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Terrestrial Saharan analogues to examine the groundwater origin of theater-headed valleys on Mars

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Abstract: Understanding the mechanism of formation of fluvial landforms on Mars, is essential for a proper assessment of its paleoclimatic and current hydrologic conditions. The origin of Martian theater-headed valleys (THV) has long been a subject of debate with several hypotheses including groundwater sapping, mega-flooding, lava flows, and landslides. We explore herein the similarities in geometry, geomorphological and geological associations between THV in the Sahara and in Ius Chasma to support a common groundwater sapping origin. Evidence include: (1) similar morphometric characteristics including theater-like heads, stubby looking geometry, propagation along fractures and occurrence along rock walls; (2) similar geomorphological settings including very low upslope contributing areas compare to minimum eroded volumes, lack of well-developed stream networks, widespread distribution along escarpments and absence of flood deposits; and (3) similar geological associations such as occurrence in highly faulted areas and association with hydrated salts in the form of layers and or veins. These findings support the hypothesis that long-lasting groundwater processes may have contributed to the formation of these valleys on Mars rather than intensive short-lived processes.

1. **Introduction:** The original groundwater sapping hypothesis is challenged by the capability of springs to cut canyons into massive rocks and alternatively mega-floods and landslides were suggested [1]. On Earth however, widespread THV cutting through the carbonate plateaus in the Sahara are confirmed to be of long-lasting groundwater processes based on recent isotopic, geochemical and hydrogeological evidences [2]. Herein, we constraint the geomorphological, lithological and textural characteristics of THV in the Eastern Sahara as a limited analog to the THV in Ius Chasma using field-supported structural and textural mapping derived from ALOS PalSAR, Landsat-8 scenes and similar settings on Mars using, MOLA and HRSC images.

2. Geomorphological similarities: THV in the Sahara and in Ius Chasma have similar morphometric characteristics (Fig. 1; insets) including theatre-like heads, stubby looking geometry, propagation along fractures and occurrence along rock walls. Additionally, THV in both areas occur along plateau escarpments with regional gradients sloping away from the THV locations (Fig. 1). This setting results in minimizing the contribution of the surface runoff to the THV locations. We derived a new geomorphological index by dividing the upslope contributing area by the minimum eroded volume across different THV in Ius Chasma and in the Sahara and then compared these values with THV of confirmed surface runoff origin such as Box and Blind canyons that cut through the Snake River Plain in Idaho, USA [1]. The results (Fig. 2) show that Box and Blind canyons have high index values that are up to seven orders of magnitude higher than those of the Saharan and Martian THV. This significant difference supports a groundwater sapping origin of THV in Ius Chasma.

3. Similar geological associations: THV in the Sahara and in Ius Chasma occur in areas with high structural control [2, 3]. In addition to the propagation of THV along fracture sets, faults provide vertical conduits for artesian upward discharge of groundwater from deep aquifers to the surface and leading to cliff sapping and evolution of the THV [2]. Moreover, hydrated sulfates (such as gypsum) are commonly reported from the sidewalls and the foothills in association with Saharan and Martian [4] THV (Fig. 3). The relatively recent sediments (younger than 2.9 Gy) on Mars also support a groundwater origin of these features. Additionally, MSL Curiosity rover images indicate abundant distribution of calcium sulfate veins [5] in the sedimentary deposits similar to those reported from the Sahara (Fig. 3).

4. Discussion and Conclusions: Similarity in morphology and geological associations between Saharan and Martian THV suggest a common origin by groundwater sapping from deep aquifers along faults. Rock disintegration by groundwater-related salt weathering could have played a key role in carving the THV.

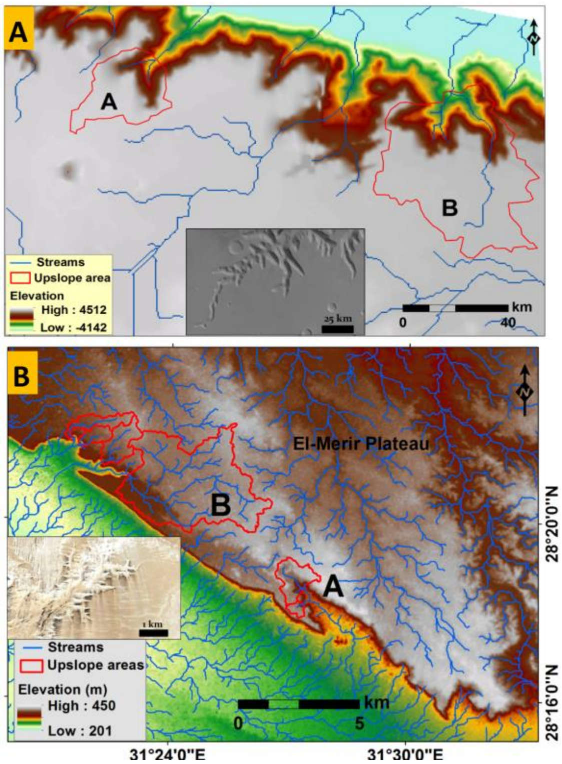

Figure 1: Stream networks superimposed on (A) MOLA DEM of THV in Ius Chasma and (B) PalSAR DEM in El-Merir Plateau showing minimal contribution from surface runoff. Insets are HRSC and Geoeye-1 images of THV examples.

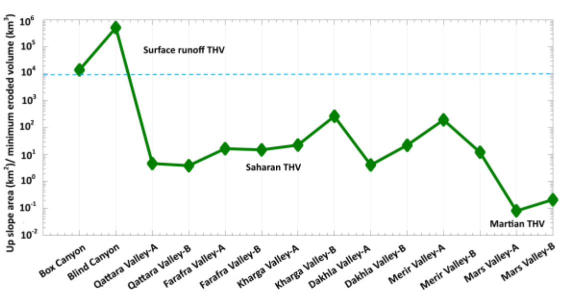

Figure 2: Geomophological index showing the low index values of Martian and Saharan THV compare to those formed by surface runoff in the Snake River Plain, USA.

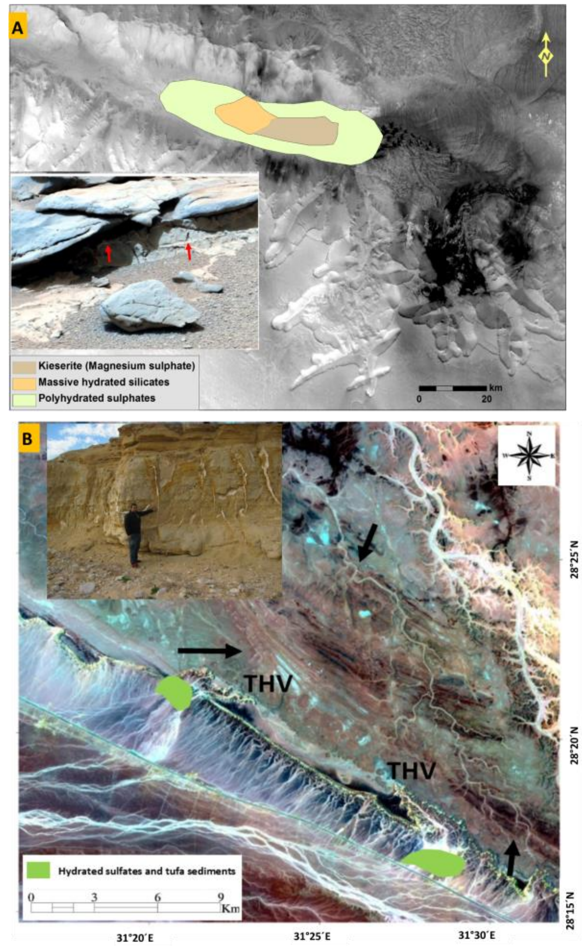

Figure 3. Association of hydrated sulfates with the locations of THV in Ius Chasma [HRSC image] (A) and El-Merir Plateau [Landsat-8 image] (B). Insets are NavCam image of the MSL Curiosity rover in Yellowknife Bay, Gale crater and field photo in El-Merir Plateau, Egypt showing abundant gypsum veins cutting through sedimentary successions. The salt veins that are cutting through different stratigraphic units suggest a groundwater-related origin and high activity of salt weathering along the rocky materials.

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