The dispersal of pyroclasts from Apollinaris Patera, Mars: Implications for the origin of the Medusae Fossae Formation

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A B S T R A C T
The Medusae Fossae Formation (MFF) has long been thought to be of Amazonian age, but recent studies propose that a significant part of its emplacement occurred in the Hesperian and that many of the Amazonian ages represent modification (erosional and re depositional) ages. On the basis of the new formational age, we assess the hypothesis that explosive eruptions from Apollinaris Patera might have been the source of the Medusae Fossae Formation. In order to assess the likelihood of this hypothesis, we examine stratigraphic relationships between Apollinaris Patera and the MFF and analyze the relief of the MFF using topographic data. We predict the areal distribution of tephra erupted from Apollinaris Patera using a Mars Global Circulation Model (GCM) combined with a semi-analytical explosive eruption model for Mars, and compare this with the distribution of the MFF. We conclude that Apollinaris Patera could have been responsible for the emplacement of the Medusae Fossae Formation.

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1. Introduction

The Medusae Fossae Formation (MFF) is an unusual geological unit characterized by its easily eroded surfaces, which form dunes, yardangs, and etched terrain (Scott and Tanaka, 1986; Greeley and Guest, 1987; Bradley et al., 2002; Mandt et al., 2008; Zimbelman and Griffin, 2009). It is located in the southern parts of Elysium and Amazonis Planitiae and the northern parts of Aeolis and Memnonia Planitiae, between the Elysium and Tharsis volcanic centers (130–230°E and 12°S–12°N). It covers an area of approximately 2.1 × 10^6 km^2 and has an estimated volume of 1.4 × 10^7 km^3 (Bradley et al., 2002) (Fig. 1).

The Medusae Fossae Formation has been dated as Amazonian in age on the basis of superposed craters (Scott and Tanaka, 1982, 1986; Greeley and Guest, 1987; Werner, 2005) and stratigraphic relations (Bradley and Sakimoto, 2001; Bradley et al., 2002). However, several authors have suggested that, due to the highly eroded nature of the deposit and the rapid degradation rate of craters formed in it, ages derived from crater counts may not be representative of the emplacement age (Schultz and Lutz, 1988; Schultz, 2002; Hynek et al., 2003; Kerber and Head, 2010). Recent analysis of stratigraphic relationships in the MFF has provided evidence that the unit is older than previously inferred, with some parts dating at least as old as the Hesperian (Kerber and Head, 2010).

The origin of the MFF has long been enigmatic, with a wide range of hypotheses proposed, including ancient reworked aeolian material (Tanaka, 2000), paleo-polar deposits (Schultz and Lutz, 1988), atmospheric deposition of ice nucleated on dust at high obliquity (Head and Kreslavsky, 2004), ignimbrites (Scott and Tanaka, 1982), and ashfall (Malin, 1979; Scott and Tanaka, 1986). Detailed analyses of the proposed hypotheses are presented by Hynek et al. (2003) and Mandt et al. (2007). A volcanic origin as ashfall or pyroclastic flows has been favored by several authors (Scott and Tanaka, 1982; Head and Wilson, 1998; Bradley et al., 2002; Hynek et al., 2003; Mandt et al., 2007). The MFF deposits appear to drape unconformably over topography, suggesting deposition by airfall (Bradley et al., 2002), and places where the deposit has eroded away reveal unaltered craters and landforms, indicating that the emplacement process was non-destructive (Scott and Tanaka, 1982). Recent radar investigations have determined a dielectric constant for the deposit which is consistent with a low density material (less than 1900 kg/m^3) depth-averaged density (Watters et al., 2007), which may be more consistent with compacted ash fall (originally 600–800 kg/m^3) than welded pyroclastic deposits (originally > 2000 kg/m^3) (Mason et al., 2004).

The Medusae Fossae Formation is surrounded by possible volcanic sources, including the Tharsis volcanic complex to its east, the Elysium volcanoes and the Cerberus Fissures to its north, and...
Apollinaris Patera, which is located near the center of the deposit (Figs. 1 and 2). Early researchers suggested that the MFF could have been formed during activity in a volcanic zone located between Apollinaris Patera and the Tharsis Montes, perhaps consisting of large, low-relief calderas that formed along faults and eventually buried themselves with ignimbrites (Malin, 1979; Scott and Tanaka, 1982). Later authors proposed that the MFF could have been formed as ash fall from the Tharsis Montes during periods of explosive activity from the otherwise dominantly effusive centers (Head and Wilson, 1998; Hynek et al., 2003) The Cerberus fissures are the source of an extensive, low-viscosity, late-Amazonian flood lava (e.g., Tanaka et al., 2005). Keszthelyi et al. (2000) calculated
that if 10% of the erupted mass from the Cerberus fissures was composed of pyroclastic material, this mass would be on the same order as that calculated for the volume of the MFF.

The Apollinaris edifice stands between 5 and 6 km in relief. It is nearly 200 km in diameter at its base, with slopes of about 1.4–5° (Plescia, 2004). The summit region of Apollinaris has at least two separate calderas, an inner caldera (approximately 60 × 50 km) and an outer caldera (approximately 85 × 70 km) (Fig. 2). Both of these calderas would be among the largest calderas on the Earth (Mason et al., 2004), and the outer caldera is larger than the calderas of Olympus, Ascraeus and Pavonis Mons. These features represent only the last few large, caldera-forming eruptions from Apollinaris: episodic eruptions and caldera formation could have taken place throughout the growth of the edifice. The size of a caldera generally increases with the volume of materials erupted from it (Lipman, 1997), but because of infilling and erosion, the link between eruption volumes and caldera diameters is not always straight-forward (Mason et al., 2004). Apollinaris Patera is thought to have been active during the early to mid-Hesperian (Scott et al., 1993). Early edifice-building activity was followed by the construction of a giant fan of slightly more competent material on the southeast flank of the volcano, thought to be composed of low-viscosity lavas or pyroclastic deposits (Robinson et al., 1993; Farrell and Lang, 2010).

Like the highland paterae (Tyrrenha, Hadriaca, Peneus, and Amphritites), Apollinaris Patera has been interpreted to be composed of pyroclastic material on the basis of its friable nature, lack of discernable lava flows, slumps, and sharply incised valleys (Crown and Greeley, 1989; Robinson et al., 1993) (Fig. 2). Apollinaris Patera also is located near the Mars Exploration Rover (MER) Spirit landing site in Gusev Crater, where tephra deposits are interpreted to be exposed in the Columbia Hills (Dalton and Christiansen, 2006). However, because the Medusae Fossae Formation has been dated as late Amazonian in the past, Apollinaris Patera has been largely overlooked as a possible source because of its Hesperian age. On the basis of the new age determinations for the Medusae Fossae Formation (Kerber and Head, 2010), and taking into account the location of Apollinaris Patera in the center of the deposit (Fig. 1) as well as the evidence for other pyroclastic activity from this center, we test the hypothesis that Apollinaris could have been the source for the Medusae Fossae Formation.

2. Observations and methods

In order for Apollinaris Patera to be considered a good candidate source for the Medusae Fossae Formation, it would have to meet the following criteria: (1) Proximity to the formation; (2) Evidence of explosive volcanism; (3) Evidence of activity during the emplacement of the MFF; (4) Ability to disperse ash across the entire deposit; (5) Evidence suggesting that this source might be a better candidate than other possible sources.

2.1. Stratigraphic relations

As discussed above and shown in Figs. 1 and 2, the volcano meets the first two criteria of proximity to the deposit and evidence of explosive volcanism. The contacts between the MFF and nearby units are almost always difficult to interpret, due to the fact that the MFF is continuously eroding and either retreating from contacts or shedding material onto adjacent surfaces. Both processes tend to obscure the true relationship between units. In the case of the contact between the MFF and Apollinaris Patera, MFF units near Apollinaris embay or abut the volcano on the north side, forming yardangs oriented around topographic features. There is a second contact on the southeast side of the volcano, where the MFF meets the Apollinaris fan material. The fan material is thought to be the result of later eruptions from Apollinaris, and is therefore slightly younger than the rest of the edifice (Robinson et al., 1993). In this area it is difficult to tell whether the yardangs of the MFF superpose the fan material or whether the fan material has embayed the yardangs. In at least one area, however, the fan has clearly buried the tip of a yardang (Kerber and Head, 2010).

The fan material also appears to breach several yardangs to the right of the buried feature and fill the trough between the next two yardang ridges (Fig. 3a). Unlike superposed yardangs, many yardangs along the contact with the fan have developed troughs or moats around them. These features are similar to features seen at lava-MFF contacts documented elsewhere by Kerber and Head (2010) and suggest that the fan embayed the MFF yardangs and the more friable yardangs subsequently eroded back from the contact, leaving a remnant wall of fan material (Fig. 3b). Fig. 3c shows an example where a yardang has eroded out from where it was surrounded by fan material, leaving a large, yardang-shaped impression. Farther south along the contact are mantled, possibly mantled or shallowly buried yardangs which underlie the topmost group of yardangs at a slightly different orientation, suggesting that there may have been multiple episodes of fan emplacement and yardang formation. These relations, together with the superposition of MFF material on the northern flank, suggest that Apollinaris was active during the period in which the adjacent MFF was being deposited. Recent work focusing on the contacts between Apollinaris Patera and the Medusae Fossae Formation (Lang et al., 2011) has led to similar conclusions.

2.2. MOLA analysis

Numerous topographic profiles were taken over each outcrop of the Medusae Fossae Formation using gridded Mars Orbiting Laser Altimeter (MOLA) data in order to determine the vertical relief of each section. The profiles were taken using ArcGIS, a geographic information software package. Gridded data was sufficient in these cases due to the large horizontal distances crossed by the profiles. Two procedures were used to estimate the maximum vertical relief. First, profiles were taken perpendicular to the regional slope to eliminate the effect of the Tharsis rise on the vertical relief measurements (Fig. 4a). The results of these measurements are shown in Fig. 4b. Second, a profile was taken radiating out from Apollinaris Patera to determine the relationship between section height and distance from the proposed source (Fig. 4a). The underlying slope was fitted with a low-order polynomial and subtracted from the raw measurement (Fig. 4c). The results of both techniques of measurement show a decrease in relief away from Apollinaris Patera with the exception of Lucus Planum, which the MOLA topography shows to be thinner than the more eastern deposits and considerably rougher than most of the other outcrops. Our MOLA results differ somewhat from similar measurements taken by Hynek et al. (2003). These authors documented a decrease in MFF outcrop relief moving away from the Tharsis rise with the exception of Gordii Dorsum, which they hypothesized was partially buried by lava flows at its base (Hynek et al., 2003). Our results differ first in that we have included a large, eastern accumulation of fine material (easternmost of those outlined in Fig. 1, labeled “Unnamed Outcrop” in Fig. 4b and c) in our definition of the MFF, based on the similar morphology of its deposits to those of the adjacent outcrops, and the inclusion of this outcrop in past studies of the MFF (Scott and Tanaka, 1982, 1986; Bradley et al., 2002). Secondly, we find that measuring the profile of the outcrops perpendicular to the regional slope yields a thickness for Amazonis Mensa which is less than that of Eumenides Dorsum (Fig. 4b). In summary, we conclude that the deposit is thickest at Eumenides Dorsum and generally thins with distance from this...
The deposit thins away from Apollinaris Patera, as would be expected if it were the source, with the exception of the heavily eroded Lucus Planum deposit.

2.3. Ash dispersal modeling

One of the criteria necessary for Apollinaris Patera to be considered a feasible source for the Medusae Fossae Formation is the ability for the volcano to disperse material to an appropriate distance. Given the friable nature of the MFF and the billions of years that have elapsed since its emplacement began, it would be expected that the boundaries of the MFF and its mass distribution have undergone considerable change. In particular, any original erupted distribution would have become greatly flattened over time. For this reason we test the ability of Apollinaris Patera to disperse material across the length and breadth of the formation, rather than attempting to stringently match the current boundaries or mass distribution of the deposit. We do, however, explore the conditions under which the general mass distribution can be replicated.

Prior to the refinement of Mars global circulation models, the distribution of volcanic ash from vents close to the MFF was of necessity estimated using the location of prospective vents and prevailing wind directions (Edgett et al., 1997; Head and Wilson, 1998). Hynek et al. (2003) used an improved approach, calculating dispersal based on averaged wind profiles selected from a Mars global circulation model (GCM) (Forget et al., 1999) for three different seasons. It is now possible to calculate a time-varying three dimensional dispersal of ash by combining a model of explosive eruption with the global circulation model and advecting the ash from its release from the plume to its final accumulation on the surface. At the same time it is now possible to provide the eruption model with evolving atmospheric pressure and wind profiles at the vent elevation retrieved from the GCM. Modeling of the ascent and explosive eruption of pyroclasts into the martian atmosphere has been explored in detail by several authors (Wilson and Head, 1994, 2007; Hort and Weitz, 2001; Glaze and Baloga, 2002). In this work we make use of the Wilson and Head model (1994, 2007), which consists of a semi-analytical explosive eruption model for Mars, beginning from the point of pressure equilibration between the erupting fluid and the atmosphere. In this model, erupting pyroclasts transfer heat to the surrounding atmosphere. The plume entrains air and convects upwards until it can no longer entrain enough air to remain buoyant. The rate at which the plume can entrain air depends on the temperature and pressure of the surrounding ambient atmosphere. This model was originally designed to calculate the entrainment constant for the volcanic plume using a single wind and pressure profile. Using this entrainment constant, the height of a plume and the height of release for various clast-sizes could be calculated (Wilson and Head, 1994).

The Laboratoire de Météorologie Dynamique Mars global circulation model (GCM) was created through the modification of a dynamical core from a terrestrial GCM (e.g., Hourdin, 1992). Since this time, a number of improvements have been made to the model which have had repeated success in reproducing both current (Forget et al., 1999) and inferred past climate scenarios (Madeleine et al., 2009). A detailed description of the LMD-GCM can be found in Forget et al. (1999). By combining the eruption model with the LMD-GCM (Forget et al., 1999), we were able to extract temporally varying wind and pressure profiles for the specific latitude and longitude of Apollinaris Patera. The eruption model determines the fall-out height of clasts of various sizes and relays this result to the GCM, which releases the clasts into the model at a specified flux. The clasts are then carried to the surface through the spatially and chronologically-evolving GCM wind field. In this way, the
The eruption model was run using a range of eruption velocities (100–700 m/s), magma volatile contents (0.5–5%), and mass eruption rates (10^3–10^10 kg/s). However, most of these types of simulations (those with mass eruption rates above \(10^5\) kg/s) result in a plume that is greater than 20 km in height (Wilson and Head, 1994). Because of the increasingly low density of the martian atmosphere with higher altitude, most volcanic plumes would have difficulty entraining enough air to continue convection above about 10–20 km in height (Glaze and Baloga, 2002). As a result, most martian plumes are expected to convect to approximately 20 km (Wilson and Head, 2009). The plumes modeled in this work therefore release clasts at GCM pressure levels corresponding to approximately 19 km. The resulting distribution, in kg/m^2, was translated into meters of accumulation by dividing by the ash density assumed (700 kg/m^3, analogous to a pumice, Presley, 2006). This density is also used to compute the sedimentation velocity of the ash particles in the GCM. At the point of release from the plume, the flux was set to 3.166 \(10^9\) kg/s in order to erupt the entire volume of the Medusae Fossae Formation in the course of 1 year (volume of the MFF)/(seconds in a martian year). This mass flux was chosen in order to simulate the effects of many short eruptions (days to months) taking place over random times of the year over hundreds of millions of years, or the lifetime of the volcanic center. As the volcanic particles are merely passive tracers in the GCM and do not interact with each other, the mass flux does not affect the sedimentation of individual particles. Simulations were also run erupting the mass of the MFF during the course of each of the martian seasons to show the effects of the seasonal winds on the eruption dispersal. Seasonal simulations were launched at solar longitudes (Ls) = 0, 90, 180, and 270, and allowed to run for 90°. The mass flux from the volcano was adjusted each time so that the final erupted volume was equal the volume of the MFF.

3. Results

The height of Apollinaris (5–6 km) and its position in the center of the deposit (Fig. 1) would make it possible for the volcano to disperse voluminous amounts of ash over the widespread areas covered by the MFF (Fig. 5). The distance traveled by an individual ash particle has a large dependence on both grain size and the height at which the grain is released from the plume. Fig. 5a and b shows the year-averaged distribution for 35-μm ash particles.
(silt-sized) and for 60-μm ash particles (coarse silt/very fine sand) (Wentworth, 1922). The 35-μm particles can be dispersed throughout the extent of the MFF, with the greatest accumulation taking place at Eumenides Dorsum, which is also the thickest part of the observed deposit, as discussed above. Lucus Planum is often cited as being more intensely eroded than the more eastern deposits (e.g., Scott and Tanaka, 1986); if Apollinaris Patera was the source of the Medusae Fossae Formation, a greater number of coarse grains (of an appropriate size for saltation and aeolian abrasion) would be expected to accumulate nearer to the vent, which could be a reason for the intense erosion in this region.

Naturally, the entire formation is not expected to be composed of a single grain-size. According to theoretical calculations, the minimum ash size should be approximately ~20 μm, with a peak around 110 μm (Wilson and Head, 1994, 2007). Smaller particles may form through comminution, but they would not be expected to make up a large proportion of the deposit. It has been suggested that eruptions from Apollinaris Patera may have been phreatomagmatic (Robinson et al., 1993), which would greatly increase fragmentation and result in an ash distribution with a greater proportion of finer ash (Self and Sparks, 1978).

Fig. 5c–f demonstrates the effects of seasons on the ash dispersal from Apollinaris. In the spring and summer material is dominantly deposited to the east of the edifice; in the autumn and winter material is deposited both to the east and west of the edifice. Depending on what time of the year a particular eruption
took place, ash from Apollinaris could accumulate in different parts of the deposit.

The results show that given a plausible eruption column height (~19 km), a volcanic eruption from Apollinaris Patera would be capable of ejecting material over the length and breadth of the Medusae Fossae Formation. Importantly, the volcano does not deposit a great deal of material outside the edges of the deposit where accumulations of fine particles are not seen.

The time required to form the Medusae Fossae Formation by volcanic ash fall depends greatly on the size of the eruptions assumed and periods of dormancy between each eruption. For example, the Yellowstone volcanic complex experiences large (~2000 km³) caldera-forming eruptions with a ~700,000 year recurrence interval (Gansecki et al., 1998). If Apollinaris Patera erupted with this rate of recurrence (not counting hundreds of more frequent, smaller eruptions), the MFF could have been emplaced over ~500 myr. To provide another point of reference, it has been estimated that large terrestrial eruptions (erupting more than 10¹⁵ kg of material) happen with a minimum frequency of 1.4 events/myr (Mason et al., 2004). It would take 210 of these eruptions to generate the volume of the MFF; at the stated rate of recurrence it would take at least 150 myr for the MFF to be generated. Since this rate applies to the whole Earth (a much more active planet), this length of time could be considered a low minimum for the time needed to create the volume of the MFF.

It should be noted that the magma feeding these large ignimbrite and ashfall provinces on the Earth is usually silicic in composition, and thus the mechanisms of formation and the reservoir evolution at these centers may differ from the processes forming Apollinaris Patera, which was probably fed by magmas of a more basaltic composition. However, terrestrial ashflow calderas are similar in morphology to those of Apollinaris and the highland paterae (Crumpler et al., 2007), and, due to the relatively thin atmosphere of Mars, eruptions of magma of basaltic compositions are likely to be much more explosive than basaltic eruptions on Earth (Wilson and Head, 1994).

4. Discussion

In addition to the pyroclastic nature of Apollinaris, its location at the center of the MFF, the connection between its time of activity and the emplacement of the MFF, and the general correlation between the modeled dispersal of ash from Apollinaris Patera and the boundaries of the Medusae Fossae Formation, there are additional lines of evidence that suggest that Apollinaris Patera may be a good candidate for the source of the MFF.

Equatorial and mid-latitude chlorine measurements made by Mars Odyssey gamma ray spectrometer (GRS) revealed significantly elevated chlorine concentration in the Medusae Fossae Formation (Keller et al., 2006). HCl is a common component of volcanic outgassing; in conjunction with water it forms acid fogs or acidic precipitation (Keller et al., 2006). Keller et al. (2006) favored the hypothesis that the Medusae Fossae chlorine anomaly was caused by an acidic volcanic fog, possibly originating from Tharsis or hidden vents. However, the elevated chlorine concentration was found to be greatest over Lucus Planum, which is the part of the Medusae Fossae Formation proximal to Apollinaris Patera (Figs. 1 and 6). Keller et al. (2006) suggested that the Cl-enriched material has not traveled very far from its source. If the source of the Medusae Fossae Formation were Apollinaris Patera, it would be consistent that chlorine levels are greatest closest to this source. Fig. 6, from Keller et al. (2006), shows the measured distribution of chlorine compared with the extent of the MFF.

Recent work on martian crustal magnetic anomalies has revealed magnetic anomalies near Apollinaris Patera and the Medusae Fossae Formation in Lucus Planum (Langlais and Purucker, 2007; Hood et al., 2010). Original Mars Global Surveyor (MGS) magnetometer data from the mapping orbit at 400 km were re-examined and supplemented with closely spaced tracks taken at altitudes less than 100 km during the MGS aerobraking phase. The magnetic anomaly at Apollinaris Patera, which correlates with a gravity anomaly, is interpreted to be due to a large, extinct magma chamber located within the edifice (Hood et al., 2010). The magnetic anomaly associated with Lucus Planum is interpreted to be due to the MFF materials themselves, given the good correlation between the shape of the anomaly and the shape of the deposit (Hood et al., 2010). The formation of magnetic minerals within cooling Fe-rich Mars analog basalts is enhanced under oxidizing conditions (Hood et al., 2010). The presence of a strong crustal anomaly associated with Apollinaris could therefore imply the presence of water in the magma chamber of Apollinaris, which would enhance the volcano’s explosivity (Hood et al., 2010). The presence of magnetic anomalies associated with both the Apollinaris edifice and the Lucus Planum deposits suggest that both were...
emplaced before the end of the martian dynamo. This result supports the assessment of an early Hesperian age for the parts of the Medusae Fossae Formation and strengthens the idea that the two features might be related.

At the time of the emplacement of the Medusae Fossae Formation, the atmospheric circulation and transport could have been different from their present-day conditions, possibly because of a thicker atmosphere or a different obliquity. The sedimentation velocity of particles larger than 10 μm is almost insensitive to pressure for pressure larger than a few hundred Pascal, but the general circulation and the height of the ash plume can be affected by increases in pressure. Higher pressure conditions would allow convection of the volcanic plume to greater heights, which would lead to longer ranges for individual ash particles. Preliminary simulations under higher pressures have shown that pressure increases (~five times current value) have only subtle effects on ash distribution, such as the narrowing of the ash plume in the east-west direction. Modeling of atmospheric dynamics under higher pressure conditions requires the inclusion of various processes (such as Rayleigh scattering and CO₂ collision-induced absorption) and is currently underway (Wordsworth et al., 2011). GCM simulations performed with obli quirities different from the present-day value indicate that ash travels slightly farther with increasing planetary obliquity, and slightly more accumulation is expected to the west of Apollinaris Patera than at current obliquity. The resulting distributions for either higher pressure or higher obliquity are thus broadly similar to present-day modeled distributions, with the majority of ash traveling east and west of the edifice. The direction of ash dispersal remains the same because it is dominated by the spin direction of the planet and the broad-scale topography. In this part of the planet the Tharsis bulge is the dominant topographic feature; it is thought to have been present since the Noachian time period, with the superposed northeast-trending Tharsis rise developing in the Late Noachian or Early Hesperian (Tanaka et al., 1991; Tanaka, 2000). True polar wander is thought to have been minimal since its emplacement (Grimm and Solomon, 1986; Tanaka, 2000). The simulated deposition pattern is thus plausible, and should be confirmed by specific models of the early Mars climate system.

Several outstanding questions remain. First, the Medusae Fossae Formation is found as several large outcrops with only lightly coated terrain between them. A deposition by volcanic ash-fall should result in a fairly continuous blanket of material that thins away from the source. In order for Apollinaris Patera (or any other single volcano) to be the source, some post-depositional reworking of the deposit had to have taken place. Given the large amount of time since the interpreted deposition of the deposit, it is possible that the MFF has been significantly reworked by aeolian processes (Kerber and Head, 2010). Second, Eumenides Dorsum has the greatest vertical relief of the outcrops of the Medusae Fossae Formation, even though it is farther away from Apollinaris Patera than Lucus Planum. We have suggested that this discrepancy may be due to the more intense erosion experienced at Lucus Planum, but an alternative hypothesis would be that Eumenides Dorsum itself may represent some kind of buried source. This hypothesis would be consistent with the observed thickness of the deposit, but not with the chlorine detections made by Keller et al. (2006). Third, the morphology of the Apollinaris Patera edifice is somewhat different than the morphology of the MFF. In order for the Apollinaris edifice and the surrounding MFF deposits to both be composed of pyroclastic deposits (as they have been interpreted by several authors), there must have been some difference in the way they were emplaced or subsequently weathered. One possible solution could be that most of the edifice was emplaced by pyroclastic flows, while the MFF was the result of pyroclastic airfall.

In this analysis we have assumed a volcanic origin for the MFF. In doing this we do not necessarily rule out other, non-volcanic origins, but instead establish that an origin for the MFF by volcanic processes is both feasible and consistent with observations.

5. Conclusions

Modeling of ash dispersal from Apollinaris Patera has shown that this volcanic point source could have been responsible for the emplacement of the Medusae Fossae Formation in terms of plausible dispersal patterns and eruption duration. Apollinaris is a compelling possibility for the source of the Medusae Fossae Formation because it has been dominated by pyroclastic activity for most of its history (unlike the large shield volcanoes and fissures which are dominated by effusive flows), it is centrally located in the deposit, it is of Hesperian age, it is correlated with a large chloride anomaly which may have been caused by volcanic fog from a proximal source, and both it and nearby Lucus Planum show evidence of a magnetic signature. Thus, on the basis of this analysis, we conclude that Apollinaris Patera is a very plausible candidate for the source of the Medusae Fossae Formation and that the MFF could be dominantly pyroclastic in origin. The apparent Amazonian age of the MFF is interpreted to be a crater retention age rather than the initial age of emplacement.

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