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New evidence for a magmatic influence on the origin of Valles Marineris, Mars

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A R T I C L E I N F O

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A B S T R A C T

In this paper, we show that the complex geological evolution of Valles Marineris, Mars, has been highly influenced by the manifestation of magmatism (e.g., possible plume activity). This is based on a diversity of evidence, reported here, for the central part, Melas Chasma, and nearby regions, including uplift, loss of huge volumes of material, flexure, volcanism, and possible hydrothermal and endogenic-induced outflow channel activity. Observations include: (1) the identification of a new >50 km-diameter caldera/vent-like feature on the southwest flank of Melas, which is spatially associated with a previously identified center of tectonic activity using Viking data; (2) a prominent topographic rise at the central part of Valles Marineris, which includes Melas Chasma, interpreted to mark an uplift, consistent with faults that are radial and concentric about it; (3) HiRISE-identified landforms along the floor of the southeast part of Melas Chasma that are interpreted to reveal a volcanic field; (4) CRISM identification of sulfate-rich outcrops, which could be indicative of hydrothermal deposits; (5) GRS K/Th signature interpreted as water–magma interactions and/or variations in rock composition; and (6) geophysical evidence that may indicate partial compensation of the canyon and/or higher density intrusives beneath it. Long-term magma, tectonic, and water interactions (Late Noachian into the Amazonian), albeit intermittent, point to an elevated life potential, and thus Valles Marineris is considered a prime target for future life detection missions.

1. Introduction

Stratigraphic, paleotectonic, spectroscopic, and geophysical information of Mars, compiled through geologic mapping investigations at global to local scales, demonstrate that magmatic-driven processes significantly contributed to a dynamic geologic history. This may be best exemplified at Tharsis and its surrounding regions (e.g., Scott and Tanaka, 1986), where five major stages of pulse-like geologic activity resulted in the formation of a magmatic complex, encompassing a total surface area of approximately 2×10^7 km^2 (Dohm et al., 2001a, 2007). Tharsis is an order of magnitude larger than the largest terrestrial igneous plateau, Ontong Java, which covers a total surface area of approximately 2×10^6 km^2 (Maruyama, 1994; Richardson et al., 2000). Tharsis evolution reportedly includes plume-driven activity, possibly ranging from a mantle plume (e.g., Raitala, 1987; Mège and Masson, 1996) to a superplume (Maruyama et al., 2001; Baker et al., 2001, 2007; Dohm et al., 2001b, 2007), as well as dike emplacement (McKenzie and Nimmo, 1999; Ernst et al., 2001; Wilson and Head, 2002), and crustal/lithospheric flexure related to its growth (e.g., Golombek, 1989; Banerdt et al., 1992; Phillips et al., 2001). Such activity resulted in

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volcanic constructs of diverse sizes and shapes and extensive lava flow fields (Scott and Tanaka, 1986), large igneous plateaus (Dohm and Tanaka, 1999; Dohm et al., 2001c), catastrophic outflow channels (Scott and Tanaka, 1986; Dohm et al., 2001c, 2007), episodic inundations on the northern lowlands (Fairén et al., 2003), putative ash-flow and air-fall deposits (Malin, 1979; Hynek et al., 2003), and systems of radial faults and circumferential systems of wrinkle ridges and fold belts (Schultz and Tanaka, 1994) centered about local and regional centers of magmatic-driven activity (Anderson et al., 2001).

One of the most conspicuous features of Tharsis is Valles Marineris, a vast and deep canyon system with Melas Chasma near its center (Figs. 1–3). A variety of processes have been proposed to explain the development of Valles Marineris, including: (1) rifting (Schultz, 1991); (2) collapse of near-surface materials due to the withdrawal of underlying material such as magma (McCauley et al., 1972) or opening of tension fractures at depth (Tanaka and Golombek, 1989); (3) development of keystone grabens at the crest of a bulge (e.g., Lucchitta et al., 1992 and references therein); or (4) rotation of the Thaumasia plateau (as a lithospheric block) during the Late Noachian or Early Hesperian (Anguita et al., 2001) (there are three periods defined for the history of Mars, as follows from oldest to youngest: Noachian, Hesperian, and Amazonian).

To further investigate the origin of Valles Marineris, we mainly focus on its central region, which includes Melas Chasma through application of a multidisciplinary approach. Our approach, which includes tier-scalable reconnaissance, is likened to the geologist who compiles the diverse layers of information at various scales for comparative analysis and ultimate interpretation. Through this approach, tectonic, volcanic, topographic, fluvial, spectral, geophysical, and elemental information in and near Melas Chasma (detailed below)

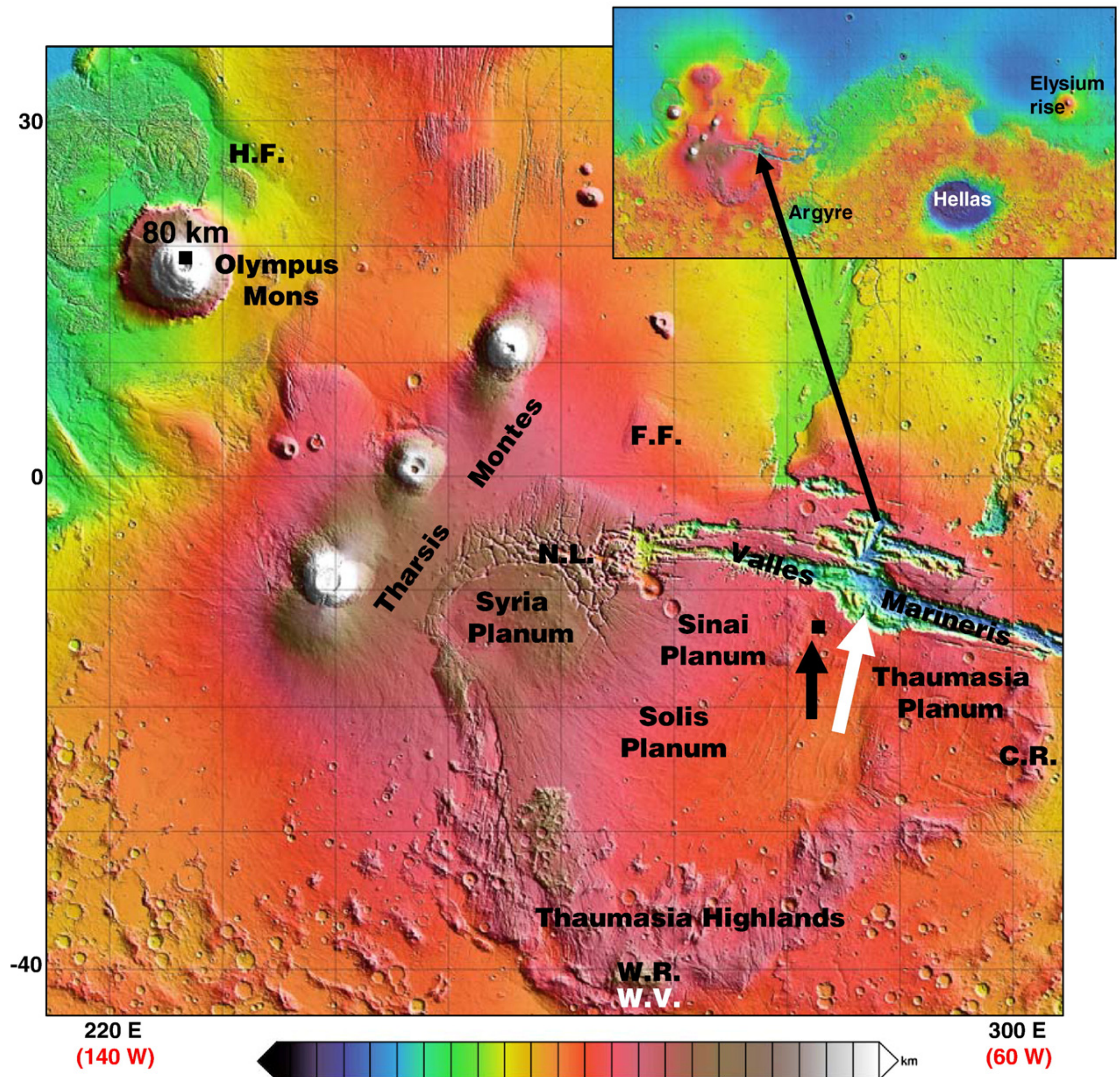

Fig. 1. MOLA shaded relief map showing that the diameter of the newly identified vent structure (short black arrow) located to the southwest of the central part of Valles Marineris, Melas Chasma (white arrow), approximates the diameter of the caldera complex of Olympus Mons. Also shown are the northeast-trending chain of giant shield volcanoes, Tharsis Montes, the vast complex canyon system, Valles Marineris, Warrego rise (W.R.), Warrego Valles (W.V.), the Noachian mountain ranges with complex structure and magnetic signatures, Thaumasia highlands and Coprates rise (C.R.) (Dohm et al., 2001a,c, 2007), a Late Noachian–Early Hesperian tectonic province, Thaumasia Planum (Dohm et al., 2001c), Early Hesperian–Late Hesperian lava plains of Solis and Sinai Planae, and the locations of Noctis Labyrinthus (N.L.), Halex Fossae (H.F.), and Fortuna Fossae (F.F.), the latter two of which are interpreted to mark caldera/vent-like structures. Also shown is the regional context map showing the location of central Valles Marineris (long arrow), Elysium rise, and the impact basins, Hellas and Argyre in the eastern and western hemispheres, respectively. (For figure legend, the reader is referred to the web version of this article.)