MASS MOVEMENTS AND DEBRIS DEPOSITS IN THE GRAND CANYON AND GEDIZ VALLIS, GALE CRATER, MARS.

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Introduction: Curiosity during its extended mission in Aeolia Mons (Mount Sharp) will traverse Gediz Vallis (GV) and explore a debris ridge that fills an interior valley (Fig. 1). The ridge is similar to well-preserved debris deposits on the walls of the Grand Canyon (GC) on western side of Aeolis Mons (Figs. 2-4). This abstract focuses on the characteristics of the GV and GC mass movements and debris deposits, and why water is required for their formation.

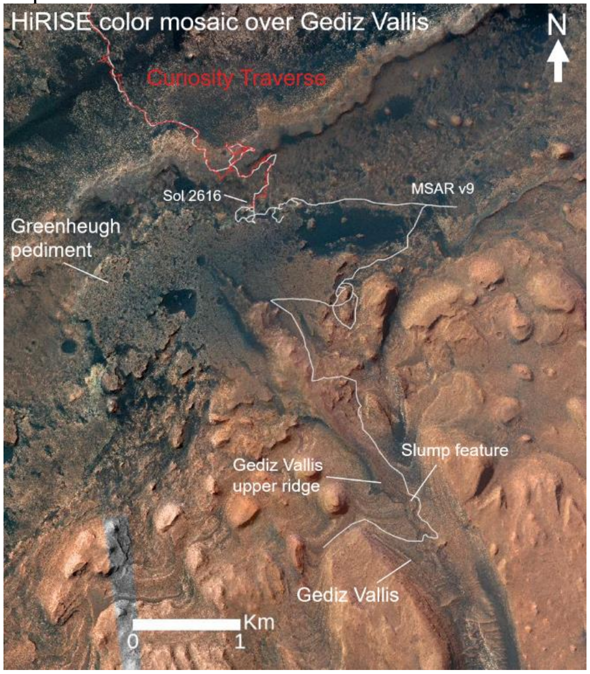

Figure 1: HiRISE mosaic over Gediz Vallis and Greenheugh pediment on northern Aeolis Mons. Curiosity's traverse is shown through sol 2616. The planned Mount Sharp Ascent Route (MSAR_9) is shown in white. A slump feature within the Gediz Vallis upper ridge is labeled.

Gediz Vallis Upper Ridge: GV is a U-shaped valley that is ~10 km long, ~0.9 km wide, and 100 m deep [1]. The narrow ridge within a central narrow valley cut into GV is ~100 m wide and varies in height but is typically ~10 m. Blocks ranging up to ~20 m wide are evident in the poorly sorted debris that comprise the ridge. In addition, several slump blocks are evident on the ridge sides. CRISM spectral data indicate the ridge debris consists of polyhydrated sulfates similar to valley wall outcrops [1].

Grand Canyon: GC is ~35 km long, ~1.8 km, wide, and ~250 m deep [1]. There are 13 identified mass movement features within the canyon, but only the five best preserved are discussed here. Some mass movements have channeled into the surrounding strata, such as Feature 1 (Figure 3). Most of these features connect to interior debris ridges. CRISM spectral data indicate the debris deposits are polyhydrated sulfates similar to the valley wall deposits. (Figs. 2-4). Features 1 & 2 have well preserved scarps at their upper extent and Feature 1 has levees, (Figure 3). Features 11, 12, and 13 also have scarps at their upper extent, and Feature 12 preserves levee remnants, however they are more eroded than the levees associated with Feature 1 (Figure 4).

Formation Mechanisms: The geomorphology and mineralogy of the debris deposits within GV and GC, the levees in GC, and the relatively low slopes for the features suggest that water was needed to initiate failure and cause downhill movement. Slopes are generally too low to have caused dry mass movement and levee formation [2]. The amount of pore water needed to initiate failure was quantified by us using the steady state infinite-slope model (SSISM), which assumes surface-parallel flow and steady-state runoff [3].

Specifically, the SSISM [3] predicts the slope at which failure will occur based on Mohr-Coulomb material properties (cohesion and angle of internal friction) at the incipient failure plane, the and the degree of water saturation needed for a given slope to cause failure. For specific Mohr-Coulomb properties and slope the model defines the water saturation (i.e. the buoyancy) needed to reach the Mohr-Coulomb failure criterion.

SSISM models were run with varying Mohr-Coulomb properties and slopes and results examined within the context of well-preserved slumps, channels, and deposits (Fig. 5). Results imply that the failure planes that led to mass movements had low values of cohesion and for the low slope features likely involved exfiltration of water (i.e., surface water) as opposed to failure due to buoyancy associated with subsaturated conditions.

Discussion: The well-preserved GC channels, levees, and debris deposits are interpreted to have been formed as infiltrating ground waters led to increased buoyancy, thereby causing the slope failures. The deposits assembled on the GC floor and migrated down the canyon. The morphology of the mass movements and presence of channels and levees depends on the amount of groundwater that was available during slope failure. The GC features also provide insight into the origin of the GV ridge deposits in that they are interpreted to be the wind-eroded remnants of a once more extensive set of debris deposits and associated valley wall channel and levee systems.

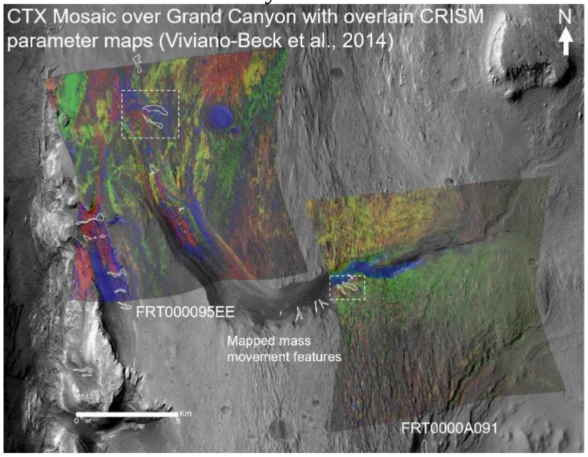

Figure 2: CTX mosaic over the Grand Canyon on western Aeolis Mons. Overlain are parameter maps from CRISM scenes FRT000095EE and FRT0000A091. RGB as hydrated sulfates,1.9 μm hydration, and high calcium pyroxene [4]. Channels and debris deposits are outlined in white. The dashed boxes show the locations of Figs. 3 and 4.

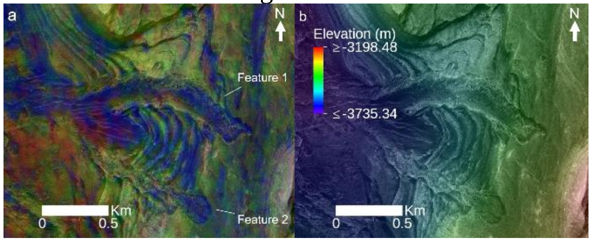

Figure 3: a) CRISM-based parameter map overlain on a HiRISE image of mass movement Features 1 and 2. b) Color-coded elevations overlain on the same area. Slopes for the two features are 7.4° and 11.6° at their heads.

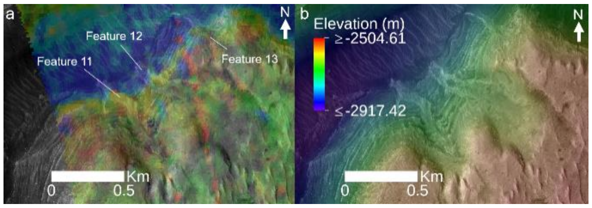

Figure 4: a) Parameter map overlain on HiRISE image of mass movement Features 11, 12, and 13. b) Elevation overlain on the same area. Slopes for the features are 13°, 11.5° and 18.9° at their heads.

It is also likely that the preservation of the debris deposits in GV and GC is associated with the high solubility of Mg-bearing sulfate minerals (Fig. 6). Sulfate dissolution and transfer as solutes within the debris would lead to cementation as the pore waters evaporated and/or water ice sublimated. When Curiosity traverses to the GV ridge deposits the hypotheses presented in this abstract will be tested using the rover's remote sensing and contact science capabilities.

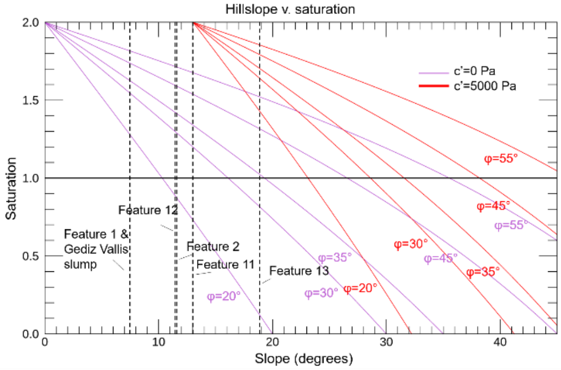

Figure 5: Plot showing the saturation needed to cause failure for different hillslopes, cohesion values, and angles of internal friction. Cohesion of 0 Pa is shown in purple, and cohesion of 5 kPa is shown in red. The mean slopes just uphill of the best-preserved debris features are indicated with the black dashed lines. Saturation values >1 correspond to exfiltration of ground water and associated run-off, as opposed to sub-saturation of pore water.

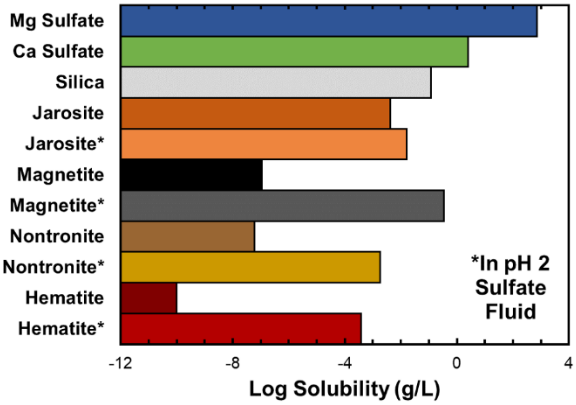

Figure 6: Plot showing the log solubility of relevant secondary minerals in Martian environments. Minerals without an asterisk are showing the solubility in pH 7 water. Minerals with the asterisk are showing solubility in a pH 2 solution.

References: [1] Hughes M. N. et al. (2019) *Mars IX*, Abstract #6082. [2] Takahashi T. (1978) *Journal of the Hydraulics Division*, *104*(8), 1153-1169. [3] Dietrich W. E. et al. (1993) *Hydrological Processes*, *9*, 383-400. [4] Viviano-Beck C. E. et al. (2014) *JGR:P*, *119*, 1403-1431.