MINERALOGICAL EVIDENCE FOR ENVIRONMENTAL CHANGE IN THE CLAY-SULFATE TRANSITION AT GALE CRATER, MARS. E. B. Rampe[1], T. F. Bristow[2], D. F. Blake[2], S. J. Chipera[3], D. T. Vaniman[3], C. N. Achilles[4], R. T. Downs[5], D. W. Ming[1], R. V. Morris[1], S. M. Morrison[6], S. L. Simpson[1], V. M. Tu[7], M. T. Thorpe[8], A. S. Yen[9], D. J. Des Marais[2], G. Downs[10], J. P. Grotzinger[11], R. M. Hazen[6], A. H. Treiman[12], N. Castle[3], P. I. Craig[3], E. M. Hausrath[13], T. S. Peretyazhko[7], B. Tutolo[14], M. Szczerba[15], J. A. Berger[7], J. V. Clark[16], L. A. Edgar[17], M. Meyer[18], W. Rapin[19], J. Schieber[20], B. Sutter[7] [1]NASA Johnson Space Center (elizabethb.rampe@nasa.gov), [2]NASA Ames, [3]PSI, [4]NASA GSFC, [5]Univ. Arizona, [6]Carnegie Institution for Science, [7]Jacobs at NASA JSC, [8]UMD/GSFC, [9]JPL, [10]Stanford Univ., [11]Caltech, [12]LPI, [13]UNLV, [14]Univ. Calgary, [15]Polish Academy of Sciences, [16]Geocontrols at NASA JSC, [17]USGS, [18]Brown Univ., [19]IRAP, [20]Indiana Univ.

Introduction: A primary reason for selecting Gale crater as the Mars Science Laboratory (MSL) *Curiosity* rover landing site was a clear mineralogical transition from Fe/Mg smectite in older strata to hydrated Mg sulfate salts in younger strata observed in orbital visible/shortwave-infrared reflectance data [e.g., 1,2]. This transition has been observed in other early-Hesperian terrains on Mars and has been hypothesized to signal a planet-wide change in climate from relatively warm and wet to cold and dry [e.g., 2,3]. *Curiosity* studied the sedimentology and geochemical and mineralogical composition of rocks in this “clay-sulfate transition” region from sols 3052 to 3572 (i.e., March 2021 to August 2022), with arrival at the sulfate unit on sol 3574. Here, we report on the mineralogical measurements made by the CheMin X-ray diffractometer of the six drill targets in the clay-sulfate transition and the first drill target in the sulfate unit. We use compositional data and sedimentological observations to interpret depositional and diagenetic environments and present hypotheses to explain the transition from clay minerals to hydrated Mg sulfates.

Drill targets: The six targets drilled in the clay-sulfate transition and their elevations include: Nontron (abbreviated NT, -4073.5 m), Bardou (BD, -4066.5 m), Pontours (PT, -4041.2 m), Maria Gordon (MG, -4016.1 m), Zechstein (-3992.0 m), and Avanavero (AV, -3910.0 m). Canaima (CA, -3879.8 m) was drilled from the sulfate unit in “Marker Band Valley” (Figure 1). NT was drilled from mudstone with faint laminations. BD was drilled from sandstone. PT was drilled from an interval with a strong diagenetic overprint such that grain size is indeterminate. MG, ZE, and AV were drilled from cross-stratified sandstone, and CA was drilled from a sandstone showing pinstripe lamination.

CheMin instrument and analyses of drill powders: CheMin is an X-ray diffractometer/X-ray fluorescence spectrometer that operates in transmission geometry with a Co X-ray source [4]. A few 10s of mg of rock powder are delivered from the drill bit to sample cells with Kapton or Mylar windows. Samples are typically analyzed for a total of 22 hours over three different nights. 2D diffraction patterns are summed circumferentially to create traditional 1D patterns [5]. Rietveld refinement and full-pattern fitting methods return quantitative mineralogy with a detection limit of ~1 wt.%, unit-cell parameters of major phases, and the amount of X-ray amorphous material. We estimate the composition of the amorphous component from mass balance calculations using CheMin-derived mineral abundances and crystal chemistry and bulk chemistry from the Alpha Particle X-ray Spectrometer [e.g., 6,7].

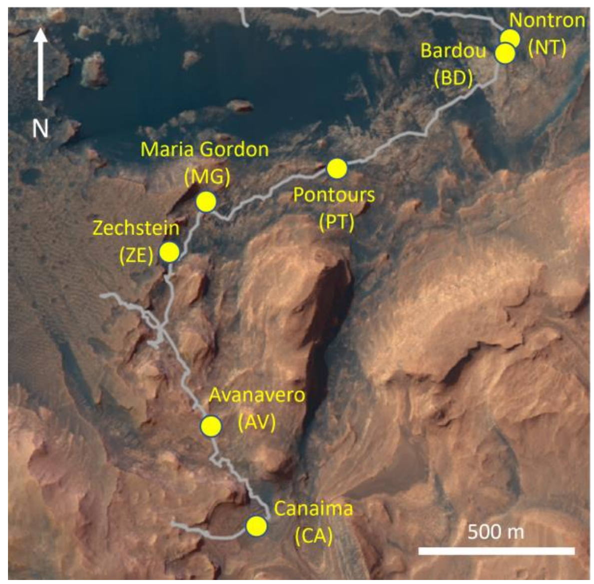

Figure 1. *Curiosity’s* traverse through the clay-sulfate transition (gray line) and location of drill targets.

Mineralogical changes across the clay-sulfate transition: CheMin data demonstrate substantial changes in phyllosilicate content and the type and abundance of Fe(III) oxides/oxhydroxides and sulfates along the clay-sulfate transition (Figure 2).

Phyllosilicate. A 10 Å phyllosilicate, consistent with collapsed montmorillonite (similar to what was found in previous drill targets in Glen Torridon), is abundant at the beginning of the transition and the base of the section in NT and BD. PT has a trace amount of 10 Å phyllosilicate, but all drill targets stratigraphically above PT lack phyllosilicate.

Fe(III) oxides/oxyhydroxides. Hematite is prevalent in all samples. Goethite was detected by CheMin for the first time in the mission at NT. There is a general increase in goethite abundance going up section.

Sulfates. Ca-sulfate minerals are present in all drill targets and include a combination of anhydrite, bassanite, and gypsum. Gypsum composes ~one third of the crystalline component of ZE. Crystalline polyhydrated Mg sulfate was detected by CheMin for the first time on the mission in CA. Amorphous Mg sulfate is also a substantial component of CA [7,8].

Interpretations of depositional and diagenetic environments: Compositional and sedimentological data from the clay-sulfate transition indicate this interval was marked by arid surface environments and groundwaters enriched in sulfate ~25% relative to underlying rocks. Phyllosilicate is prevalent in the fluvio-lacustrine deposits at the base of the clay-sulfate transition but is absent in the eolian cross-bedded and pinstripe laminated deposits above PT, suggesting phyllosilicate formation is tied to change in depositional environment. We hypothesize that aqueous environments at the base of the section had poor drainage, basic pH, and high activity of Si and Mg to promote neoformation of smectite [e.g., 9]. The drier climate above PT marked by eolian deposits did not have sufficient surface or groundwater to support phyllosilicate formation. The detection of goethite and its abundance toward the top of the section is consistent with a lower degree of diagenesis up section because goethite undergoes thermal dehydration to hematite [e.g., 10]. Alternatively, these phases may have formed together from ferrihydrite and can help us constrain pH [e.g., 11]. The groundwaters that moved through eolian deposits above PT were likely enriched in sulfate. The lack of physical attributes of evaporite deposits (e.g., evaporite mineral crystals or crystal molds) suggests the Ca and Mg sulfates are not primary precipitates in an interdune playa. Abundant Ca sulfates in ZE are likely in the matrix and veins, suggesting at least some of the Ca sulfates were precipitated during early diagenesis. Results from *Curiosity* thus far suggest the sulfate unit had a different genesis than the sulfate-rich evaporite deposits at Meridiani Planum [e.g., 12].

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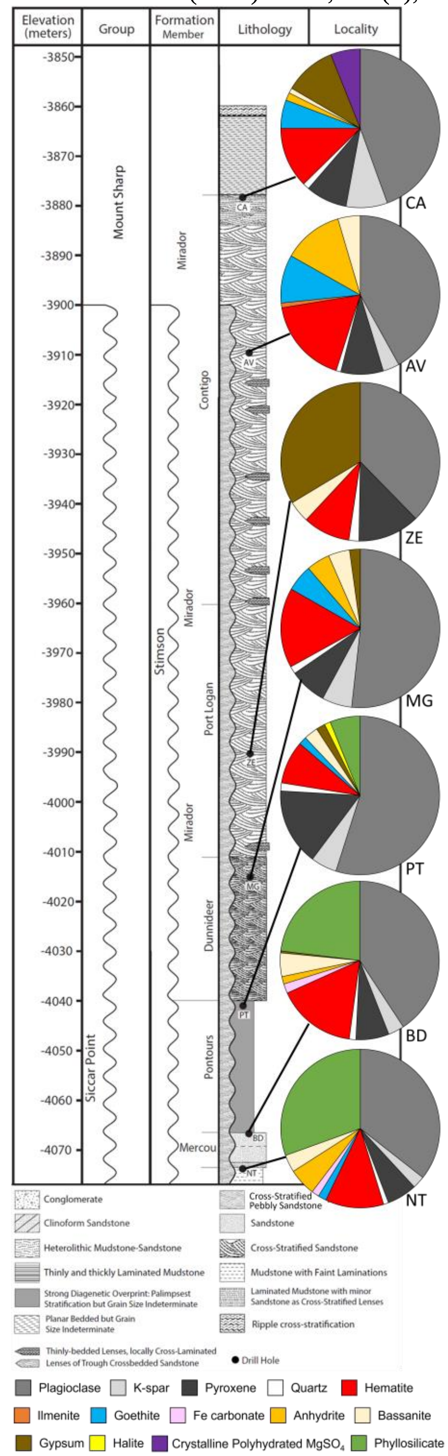

Figure 2. Strat column for the clay-sulfate transition through *Curiosity's* current location (credit: MSL sed-strat team). Pie diagrams show mineral abundances renormalized without the amorphous component.