A SYNOPTIC APPROACH TO EVALUATING THE ORIGIN OF THE MEDUSAE FOSSAE FORMATION, MARS. K. E. Mandt[1], S. de Silva[2], J. R. Zimbelman[3], D. A. Crown[4] [1]Department of Space Studies, University of North Dakota, Grand Forks, ND 58202 kathymandt@yahoo.com, [2]Department of Geosciences, Oregon State University, Corvallis, OR 97331-5506 desilvas@geo.oregonstate.edu, [3]CEPS/NASM MRC 315, Smithsonian Institution, Washington D.C. 20013-7012, [4]Planetary Science Institute, 1700 E. Ft. Lowell Rd. Ste. 106, Tucson, AZ 85719.

Introduction: The Medusae Fossae Formation (MFF) is an enigmatic deposit located along the equator of Mars between the Tharsis and Elysium volcanic centers, stretching for more than 5000 km. Stratigraphic relations suggest that the deposit is Amazonian in age [1,2], but that deposition may have begun as early as the Hesperian [3]. The MFF has been a focus of nearly three decades of research because its age, distribution, and material properties have implications for Martian history. However, despite general agreement that the MFF is a deposit of fine-grained material, its origin is still debated. A variety of disparate hypotheses have been proposed for its geologic origin including pyroclastic flows [2,4], aeolian deposits [1,2,3], polar deposits [5], exhumed faulted rocks [6], carbonate platform [7], rafted pumice [8], lacustrine [9], ash fall [10,11,12], and subsurface aquifer [13].

To bring some clarity to the issue we have compiled and analyzed all the published information on the MFF in search of an approach that may help advance the debate. We find that several hypotheses can be ruled out. For instance, the demonstrably Amazonian age of the MFF rules out the paleopolar deposit, exhumed fault rocks and lacustrine deposit hypotheses. Improved resolution provided by Mars Global Surveyor has allowed the carbonate platform [11] and rafted pumice deposit [14] hypotheses to also be ruled out. Of the original nine hypotheses only three can be considered rigorous; the deposits of pyroclastic flow or fall , and aeolian deposition.

We also find that the continued discussion on the origin of the MFF stems from the variety of different scales at which previous work has been conducted. Many studies have had a local focus that has resulted in solitary features being isolated and emphasized over whole deposit characteristics. Our approach has been to take a more synoptic perspective and to assess all the available observational evidence to focus on properties and features that occur throughout the deposit because they characterize the MFF as a whole.

Our analysis of the literature finds that more than 60 separate lines of evidence have been used in previous studies and that these can be divided into seven categories – large scale, linear, circular, and semi-circular features, depressions, layering, and textural features. On the basis of this analysis we identify the following as general characteristics of the MFF.

Fine grained: Several lines of evidence have been given to suggest that the material of the MFF is fine-grained, including: depth-to-diameter ratios of impact craters [15], radar signature [7,16] and infrared measurements [10,12].

Yardangs: These are the most commonly referenced feature throughout the MFF (figure 1A). Yardangs are elongate ridges formed by wind erosion which resemble inverted ship hulls. They tend to form in fine-grained material that has some degree of induration and can be as large as a few kilometers in length

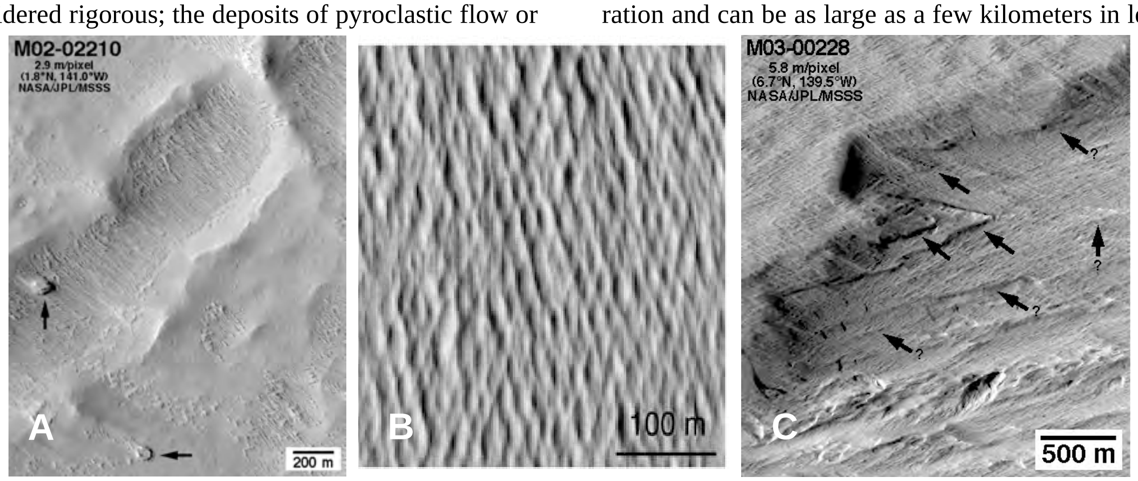

Figure 1 - Images of features that can be used to define formation-wide properties of the MFF. (A) MOC image (M0202210) showing yardangs with arrows pointing to places where the initial thickness of the deposit may be preserved. (B) Portion of MOC image (M0801561) showing bidirectional yardangs intersecting at 41 degrees. Source: Bradley et al 2002. (C) MOC image (M0300228) showing internal layering that may correspond to differential induration or welding.

and 100 m high [17]. All members of the MFF display evidence of yardangs so this is clearly a formation-wide characteristic.

Jointing: Serrated cliffs and bidirectional yardangs (figure 1B, C) seen in places throughout the formation have been cited as evidence for jointing [2,4,11]. Jointing is a system of fractures within a rock that is caused by contracting and cooling of volcanic rock, compaction and drying of sediments, or tectonism.

Layering: Many authors have observed signs of layering throughout the deposit (figure 1C). One cause of layering could be bedding or stratification, the division of sedimentary rock into parallel layers often evidencing different chemical compositions or grain sizes. Another possible cause for the appearance of layering could be the result of different zones of welding within a pyroclastic deposit, because these zones will differentially erode [18].

Evaluation: We have made the following observations regarding these properties of the MFF:

1. Yardangs imply fine-grained material with some degree of induration [17]. A detailed study of MFF yardang orientation [11] concluded that material properties and not just wind direction was a factor in determining yardang orientation.
2. The previously-mentioned study of yardangs [11] concluded that the jointing was probably caused by cooling and contraction of extrusive rocks.
3. The layering that has been observed in the MFF could be either bedding or differential erosion of layers of different compactness. THEMIS images show horizontal layers in cliffs with lower temperatures than the surrounding layers [20]. This has been interpreted as a welded layer between less consolidated layers.

By analogy with terrestrial analogues, these characteristics are most typical of pyroclastic deposits and not aeolian deposits. Interweaving of lava flows and MFF material [16] and the fact that potential sources of such a large amount of fine-grained material is limited in the Amazonian to volcanic activity [10] also supports a volcanic origin. In our opinion the debate on the origin of the MFF rests on whether the MFF was deposited by pyroclastic fall or flow.

We assume that deposit material properties of pyroclastic rocks on Mars are largely the same as those on Earth and that broadly similar morphological features should be expected on the two planets. On Earth we argue that there is a clear distinction of the characteristics of regional scale pyroclastic fall and flow (ignimbrite) deposits and we find that this has been obfuscated in the literature for the MFF.

Table 1 - Properties of terrestrial pyroclastic deposits

Property	Ignimbrite	Ash Fall
Yardangs	Common in arid regions	Not Known
Zoning	Common	Rare, local
Bedding	Rare	Common
Jointing	Common	Rare, local

In table 1 we show that the main features identified for the MFF are more typical of regional scale ignimbrites than of fall deposits. On earth, there are no known extensive yardang fields associated with ashfall deposits as these are rarely pervasively indurated enough to support extensive jointing and steep cliffs that characterize yardangs. Ignimbrites on the other hand are extensively chemically and thermally indurated and demonstrably support yardangs. While bedding is common in fall deposits and can manifest as layering, ignimbrites give the appearance of layering due to differential compaction and welding [18]. A key factor is that the layering in ignimbrites and fall deposits are of quite different scales and character. We find that the "layering" identified in the MFF is more consistent with ignimbrites than fall deposits.

While we prefer the ignimbrite hypothesis at this stage, our analysis identifies several areas that are key to addressing this further: 1) A better characterization of the features that have been interpreted as either bedding or zoning in the MFF; 2) More resolution of the nature of the jointing in the MFF; 3) A better understanding of yardang formation. Our continued efforts will focus on these features.

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