IGNEOUS DIFFERENTIATION ON MARS: TRACHYBASALTS IN GALE CRATER. J. C. Bridges[1], P. H. Edwards[1], R. Anderson[2], M. D. Dyar[3], M. Fisk[4], L. Thompson[5], P. Gasda[6], S. P. Schwenzer[7], W. Goetz[8], D. Blaney[9], J. Filiberto[10], R. C. Wiens[6], [1]Space Research Centre, University of Leicester UK j.bridges@le.ac.uk [2]USGS Astrogeology Science Center, Flagstaff, AZ, [3]Mt. Holyoke College, Ma, [4]Oregon State Univ., [5]Planetary and Space Science Centre, University of New Brunswick, Can., [6]Los Alamos National Lab., NM, [7]Open University, UK, [8]Max Planck Inst., Göttingen, Gemany, [9]JPL, Pasadena, Ca, [10]Southern Illinois University Carbondale, Il.

Introduction: Since landing in 2012 the Mars Science Laboratory (MSL) rover Curiosity has analysed a a large number of float rocks and conglomerate clasts. Many of these are of igneous origin emplaced through fluvial and probably impact processes postdating the formation of Gale Crater itself in the early Hesperian [1]. Here we use the ChemCam instrument on MSL [2] in order to determine the compositions of the igneous rocks. This unique, large dataset enables representative, average compositions to be identified for the different igneous rock types, and comparisons with basaltic shergottites, MER basalts [3-5] and Gale sediments to be made in order to better understand igneous differentiation of the Mars lithosphere.

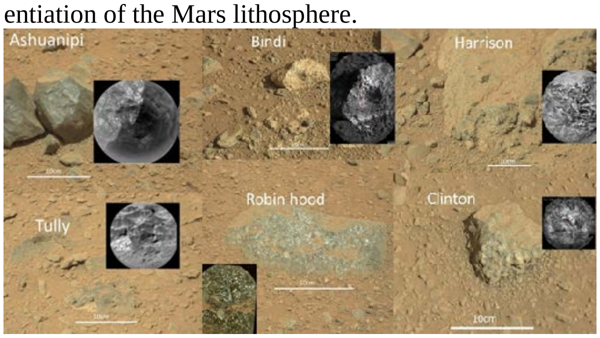

Fig. 1. Mastcam and RMI of Gale basalts and trachybasalts showing their coarse feldspar-rich mineralogy.

Methods: ChemCam contains a NIR laser and telescope within MSL's mast and 3 spectrometers inside the body unit [2]. It remotely analyses targets by Laser Induced Breakdown Spectroscopy LIBS, with optimal performance at ≤4 m, and also has a Remote MicroImager (RMI). Each time the laser is fired is termed a shot. Typically there are around 30-50 shots on a single observation point in a raster (e.g. 3x3), on a target. ChemCam uses a combination of ICA and PLS to derive quantitative compositions [6]. The large number of shots means that frequency and density plots are well suited to show the unnormalised average compositions of the rock types. Igneous float rocks and conglomerate clasts were selected for LIBS in MastCam and RMI images.

Results: Twenty five igneous float and conglomeate rocks were identified over the first 530 sols (Fig. 1). A textural classification was initially described in [7]. One type of igneous rock is volcanic and includes dark, fine grained basaltic samples (e.g. Ashuanipi float rock). Coarse-grained >500 µm [7], feldspar-rich samples are also notable e.g. Robin Hood and the Harrison clast - the latter from the Hottah faces conglomerate (sols 365, 514).

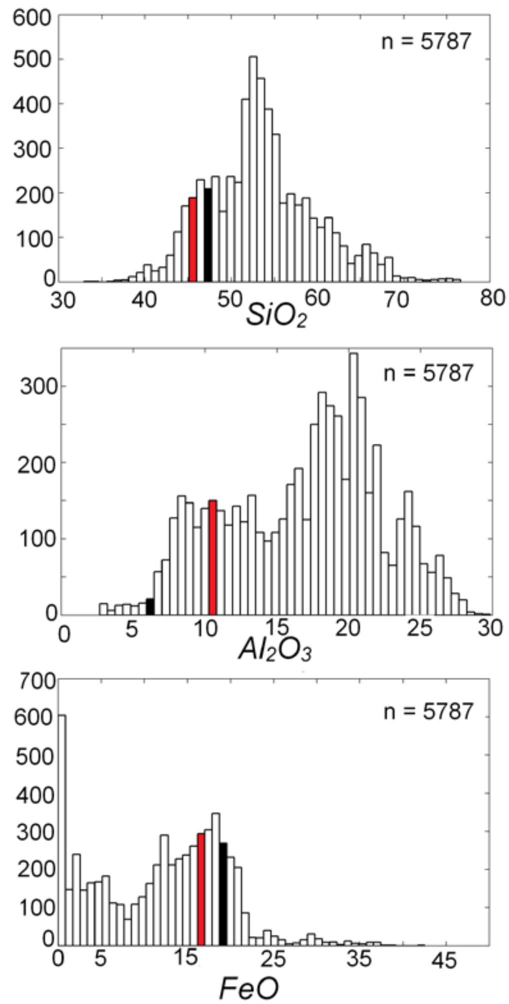

Fig. 2. Frequency plots of Gale igneous ChemCam shots (wt% SiO_2, Al_2O_3, FeO). Red columns = av. MER Spirit basalts [3-4], black = av. shergottite.

Feldspar was identified on the basis of the pale colour and tabular, mm-size crystal forms, subsequent LIBS analyses supported this identification [8].

Igneous Rock Compositions. The Fig. 2 frequency histograms and Fig. 3 density plots show differences in composition between the igneous float rock and sedimentary outcrop samples from the first 1000 sols. The sedimentary outcrop analyses have a focal point of ~45 wt% SiO_2 (Fig. 3) but the igneous analyses are less homogenous. The igneous data range from 6-25 wt% Al_2O_3 with local maxima at 11 and 22 wt % (Fig. 2). The Gale igneous groups have much less MgO than the average shergottites (16 wt%). The shergottites have considerably less alkalis than either the sedimentary or igneous samples which are both very similar for K_2O but have much higher Na_2O contents in the igneous samples. The MER Spirit samples are broadly similar to the sedimentary targets, particularly SiO_2 (Fig. 3) but also Al_2O_3, CaO, Na_2O and K_2O though FeO is lower in the MER basalts with correspondingly higher MgO.

The feldspar-rich igneous group has relatively high SiO_2 (av. ~53 wt%), high Al_2O_3 and alkalis and is low in FeO and MgO – similar in composition to terrestrial trachybasalts (Fig. 2, 3). In contrast, the dark, basaltic group is much more similar to the Gale sedimentary rocks and terrestrial basalts – high in FeO and MgO whilst lower in SiO_2, (av. on Fig. 3. ~45 wt%), Al_2O_3, Na_2O and K_2O oxides.

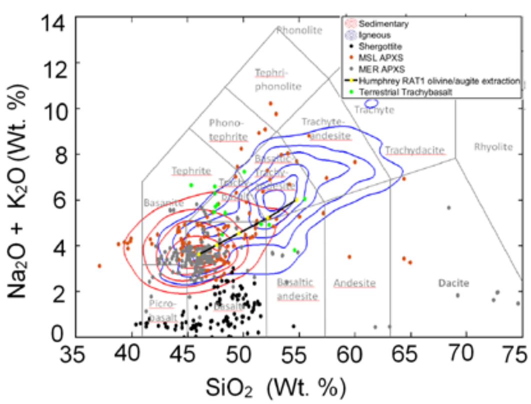

Fig. 3. Density contours for Gale igneous and sedimentary samples from first 1000 sols. Each contour encloses an equal amount of data (total 33200 shots). Terrestrial trachybasalts, shergottites, MER Spirit, MSL APXS [3-5,9] also plotted. Crystal fractionation line shows differentiation from Spirit basalt composition.

Discussion: *Igneous Rock Types*. The silica contents of the Gale igneous samples, e.g. much of the data focused around 45-55 wt%, show that a significant amount of differentiation has taken place to form the high SiO_2 samples. The dark, fine grained basalts are similar in composition to MER basalts whereas the feldspar-rich samples can be classified texturally and compositionally as trachybasalts. The CIPW compositions (Fig. 4) are olivine and hypersthene normative for the representative basalt and trachybasalt compositions derived from the density plots. Thus the great majority of these igneous rocks have tholeiitic affinities. However, the presence of alkali-rich feldspars in some of the sediments e.g. [10,11] may indicate the local presence of alkaline igneous rocks as well [9].

Crystal Fractionation. The differentiation trend e.g. increasing silica, was modelled assuming crystal fractionation dominated by olivine with lesser pyroxene. Starting from a MER Spirit Humphrey_RAT composition [3] 20% augite was subtracted and olivine subtraction in divisions of 10% (Fig. 3). The fractionation line is close to the two densest points on the igneous distributions, this means that olivine being removed from a MER-like basalt through crystal fractionation can readily explain the compositional trends.

Gale Samples and Differentiation of the Mars Lithosphere: The Gale and MER basalts have high Fe, Al and alkali abundances suggesting they were derived from similar mantle source regions beneath the ancient highlands. In contrast, the shergottites - more likely derived from the northern plains and Tharsis - have a more Al, alkali-poor composition which probably reflects differences in their mantle source composition. The Gale igneous samples' compositional variation, from basalt to trachybasalt, can be understood as the result of crystal fractionation within localized crustal magma chambers rather than regional differentiation of the basaltic Mars crust. This is likely to be anhydrous fractionation as no signs of amphibole have yet been detected by CheMin e.g. [9] in the sediments which may share a source region with them.

References: [1] Grotzinger J. P. et al. (2015). Science, 10.1126/science.aac7575 [2] Wiens R.C. et al. (2012) *Space Sci. Rev* 170, 167-227; Maurice S. et al. (2012) *LPS*, XXXXIII, #2899 [3] McSween H. Y. et al. (2006) *JGR*, 111, doi:10.1029/2006JE002698; pds.nasa.gov [4] McSween H. Y., et al. (2009) *Science*, 324, 736-739. [5] Gellert R., et al. (2009) *LPS XXXX* #2364 [6] Clegg et al. (2016) *Spectrochim Acta*, subm. [7] Sautter V. et al. (2014) *JGR*,119, 30–46. [8] Gasda P. et al. (2016) *LPS*, [9] Schmidt M. E. et al. (2014) *JGR*, 119, 64–81. [10] Anderson R. et al (2014) *Icarus*, 249, 2-21. [11] Vaniman D. T. et al. (2014). *Science*, 10.1126/science.1243480.

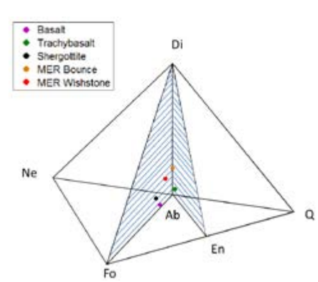

Fig. 4. Basalt tetrahedron with CIPW normative compositions of av. Gale basalt and trachybasalts, av. shergottite, MER Bounce and Wishstone [3,4].