FORMATION OF BOXWORK STRUCTURES ON MOUNT SHARP, GALE CRATER, MARS.

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Introduction: The Mars Science Laboratory *Curiosity*'s primary objective is to search for potentially habitable environments, particularly those where organic carbon may have been preserved. Preservation of organic materials on Earth is most often associated with rapid mineralization of deposits. Here we report a set of large-scale boxwork structures in a sedimentary layer on Mount Sharp, Gale Crater's central mound, that are indicative of extensive groundwater cementation and represent a possibly habitable environment where organic molecules may have been preserved (Figure 1). Mapping of the structures is used to constrain a minimum volume of water at this site, which is recommended for *Curiosity's* future traverse.

Methods: Mapping of the fracture networks was completed by overlaying HiRISE, CTX, and THEMIS imagery over MOLA topography. HiRISE Digital Terrain Models (DTMs) were added where available.

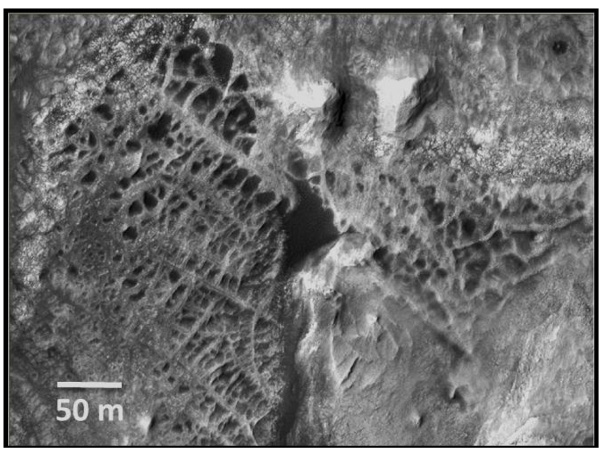

Figure 1. Example of boxwork structures on Mount Sharp, showing pattern of polygonal light-toned ridges separated by topographic lows full of windblown dark sediment.

Observations: Resistant fracture networks on Mount Sharp were first identified and described by Anderson and Bell and Thomson and Bridges [1,2,3]. These networks are found in the dark-toned layered yardang-forming unit of the mound [2], and in the upper member of the lower mound-forming unit as mapped by Milliken [4]. This unit shows a dominant sulfate signature in CRISM data [4].

The resistant fractures were mapped over 1 km^2 of the surface within a sedimentary layer with an average elevation of -3620 m, 880 m above *Curiosity's* landing site in the bottom of Gale Crater. The stratigraphic layer with fracture fills is approximately 40 m thick, abruptly overlain by light-toned fractured rocks and dissipating down into alternating resistant and covered intervals.

The fracture network is expressed as light-toned ridges separated by shallow depressions filled with dark windblown sediment. Ridges average 4-5 m in width and are sometimes marked by a thin dark strip down the center of the ridge. Hollows are usually 0.2-0.5 m deep, but can be separated from the ridges by steep walls up to 3.5 m deep.

Interpretations: The resistant fracture networks are interpreted as boxwork structures, formed when cements filled existing pore spaces and fractures in fractured rock, and these cements were left as topographic ridges after erosion. Boxwork structures were first described in Wind Cave, South Dakota, U.S. [5]. This interpretation is supported by previous work on Mount Sharp [2,3].

Boxwork formation implies a series of post-depositional processes at this sedimentary interval. Initial sediments were lithified, then fractured, then buried and cements were deposited. Lithification of initial sediments is most likely related to initial water-based cementation of deposits. Fracturing likely occurred due to contraction stresses from thermal changes or dehydration of the surface, and based on the fracture geometry and organization, as well as the lack of similar fracture in the unit above the boxwork, the boxwork layer was probably exposed at the surface when it was fractured.

The dark central line on some of the ridges is diagnostic of cementation in the phreatic groundwater zone, indicating that this layer was buried again when the fractures were cemented and cementation occurred evenly on all available surfaces. From orbital data, it is unclear whether the dark line is a still-open fracture or a dark-toned fracture fill, and it is also unknown whether the light-toned ridges are composed of fracture-filling cements or pore-occluding cements, so there are 4 possible interpretations of the light-toned ridges. However, since the dark lines are a relatively small fraction of the ridges, the two end-member hypotheses are that either (a) the ridges are entirely fracture-filling cement, or (b) the ridges are primarily host rock, with pore-occluding cements making up about 30% of the ridges.

Water Volume Estimation: The boxwork structures are unique on Mars because they represent a volume of diagenetic cements measureable from orbital data. Work on carbonate reefs on Earth has provided a structure for doing "pore-volume" calculations, or calculating the number of equivalent volumes of water required to fill a pore space with cement, based on a desire to understand the time required to deposit cement given a groundwater flow rate (e.g., [6,7]). For this calculation, a cement composition is assumed based on a brine derived from acid-sulfate weathering of synthetic Martian basalts [8] and selected based on its similarity to cemented rocks observed by the Opportunity rover [9,10].

Based on the mapped spatial area of boxwork ridges, assumed 5 m thickness of the fractures (based on the thickness of the resistant layers that show the fractures), and the two endmember hypotheses for ridge formation, the minimum volume of diagenetic cements is 1.75×10^6 m^3 for fracture-filling cement, or 0.52×10^6 m^3 for pore-occluding cement. This is a minimum cement volume because the fractures were observed to extend down through ~40 m of stratigraphy (although some units within were covered) and the boxwork unit may well be expected to continue in unexposed areas within Mount Sharp.

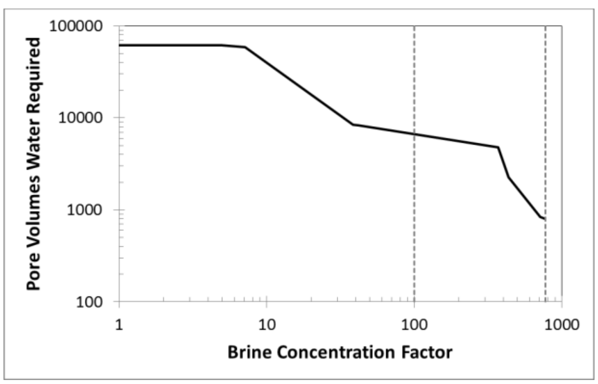

Figure 2. Log-log plot showing the number of equivalent volumes of water required to deposit a volume of cement based on the modeled evaporation of a Martian brine [12]. The more the brine evaporates, the more cement evolved per volume of water. The two vertical lines are selected examples for estimating the specific volume of water required to form the visible cements based on 99% evaporation and 99.86% evaporation.

The evaporation of the selected brine was modeled by Tosca in Geochemists Workbench [10] to determine the unit volume of cement precipitated per unit volume of water (Figure 2). If 99.0 to 99.86% of the water evaporated, 6600 to 800 pore volumes of water would be required per unit of cement. For the measured boxwork ridges, this implies a minimum of 1.4 km^3 (fracture-filling cements) or 0.42 km^3 (pore-occluding cements) of water was present at this interval to form the mapped boxwork. This is a significant volume of water depositing cements in a location *Curiosity* could drive to, and this site is recommended as a potentially habitable environment for *Curiosity* to visit and investigate.

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