**CONSTRAINTS ON MARTIAN ANCIENT MAGMATIC PROCESSES USING MINERAL CHEMISTRY OF SEDIMENTARY ROCKS IN GALE CRATER, MARS.** V. Payré[1], K. L. Siebach[1] R. Dasgupta[1], S. M. Morrison[2], E. B. Rampe[3], and A. Udry[4], [1]Department of Earth, Environmental and Planetary Science, Rice University, Houston, TX, USA (vpayre@rice.edu), [2]Carnegie Institution for Science, Washington DC, USA, [3]NASA JSC, Houston, TX, USA, [4]University of Las Vegas, Las Vegas, NV, USA.

**Introduction:** If Mars has been assumed to be mostly basaltic for a long time, a series of recent discoveries have challenged this simplistic view. Orbital data indicated feldspar-rich rocks in Noachian terrains, likely supporting ancient evolved magmatism [1]. The first indurated regolithic martian meteorite breccia NWA 7034, dated at 4.43 Gyr, contain several leucocratic felsic clasts identified as monzonitic and trachyandesitic, containing feldspars including K-spars and Na-rich plagioclases, pyroxenes, ilmenites and apatites [2-3]. These clasts have been interpreted as the result of crystallization of a large impact pond [2]. The Mars Science Laboratory rover (Curiosity), travelling within sedimentary bedrock on the floor of the Gale impact crater, discovered feldspar cumulates and a trachyandesite suggesting fractional crystallization of a basaltic melt [4-5]. In addition, in the Bradbury group of fluvio-deltaic rocks (observed during the 1$^{st}$ 750 sols), sedimentary rocks are mostly comprised of secondary phases and detrital igneous minerals like feldspar, and pyroxene that are thought to come from Noachian-aged magmatic sources [6], although no definite origin and igneous processes have been inferred.

In-situ analyses cannot provide bulk igneous compositions as we typically measure on Earth. In this abstract, we instead focus on the composition of detrital igneous minerals in sedimentary rocks in order to constrain ancient magmatic processes around Gale crater that contributed to sedimentary rocks found within the crater. We show that, even in terrains lacking igneous rocks, as may be true for Mars 2020 landing site except for the crater floor [7], we can constrain magmatic processes with detrital mineral chemistry.

**Methods:** Onboard the Curiosity rover, an X-ray diffraction instrument (CheMin) enables the detection of minerals in drilled rocks and gives their compositions [8]. An alpha-particle X-ray spectrometer (APXS) measures the composition of rock surfaces within a 1.6 cm diameter circle in contact with the instrument [9], and a laser induced breakdown spectrometer (LIBS) part of the ChemCam suite analyzes the elemental composition of rocks at a sub-millimeter scale (350-550 µm) at distances up to 7 m, potentially giving the composition of pure minerals larger than the beam size (>> 600 µm) [10].

All three of these instruments provide constraints on mineral chemistry in the fluvio-lacustine rocks from the first 750 sols of MSL's traverse (Fig. 1). Three relevant samples were analyzed by CheMin, and their feldspar and pyroxene mineral compositions are shown [8]. ~120 APXS analyses provided a basis for Monte Carlo modeling of sedimentary compositions to broadly constrain igneous mineral chemistry [6]. Stoichiometric filtering on ~5000 ChemCam compositions has allowed filtering so that only pure feldspar and pyroxene compositions have been retained (Fig. 1).

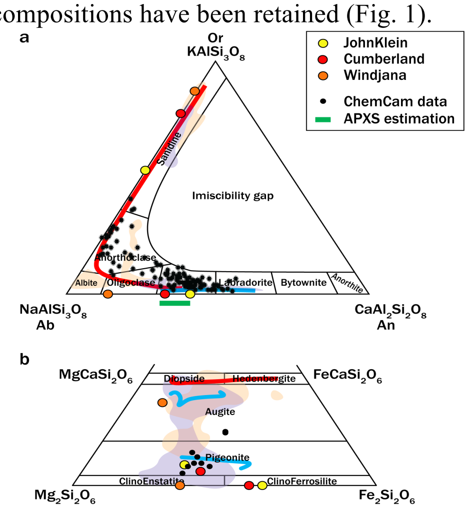


*Figure 1. Ternary diagrams of (a) feldspars and (b) pyroxenes from CheMin (colored dots), ChemCam and APXS analysis. For reference, orange and blue patches are the composition of feldspars and pyroxenes from NWA 7034 felsic and mafic clasts respectively. The red and blue lines are MELTS models showing the mineral composition of a melt produced by fractional crystallization at 1 kbar and FMQ +1 of a low- and high- degree partial melt (10% and 23%) from a primitive mantle composition [11], respectively.*

**Composition of Detrital Minerals:** Based on results from three different instruments, feldspar and pyroxene compositions are well-constrained. First, CheMin analyses revealed the occurrence of K-spars identified as sanidine, and Na-rich plagioclases with an anorthite (An) component < 45. Monte Carlo modeling also favors Na-plagioclase with An < 45. LIBS measurements evidenced a similar compositional range, with plagioclases of An < 55. In contrast to CheMin, no pure K-feldspars have been analyzed by ChemCam, indicating that they are too small to be individually hit by LIBS. Concerning pyroxenes, all instruments detected pigeonites, along with augites (Fig. 1).

**Chemical Weathering:** The detrital minerals of interest were transported by streams and deposited in the floor of Gale, where they cemented, forming the sedimentary bedrock the Curiosity rover analyzed. Thus, the minerals could have been chemically weathered. APXS measurements indicate minimal open system cation loss; the chemical index of alteration (CIA) based on Al, Ca, Na and K abundances in these rocks is low, and Monte Carlo modeling of bulk compositions is consistent with sorting of primary igneous minerals without cation loss [6]. Since we focus on compositions of measured igneous minerals, the only type of chemical weathering we are concerned with is incongruent weathering of minerals, which would change cation ratios. The significant fraction of detrital igneous minerals, negligible open-system chemical weathering, and limited variability of observed mineral compositions is consistent with minimal incongruent dissolution; here we consider a shift of the maximum An component up to $An_{60}$.

**Ancient Magmatic Processes:** Using the thermodynamical software package pMELTS and rhyolite-MELTS, a series of tests were performed to match the compositions of the detrital igneous minerals. The best results are shown in Fig. 1. Partial melting of a primitive mantle composition [11] during adiabatic decompression from 2 GPa cannot reproduce the compositional range of minerals. Fractional crystallization is needed to form feldspars, especially K-feldspars, and Ca-augites as inferred by experiments in [12]. Using models based on fractional crystallization at low pressure of melts formed by distinct extent of partial melting (5-25%) of the primitive mantle composition as starting compositions (Fig. 2), we infer that the crystallization of a single starting melt cannot reproduce the whole compositional range of the detrital minerals: a low degree melt would form exclusively alkali feldspars and Na-rich plagioclases along with Ca-pyroxenes only, while a high degree melt would crystallize plagioclases only (Fig. 1). We thus propose that the range of feldspars and pyroxenes we observe in the sedimentary bedrock from the Bradbury group, crystallized from basaltic melts issued by at least two distinct degree of partial melting coming from a single source (Fig. 2). Alkali feldspars likely formed from a low degree melt (~10%) relatively richer in Ca, Na, and K (red dot Fig. 2), while plagioclase, augite, and pigeonite formed from a higher extent of melt (23%) relatively richer in Mg and Fe (blue dot Fig. 2). This is in agreement with the suggested occurrence of at least two magmatic sources at the origin of the Windjana sample analyzed by CheMin [13]. This process is very common on Earth during the formation of MORBs.

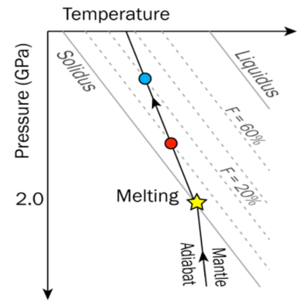


*Figure 2. Sketch of partial melting during adiabatic decompression. The red dot illustrates a low degree melt and the blue one shows a higher degree melt.*

This scenario implies that alkali feldspars may have been formed before plagioclase and pigeonite. This is in agreement with the timing suggested for the early formation of K-spars bearing felsic igneous rocks from Gale in comparison with mafic mineral-bearing basalts [14].

**Conclusion:** With the chemical composition of detrital igneous minerals, we are able to decipher a part of the ancient magmatic history of Gale. Fractional crystallization at low pressure of two distinct extents of melt coming from partial melting of the same source can form the compositional range analyzed by three distinct instruments onboard the rover. Other scenarios can be envisioned, like the fractionation and crystallization of impact melts as inferred for igneous clasts from NWA 7034, which we have also modeled. In any case, a relatively alkali-rich melt and a more Mg-rich melt are needed to form the whole compositional range of igneous minerals analyzed in Gale crater.

This study shows that constraining magmatic processes from sedimentary bedrock is possible, which is especially of importance in the case where the igneous sources of sediments cannot be identified in situ and from orbit. This provides additional inputs to igneous rock studies [4,5,14]. This is encouraging for understanding the igneous processes at the Mars 2020 landing site where most rocks are expected to be sedimentary likely originating from other igneous materials than the volcanic crater floor [7].

**References:** [1] Carter J. and Poulet, F. (2013) *Nat. Geosc.*, 6, 1008-1012; [2] Humayun, M. et al. (2013) *Nat.*, 503, 513-516; [3] Santos, A. R. et al. (2015) *GCA*, 157, 56-85; [4] Sautter, V. et al. (2015) *Nat. Geosc*., 8, 605-609; [5] Udry, A. et al. (2018) *JGR*, 123, 1525-1540; [6] Siebach, K. L. et al. (2017) *JGR*, 122, 295-328; [7] Schon, S. C. et al. (2012) *PSS*, 67, 28-45; [8] Morrison, S. M. et al. (2018) *Am. Min.*, 103, 857-871; [9] Gellert, R. et al. (2009) *LPSC* XL, Abstract #2364; [10] Wiens, R. C. et al. (2012) *SAAB*, 82, 1-27; [11] Wanke, H. and Dreibus, G. (1988) *Phil. Trans. Roy. Soc.*, 325, 545-557; [12] Collinet, M. et al. (2015) *EPSL*, 427, 83-94; [13] Treiman, A. H. et al. (2016) *JGR*, 121, 75-106; [14] Cousin, A. et al. (2017) *Icarus*, 288, 265-283.