sedimentary record as well as identify the source of compositional change between the Bradbury Group and studied Murray formation.

**Methods:** ChemCam acquires major, minor and trace element compositions through ablating a target host rock or soil between 2.2–7 m from the rover mast with its Laser-Induced Breakdown Spectroscopy instrument [9,10]. Between 30–50 spectral analyses are

acquired per observation point and averaged to give the observation point compositions used in this study [9].

ChemCam observation point analyses were classified according to sample morphology, stratigraphic position and grain size [11]. This study focuses on points that have analysed *in situ* sedimentary outcrop in order to distinguish geochemical source characteristics. Observation points identified to have hit obvious diagenetic features (such as veins, nodules, raised ridges and haloes), soil targets, float, pebbles, drill tailings and dump piles have been removed from the refined database to acquire the best representation of whole rock compositions.

Due to ChemCam's small sample footprint (350–550  $\mu\text{m}$ ), point analyses are not fully representative of whole rock compositions. This is especially true for coarse-grained targets (>1 mm) where points are more representative of targeted mineral phases. In order to minimize this effect, individual point compositions are plotted on a series of scatter and density contour plots for their associated stratigraphic groups and units. This displays the compositional spread of the data population, highlighting average compositional foci and geochemical trends across the stratigraphy. This method should also minimize geochemical variation associated with closed system alteration within the stratigraphy.

Grainsize is shown to possess a strong influence on whole rock geochemistry for sedimentary deposits [12], particularly those associated with deposition in a distal, fluvio-lacustrine system [13,14]. Hence, endmember compositions are discussed in relation to grainsize dependent subgroups to reduce this effect on provenance analysis. Grainsize subgroups are classed as coarse (>1 mm), sandstone (0.063 mm – 1 mm) and mudstone (<0.063 mm) according to the literature [15].

**Results and Discussion:** On average, the Bradbury Group is more depleted in  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{K}_2\text{O}$  but enriched in  $\text{CaO}$  compared to the Mt Sharp Group (Murray formation). Bradbury density contours also show a distinct bimodality in  $\text{MgO}$ ,  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  compositions. This bimodality is associated with grainsize as individual observation point analyses from the coarse units and coarser members of the sandstone group plot closer towards Gale crater felsic mineral compositions. On Earth, sediments coarser than 1 mm

are shown to maintain source rock characteristics [12] and as the Bradbury group high-aluminium subfocus also matches that of the Gale trachybasalt igneous group suggesting the same is true for Mars. The higher proportion of felsic minerals in sediments derived from this endmember may have increased its survivability in coarse grained units according to fluvial mineral sorting regimes of volcanoclastic material [13, 14].

Murray mudstone is unimodal and possesses a geochemistry indicative of a greater proportion of felsic minerals (rich in  $Al_2O_3$ , alkalis and depleted in MgO) compared to the mafic geochemistry of the Bradbury low-Al subgroup, defined by the majority of its fine sandstone and mudstone units. Elevated silica content is also a defining feature of the Murray formation compared to the Bradbury Group, especially in one area – Marias Pass (sols 995 – 1066), though here the extreme silica content (>75 wt%) is associated with the high abundance of tridymite and cristobalite detected in the Buckskin drill hole [6] which are not detected anywhere else in Gale’s stratigraphy. Hence, with other Murray drilled samples showing a basaltic mineralogy, silica-rich diagenetic features [16] removed and minimal open system alteration inferred from secondary mineralogy [17], the source of the Murray studied here is hypothesized to be dominated by a silica-saturated tholeiitic provenance.

**Conclusions:** In total, five endmembers associated with unique igneous source regions have been identified (Fig. 1).

*Endmember 1:* A regional subalkaline basalt endmember which is similar in composition to the tholeiitic Adirondack Class basalts [18] of Gusev Crater and is the dominant composition observed in Bradbury Group sandstones and mudstones,

*Endmember 2:* A trachybasalt, mostly identified within Bradbury Group conglomerate and coarse-grained sandstone units, this endmember was initially observed in Gale igneous float and clasts [7] and is seen to dominate conglomerate geochemistry encountered before The Kimberley formation (sol 574).

*Endmember 3:* A potassium-rich volcanic source, identified by [5] in the Windjana drill hole analysed at The Kimberley, and a similar source in Shaler [19]. Associated with strong potassium-enrichment and a high abundance of sanidine, this endmember is present in fluvial sandstone identified near the top of the analysed Bradbury succession (from sol 574 to the base of Mt Sharp), and is also recognised throughout the lower Murray formation,

*Endmember 4:* A highly evolved silica-rich igneous source, identified by [6] in Murray formation Marias Pass mudstones sediments from this source possess

extreme silica-enrichment associated with elevated amounts of tridymite and cristobalite.

*Endmember 5:* A fractionated Si-rich tholeiite seen to influence the majority of the Murray formation’s geochemistry. This endmember is proposed as the cause of the marked geochemical difference between Bradbury and Mt Sharp group mudstones and the source of the low Ca and intermediate Fe/Mg pigeonite compositions identified by CheMin [20].

**References:** [1] Grotzinger J. P. et al. (2014) *Science*, 343, 1242777. [2] Grotzinger J. P. et al. (2015) *Science*, 350, aac7575. [3] Thomson B. J. et al. (2011) *Icarus*, 2, 413-432. [4] McSween H. Y. et al. (2009) *Science*, 5928, 736-739. [5] Treiman A. H. et al. (2016) *JGR: Planets*, 121, 75 – 106. [6] Morris R. V. et al. (2016) *PNAS*, doi: 10.1073/pnas.1607098113. [7] Edwards P. H. et al. (in rev.) *MAPS*. [8] Cousin A. et al. (2017) *Icarus*, 288, 265-283. [9] Wiens R. C. et al. (2012) *Space Science Reviews*, 170, 167-227. [10] Maurice S. et al. (2012) *Space Science Reviews*, 170, 95-166. [11] Bedford C. C. et al. (subm.) *GCA*. [12] Bloemsma M. R. et al. (2012) *Sedimentary Geology*, 280, 135-148. [13] Fedo C. M. et al. (2015) *EPSL*, 423, 67-77. [14] Siebach K. L. (2017) *JGR: Planets*, 122, 295-328. [15] Mangold N. (2017) *Icarus*, 284, 1-17. [16] Frydenvang J. (2017) *GRL*, 44, 4716-4724. [17] Rampe E. B. et al. (2017) *EPSL*, 471, 172-185. [18] McSween H. S. et al. (2006) *JGR: Planets*, 111, 2156-2202. [19] Anderson R. et al. (2015) *Icarus*, 249, 2-21. [20] Morrison S. M. (in rev.) *American Min.*

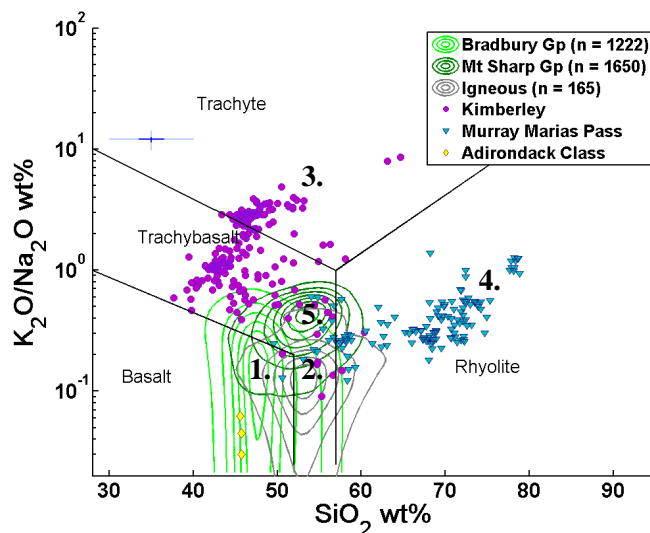


Figure 1. A  $K_2O/Na_2O$  vs  $SiO_2$  plot of stratigraphic units most influenced by unique end members. Compositionally unique endmembers are 1. A subalkaline basalt, 2. A trachybasalt, 3. A potassium-rich volcanic source, 4. A highly evolved, Si-rich volcanic source and 5. A Si-rich tholeiite. Adirondack MER APXS [NASA PDS, 18]