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Citation

Bridges, J. C.; Bedford, C. C.; Schwenger, S. P.; Frydenvang, J.; Thompson, L. and Wiens, R. C. (2017). The igneous end member compositions preserved in Gale Crater sediments. In: 48th Lunar and Planetary Science Conference, 20-24 Mar 2017, Houston.

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THE IGNEOUS END MEMBER COMPOSITIONS PRESERVED IN GALE CRATER SEDIMENTS. J. C. Bridges¹, C. C. Bedford², S. P. Schwenzer², J. Frydenvang³, L. Thompson⁴ and R. C. Wiens³ ¹Space Research Centre, Leicester Institute for Earth and Space Observation, University of Leicester, UK, j.bridges@le.ac.uk, ²Faculty of Science, The Open University, UK, ³LANL, New Mexico, ⁴Planetary and Space Science Centre, Univ. of New Brunswick, Can.

Introduction: The sedimentary outcrop and float rocks in Gale Crater contain evidence of a mixture of igneous protoliths: basaltic, trachybasaltic, SiO₂-rich, and alkali-rich [1-3]. The fine grain size of many of the sediments offers the possibility of estimating accurate bulk compositions of igneous protoliths. However, the sediments also have undergone extensive diagenesis [4-6], veining and silica-rich alteration zones [7]. Here we test a hypothesis that end member igneous compositions are recorded within the Gale Crater sediments, compare to other martian datasets, and distinguish alteration trends from the igneous detrital input sourced in the ancient highlands. We analyse this data from the first 1500 sols of *Mars Science Laboratory* operations using the Gale stratigraphic column [8,9].

With over 400,000 ChemCam LIBS spectra, 198 APXS analyses and 19 CheMin analyses, the MSL results provide a unique compositional and stratigraphic sampling of the martian crust. The use of density contours with the large ChemCam dataset allows us to distinguish the key compositional end members from fractionation based on mineral density during deposition, or localised remobilisation during post depositional alteration.

Methods: ChemCam remotely analyses targets by Laser Induced Breakdown Spectroscopy LIBS, with optimal performance at ≤ 4 m [10]. ChemCam combines ICA and PLS to derive quantitative compositions [11]. The large amount of data points means that density contour plots are well suited to show the unnormalised average compositions of the rock types. We have removed ridges, veins, and fracture observations to help reduce the effects of localised remobilisation. The Alpha Particle X-ray Spectrometer (APXS) provides complementary analyses on many of the same targets [12].

Results: There are two main stratigraphic units with distinct compositions: the Bradbury Group – including Sheepbed mudstone – and the overlying Mt Sharp Group, which is largely composed of Murray mudstone. The Bradbury Group MgO at the focus of the LIBS density contours is 8.5 wt%, and similar to the MgO of the Adirondack class Gusev picritic basalts [13], (Fig. 1A). The SiO₂ contents of ~47 wt% and average Al,Na,K contents are also similar to Adirondack basalts (Fig. 1B,C).

In contrast, the Mt. Sharp Group has a LIBS focus at higher SiO₂ at 55 wt%, and higher Al₂O₃ 13 wt%, com-

pared to 11.5 wt%, and lower MgO (4.5 wt%) in Bradbury. Both groups are characterised by high FeO contents with averages of 19-20 wt% (Fig. 1B). The corresponding 100Mg# of the groups are 30 and 45. The third group – Siccar Point, which contains the Stimson aeolian sandstones and unconformably overlies the two other groups [9] – has a wider range of compositions which overlap those of Bradbury and Mt. Sharp (Fig 1). While data of clearly altered material was removed, some Al and Mg may still be due to alteration effects.

Igneous Clasts and Silica. The Bradbury Group contains trachybasalt clasts in some units, and these have been the subject of separate ChemCam studies [1,14]. The focus of the trachybasalt igneous clast compositions is SiO₂ 53 wt%, Al₂O₃ 20 wt%, Na₂O+K₂O 6 wt%, and reflects the feldspar-rich mineral assemblage.

Alkali enrichment is shown in the Kimberley, and parts of the Shaler formation, within the Bradbury Group. These have notable K₂O enrichments, e.g., to 4-11 wt% [15] in individual observation points, reflecting the high abundance of sanidine grains [16].

A third compositional fractionation identified by MSL is silica enrichment as detrital tridymite within the Mt. Sharp Group (Murray mudstone). Remobilisation of silica has occurred within fractures in the Murray mudstone (Bridger Basin, Mariah's Pass, sols 997-1112) and Stimson sandstone. This is shown on Fig. 1C, [7].

Igneous End Member Mixing or Alteration Trends? Although much of the detrital igneous mineral and amorphous component of Bradbury recrystallised during diagenesis, potentially through exposure at ~50 °C to a near-neutral groundwater [17], the overall major element variation suggests that water-rock reaction has not greatly changed bulk major element compositions when averaged within the different sedimentary units. The Bradbury Group is dominated by a mixture of relatively Mg-rich basalt, similar to the composition identified at Gusev, with lesser amounts of trachybasalt. The latter rocks might have formed by fractional crystallisation of an Adirondack-type basalt [1].

The overlying Mt Sharp Group (Murray formation), with its higher average Al₂O₃ and SiO₂, lower MgO, Mg#, has a distinct composition. It has been suggested that higher Al contents in Gale sediments are the result of acid-sulfate alteration acting to remobilise this element [18]. However, the near absence of jarosite, and abundance of clay, in mineral assemblages determined

by CheMin [4] argue that in the first 1500 sols, sediments encountered a near neutral, oxidising groundwater [17]. Use of A-CNK-FM plots suggest no more than a small amount of chemical weathering.

The position of the Mt. Sharp Group data on Fig. 1C suggests that it cannot be a simple mixture of a MER-like basalt and trachybasalt. However, the presence of tridymite in some Mt Sharp mudstone horizons led [2] to argue that it had sampled a rhyolitic igneous source. However, as for the Bradbury Group, the major compositional signature is dominated by a subalkaline basalt. The relict igneous mineral assemblages when observed, e.g. high and low Ca pyroxene, plagioclase, (\pm olivine) [4] suggest tholeiitic basalts [1]. The Mt. Sharp basalt source was slightly more differentiated, and at Marias Pass it also seems to include the most evolved silica-rich (tridymite) igneous component – but this is relatively minor in abundance compared to the dominant basaltic signature.

Conclusions: The MSL mission has encountered, within the Bradbury Group, a predominantly subalkaline, Mg-rich basalt similar to MER Spirit basalt. This has mixed with a subordinate proportion of trachybasalt and alkaline igneous rocks. In contrast, the overlying Mt. Sharp Group (Murray) is dominated by a more evolved, higher Si,Al, lower Mg, basalt source input. It is unlikely that the Mt. Sharp Group sediments could be derived from alteration of Bradbury/MER-like compositions, as the major element geochemistry precludes intense remobilisation. For instance, the silica enrichment within the Mt. Sharp Group is associated with discrete fractures and does not include Al-enrichment.

Both the Bradbury and Mt. Sharp dominant basalt protoliths are subalkaline, tholeiitic. The presence of tridymite-rich horizons shows that the Mt. Sharp Group has also sampled a silica-oversaturated component, which could potentially be linked through crystal fractionation from a tholeiitic basalt protolith.

Diagenesis, fracturing and vein formation evidence localised remobilisation of major elements but, when analysed using the large amount of ChemCam and APXS data, in the context of distinct stratigraphic units, the sediments are seen to have preserved the average compositions of 2 major igneous protoliths and traces of up to 3 minor ones.

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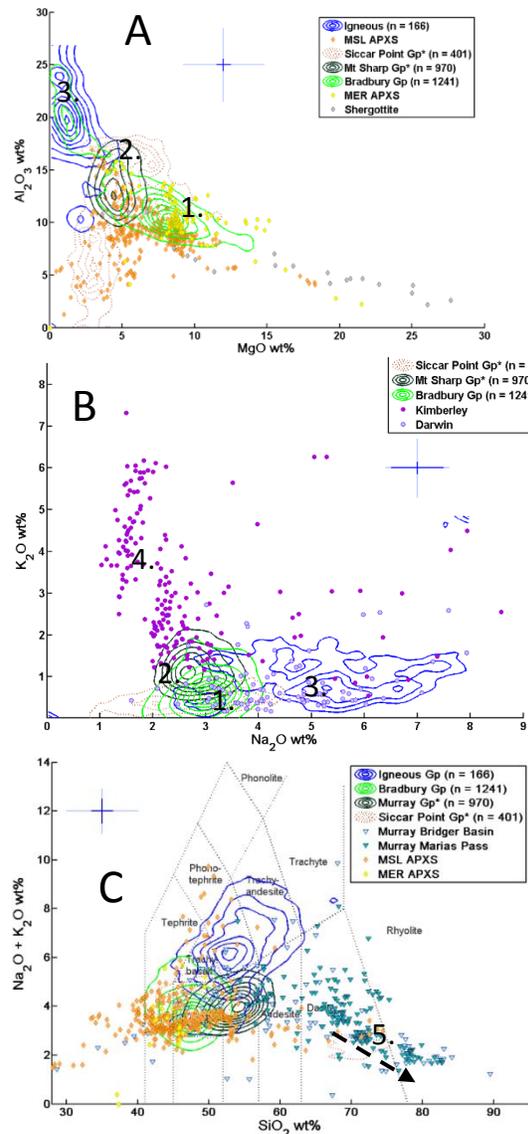


Figure 1. Igneous Components in Gale (LIBS and APXS data). A. Al₂O₃ v. MgO B. FeO v. SiO₂. C. Na₂O+K₂O v. SiO₂. The Bradbury and Mt. Sharp Groups have preserved two distinct basaltic average compositions (1. and 2.). Trachybasalt component contours (3) from [1]. Numbers 4, 5 are alkali and silica-enriched minor components. Shergottites [1], MER APXS [12]. Mt. Sharp Group contours exclude Bridger Basin and Mariah's Pass data. LIBS 1 sigma error accuracy.