THE GEOMETRY OF CHASMA BOREALE, MARS USING MARS ORBITER LASER ALTIMETER (MOLA) DATA: A TEST OF THE CATASTROPHIC OUTFLOW HYPOTHESIS OF FORMATION Kathryn E. Fishbaugh[1] and James W. Head III[1], [1]Brown University Box 1846, Providence, RI 02912, kathryn_fishbaugh@brown.edu, james_head_iii@brown.edu

Introduction

Chasma Boreale is a large reentrant in the northern polar layered deposits of Mars. The Chasma transects the spiraling troughs which characterize the polar layered terrain. The origin of Chasma Boreale remains a subject of controversy. Clifford [1] proposed that the Chasma was carved as a result of a jökulhlaup triggered by either breach of a crater containing basal meltwater or by basal melting due to a hot spot beneath the cap. Benito et al. [2] suggest an origin in which catastrophic outflow is triggered by sapping caused by a tectono-thermal event. A similar origin is proposed for Chasma Australe in the Martian southern polar cap [3].

Until accurate topographic data became available with the use of the Mars Orbiter Laser Altimeter (MOLA), the topographic geometry of the Chasma and its distal deposit regions had been poorly understood. This study utilizes MOLA data to describe the topography of the Chasma and distal deposits and uses these observations to better constrain the viability of a catastrophic outflow method of formation as well as to compare with terrestrial jökulhlaup features.

Further study will include using the topographic data to better understand the specific features predicted to result from the trigger mechanisms proposed by Clifford [1] and Benito et al. [2]. If Clifford's model applies, topographic data should provide evidence for an initially small Chasma enlarged by frictional melting and eventually reaching the surface of the cap [1]. In addition, ice chunks resulting from the catastrophic flow would be later sublimed, leaving behind sediment to be modified by eolian erosion which should be evident in the topography [1]. If Benito et al.'s model applies, the largest of the described flood features should be evident in the topography such as giant current ripples and inner channels as well as evidence for tectonic control such as orthogonal cliffs and straight walls [2]. Benito et al. suggest that evidence of sapping would be later destroyed by outflow [2].

Observations

General topography: The acquisition of new topography data from MOLA has allowed the creation of a modified topographic map of Chasma Boreale (Fig. 1). According to Benito et al.'s model [2], the linear shape of the Chasma is best explained by a tectonically-controlled origin. Fig. 1 does show a generally linear southeast-facing wall until about 55°W, but there it begins to curve eastward. The slopes on either side of the Chasma wall are notably asymmetric. Between 55°-45°W, the Chasma mouth slopes toward the surrounding terrain. However, the Chasma ends mostly as a scarp between 55°-60°W.

Benito et al. [2] describe an amphitheater-shaped erosive scarp at 85°N, 0°W with orthogonal frontal and southern scarps having a tectonic origin. In Fig. 1, this scarp would lie near the Chasma source; there does not appear to be definite evidence of a scarp with orthogonal sides, nor does this location appear significantly different from other steep sections of the Chasma wall. Similar observations apply to the 2nd described scarp at 85°N, 17°W. Previously described giant current ripples [2] would lie within the lower left-hand corner of Viking image 560B44 on the higher elevations of the floor. The size of these ripples is below the resolution of MOLA, but they may be able to be imaged by MOC.

Geometry of the Chasma: Six MOLA topographic profiles (four are shown in Fig. 2) were chosen to represent the general geometry of the main section of the Chasma. From Fig. 2, it is evident that the elevation of the Chasma floor varies along the length of the Chasma. The Chasma begins with a U-shaped profile which becomes more V-shaped. The heights of the walls also vary along the length.

The distal deposits (Fig. 3a): This image lies mostly within polygonal plains [4]. MOLA track 255 (Fig. 3b) crosses the Chasma wall, defined polygons, and distal scarp. The Chasma wall has a slope of about 5°. The polygons form a rough surface at this scale. The polygons then slope upward to a smoother region of material probably slumped from the scarp. The profile then drops off, becoming a scarp with a slope of about 9°. Below the scarp, the surface is smoother, and beyond this lie dunes which are not visible in Fig. 3a.

Discussion

Chasma Boreale exhibits some features similar to those associated with terrestrial jökulhlaup events. Single flood events on Earth show a variety of flood conditions, and outburst floods also exhibit several flood peaks [5] which could explain the irregular nature of the Chasma floor, the discontinuity of terracing, and the non-uniform profile shape. The asymmetry of the floor at the base of the walls in (Fig. 2 b) could be due to ice blocks mostly being deposited along the walls as in terrestrial examples [6]. The non-uniform profile shapes and asymmetries along the floor could also be due to sliding and debris avalanching [7]. These observations are in agreement with predictions made by Clifford [1] that ice chunks should result from the flow and later sublime, leaving behind sediment and possible kettles.

Terracing could also be explained by the fact that terrestrial tunnels carved by outflows increase in size with time as the flood level is reaching its maximum value [8]. Terracing would also be expected according to Clifford's [1] prediction that the Chasma would begin small and enlarge due to frictional melting.

The distal deposits may form a debris fan, typical of terrestrial jökulhlaups, in the form of a lobe extending beyond the Chasma mouth.

The size of Chasma Boreale (60 km in width) is much larger than the typical size (10s-100s m in width) [5, 6, 9] of terrestrial outflow channels. However, this may be due purely to the scale of the parent ice sheets.

Benito et al. [2] calculated outflow estimates based on lower-resolution topography and used the Manning equation. This calculation may not be appropriate for a number of reasons. 1) An average channel bed slope is not appropriate for this particular geometry. 2) The hydraulic radius is quite complicated. 3) Observation of terrestrial jökulhlaups has lead to a wide range of velocity models which depend on the amount of sediment in the water [5] which would be difficult to estimate due to the poorly constrained dust/ice ratios for the layered deposits. 4) The peak outflow discharge of a jökulhlaup depends upon several factors such as: volume available for drainage, the stability of the confining ice to erosion, the geometry of the breach (poorly constrained without accurate topography data), the initiating event, and the height of, in this case, the rim of the crater which held the basal lake [8].

The distal deposits present complicated clues to the outflow hypotheses. Several scenarios for their depositional environment could have existed, including: 1) deposition under ice, 2) deposition into a possible former body of water [10], and 3) deposition into flat plains. Due to the fact that most of the outwashed sediment came from the erosion of polar layered terrains, it can be assumed that the sediment consisted chiefly of dust [11].

Benito et al. [1] observed only one possible example of an esker and attributed the polygons to possible subglacial (or proglacial) braided channels. Kargel and Strom [12] do not report any glacially modified morphology in this region.. The dearth of evidence for subglacial activity [12, 2] and the difficulty of searching for evidence in topography of small scale features not seen in Viking images does not tend to point toward the first scenario as being likely.

In the second scenario, the sediment would be expected to form a deltaic fan. Erosion of a previous delta into the current shape with aysmmetric slopes could then be considered. The erosional process would have had to form a 1-9° slope on the western side of the deposits and a more gradual slope on the Eastern side.

Due to the prevailing wind direction (inferred from local dune orientation) to the southeast [4], asymmetric erosion by wind may have been possible. A delta, composed mostly of dust, would have been much more easily eroded than the surrounding plains material. Examination of Fig. 3a reveals that the polygons at the base of the scarp must have been there before the formation of the scarp, because material mass-wasted from the scarp is observed to cover some of these polygons (also observed by Benito et al. [2]). The subdued polygons may be due to mantling by a debris fan. Wind may therefore have partially exhumed the more defined polygons leaving a scarp between the defined and mantled polygons.

An alternative asymmetric method of erosion might result from multiple episodes of outflow. In this scenario, during the waning stages of the flow, sediment and ice blocks were deposited as a dam(s) as has been observed in terrestrial glacial outburst flows [6]. Further influx of water then built up hydrostatic pressure within the dammed area(s), causing a second outflow over the top of the dam(s) which followed the lower elevation of the floor (darker blue in Figure 1) and eroded the eastern side of the delta.

In the third scenario, the scarp would be constructional, with the debris fan formed as a glacial flood deposit onto flat plains. For example, Desloges and Church [8] observe near vertical scarps formed in glacial deposits and at the base of eroded avalanche fans associated with jökulhlaup events.

The asymmetry in the overall wall slopes (Fig. 2) could be due to the preferential sublimation of the southwest-facing continuation of the east wall as is hypothesized to be associated with the formation of troughs in polar layered terrain [11]. This asymmetry is in the opposite sense to that of the distal deposits and mesa.

Conclusions

MOLA topographic data reveal some features observed and predicted by both Clifford [1] and Benito et al. [2] which suggests that outflow, whatever the trigger mechanism, is possible; however, evidence for associated tectonism appears weak. These data, while exhibiting some features seen in terrestrial outburst flows, reveal that the Chasma cannot by described by simple terrestrial examples or by simple flow equations and lead to the following conclusions. 1) The arcuate, deep, closed-depression form of the two topographic lows centered at 0°W and 20°W are consistent with melting and collapse over a localized heat source rather than formation by sublimation or tectonism. 2) The distal outflow deposits postdate the polygons as shown by the substantial height of the scarp (300 m) and the mantling of polygonal terrain by these deposits. 3) The topography of the distal deposits, extending beyond the Chasma mouth and mantling the polygonal terrain, is consistent with deposition by outflow. If the polygons are associated with desiccation of paleo-ocean sediments, then this outflow postdates the existence of the possible ocean. 4) The layered terrain troughs extending to the northwest of the Chasma appear not to have branched off from the Chasma, but to be cut off by the Chasma, suggesting that the Chasma was carved after the formation of the troughs. 5) The volume of the Chasma is 2.6 x 10^4 km^3. If this amount of water and sediment were washed out into the north polar basin, it would fill the lowest portion of the basin to a depth of a few 10s of meters. Assuming a dust content in the polar layered terrain of 40% [13], the sediment depth would be several meters.

References: [1]Clifford, S. , *J. Geophys. Res.*, 92, No. B9, 9135-9152, 1987. [2]Benito, et al., *Icarus*, 1997. [3]Anguita, et al., *LPI Contribution*, 953, 1, 1998. [4]Dial, A.L., *U.S. Geol. Survey Misc. Inv. Map I-1640*, 1984. [5]Maizels, J., *J. Sed. Petrol*., 59, 204-223, 1989. [6]Russel, A., *Sedimentology*, 40, 1091-1111, 1993. [7]Desloges, J., M. Church, *Can. J. Earth Sci*., 29, 551-564, 1992. [8]Blown, I., M. Church, *Can. Geotech. J*., 22, 551-563, 1985. [9]Clarke, G., W. Matthews, *Can. J. Earth Sci*., 18, 1452-1463, 1981. [10]Parker et al., *JGR*, 98, no. E6, 11061-11078, 1993. [11]Thomas, P., et al., in *Mars*, Univ. Arizona Press, 767-795, 1992. [12]Kargel, J. R. Strom, *Geology*, 20, 3-7, 1992. [13] Herkenhoff, K., *LPI Contribution*, 953, 18-19, 1998.

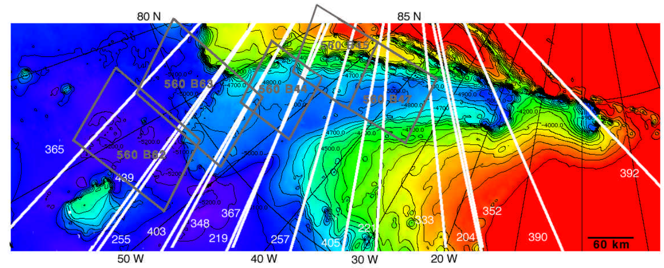

Figure 1. Topographic map of Chasma Boreale in polar projection using MOLA data. Elevations range from -5300 m (purple) to -3500 m (red), and contours lie at every 100 m. The white numbered lines indicate MOLA SPO 1 and SPO 2 tracks discussed in this paper. The grey numbered boxes indicate the location of Viking Orbiter images.

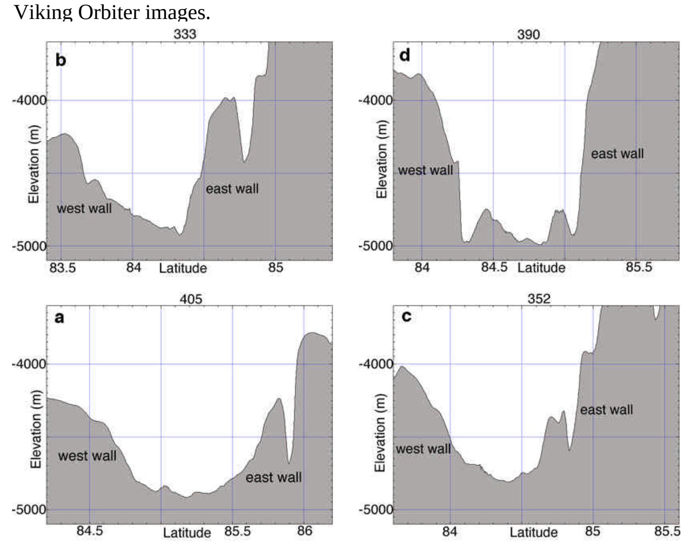

Figure 2. Representative topographic profiles transecting the Chasma. These profiles are stacked in order to give a cross-sectional view running up the Chasma (a-d). Vertical exaggeration = 69. a) This profile shows a U-shaped profile. Terracing on the scale of 10s of m is visible on the west wall. A polar trough lies northward of the east wall. The floor shows three minima in elevation which may be inner channels, about the width of those described by [2] (6 km) but about half as deep (100 m). b) Profile is now V-shaped. The floor slopes gradually upward towards the west wall. This profile also exhibits a possible inner channel. c) The floor exhibits a less defined V-shape, is less asymmetric, and flattens at the base of the walls. d) The west wall rise shows terracing, and the east wall shows a rough surface. The steeper walls are actually associated with layered terrain troughs. The floor exhibits two possible inner channels.

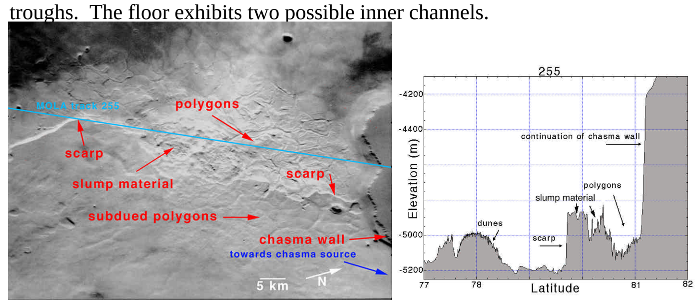

Figure 3. a) Viking image 560 B63, with a resolution of 115 m/pix. See Fig. 1 for orientation of this image with respect to the Chasma, but note that the rectilinear projection of this image is different from the polar projection of Fig. 1. b) MOLA track 255 which shows a profile crossing the Viking image as indicated. Vertical exaggeration = 270.