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The Ophir Chasma Dyke Swarm: Description and Implications for the Genesis of the Valles Marineris Northern Troughs

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An extensive survey of dykes in the Valles Marineris troughs (chasmata) on Mars has been undertaken. Most dykes are observed along the chasma walls (Mège and Gurgurewicz, 2016), in the spur-and-gully morphology that characterises the bedrock exposures (Lucchitta et al., 1992). We report here on a dyke swarm exposed in the central Ophir Chasma floor, and stress the major implications for the formation mechanisms of Valles Marineris.

The southern Valles Marineris chasmata have a clear structural origin (e.g., Schultz, 1991; Peulvast et al., 2001). The northern chasmata are oval-shaped ("ancestral basins", Schultz, 1998) and for this reason, alternative mechanisms of formation have been sought, such as collapse into deep fractures (Tanaka and Golombek, 1989) or subsidence (Andrews-Hanna, 2012). Ophir Chasma belongs to the northern chasmata (Figure 1).

The floor of Ophir Chasma displays a dense network of dykes (Figure 2), which can be observed on CTX images in the visible spectral range (5 m/pixel) and at HiRISE resolution (25 cm/pixel). The thickest dykes are almost apparent on THEMIS thermal infrared images (100 m/pixel). Many of those that can be mapped at HiRISE resolution are several tens of meters thick (Figure 3). CRISM spectral data reveal a mafic composition, with Mg-rich olivine and high-Ca pyroxene.

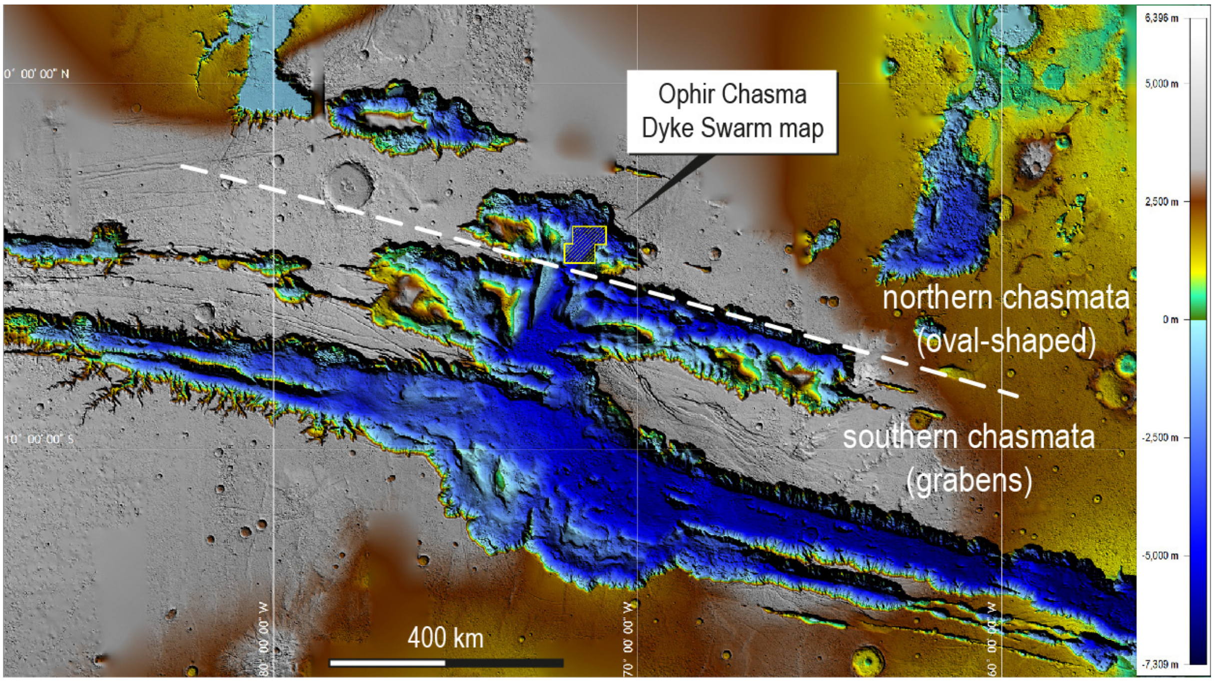

Fig. 1. Location of the Ophir Chasma Dyke Swarm, and boundary between two Valles Marineris areas that require two distinct chasma formation mechanisms.

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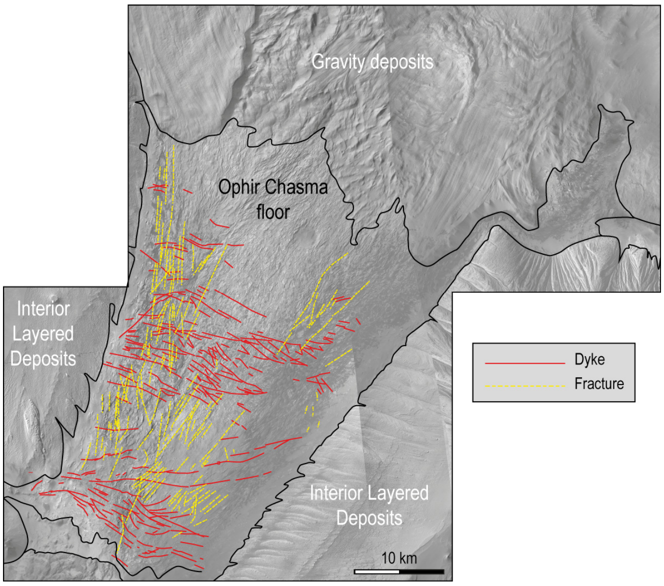

Fig. 2. The Ophir Chasma Dyke Swarm (red). The background image is a CTX image mosaic (5 m/pixel).

Dyke thickness primarily depends on the Young's modulus of the host rock (e.g., Gudmundsson and Loetveit, 2005), which increases with hydrostatic pressure, hence globally, with depth. The widespread occurrence of dykes several tens of meters thick on the floor of Ophir Chasma suggests that the current exposure level is closer to the level of neutral buoyancy of Martian mafic magmas, estimated to ca. 11 km (Wilson and Head, 1994), than to the surface. It therefore suggests that the exposed chasma floor has been intensely eroded, precluding trough formation by plateau subsidence. Chasma formation by plateau material collapse into deep tension fractures is not either supported because there is no observational evidence of huge tension fractures that would have drained plateau material downward.

Mège and Bourgeois (2011) and Gourronc et al. (2014) showed that the current Valles Marineris landscape has been primarily shaped by glacial activity, during a period which is not well constrained but could have lasted for hundreds of million years or more during the Hesperian and/or Amazonian epochs. We suggest that glacial erosion may be the main cause for Valles Marineris trough formation in Ophir Chasma. Thomson et al. (2013) reported 1600-2500 m of bed erosion since 34 Ma in the trough below the Lambert glacier East Antarctica (0.047 – 0.073 mm/yr). At a similar rate of 0.050 mm/yr in Valles Marineris, 8000 m of cumulated erosion (the elevation difference between the Ophir Chasma floor and the surrounding plateau) would be achieved in only ca. 160 my. However, on Earth, glacier bed erosion rate may be significantly faster in some cases: 300–600 mm/yr of subglacial erosion has been measured below Pine Island Glacier, West Antarctica, over 49 years, a high rate achieved by fast flowing ice and the presence of soft water-saturated sediments, (Smith et al., 2012). Up to 1 m/yr has been interpreted at the Rutford Ice Stream (Smith et al., 2007).

Glacier bed erosion by several thousands of meters in Valles Marineris troughs would therefore not be exceptional, nor irrealistic in terms of required time. However, erosion of several thousand meters of glacier bed is more easily achieved by multiple cycles of ice flow, glacier bed deepening, ice melting (Earth) or sublimation (more likely in common Mars conditions), and isostatic rebound. Such a cyclicity has been observed in Antarctica and has been attributed to orbital changes (Pekar and DeConto, 2006). Orbital cycles are exacerbated on Mars (Laskar et al., 2004), due to the absence of orbit stabilisation by a heavy natural satellite such as the Earth's Moon. Multiple glacial erosion cycles, the terms of which remain to be explored, may have vigorously contributed to erosion and deepening of the Ophir Chasma floor.

This work shows that erosion, perhaps glacial erosion, may have been the main mechanism by which Ophir Chasma, and perhaps other northern chasmata of Valles Marineris, may have formed. The dyke density on the Ophir Chasma floor testifies, however, to significant

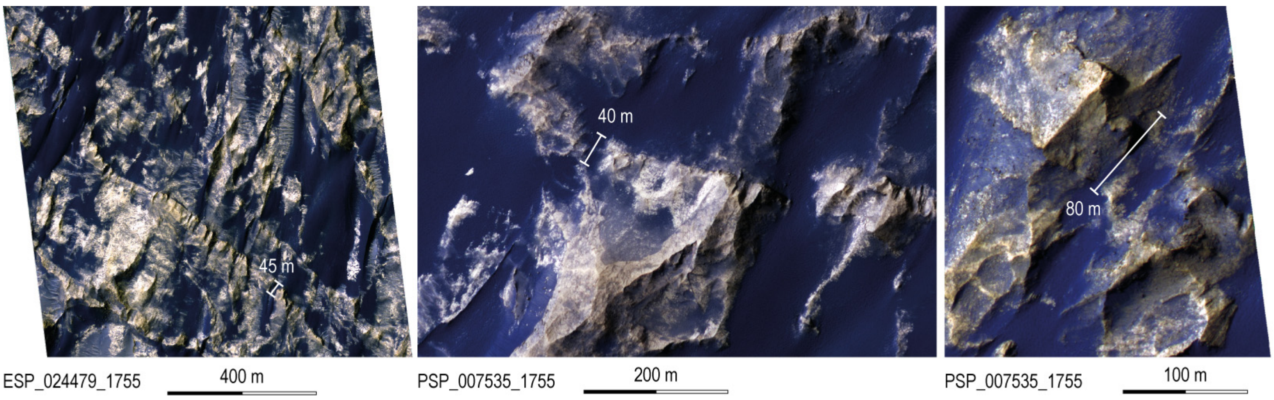

Fig. 3. Examples of dyke outcrops on the floor of Ophir Chasma, imaged by the HiRISE camera.

crustal dilation, implying significant extensional tectonics too. The first step in the formation of Ophir Chasma is thus interpreted to have been tectonic stretching, and the second step, glacier bed erosion, resulting in several kilometers of additional topographic lowering. Other Valles Marineris northern chasmata might have formed in a similar way.

References

Andrews-Hanna JC, 2012. The formation of Valles Marineris: 1. Tectonic architecture and the relative roles of extension and subsidence. *Journal of Geophysical Research*, 117: E03006, doi: 10.1029/2011JE003953.

Gourronc M, Bourgeois O, Mège D, Pochat S, Bultel B, Massé M, Le Deit L, Le Mouélic S, and Mercier D, 2014. One million cubic kilometers of fossil ice in Valles Marineris: relicts of a 3.5 Gy old glacial landsystem along the Martian equator. *Geomorphology*, 204: 235–255.

Gudmundsson A, and Loetveit IF, 2005. Dyke emplacement in a layered and faulted rift zone. *Journal of Volcanology and Geothermal Research*, 144: 311–327.

Laskar J, Correia ACM, Gastineau M, Joutel F, Levrard B, and Robutel P, 2004. Long term evolution and chaotic diffusion of the insolation quantities of Mars. *Icarus,* 170: 343–364.

Lucchitta BK, McEwen AS, Clow GD, Geissler PE, Singer RB, Schultz RA, and Squyres SW, 1992. Valles Marineris. In: Kiefer WS, et al. (Eds.), *Mars*. University of Arizona Press, Tucson, pp. 453–492.

Mège D, andBourgeois O, 2011. Equatorial glaciations on Mars revealed by gravitational collapse of Valles Marineris wallslopes. *Earth and Planetary Science Letters,* 310: 182–191.

Mège D, andGurgurewicz J, 2016. *On Mars, location and orientation of dykes exposed along the Valles Marineris walls reveal expected and unexpected stress fields*. Int. Dyke Conference 7, Abstract.

Pekar SF, andDeConto, RM, 2006. High-resolution ice-volume estimates for the early Miocene: evidence for a dynamic ice sheet in Antarctica. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 231: 101–109.

Peulvast JP, Mège D, Chiciak J, Costard F, and Masson P, 2001. Morphology, evolution, and tectonics of Valles Marineris wallslopes (Mars). *Geomorphology*, 37: 329–352.

Schultz RA, 1991. Structural development of Coprates Chasma and western Ophir Planum, central Valles Marineris rift, Mars. *Journal of Geophysical Research*, 96: 22777–22792.

Schultz RA, 1998. Multiple-process origin of Valles Marineris basins and troughs, Mars. *Planetary and Space Science,* 46: 827–834.

Smith AM, Bentley CR, Bingham RG, andJordan TA, 2012. Rapid subglacial erosion beneath Pine Island Glacier, West Antarctica. *Geophysical Research Letters,* 39: L12501, doi: 10.1029/2012GL051651.

Smith AM, Murray T, Nicholls KW, Makinson K, Adalgeirsdottir G, Behar AE, andVaughan DG, 2007. Rapid erosion, drumlin formation, and changing hydrology beneath an Antarctic ice stream. *Geology*, 35: 127–130.

Tanaka KL, andGolombek MP, 1989. Martian tension fractures and the formation of grabens and collapse features at Valles Marineris. *Proc. Lunar and Planetary Science Conference 19th*, 383–396.

Thomson SN, Reiners PW, Hemming SR, andGehrels GE, 2013. The contribution of glacial erosion to shaping the hidden landscape of East Antarctica. *Nature Geoscience,* 6: 203–207.

Wilson, L, andHead J.W. III, 1994. Mars: review and analysis of volcanic eruption theory and relationships to observed landforms. *Reviews of Geophysics*, 32: 221-263.