DIVERSITY OF SULFATE-BEARING SEDIMENTARY ROCKS AND PALEOENVIRONMENTS AT GALE CRATER. W. Rapin, B. L. Ehlmann1,2, G. Dromart4, J. Schieber4, L. Le Deit5, K. Stack7, S. Le Mouëlic5, V. Fox1, W.W. Fischer1, B. Clark6, L. Kah7, N. Mangold3, R.C. Wiens8, L. Thompson4, T.S.J. Gabriel10, C. Hardgrove10, A. Vasavada2, K.S. Edgett11, A.L. Reyes-Newell5. 1Caltech-GPS, wrapin@caltech.edu; 2Caltech-JPL; 3Univ. Lyon, LGLTPE, France; 4Indiana University, Bloomington; 5LPG, Nantes, France; 6Space Science Institute; 7Univ. Tennessee-Knoxville; 8LANL; 9Univ. New Brunswick; 10Arizona State Univ. SESE; 11MSSS

Introduction: Carbonate, chloride, and sulfate salts provide fingerprints of the past chemistry of lake basins [1]. On Mars, a diversity of salts has been observed and thick layered sulfate-bearing outcrops are prominent at a number of late Noachian to late Hesperian locations (~3.5 Ga) [2]. Their apparent absence in older strata suggests that they represent the diminishing availability of liquid water on Hesperian Mars [3]. Gale crater provides an exemplary sedimentary succession with clay mineral detections transitioning to sulfate detections over hundreds of meters of stratigraphy [4,5]. Understanding the reason for this transition is a primary objective of the Mars Science Laboratory (MSL) Curiosity rover investigation. So far, the rover has explored a clay-bearing fluvialacustrine sedimentary sequence exposed in the lowermost strata of Aeolis Mons [6]. Sulfates have been observed mostly as late diagenetic Ca-sulfate fracture-fills [7,8] and as sparse concretions and dendrites enriched in Mg-sulfates [9], but importantly also within the bedrock in diverse other forms. Here we synthesize observations of bedrock sulfate enrichments: as grains, crystals or crystal pseudomorphs associated with Ca-sulfates (Figure 1), as finely disseminated Ca and Mg-sulfates, and we preview outcrops in the sulfate-bearing unit via long-distance imaging (Figure 2).

Methods and observations: Bedrock enriched in Ca-sulfate relative to typical surrounding rocks of the Murray formation were analyzed by both the Alpha Particle X-ray Spectrometer (APXS) and ChemCam Laser Induced Breakdown Spectroscopy (LIBS) instruments. ChemCam’s submillimeter footprint highlighted the point-to-point homogeneity of these enrichments which indicates that the salt is finely disseminated in the bedrock. Major elements are quantified from ChemCam spectra using a multivariate calibration process [10]. Sulfur quantification with a dedicated model [11] helps to confirm the presence of Ca- or Mg-sulfates. Targets with bulk sulfate enrichment were carefully selected based on high-resolution (<0.5 mm/pixel) Remote Micro Images (RMI), and larger scale context from MastCam images, to ensure the sulfate was not a contribution from fracture-fill Ca-sulfate vein.

Within the Murray formation a total of 31 ChemCam targets correspond to these bulk enrichments. They are found intermittently within a stratigraphic section where the bedrock was sampled by 420 other targets devoid of Ca-sulfate enrichment (Figure 2). Bedrock enrichments of similarly disseminated hydrated Mg-sulfate were also identified [11]. In addition, close-up images by the Mars Hand Lens Imager (MAHLI) show white possibly detrital grains, diagenetic crystals, or filled crystal molds at several locations in the Murray formation (Figure 1). For some of these occurrences documented by MAHLI, ChemCam analyses show an association with Ca-sulfate.

Long-distance RMI of outcrops in the sulfate-bearing unit that lies above the Murray formation, further up Aeolis Mons (Figure 2a-c) provide details with a resolution of 2.5–5 cm for the most distant to the nearest outcrop, 6–12 times higher resolution than HiRISE observations and a side view of the exposures.

Results and discussion: Rover observations indicates that sulfates occur throughout Gale crater sedimentary rocks in diverse forms: as fracture and void fills, crystals in mudstones, white grains in sandstones, and as a finely disseminated component in the bedrock. The timing as to when these sulfates formed relative to the depositional history of these strata is crucial to
understanding their environmental implication. Ca-sulfates associated with fracture fills are interpreted as late-stage diagenesis, but sulfates observed within Murray bedrock and not associated with fractures might result from early diagenesis or primary deposition. On the other hand, clear depositional textures expected for primary salts, such as displacive fabrics and beds with bottom-growth or cumulate crystals, are not observed. Although late-stage formation cannot be discounted, we suggest that early diagenetic precipitation in pore spaces from episodically saline waters best explains the intermittent presence of significant quantities (30 to 50 wt%) of finely disseminated sulfates in strata that are otherwise devoid of sulfate enrichment (Figure 2). Ca-sulfate grains and crystals or crystal pseudomorphs (Figure 1) suggest early intrasediment salt growth, at least prior to any significant compaction (loss of permeability). In this early diagenetic scenario, saline waters may have crystalized by evapo-concentration at lake margins, while most of the lake basin was undersaturated, a depositional environment consistent with the heterolithic mudstone-sandstones facies [13] (Figure 2). The Mg-sulfate deposits might represent episodic or localized extreme evapo-concentration [11]. Other mineralogical and sedimentary observations support shrinking of the lake and arid conditions occurred episodically during the deposition of the upper portions of the Murray formation [14–16].

Outcrops observed in the distance highlight that diverse depositional environments can be expected for the sulfate-bearing unit (Fig. 2). Massive erosion-resistant beds capping recessive sections repeat periodically at a decameter scale [17] (Fig. 2a). Rhythmic bedding with consistent bed thickness of ~15 cm is observed as well as possible meter scale cross bedding in the lower most strata (Fig. 2b-c). The lack of thick fracture-fill vein networks suggests that the sulfates detected from orbit in this unit are a finer component of the outcrops.