PROPOSING A HIGH VOLATILE CONTENT IN THE EQUATORIAL LAYERED DEPOSITS INCLUDING THE MEDUSAE FOSSAE FORMATION, MARS. E. R. Fuller and J. W. Head, III, Planetary Geosciences Group, Department of Geological Sciences, Brown University Box 1846, Providence, RI, 02912 (elizabeth_fuller@brown.edu).

Introduction: This study seeks to understand the origin of the equatorial layered deposits (ELDs), including the Medusae Fossae Formation (MFF) and the filled craters of Elysium and Arabia Planitiae (e.g., Gusev and Henry Craters). Several origin hypotheses have been proposed for the MFF [c.f. summary in 1], most involving a pyroclastic origin but one proposing formation at the poles [2]. Previous work using MOLA to test the polar formation theory found that there are both similarities and significant differences between the equatorial and polar layered deposits, and concluded that the MFF may be volatile rich, but did not form at the poles [3]. Another MOLA-based study similarly found that the deposits were not polar in origin, and instead concluded that they were most consistent with a welded ashfall tuff [4]. [5] further showed that the ELDs could not be evidence of true polar wander on the basis of the time scales necessary for polar wander to have occurred.

Morphological evidence also indicates that while there are similarities between the poles and the ELDs, including extensive layering at multiple scales, unusual smoothness at several scales [see also discussion in 6], steep slopes (~1-6° in the MFF, ~1-10° at the poles), and distal thinning of the materials, there are also fundamental differences, notably the lateral extent of the ELDs: the MFF itself reaches across 90° of longitude (Figure 1), and filled craters are present around the globe. If the ELDs did form by a mechanism similar to that of the poles, what were the sources of the volatiles, and how did they reach the equator?

Volatile sources: There are three Amazonian-aged volatile sources in the equatorial region: degassing from nearby volcanism, Elysium-region catastrophic outflow, and polar material migration during periods of high obliquity. 1) Degassing: The Tharsis Montes, Olympus Mons, and Elysium Mons were all active during the Amazonian. [7] showed that these eruptions were most likely plinian, with extensive magmatic degassing releasing CO₂ and H₂O. 2) Regional outflow: [8] and [9] have shown that water-rich debris flowed down the northwestern flanks of Elysium Mons in the mid-late Amazonian. Additionally, in the late Amazonian there was repeated catastrophic release of water in Elysium Planitia, through Marte Vallis, debouching into Amazonis Planitia [10]. 3) Migration of polar materials: At periods of maximum obliquity, the poles receive more insolation than the equator. As the poles warm, ice becomes unstable and is forced to migrate to a new cold trap (see below) [11].

Transportation to the equator: Under current climatic conditions, the thin martian atmosphere is nearly saturated with water. Accordingly, any water vapor released would rapidly precipitate as frost. If it precipitated onto a surface where water ice is not stable (which during periods of high obliquity would be the poles and high latitudes), it would rapidly sublime, re-precipitate, re-sublimate, and re-precipitate until it found a cold trap, a region where surface ice is stable. Crater interiors could serve as a cold trap [12], as could the equatorial dichotomy boundary; as air moved across the boundary, it would rise and be forced to precipitate due to adiabatic lapse. Wind-deposited dust and ash would be trapped in such materials, forming layered, indurated deposits.

Materials: The ubiquitous presence of yardangs in the MFF has frequently been used as evidence that the it is highly friable, possibly an unconsolidated ashfall or aeolian deposition, but the conclusion that these are unlihtifed or poorly consolidated materials is not warranted [e.g., 13]. The MFF is certainly more susceptible to aeolian erosion than the materials it overlies, but yardangs of this scale (10s of m to 10s of km long, and over 100 m high [4]) require substantial induration. Yardangs are most frequently found on earth in limestones [e.g. 14] and sandstones [e.g. 15], and notably in a basalt in Argentina [16]. Yardangs in unconsolidated materials (including bedded sands [17] and the lacustrine deposits of Rogers Dry Lake [18] are typically at the scale of one meter tall and less than ten meters long. Terrestrial yardangs in consolidated sediments range from meter scale up through the “crêtes et couloirs” (ridges and troughs) of the Tibesti plateau that are tens of meters to several kilometers wide and hundreds of kilometers long [19].

In a yardang study noteworthy both for its scale and comprehensiveness, [14] examined the origin and evolution of yardang fields in western Egypt; the regional climate has been hyper-arid for the last 2.4 Ma and is correspondingly nearly vegetation-free. Wind is therefore the primary and essentially sole erosional agent. That study found that yardangs develop from lineated terrain that is cross-cut en échelon by fissures or joints; this segmentation allows for a rapid streamlining of the terrain into the
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traditional yardang form. There was no other evidence for a change in wind direction or tectonic stresses, and modeling showed that the segmenting of long lineations concentrates erosional energy at a lower level [14]. This suggests that the en échelon pattern noted by [4] may simply be a function of erosion efficiencies.

Other proposed origins of the MFF: Some previous researchers have concluded that the Medusae Fossae Formation is a welded ignimbrite or welded tuff [e.g., 20, 4]. Both of these lithify from a combination of heat (from the volcaniclastic origin) and pressure from overburden. The lithification is therefore strongest at the base of the unit; this is inconsistent with the clear presence of a 5-10 m caprock in many of the MFF layers [21]. [22] discusses densely welded pyroclastics that cannot be explained by loading and argues that welding is caused by volatile resorption, suggesting that the presence of volatiles in the ELDs might resolve this inconsistency. Another proposed origin of the MFF is variably indurated aeolian deposits [e.g., 21]. Wind-born dust and ash form friable deposits which could not support the kilometer-scale yardangs of the MFF; the diagenesis of loose materials usually requires burial and compaction, but the emplacement of volatiles, as discussed above, could have formed an ice matrix. The period of high obliquity ended and ground ice was no longer stable in equatorial regions, the near-surface ice would have sublimated away. How, then, could the materials remain lithified at the present? The Viking landers and Pathfinder found dust with salts [e.g., 23], suggesting that these could have been deposited together in the ELDs. The matrix therefore could have contained dissolved salts that would have precipitated when the ice sublimated, forming a salt cement similar to that discussed by [15].

Morphology: [4] found that the Medusae Fossae Formation has layers at three characteristic scales: <10 m, 50-60 m, and hundreds of meters in thickness. There is also clear evidence of differential resistivity to erosion between different layers. This suggests that there is vertical as well as lateral heterogenaeity within the MFF [4]. This could easily be explained by layers with varying volatile content and relative ash/dust concentrations.

The proximity of the MFF to the major volcanic provinces of Mars suggests that the presence of ash layers is virtually inevitable. The unique characteristics of the ELDs, their morphological similarities to the polar deposits, and their concentration in the equatorial region, however, suggest that volatiles, probably emplaced during a period of high obliquity, may have played a fundamental role in their formation. Future work will include testing this theory to determine whether the presence or absence of volatiles from the equatorial layered deposits can be conclusively determined.

References:

Figure 1: The Medusae Fossae Formation, presented as MOLA topography draped over a MOLA-derived gradient map.