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SULFATE-BEARING STRATA SEQUENCE EXTENDS EARLY MARS ENVIRONMENTS CONDUCTIVE TO PREBIOTIC EVOLUTION. W. Rapin¹, G. Dromart², J. Schieber³, B.C. Clark⁴, L. Kah⁵, D. Rubin⁶, S. Gupta⁷, A. Roberts⁷, G. Caravaca¹, L. Edgar⁸, R. Y. Sheppard⁹, M. Loche¹, E. Dehouck², P. Beck¹⁰, S. Le Mouélic¹¹, A. Bryk¹², W. E. Dietrich¹², P. Gasda¹³, O. Gasnault¹, N. Lanza¹³. ¹IRAP/UPS/CNRS, Toulouse, France (william.rapin@cnrs.fr), ²Univ. Lyon, LGL-TPE, ³DGS, Indiana Univ., ⁴Space Science Institute, CO, ⁵University of Tennessee, ⁶UC Santa Cruz, ⁷Imperial College London, ⁸USGS, ⁹IAS, ¹⁰IPAG/ISterre, ¹¹LPG, Nantes, ¹²UC Berkeley, ¹³LANL.

Introduction: Mars sedimentary record dates as far back as 4.3 Ga, perhaps earlier [1], and the early presence of habitable environments is now well-documented [2]. Yet, much more uncertain is whether early surface conditions were conducive to an independent emergence of life [3,4]. Prebiotic chemistry which may lead to incipient life forms is thought to be restricted not only to certain limited conditions, but may even require a specific succession of distinct environmental changes for it to succeed [5]. As such, it differs substantially from more broadly defined requirements for habitability.

After exploring strata dominated by clay-bearing mudstones in Gale crater, the Curiosity rover reached the sulfate-bearing unit, which is hundreds of meters thick and represents evidence for a major environmental transition characteristic of stratified terrains found in other regions across Mars [6]. At this transition data collected by the rover uncovered a new type of sulfate-enriched stratigraphic sequence.

Geochemistry and distribution of sulfates: The clay-sulfate transition succession is marked by the variable occurrence of bedrock with nodular texture associated with sulfate enrichments (Fig. 1). The rover analyzed the composition of three dominant bedrock components (Fig. 2): (i) a smooth host bedrock, drilled at multiple locations, which revealed the disappearance of clay minerals in X-ray diffraction (XRD) [7] (ii) bedrock with mm-scale nodular textures which became abundant within the sulfate-bearing unit ; (iii) a cm-scale nodular bedrock, which was not drilled due to its uneven surface, and showing Mg-sulfate enrichments as measured by ChemCam. Ca-sulfates are present in smooth host bedrock in variable amounts across the stratigraphy, but also sporadically as submillimeter heterogeneity within nodules as well as within dark-toned horizons, a bedrock facies associated with sodium and fluorine enrichments occurring intermittently in the upper sulfate-bearing unit [8]. Overall, the bulk bedrock (combining smooth and nodular) shows an increase in sulfate content relative to prior strata, nodular textures being a key component of that change (Fig. 1).

High-frequency wet-dry cycling: Unusual nodular textures have been observed within sulfate-bearing strata. In particular, it is observed forming regular patterns of centimetric polygonal ridges near the base of the succession (Fig. 2e). These sulfate-enriched ridges

are interpreted as exhumed columnar soils formed by sustained wet-dry cycles at the surface [9]. The presence of these paleosols across stratigraphic thickness implies that regular wet-dry conditions were maintained at least episodically in the long-term. Mature, nearly hexagonal, centimetric patterns indicate repeated surficial drying cycles of regular intensity, likely seasonal, but potentially also active on shorter time scales [10].

Water table fluctuations: The terrains orbitally defined as part of the clay-sulfate transition and leading upward to the sulfate-bearing unit show sedimentary structures consistent with a change towards generally drier paleoenvironments, yet with multiple indicators of locally and intermittently wet environments [13,14]. In particular, polygonal ridges in the basal section as well as lenses with wave ripple laminae in the upper section and within the Marker Band [15], a region-wide deflation surface. Importantly, the density of observed sulfate-enriched nodular bedrock is higher within wetter

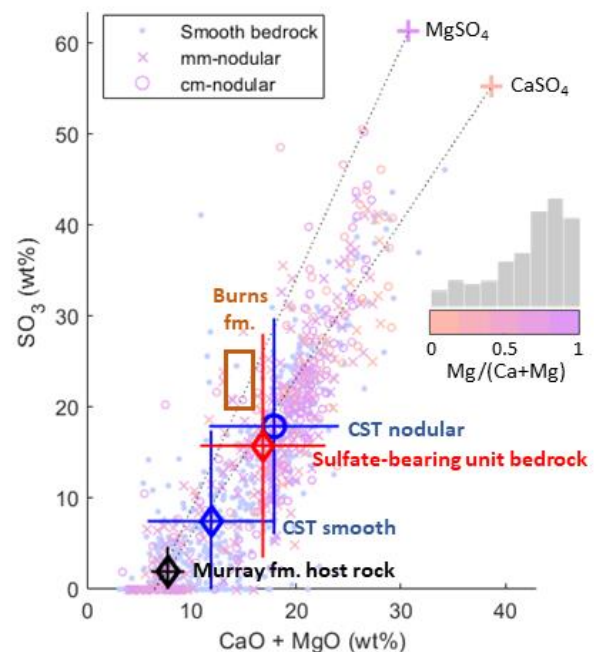


Figure 1: Sulfate content [11] as a function of MgO and CaO content measured at submillimeter-scale by ChemCam, with hydrated Mg/Ca-sulfates references. Average compositions for bedrock in the clay-sulfate transition (CST) as either nodular or smooth show the specific increase of Ca/Mg-sulfate enrichments, error bars indicate standard deviation. Burns fm. (Meridiani Planum) shows excess sulfate content related to jarosite and Fe-sulfates [12].

intervals [16]. This association and the general stratigraphic control on the type and density of sulfate-enriched nodules is consistent with their formation within the sediments due to evaporation where a sulfate-rich water table reached or came close to the surface in a variably dry climate. This type of intrasediment salt growth, producing nodular enrichments with 30 to 50 wt.% Ca/Mg-sulfates, were also considered for intermittent centimetric nodular horizons within underlying Murray formation bedrock [11]. The now widespread occurrence of such enrichment within the hundreds meter thick sulfate-bearing unit suggests this mode of saline water table fluctuation and evaporation may be a dominant form of sulfate deposition for Gale Mt Sharp group, and related sulfate-bearing sedimentary units on Mars.

Discussion: Gale's sulfate-bearing strata may appear similar to the Burns fm. evaporites in terms of bulk abundance (Fig. 1), but Gale unique stratigraphic and lithologic distribution as well as associated mineral assemblages provides new perspectives on environments of the Noachian-Hesperian transition. While jarosite was identified and widespread in the Burns fm., indicating a highly acidic environment, it is notably absent in Gale's sulfate-bearing strata. Instead, siderite has been identified in multiple recent drill samples and interpreted as chemical sediment [17], indicating neutral to low pH, and ruling out strongly oxidizing environments [18]. Curiosity data now provides new evidence on the episodicity of Mars'

hydroclimate. On long time scales, the climate has been variably dry, and sulfate deposits may have tracked wet surface environments and saline water table fluctuations and evaporation. On shorter time scales, these strata provide the first tangible evidence for sustained wet-dry cycling, a process known to strongly promote prebiotic polymerization [19,20]. Widespread documentation of preserved indigenous organics in Gale crater sediments [21] combined to the evidence of sustained drying cycles at various time scales, supports the conclusion that conditions were here conducive to prebiotic chemical evolution, a record that is no longer available on Earth [22]. Upcoming exploration of upper sulfate-bearing strata will evaluate the long-term prevalence and evolution of these conditions on early Mars.

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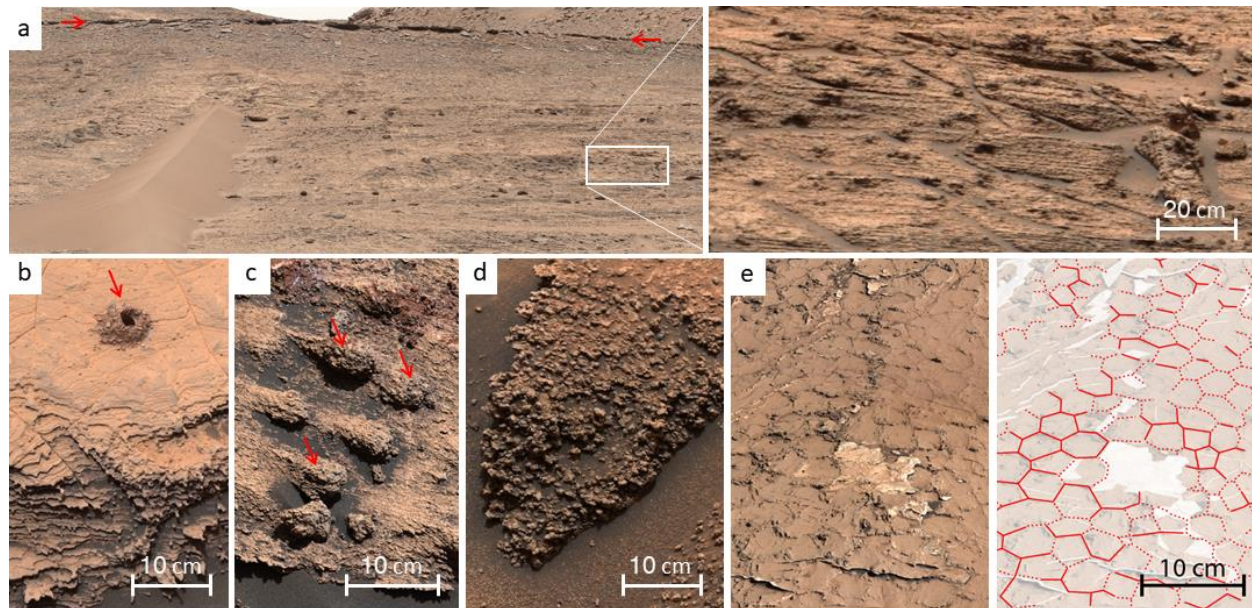


Figure 2: Exposed bedrock of Gale sulfate-bearing unit below the Marker Band regional erosion-resistant surface (red arrows), forming a densely coalescent nodular sulfate-enriched texture within more than a decameter of stratal thickness (a). Notable nodular bedrock (b-e) highlights the diversity of textures observed with distinct sulfate-enriched composition. Drill sample at Canaima (arrow) with a mm-scale nodular texture (b); cm-scale concretions (arrows) (c); saturated overprint of hydrated Mg-sulfate-rich nodules (d); regular pattern of polygonal ridges (e).