ANALYSIS OF THE OLYMPUS MONS AUREOLE MATERIAL USING MARS GLOBAL SURVEYOR DATA

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ABSTRACT

Since their discovery in 1972 by Mariner 9, the aureole materials around Olympus Mons, have remained a mysterious feature to the community of scientists studying Mars. Proposed origins have included massive landslide deposits and tectonic uplift. Recent work by P. Mouginis-Mark and L. Wilson have proposed the landforms have possible igneous origins. In this paper I attempt to reach a consensus on what we are observing by studying the new images and topographic data of the aureoles that have been collected by Mars Global Surveyor. High resolution MOC images reveal the individual blocks in the aureole to have no apparent layering or stratigraphy in their vertical faces nor do they have the appearance of exhumed dikes. The ridges also have no preferred orientation, length, or height. MOLA topographic data was useful for a more accurate calculation of volume in the aureole to compare with the volume missing from the volcano's perimeter scarp, which would suggest a landslide origin for the aureole. A value of 642,000km^3 for the northern deposit was calculated adjacent to that portion of the scarp lacking 800,500km^3, and 856,000km^3 was estimated for the eastern deposit neighboring the scarp missing 1,070,000km^3.

INTRODUCTION

The tallest volcano in the solar system, Olympus Mons, has a series of unique lobate features, which extend in a northwest, north, and northeast direction radially away from the perimeter scarp. Despite the abundant data of Mars obtained form Mariner 9 and the Viking missions, the aureole material has remained an enigma to scientists attempting to decipher its origin. Some of the theories proposed include:

1. Thick lava flows which have been deeply eroded since their emplacement (McCauley *et al.*, 1972).
2. Eroded remnants of shield volcanoes that predate Olympus Mons (Carr, 1973).
3. Emplacement of lava flows under glaciers followed by melting of the ice and subsequent erosion of the deposits (Hodges and Moore, 1979).
4. Catastrophic landslides of the outer slopes of the volcano thus forming the majestic perimeter scarp (Lopes *et al.*, 1980, 1982).
5. Pyroclastic eruptions originating from fissures or vents prior to the construction of Olympus Mons (Morris, 1982).
6. Ice lubricated gravity sliding (Tanaka, 1985).

In a 1974 paper by King and Riehle, the authors propose the theory that the outer slopes are composed of ash flow tuffs. This type of relatively unconsolidated volcanic deposit will more readily erode with the aid of wind and water and catastrophically fail in a landslide capable of achieving great horizontal distances. The authors also point out that the very circular perimeter of the volcano can be explained by the fact that compaction of the ash sheets decreases as distance increases from the vent. The hotter the particles are when they fall, the better they will cement together, and the further the particles travel from the vent, the cooler they get. The paper also notes that higher resolution images would help to identify stratigraphy that would support this theory.

In the 1980 Lopes et al. paper the authors found that the features indicate movement away from volcano, the local topography slopes down in a northeastern direction and the length of the lobes appear to have been controlled by this slope. They noted that the volume in the lobes is consistent with the height of the adjacent scarp and the amount of material missing.

One of the largest shortcomings of these papers was the lack high quality high-resolution images (compared to what is now available) and accurate topographic data of the Martian surface. New data from the Mars Global Surveyor (MGS) spacecraft have been collected since September 1997. The spacecraft carries two instruments of use to this research. The Mars Orbiting Camera (MOC) produces a daily wide-angle image of Mars similar to weather photographs of the Earth shown on the nightly news. In addition, the narrow-angle lens can capture images of objects as small as 1.5 meters across. The Mars Orbiter Laser Altimeter (MOLA) bounces beams of light off of the surface of the planet to measure the heights of mountains and depths of valleys. Each measurement is 300 meters apart and has an accuracy in its elevation information of less than 10 centimeters.

These better images and topographic profiles allow for taking new measurements and making calculations of the aureole materials in an effort to determine what their origin really is. We are now able look at the highest resolution images and topographic data in order to look at geologic structures and determine heights, slopes, and volumes of the aureole materials. If the aureole materials were emplaced from collapse of the volcano, which formed the perimeter scarp, then the volume of the aureole should match the "missing" volume of the edge of the volcano. Landslides would (probably) be turbulent flows. So any alignment of the blocks would suggest a different process. If the deposits were gravity driven, the local topography will influence the direction and shape of the landslide deposits.

A newly proposed idea is that the aureole may be dike swarms exposed at the surface by erosion of overlying material. Some high resolution MOC images [fig. 1] reveal linear ridges that are more resistant to erosion than the surrounding terrain. The blocks show no apparent stratigraphy in their vertical faces - a feature that would be expected if the materials were depositional. The ridges also show a meandering strike, which is a feature observed in terrestrial dikes, like the dike swarms on Oahu. If the aureole is indeed dike swarms we would expect to see a common slope angle and orientation of ridges. The orientation of the blocks should reveal a center of an igneous complex responsible for the intrusion.

Figure 1: piece of aureole material (lighting from right)

DATA ANALYSIS

The project began with the analysis of a Viking photomosaic of the entire volcano and its aureole [fig 2]. Observing the entire structure one can see trends in the orientations of the ridges. It is also apparent from the map that the aureole formed in segments, rather than as a single unit. Any geologic model for its formation would have to account for these different segments or "lobes". I outlined five of these lobes in the aureole that are distinguished from each other by their semi-circular shape that appear to have different centers (although it could be argued that lobes 2 and 3 are in fact one lobe). The "sub-lobes" are similar features that are much older and therefore more weathered. Within the lobes I outlined different sections based on different general orientations of the ridges.

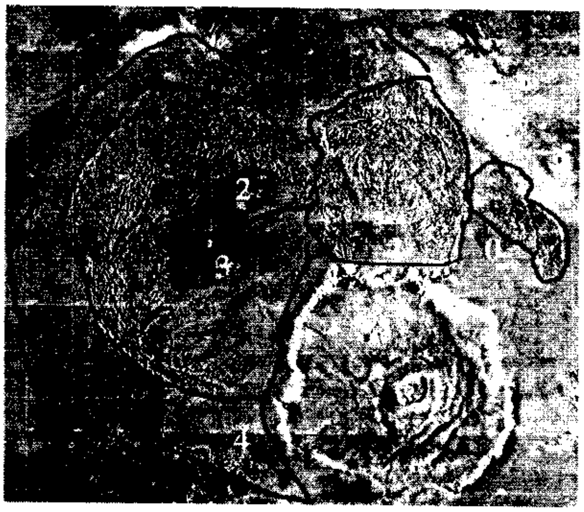

Figure 2: Lobes and sublobes in the Olympus Mons aureole

I compared over 200 high resolution MOC images of the area in order to determine whether smaller blocks in the aureole did indeed continue in the trends observed in the larger blocks visible in the Viking images. Although it is obvious that large blocks in the aureole do show a definite trend, smaller blocks discernable from the MGS camera do not show this consistent orientation. Other work attempting to relate ridge lengths and orientations with distance from the summit caldera did not show a correlation. In none of these images could I see any layering or stratigraphy to the blocks. Although a few of these blocks have prominent ridges at their crests, no examples that could confidently be described as exhumed dikes could be found.

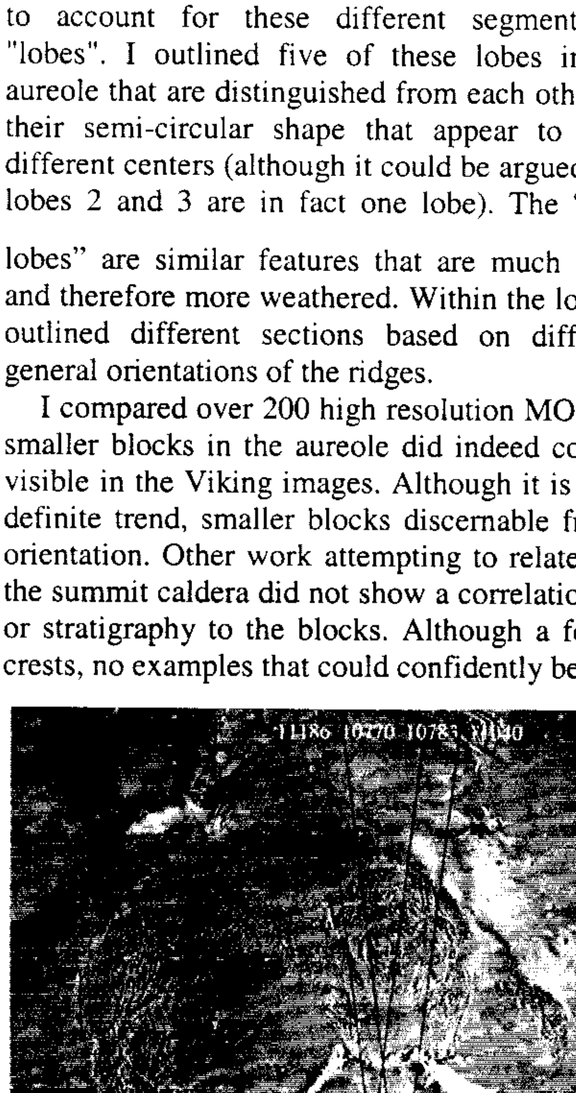

Figure 3: Positions of the four MOLA profiles used for detailed analysis

Some of the more valuable information obtained from this project involved analysis of over 100 MOLA swaths that traverse the volcano's slopes and aureole. With this data I was able to determine a more accurate estimate of the volume of material in the aureole material and see if it matched the volume of material that would have existed before the proposed landslide that formed the perimeter scarp. Because of the overwhelming amount of data available from the MOLA tracks, I had to limit detailed analysis of individual ridge heights to only four tracks (orbital numbers 10770, 10783, 11040, and 11186) that ran perpendicular to the trend of the ridges in lobe 1 [fig 3]. What was first evident was that the blocks comprising the aureole sit atop a mound with an amplitude of about 1.5km of probably consolidated aureole material that slopes to and away from the volcano in every case. With these tracks I measured individual ridge heights above mean datum, 2.25km below mean datum - a height which appeared to be the base level the aureole sits atop, and as compared to the troughs between individual ridges. Detailed observation of these four MOLA profiles also helpful in comparing slope variations of the different blocks.

Volume estimates of the aureole material were made assuming the material all sat upon a base of -2.25km for lobe 1 and -3km for lobes 2 and 3 (these lobes' base actually slopes down in a northwest direction with the base level starting at -2km and ending at -4km). Using MOLA topographic data I found the material missing from the scarp (assuming the volcano originally continued in the same slope down to the substrate) has a value of about 800,000 km^3 in front of lobe 1 and about 1,000,000 km^3 missing in front of lobe 2 and 3 [table 1]. The amount of material calculated comprising lobe 1 is about 640,000km^3. Lobes 2 and 3 contain a volume of about 850,000km^3. Assuming much of the material in the aureole has been eroded due to wind (and possibly water) over time, it is apparent the material in these lobes would fit well with material missing form the adjacent lobes.

Lobe measurements	Estimated area	Average height (of blocks)	Estimated volume
Lobe 1	642,000km^2	1km	642,000km^3
Lobes 2&3	856,000km^2	1km	856,000km^3
Scarp adjacent to:		Average height (of scarp)	
Lobe 1	117,700km^2	6.8km	800,500km^3
Lobes 2&3	214,000km^2	5km	1,070,000km^3

Table 1

DISCUSSION

The intent in this study was to look for the origin of the aureole material that might be discernible from MOC images and MOLA topographic profiles. It was my hope to attempt to find evidence that may support or refute earlier theories of this baffling feature of Olympus Mons. Observation of the high resolution photos showed that the blocks consistently showed a lack of stratigraphy as referred to in the King and Riehle paper as necessary to support the theory that the aureole is composed of layers of volcanic ash.

Results obtained from the detailed analysis of the four MOLA profiles crossing lobe 1 indicate the origin of the aureole is most likely not associated with a dike swarm. There is no evidence of a center to a series of dikes with the observed orientation and the slope of the

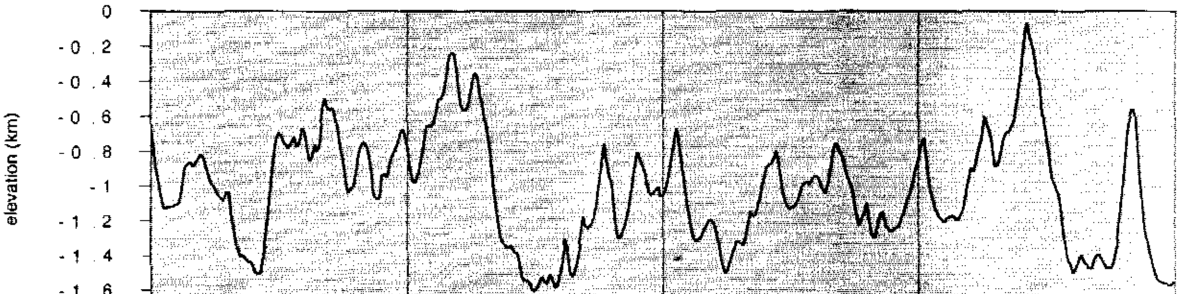

Figure 4: Detail of MOLA track 10770 over aureole material of lobe 1.

individual blocks do not have a related value. The slopes on individual blocks suggest a haphazard direction, and most of the slopes are not consistent with the angle of repose associated with loose material eroding off of a more resistant intruding rock. If the blocks were composed of exposed dikes we would expect to see in the profile steep sloped "tongues" sticking out of more shallow sloping (~30°) loose material. Instead the profiles resemble a saw where the individual teeth have different heights, widths, and orientations [fig 4].

CONCLUSION

Although estimates of the volume of material in the aureole and that missing from the scarp are somewhat crude, they are nonetheless good approximations and show that the theory that their origin is the result of a series of massive landslides fits well with the data. As stated in the work of Lopes et al., there are a few points of evidence in favor of the aureole materials being the deposits of a sequence of mass landslides and that my own research seems to support.

1. The material does indeed flow away from the volcano's scarp and moves down a local slope. This is particularly evident in lobes 2 and 3.
2. The volumes of the largest lobes of the aureole is coincident with the tallest portions of the scarp.
3. The aureole lobe is a broad topographic high with an amplitude of about 1.5km [fig 5].
4. The lack of any preferred orientation of individual blocks in the aureole suggests a turbulent flow and haphazard emplacement.

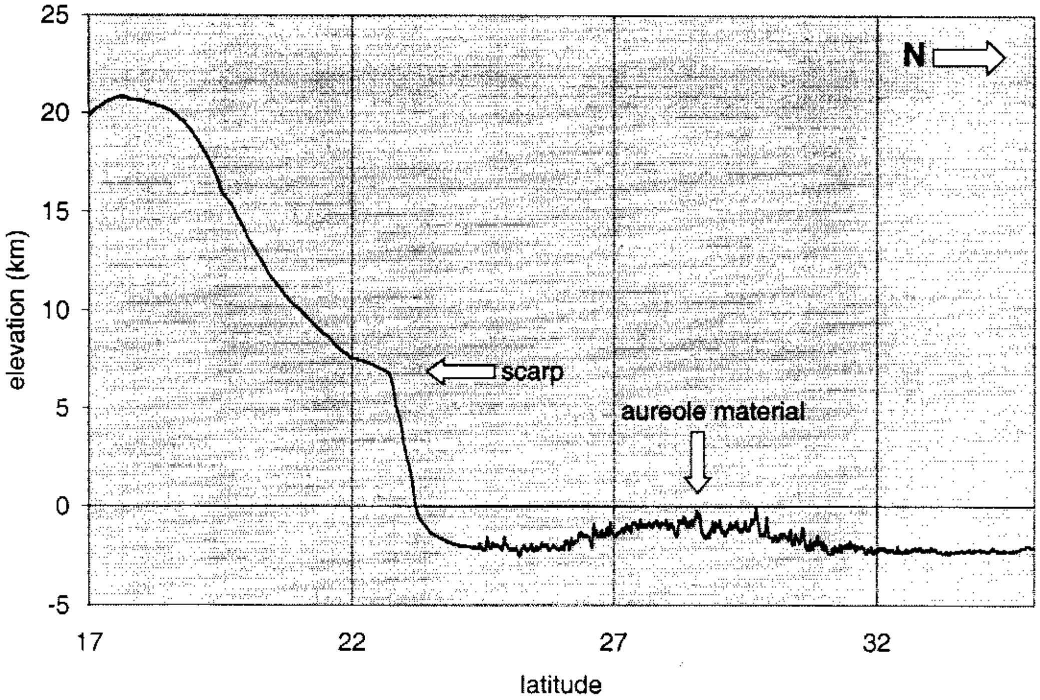

Figure 5: MOLA track 10770

One piece of the puzzle that doesn't fit well with a landslide origin comes from another feature of Mars Global Surveyor - its ability to distinguish gravity anomalies from the amount of distance the satellite is pulled toward the planet's surface as it orbits. MGS clearly identified a gravity high associated with the aureole material. This would suggest the aureole is in fact composed of denser material than the rest of the substrate, like intrusive igneous rock. Sediments inflated with the air it captured during its slide downslope would be expected to have a lower gravity anomaly, not the opposite.

Mars Global Surveyor data are some of the most accurate available for any planetary body, including the Earth. It seems therefore, in my opinion, that any remaining uncertainty of the origin of the aureole will not be alleviated by better satellite images and altimeter readings. It appears we have reached a point in our knowledge of this planet that to learn anymore it is necessary to retrieve actual samples from the Martian crust or make in situ field observations to arrive at a more accurate interpretation of the enigmatic features of this planet.

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