DISTRIBUTION OF MINERALIZAED VEINS FROM YELLOWKNIFE BAY TO MOUNT SHARP, GALE CRATER, MARS: INSIGHT FROM TEXTURAL AND COMPOSITIONAL VARIATION

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Introduction: A diverse suite of diagenetic features has been identified by the Curiosity rover during its traverse from Bradbury Landing to Yellowknife Bay and onward to the foothills of Mount Sharp. Such features include nodules, raised ridges, and mineral-filled fractures [1,2,3]. Among the diagenetic features at Gale Crater, mineralized fractures, or veins, occur in almost every unit along Curiosity's traverse. Understanding the origin of these veins will provide a critical constraint on the range of post-depositional fluids that may have interacted with the sedimentary package preserved within Gale crater.

Data Collection: A detailed survey of images was carried out to reconstruct the distribution, texture, and chemistry of mineralized veins at Gale Crater from Yellowknife Bay to Mount Sharp (from approximately sols 180-820). Images acquired from Mastcam, MAHLI, ChemCam/RMI, and Navcam were used to define the distribution and texture of mineralized veins, and data from ChemCam/LIBS and CheMin were used to determine potential compositions.

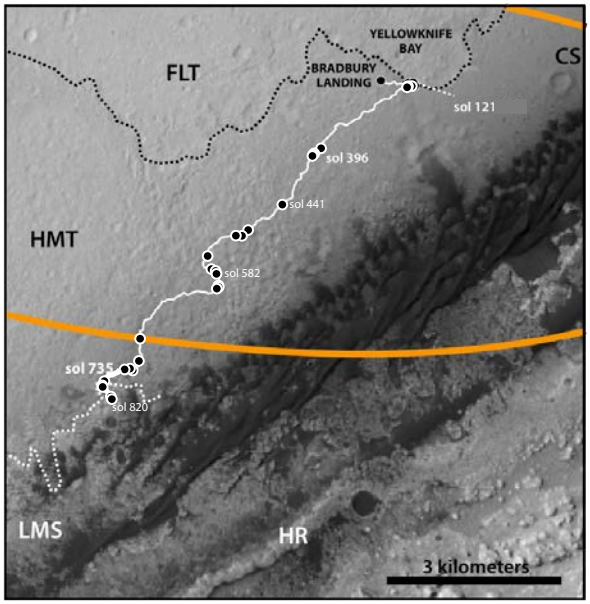

Figure 1. Curiosity's traverse from Bradbury Landing to its position on sol 820. strata of lower Mount Sharp lies south of Bradbury Rise (white dotted line). Black dots represent positions of well defined mineralized veins.

Spatial Distribution of Mineralized Veins: Mineralized veins were first clearly evident in strata of the Yellowknife Bay formation. This formation represents a 5-meter-thick section of clay-rich lacustrine deposits, overlain by deposits of fluvial origin [4]. During the >400 sol traverse across Bradbury Rise (Fig. 1), Curiosity imaged a variety of mineralized veins. This traverse represents nearly 100 meters of vertical section. An additional suite of mineralized veins has been well documented in the Pahrump locality (sols 753-820), which represents strata of lowermost Mount Sharp.

Observations at Yellowknife Bay: Light-toned veins occur throughout the 5-meter-thick section of Yellowknife Bay strata. Mineralized veins are most abundant in the mudstone of the Sheepbed member, where two distinct families of veins occur. Arcuate, intersecting fractures (10-20 cm in length) that have distinct, spindle terminations—termed raised ridges—develop only within the Sheepbed mudstone, and are filled with a distinct, erosionally-resistant, multi-generational cement [3]. A second generation of mineralized veins, consisting of predominantly erosionally recessive, bright white mineral fill is also present within the Sheepbed mudstone, but occurs in the Gillespie and Glenelg members as well (Fig. 2). Across all three units, veins do not appear to exhibit preferred orientations and often cross-cut earlier diagenetic features, such as nodules and raised ridges. ChemCam elemental analyses confirm the presence of calcium-rich sulfate at vein locations, with varying states of hydration [1].

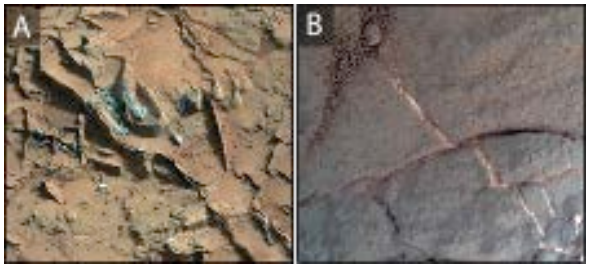

Figure 2. Diversity of light-toned veins in the Sheepbed mudstone unit at Yellowknife Bay, Gale Crater. (A) Raised ridges with erosionally-resistant cement fill (Mastcam image 0164MR0008830070201519E01), (B) Erosionally-recessive, bright white, mineralized fill (from MAHLI image 0161MH0001680020101783C00).

Observations along Bradbury Rise: Veins remain a pervasive feature of sedimentary rocks on Curiosity's trek toward Mount Sharp. Across Bradbury Rise, mineralized veins are defined by a variety of textures. Veins are predominantly straight, are often oriented near vertically, and cross-cut depositional features of predominantly fine-grained host-rock. These veins can be either erosionally resistant or erosionally recessive (Fig. 3), are typically light-toned with little texture to mineral infilling. It is unclear, at present, to what extent erosional resistance of mineralized veins reflects the vein-filling material versus the host rock material. A distinct suite of veins that show granular textures cross-cut conglomerates, and will not be detailed here.

Across Bradbury Rise, ChemCam data confirm the presence of calcium sulfate in veins, especially at Tingey on sol 407 [5]. Sol 624 ChemCam LIBS data taken at the Windjana waypoint also identify Mn (and potentially Zn) enriched relative to previous detections.

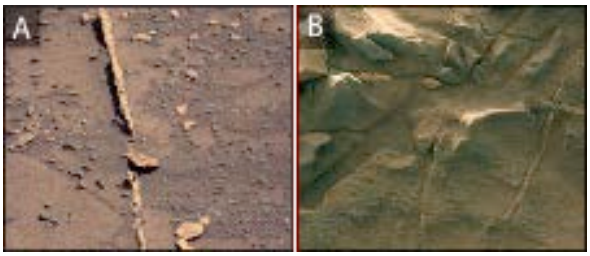

Figure 3. Diversity of veins observed during Curiosity's traverse across Bradbury rise. Light-toned, mineralized veins can be either (A) erosionally resistant (0538MR-0021220010303447E01), as well as (B) more erosionally recessive (0706MR0029980000402464C00).

Observations from Lower Mount Sharp: On sol 753, Curiosity entered the first exposures of lower Mount Sharp. At the Pahrump locality, mineralized veins (Fig. 4) occur in association with all host-tock lithologies. Mineralized veins are represented by both recessive and resistant mineral fills. Light-toned veins are predominantly recessive, except where they are preserved from erosion by overlying outcrop (Fig. 4C). More resistant mineral infilling, with a slightly darker tone occurs in conjunction with diagenetic crystal features. In both cases, fractures are predominantly vertical, although multiple orientations are observed. Discrete ligh-toned veins also undergo changes in orientation as they intersect different host materials (e.g. mudstone to cross-bedded sandstone).

ChemCam LIBS data were taken on light-toned veins at Pahrump and suggest the presence of enriched sulfur and calcium with respect to the host rock. Data suggest a nearly pure calcium sulfate mineral phase, distinct from the darker-toned veins that are enriched in magnesium, sulfate, and trace metals (Ni, Zn).

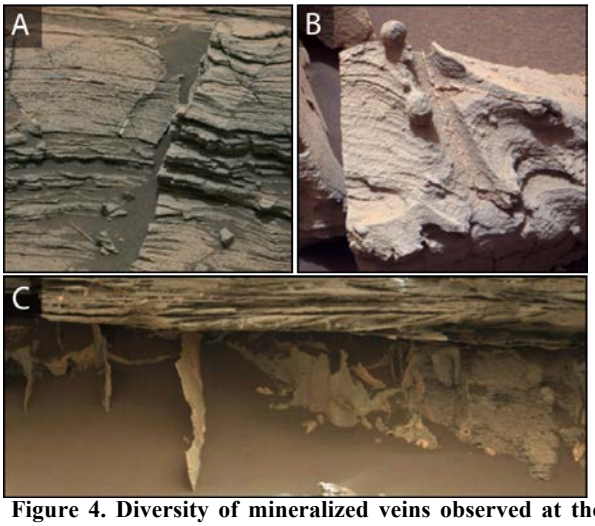

Figure 4. Diversity of mineralized veins observed at the Pahrump locality. Mineralized veins are represented by both (A, B) erosionally-recessive and erosionally-resistant light toned material (0794MR0034650170500135E01, 0782MR0034150000204174E01). Differences in erosional resistance around vein material (C) provide direct evidence for interaction of fluids with host rock materials (0796MR0034760190500165E01).

Discussion and Interpretation: The Curiosity rover observed mineralized veins in nearly every depositional unit encountered in Gale Crater. Together, these strata occur over a vertical distance of nearly 100 meters. Although several different textures of veins are observed, the most common are erosionally recessive to resistant, light-toned veins. In most localities where these veins have been analyzed by geochemical instruments onboard Curiosity, data suggest calcium sulfate mineralization. Such veins may represent the overpressuring of pore-fluids and hydrofracturing of sediments during burial diagenesis and may reflect remobilization of gypsum from some of the earliest sedimentary units within Gale Crater.

More localized veins, such as granular veins and those associated with dendritic features at Pahrump, suggest multiple origins and fluid events. Understanding vein distribution and vein fill chemistry will help constrain water-rock interactions and the complex stratigraphic relationships in Gale Crater.

References: [1] Nachon M. et al. (2014) *JGR Planets*, 119, 1-26. [2] Stack, K.M. et al. (2015) *JGR Planets*, 119, 1637-1664. [3] Siebach K.L. et al (2014) JGR Planets, 119, 1597-1613. [4] Grotzinger J.P. et al. (2014) *Science*, 343, 10.1126/science.1242777. [5] Vasavada A.R. et al. (2014) *JGR Planets*, 119, 1134-1161.