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A branching, positive relief network in the middle member of the Medusae Fossae Formation, equatorial Mars—Evidence for sapping?

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ABSTRACT

The Medusae Fossae Formation (MFF) is a geological formation comprising three geological units (members) spread across five principal lobes. It dominates a quarter of the longitudinal extent of the equatorial region of Mars. Positive relief features referred to as 'sinuous ridges' (commonly interpreted as inverted paleoflow channel or valley fills) have been observed in the lowest member of the western MFF, but have not been identified within the central and eastern portions of the formation, in the middle and upper members. This paper presents the identification and analysis of a branching, positive relief system which occurs in the central lobe of the MFF in what appears to be an exposure of the middle member. A simple geomorphological map of the system is presented, from which we have adopted the working hypothesis that this is an inverted fill of a branching fluvial channel or valley system. A suite of morphological and topographic evidence supporting this hypothesis is presented, including analysis of the network using a ~15 m/pixel digital terrain model derived from a Context Imager (CTX) stereo image pair. The evidence supporting this hypothesis includes: (1) the local slope and topography of the upper surface of the network are consistent with a contributory network; (2) the braided, fan-like form at the termination of the branching network is consistent in morphology with it being a depositional fan at the end of a fluvial system; (3) the terminal fan and surrounding deposits show layering and polygonization; and (4) there is strong association between the lower order branches and amphitheater shaped scarps in the depression walls. We evaluate the possible origins of this fluvial system and suggest that seepage sapping is the most probable. Two possible models for the evolution of the network and related features are presented; both require melt of ice within the MFF to form liquid water. We conclude that at least some portions of the Medusae Fossae Formation, if not the entire formation, were once volatile-rich. Finally, we note that our observations do not rule out the case that this network formed before MFF emplacement, and has since been exhumed. However, this conclusion would suggest that much of the surrounding terrain, currently mapped as middle-member MFF, is not in fact MFF material at all.

1. Introduction

This work details the mapping and analysis of an unusual set of martian geomorphological features (Fig. 1) located on the central lobe of the Medusae Fossae Formation (MFF), centered at roughly 5°S, 179°E. These features include a branching linear positive relief system located within a scallop-edged depression and an associated large crater. The whole assemblage occurs within terrain mapped as MFF material. The MFF is a geological formation comprising three geological units (members) (Greeley and Guest, 1987; Scott and Tanaka, 1986) spread across five principal lobes (for the purposes of this work labeled A, B, C, D and E). The MFF dominates roughly a quarter of the longitudinal extent of the equatorial region of Mars (Fig. 2), extending east–west across a distance of ~5500 km between the southern Elysium Planitia and the Tharsis region (130–240 E, 15 N–15S) (Bradley et al., 2002; Scott and Tanaka, 1986; Tanaka, 2000). The positive relief feature is the principal interest in this work, as numerous similar examples (referred to as sinuous ridges, or 'SRs'); (Burr et al., 2009; Burr et al., 2010) have been observed over the two westernmost exposures of the MFF, in the formation's lowest geological member, but have yet to be mapped any further eastward or in the middle and upper members (Burr et al., 2009; Burr et al., 2010;

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Zimbelman and Griffin, 2010). The presence of such a feature in the central lobe, within an apparent exposure of the middle member, may have important implications regarding the volatile content of the MFF.

Fig. 1. Overview of the study area. Note branching ridge system in the southern depression and the dark mantling material in the northwest of the northern crater. (CTX image P16_007394_1748_XN_05S180W, HiRISE images PSP_007394_1750 and PSP_008185_1750). Image credits: NASA/JPL/MSSS and NASA/JPL/Univ. Arizona.

1.1. Medusae Fossae Formation: regional context, morphology and origin

Overlying both the older Southern highlands and the younger Northern lowlands, the MFF deposits cover a north–south extent of many hundreds of kilometers and, in some places, up to a thousand kilometers (Tanaka, 2000). Bradley et al., (2002) estimated the areal extent of the current MFF as being 2.2×10^6 km and the palaeo-extent up to 5×10^6 km^2. However, Harrison et al. (2010) suggest this may be an underestimation of the palaeo-extent, as they identified outliers of MFF on the cratered highlands south of the main lobes. The location and stratigraphic position of the MFF, mantling the crustal dichotomy boundary and the transition between the lowlands and highlands, is particularly important, given both the unusual and enigmatic nature of the MFF deposits themselves and the boundary itself: to date no clear consensus has been reached as to the origin of either.

The MFF is typified by a surface with a discontinuous, highly eroded appearance at kilometer to meter scales. It occurs in five primary outcrops or lobes which have been further mapped into three separate geological members: lower, middle and upper (Greeley and Guest, 1987; Scott and Tanaka, 1986). As a whole, the morphologic criteria for identification of MFF materials, as reviewed by Harrison et al. (2010), are: (1) discontinuous nature; (2) the presence of yardangs, either individually or in fields; unidirectional and bidirectional; (3) other erosional and aeolian modification features; (4) the presence of ripple and ridge features; unidirectional and bidirectional; and (5) pits and pit chains, often progressing into mesa formation.

It is commonly agreed that the materials that compose the formation are fine-grained and friable in nature (Edgett et al., 1997; Parker, 1991; Zimbelman et al., 1996,1997). This long-standing interpretation is rooted in the observed prevalent modification of its surface by aeolian erosion. For example, the most prominent surficial features of the MFF are tapered ridges called yardangs, an aeolian feature that occur primarily in areas of easily erodible materials (de Silva et al., 2010; Goudie, 2007; Greeley and Iverson, 1985, p. 135). Yardangs have been found to occur ubiquitously over the formation, often in large clusters or fields, as is typical for these features on Earth (Breed et al., 1997; Greeley and

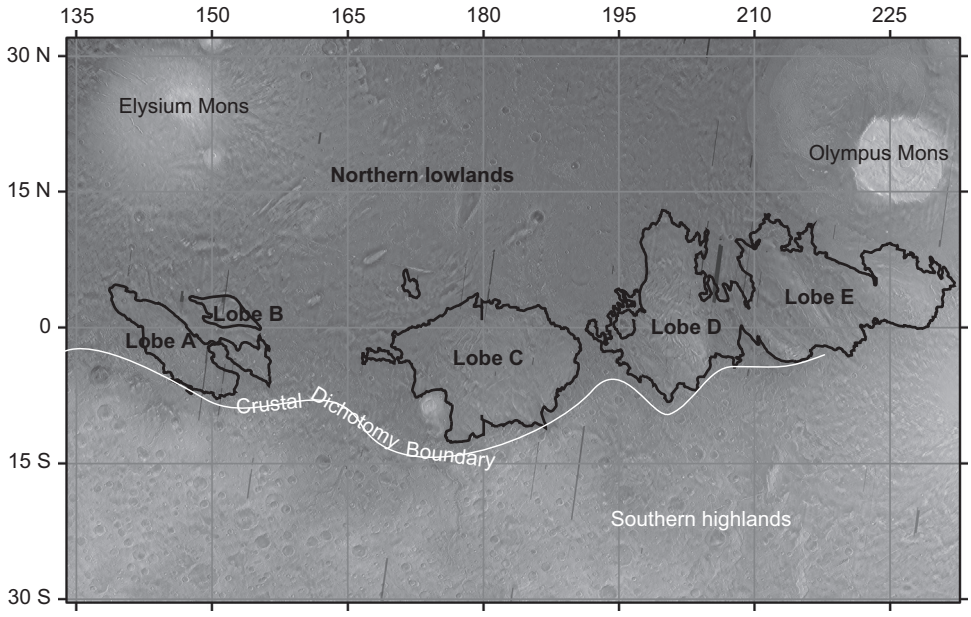

Fig. 2. Regional context of the Medusae Fossae Formation with individual lobes A, B, C, D and E labeled. The Crustal Dichotomy Boundary and two largest volcanoes of the region are also labeled. Base map is MOLA global digital elevation model overlain upon a THEMIS daytime infrared mosaic of 512 Pixels per degree. Lighter toned regions are topographically higher. Data credit: MOLA science team; (NASA/JPL/ASU).