Abstract

An arc of outlying deposits of polar material concentric to the north polar cap of Mars consists of topographically significant polar material remnants, irregular depressions which we interpret as kettles, frost-covered or residual ice-filled craters, and frost patches. Olympia Planitia is situated poleward of these deposits and was thought to be a flat, sand-covered plain. The new high resolution topographic data from MOLA show instead that Olympia is characterized by a convex-upward, positive topography, contiguous with the polar cap, which we interpret to represent an extension of the polar materials now mantled by dunes. Together, Olympia Planitia and the outliers define an arc of remnant polar deposits that we interpret to delineate the former extent of the polar cap in the 180°W direction. When this former lobe, which we refer to as the Olympia Lobe, is included with the present polar deposits, the total configuration becomes much more symmetric about the present rotational pole. These observations suggest an asymmetric retreat of the Olympia Lobe of the polar cap, resulting in deposition of sublimation lag deposits and formation of polar material remnants and kettles. The cause of the retreat of the Olympia Lobe is unknown, but its asymmetry may be due to the preferential deposition in this region of volcanic ash from Alba Patera or to subglacial volcanism.

Polar residual ice remnants and kettles

Mapped polar residual ice remnants [1,2] were identified using Viking Orbiter and Mariner 9 images. These have been postulated to be remnants of polar residual ice [1], remnants of the seasonal CO\textsubscript{2} frost cap [3], and outlying mesas of ice, frost, or polar layered materials [2]. We have now identified additional residual ice, and have better constrained the characteristics of mapped outliers using MOLA data (Fig. 1) and images taken from the 1.7m km-resolution Viking mosaic of the polar region. We propose that the mapped [1,2] outliers, a subset of the actual total population, are a mix of: 1) frost-covered or residual ice-filled craters, 2) frost patches, 3) polar material remnants, consisting mostly of polar layered material, and 4) kettles. The following observations support this: 1) Some of the mapped remnants are within a distance of one crater diameter from craters larger to or the same size as the remnants themselves. These remnants thus must represent frost-covered crater topography. 2) Some of the mapped remnants exhibit a flat topography, and thermal inertia data show that thin layers of frost are deposited seasonally and change shape [4]. These are thus not polar material remnants. 3) Some of the mapped remnants are within bright patches having no visible craters at 1.75 km resolution, have topographic characteristics which distinguish them from the surrounding terrain and from seasonal frost, and do not change shape significantly from year-to-year [5]. Thus, these must represent remnants of polar material, probably mostly layered materials as described above. 4) The proposed kettles do not exhibit a regular shape or a depth to diameter ratio similar to fresh craters, exhibit little or no rim topography, and are distinct from the surrounding cratered plains both in topography and roughness [6] maps.

Implications for the previous extent of the polar cap

On the basis of the topography of Olympia Planitia and of the mapped Apr remnant arc to the south, we conclude that the material underlying the longitudinal dunes is an extension of the polar cap deposits and that the arc of outliers and kettle-like features represent remnant morphology of a once larger cap (Fig. 2). We have termed this former extension of the cap the Olympia Lobe. Additional evidence to support this conclusion comes from the fact that circumscription of a line surrounding the presently exposed continuous residual ice deposits, Olympia Planitia, and the arc of outliers and kettles produces an areal symmetry around the present rotational pole. Clifford et al. [7] state that the current cap shape is only representative of the current climate so that the polar materials may be interbedded to great distances at depth. In addition, ridges parallel to the cap and visible up to 20 km beyond the residual cap edge in Viking images between 300-360°W may represent a former extent of the cap [8].

We calculated the volume of polar material which has been removed from the Olympia Lobe by assuming a wedge shape extending to the arc of polar outliers and lying between the slope of Olympia Planitia and the slope from the cap to the outlier arc. This minimum estimate yields a volume of ~1.6 x 10\textsuperscript{7} km\textsuperscript{3}. This volume corresponds to less than two percent of the current cap volume, a minimum volume estimate of 1.2 x 10\textsuperscript{7} km\textsuperscript{3} [8]. If this estimated volume includes about 50% dust as a maximum estimate [10], then the amount of dust is equal to 8000 km\textsuperscript{3}. This is more than enough dust to provide sediment for the north
polar ergs which have an estimated volume of 1200 km³ [11].

What could have caused retreat of the Olympia Lobe? 1) A decrease in accumulation would move the snow line further up-cap, thus causing an imbalance in the amount of ablation vs. accumulation and a slow retreat by sublimation and wind ablation. Causes for the decrease in accumulation could include: variations in H₂O supply due to obliquity cycles [e.g.,7,12] and a decrease in the amount of surface water due to inclusion of ocean and outflow channel water into the cryosphere. 2) An increase in the ablation rates could also cause retreat of the cap. As described above, the eastern half of the outlier arc is rougher than the western half. This asymmetry may be due to preferential deposition of thin layers of pyroclastic ash from Alba Patera in this region. Such ash layers could increase the sublimation rate in this region. Variations in ablation rates could also come from the obliquity cycle [e.g., 12]. 3) Basal melting could also provide a relatively fast mode of release of melted polar materials. 4) Another possible mechanism for creating glacier recession morphology would be the freezing of surface lakes into glaciers, entrainment of debris, and eventual ablation and recession, one explanation for the formation of the thumbprint terrain in the northern plains [13,14]. According to Kargel et al. [15] deglaciation may have occurred via basal melting, a greenhouse effect, high orbital obliquity, or sublimation, factors which we have considered in this study.

The current dynamic state of the cap is not clear, that is, whether it is currently in a state of net erosion or in a steady-state condition [7-8,16-18]. Significant accumulation may only be able to take place during times of moderate obliquity (i.e. the current climate) if condensation of dust particles is the major means of deposition on the poles [7]. However, the accumulation rate seems to be decreasing, as evidenced by the fact that images of the cap from different seasons expose the same layers even after the winter deposition of frost has receded. In addition, accumulation may be currently taking place near the center of the cap [5]. The cap may be accumulating in the center and having a pattern of spiraling ablation and accumulation in the form of troughs [7]. According to the authors, ablation of the cap has a greater influence in the present dynamics than does glacier flow as is evident by the existence of the troughs.

According to the “accumulation” model [16], most of the ablation of the cap may be occurring within the troughs. This ablation would leave sediment as a lag deposit, some of which would end up moving downwards so that trough migration leaves a layer of sediment at the base of the cap, an analog to a moraine. Evidence of these basal “moraine” layers in images might provide further information about the former cap edge.

The presence of a thick eolian mantling on the polar materials of Olympia Planitia would imply that sublimation or wind ablation does not affect these polar deposits. Sublimation and wind ablation are probably the main mechanisms of ablation at this time, with different parts of the cap eroding at different rates. Muhleman and Ivanov [17] propose that the current shape of the polar cap is due to ablation. Zuber et al. [18] suggest that the cap is not moving or is getting smaller (not including seasonal changes).

Further studies will include detailed examination of the kettle-like topography and morphology, investigation into possible modes of asymmetrical cap retreat with comparison to similar terrestrial processes, and examination of evidence, using MOLA and Viking/MOC images, for basal melting and cap movement.