OBSERVATIONS OF HER DESHER AND NIRGAL VALLES: AN INTEGRATED GEOMORPHIC, STRUCTURAL AND MINERALOGIC EVALUATION.

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Introduction: A widespread Fe/Mg-phyllosilicate-bearing layer identified in northwest Noachis Terra [1] is exposed along the length of Nirgal and Her Desher Valles [2]. New analyses are consistent with the phyllosilicates having been originally formed by pedogenesis, but then altered to hematite/sulfate by interaction with acidic groundwater channeled through structural controls.

Introduction: NW Noachis Terra is a highland cratered plain on Mars, extending from 20º to 80ºS latitude and 55ºW to 30ºE longitude. Two small valley systems incise NW Noachis Terra: Her Desher and Nirgal Valles (Fig 1). Nirgal is a tributary of Uzboi Vallis, while Her Desher is an isolated valley that does not obviously connect to any outlet. Both valleys are geomorphically more similar to valleys formed by groundwater sapping, as opposed to valleys formed by overland flow [3-7]. However, [8] questioned the ability of groundwater seepage to erode valleys into bedrock. We present geomorphic, structural and mineralogic evidence that suggests that these valleys were indeed formed due to groundwater processes.

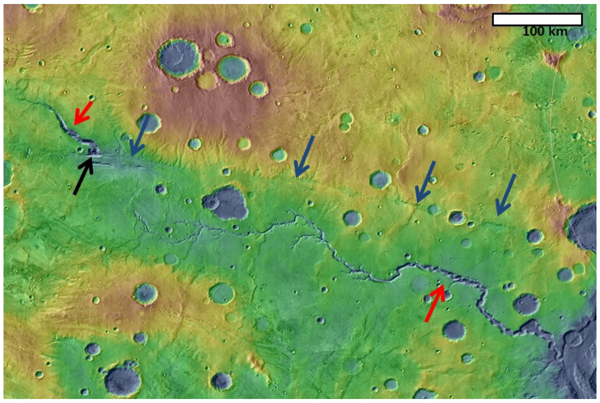

Figure 1. MOLA topography draped over THEMIS daytime mosaic of Nirgal (lower right) and Her Desher Valles (upper left). Red arrows point to portions of the valleys that are aligned sub-parallel to the regional Tharsis-radial extensional features (blue arrows). Black arrow points region of Her Desher Vallis where the valley abruptly terminates against the regional Tharsis-radial extensional features.

Geomorphic Observations: Both Nirgal and Her Desher Valles have U-shaped cross-sections, as opposed to the V-shape common to fluvial valleys [5]. They also has amphitheatre-headed source regions and tributaries [5-7], as opposed to the tapered and gradual source regions associated with fluvial valleys. Nirgal Vallis has a uniform valley width to depth ratio [5, 6], not an increasing valley width as is expected for a valley fed by overland flow. Nirgal's tributaries have a geometry specific to terrestrial groundwater sapping systems [7]. While roughly the same width along most of its length, Her Desher tapers to a point at its northern end and widens to a semi-circular pool-like feature at its southern end; it has no tributaries.

Structural Observations: There is evidence of strong circum-Tharsis structural control of both Niral and Her Desher (Fig. 1 red arrows). The main channel of Nirgal trends sub-parallel to nearby Tharsis-radial graben (Fig. 1, blue arrows), with abrupt ~90º bends along the length of the valley; many of Nirgal's tributaries trend parallel to nearby circum-Tharsis wrinkle ridges. Her Desher also shows sharp 90º bends along its length; portions of the valley align parallel to the regional Tharsis-radial graben.

Faults play an integral role in the formation of groundwater traps, acting as barriers and/or conduits to flow. Her Desher shows evidence of the structural trapping of water. The valley abruptly terminates against these graben (Fig. 1, black arrow), perhaps causing the formation of the pool-like feature at the valley's southern end. Subtle outflow channels just to the north of Her Desher and Nirgal also terminate at the regional Tharsis-radial graben, suggesting a major water trap and recharge site for a groundwater reservoir.

Mineralogic Observations: Nirgal Vallis, Her Desher Vallis and nearby craters all expose the same Fe/Mg-phyllosilicate-bearing layer, with a relatively broadened absorption at ~2.3 μm that suggests a mixture of nontronite and saponite or Mg exchange for Fe in the hydroxyl site of the phyllosilicate phase. New analyses of MTRDR hyperspectral images of Her Desher (Fig. 2) and Nirgal indicate that hematite and/or polyhydrated sulfate are present in the phyllosilicate layer. In Her Desher, the hematite/sulfate-bearing material comprises approximately 50% (by volume) of the altered layer and is present both above and below the smectite along the entire length of the valley. While the hematite/sulfate can be observed in the alteration layer in Nirgal, its exposure is only ~10% that of the smectite and while it is present in some areas, it is lacking in others.

Hydrological modeling: A source and supply of groundwater of sufficient size to erode the volume of Nirgal and Her Desher would require an integrated hydrological system of substantial extent. Probable brecciation of the Martian subsurface and known faulting of the NW Noachis Terra region could allow for groundwater flow through the basaltic materials as a hard rock aquifer.

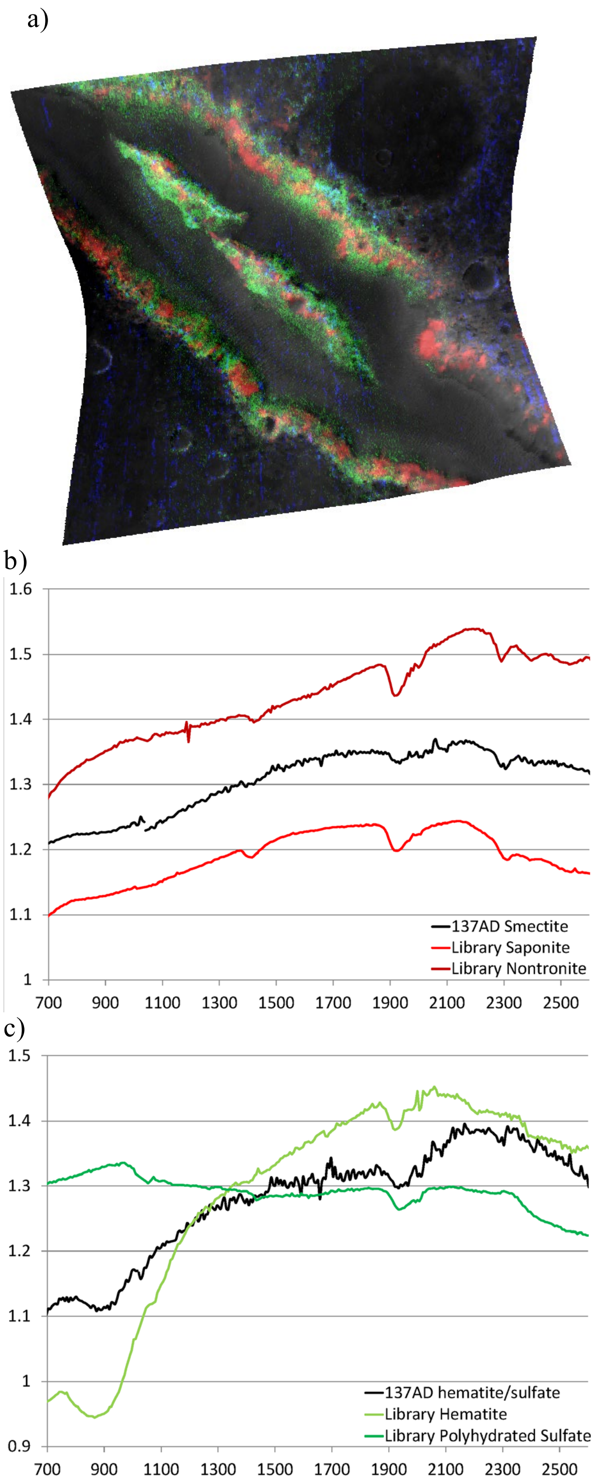

Figure 2. a) FRT 137AD summary parameter image of Her Desher Vallis. Red = D2300; Green = BD860_2; blue = SINDEX. Designed to emphasize the locations of Fe/Mg smectite (red) and hematite/sulfate (green). b) FRT 137AD spectra of "red" material, compared to library spectra of saponite and nontronite. c) FRT 137AD spectra of "green" material, compared to library spectra of hematite and polyhydrated sulfate.

Tectonic activity, such as that associated with the Tharsis bulge, can result in pressurization of surrounding aquifers. Numerical groundwater models suggest that a Tharsis source region would likely feed groundwater flow through fracture systems in NW Noachis Terra [6, 9], providing a source of water to form Her Desher and Nirgal Valles. One model specifically predicts groundwater upwelling along Nirgal Vallis [9].

Discussion: These observations are consistent with acidic groundwater converting an established phyllosilicate-bearing layer into hematite/sulfate. Mildly acidic aqueous solutions are known to convert ferrous smectites into mixtures of hematite and nontronite [10]. And phyllosilicates can weather to sulfates in the presence of sulfur-rich, acidic waters [11].

The hematite/sulfate in Her Desher is identified both above and below the smectite. This suggests that the hematite/sulfate alteration cannot be due to top-down processes, as it would then be found only above the smectites. Instead, it is more consistent with the observations that the conversion to hematite/sulfate worked its way in from the margins of the alteration layer, with smectite remaining unaltered in the interior

In addition, the percentage of hematite/sulfate is higher with proximity to Tharsis. There are more exposures in Her Desher than in Nirgal, and also more in western Nirgal than in eastern. This is consistent with the hematite/sulfate forming as an acidic, sulfur-rich groundwater flowed through an established phyllosilicate-bearing layer, converting some of the pre-existing smectite into hematite/sulfate. As sulfur ions were utilized in alteration the groundwater would become less acidic, resulting in fewer deposits of hematite/sulfate with distance from Tharsis.

Analysis of the regional structural controls and the mineralogy explains how groundwater sapping channels could have formed in the basaltic bedrock of NW Noachis Terra. While it is unlikely that groundwater seepage could erode valleys into bedrock [8], basalt previously altered into pedogenic soils would be more conducive to groundwater sapping channel formation

References: [1] LeDeit L. et al. (2012) *JGR*, doi: 10.1029/2011JE003983. [2] Buczkowski D. L. et al. (2010) *LPSC XLI*, Abs. #1458. [3] Baker V. R. (1982) *The Channels of Mars*, Univ. Texas Press. [4] Carr M. H. (1996) *Water on Mars*, Oxford Univ. Press. [5] Jaumann R. and Reiss D. (2002) *LPSC XXXIII*, Abs. #1579. [6] Harrison K. and Grimm R. (2005), *JGR*, 110, E12S16. [7] Glines, N. and Fasset, C. (2013) *LPSC XLIV*, Abs. #2011. [8] Lamb M. P., et al. (2006) *JGR*, 111, doi: 10.1029/2005JE002663. [9] Andrews-Hanna J. C. and Lewis K. W. (2011) *JGR*, 116, doi: 10.1029/2010JE003709. [10] Chemtob S. M. et al. (2017) *JGR* 122, doi: 10.1002/2017JE005331. [11] Altheide T. et al. (2010) *Geochim. et Cosmochim. Acta*, 74, pp. 6232-6248.