**MEDUSAE FOSSAE FORMATION: ICE-RICH AIRBORNE DUST DEPOSITED DURING PERIODS OF HIGH OBLIQUITY?** James W. Head[1] and Mikhail Kreslavsky[1,2], [1]Department of Geological Sciences, Brown University, Providence, RI 02912 James_Head@brown.edu, [2]Kharkov Astronomical Observatory, 35 Sumska, Kharkov 61022 Ukraine

**Summary:** On the basis of the similarity of the Medusae Fossae Formation to polar and circumpolar deposits, we propose that the unit formed from airborne ice-rich material emplaced during periods of high obliquity when polar regions underwent volatile loss and were much warmer; the northern lowland-highland topographic boundary favored upwelling of vapor-rich air and preferential condensation there. Emplacement may also have been aided considerably by abundant water supply during and immediately subsequent to outflow events. Thus, sources of volatiles include polar regions undergoing concurrent sublimation at high obliquity, and freezing and subliming water deposited from outflow channels. The complex stratigraphy of the Medusae Fossae Formation suggests that periods of emplacement were interrupted by periods of erosion and volatile loss. Previous mapping of stratigraphic relationships suggests an extended duration of emplacement in the Amazonian, and recent mapping using MOLA data suggests that the record of this type of process might extend back into the Hesperian Period. Recent parallel results from several different areas show that: 1) the MFF has enhanced water contents (Odyssey GRS/NS); 2) GCMs predict ice deposition in these general areas during periods of high obliquity, and 3) orbital calculations suggest that extended high obliquity periods may be much more common than previously thought.

**Introduction:** Thick (1-3 km), antipodal, unconformable layered deposits in the equatorial region of Mars have been interpreted to be remnants of ancient polar deposits [1]. The deposits are accumulations of easily eroded material. Early deposits are draped over underlying topography and evidence of stripping means that deposition has ceased and erosion has been going on for an undetermined period of time. Outliers suggest that the deposit covered a much broader region in the past. These deposits correspond in large part to the Medusae Fossae Formation (MFF) [2,3], which 'consists of relatively flat sheets that are generally smooth to grooved and gently undulating; deposits appear to vary from soft to indurated.' The MFF (Am) consists of three members: The lower member (Aml) is smooth to rough and highly eroded and interpreted [2,3] to be lava flows interbedded with pyroclastic rocks or eolian deposits. The middle member (Amm) is similar to the upper member but the surface appears rougher and more deeply eroded in places; it is cut by scarps and transected by intersecting joint sets [2,3] and interpreted to be welded and nonwelded pyroclastic rocks or layers of eolian deposits [2,3]. The upper member (Amu) consists of discontinuous but widespread deposits that are smooth, flat to rolling, and sculpted into ridges and grooves in places, with broadly curved, locally serrated margins. It is interpreted to consist of unwelded pyroclastics or thick accumulations of eolian debris, which have been wind-eroded, particularly along the margins [2-4]. The MFF is lightly cratered (<200 craters >2 km per $10^6$ $km^2$) and interpreted to be Amazonian in age [2,3], with the lower boundary shown to be well into the Amazonian Period. Numerous hypotheses have been proposed to account for the origin of these deposits [see summary in 5] and studies are underway to assess the full range of these hypotheses using new MGS data [5-7].

The purpose of this analysis is to contribute to the assessment of the origin of these unusual units. Specifically, we have used new MOLA topography data: 1) to test the hypothesis that these units might have formed in a manner similar to deposits presently seen in and near the poles, 2) to assess the stratigraphic relationships to other units in order to clarify the age of formation and modification of this unit, and 3) to examine hypotheses related to outflow channel formation and obliquity cycle extremes. We compare these deposits and their morphologic features to present polar deposits [8], and to ancient circumpolar deposits surrounding the South Pole [9-11]

**Present polar and paleopolar desposits:** MOLA data have enabled researchers to determine better the characteristics and stratigraphic relationships of polar and circumpolar deposits [8-11] and these views complement the characteristics determined from Viking data [12]. South circumpolar deposits (the Dorsa Argentea Formation) interpreted to be of Hesperian age [13] have the following charactristics [9-11]: they 1) are unconformable; 2) are smooth relative to other units at several scale lengths; 3) show evidence of a volatile-rich nature (channels, esker like features, cavi, chasmata, pedestal craters, etc.); 4) have a distinctive topographic profile (compared to volcanoes and other features); and 5) form thick deposits relative to surrounding terrain.

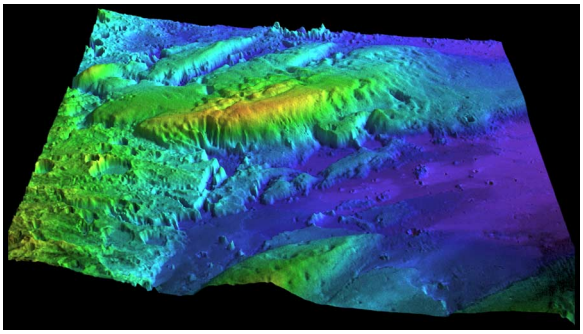

**Figure 1.** Perspective view looking west along the dichotomy boundary (left center). Top of view is about 165W. Amazonis Planitia is to the right (V. Ex. =10).

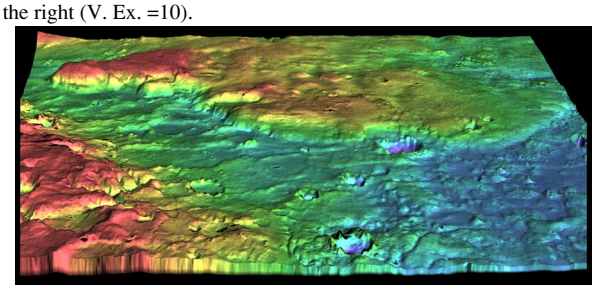

**Figure 2.** Perspective view looking west along the dichotomy boundary (left). Bottom of view is ~170W. (V. Ex. =10).

**Characteristics of the equatorial deposits:** MOLA data provide detailed information about the configuration of the deposits, their relation to surrounding terrain, the stratigraphic relationships of individual members, and high-resolution altimetry to characterize the deposits. Viking images and mosaics overlain on MOLA DEMs provide an important perspective on these issues (Fig. 1). The upper member (Amu) is seen unconformably overlying the dichotomy boundary and rising up to elevations of about 0.5 km, ~3.5 km above Amazonis Planitia, indicating a comparable unit thickness. Portions of Amm lie at the northern edge of this occurrence and slope off into Amazonis Planitia. In the foreground is seen the highly modified portions of the middle member (Amm), with teardropped shaped hills separated by large valleys [14]. From this perspective view, one gains the clear impression that Am is

heavily dissected and modified at all length scales. Troughs within the MFF cut deeply (up to 2-3 km) into the unit over very short lateral distances, and trend generally down the regional slope, sometimes parallel to channels in the uplands. These features differ from troughs in polar deposits and are more similar in morphology and scale to polar chasmata [12]. To the west along the dichotomy boundary, more extensive exposures of Amm are seen (Fig. 2); here the Noachian cratered uplands are embayed at the boundary by ridged plains, on which Am is superposed. Similar relationships to those described elsewhere along the dichotomy boundary are seen, with topography highest to the south rising up to -0.5 km, and sloping off to the north to about -2.5 km. The terrain here is also characterized by NW-trending valleys and troughs, broader here than in the area previously described (see Figure 1 of [18]). The observations outlined in this analysis underline previous conclusions that this deposit has been highly modified and significant parts of it have been eroded by a host of exhumation and modification processes. This raises the important question of what ages of the unit derived from crater counts really mean. If the unit has been undergoing constant modification since its formation, then the Amazonian ages derived from counts of superposed craters will reflect the age of formation of the modified surface, not necessarily the age of the unit itself [see also 15].

**Comparative characteristics of the equatorial deposits:** Both similarities to and differences from present polar and ancient circumpolar deposits are seen. Among the similarities in morphology and topography are: 1) thick central deposits mantling subjacent cratered terrain and thinning toward the margins; 2) unusually large thicknesses that are similar to present polar deposits; 3) unusual smoothness of deposits at several scale lengths, 4) partially exposed impact craters, very similar to features in the south circumpolar deposits which have been partly to wholly embayed by polar deposits and then exhumed by sublimation and meltback, 5) narrow sinuous and braided ridge networks, which are often very similar to esker-like ridges in the south circumpolar deposits that are interpreted to represent melting, drainage and meltback of a former ice sheet; 6) craters marginal to the deposits which often show thick accumulations of interior layered deposits and are similar to impact craters surrounding present and previous north and south polar deposits; 7) pedestal craters, which are similar to those found around some south circumpolar deposits and which provide information on the amount of material potentially removed from the deposits.

Differences include: 1) lack of abundant distinctive spiral troughs; 2) abundance of eolian stripping (e.g., yardangs) in equatorial deposits; and 3) lack of pervasive fine-scale layering observed in polar deposits.

**Stratigraphic relationships and implications for the age of formation of the Medusae Fossae Formation:** Critical to the understanding of the origin of the MFF is confirmation of the age of formation and modification of this deposit, and knowledge of its interaction with regional units. We used MOLA topography data to examine the relationships between the MFF and other units to test the interpreted Middle-Late Amazonian age [2,3]. Previous studies using MOLA data have shown that the division of the MFF into overlying members [2,3] is not everywhere consistent with topographic relationships [5,7]. We examined specific topographic and stratigraphic relationships of the MFF with surrounding units and found: 1) there is significant variation in the elevation of the mapped subunit boundaries, suggesting that the three subunits show much more complex relationships than simple sequential flat layers, supporting previous observations [7]. 2) Amu clearly unconformably overlies the earliest aureole deposits ($Aoa_1$), but shows much more ambiguous relationships with Tharsis volcanics. In some places, units mapped as $AHt_3$ (which is completely stratigraphically older than the base of the MFF [2]), appears to overlie Amm and Amu. 3) In some cases, Hesperian-aged channel deposits seen in the uplands near the dichotomy boundary appear to reemerge to the north in portions of Amm. 4) In Elysium, there is evidence that modification of the MFF has led to channel development [see also discussion in 16]. On the basis of these data and evidence that the MFF has undergone very significant exhumation and modification, we conclude that original materials that now make up the Medusae Fossae Formation may have actually been emplaced and modified repeatedly and also partly in much earlier times, perhaps at least partly in the Hesperian. Tracing of lava flow paths suggests that some of the major, presently observed topography of the MFF may have also been in existence during the Hesperian [see also 14].

**Discussion and Conclusions:** Recent parallel results from several different areas provide supporting evidence for this hypothesis. First, Odyssey GRS/NS data show elevated hydrogen abundance in these regions [19]. Secondly, GCMs predict enhanced ice deposition in equatorial regions during periods of high obliquity [20], Thirdly, recent orbital calculations show that Mars may have spent much more time at extended high obliquity than previously thought [21]. These comparisons and new data support the interpretation that the thick, unconformable layered deposits in the equatorial region of Mars are at least in part remnants of ancient volatile-rich deposits [e.g., 1] with contributions from the Tharsis volcanoes [e.g., 22] that have subsequently undergone significant erosion and degradation,. Stratigraphic evidence suggests that formation and modification of the MFF took place throughout the Amazonian and may have taken place at least partly in the Hesperian Period. We conclude that the relationships described above are consistent with two hypotheses that seem more plausible than true polar wander [1]. These both involve formation from airborne volatile-rich material: 1) emplacement during periods of high obliquity when equatorial regions were much colder. Sources of volatiles include polar regions undergoing concurrent sublimation at high obliquity, and freezing and subliming water deposited from outflow channels [23, 24]. 2) emplacement during and immediately subsequent to outflow events. In both cases, the northern lowland-highland topographic boundary favored upwelling of vapor-rich air and preferential condensation there. The complex stratigraphy of the Medusae Fossae Formation suggests that periods of emplacement were interrupted by periods of erosion and volatile loss and that admixed dust protected ice from rapid sublimation.

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