NORTH POLAR REGION OF MARS: EVIDENCE FOR RESIDUAL CAP RETREAT AND BASAL MELTING

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Abstract:

We present evidence for asymmetric retreat of the north polar cap (consisting of polar layered terrain and polar residual ice) of Mars. This evidence exists in the form of the Olympia Lobe (a portion of the cap now covered by dunes), outlying polar material remnants, and depressions interpreted to be kettles. Several possible causes of this retreat include: 1) a decrease in accumulation, 2) an increase in ablation rates, and 3) melting of polar material. Evidence of past melting exists in the form of Chasma Boreale and other, smaller chasmas. These features are interpreted to have been formed by the basal outflow of meltwater and consequent collapse of polar materials.

Polar residual ice remnants and kettles

High albedo patches south of and concentric to Olympia Planitia were identified [1,2] using Viking Orbiter and Mariner 9 images. These have been postulated to be remnants of polar residual ice [1], remnants of the seasonal CO₂ frost cap [3], and outlying mesas of ice, frost, or polar layered materials [2]. We have now identified more of these features and have better constrained their characteristics using MOLA data (Fig. 1) and Viking images. The irregular topography of these features can be contrasted with the surrounding cratered plains in Fig. 1. We propose that the prominent mesas and irregular depressions represent remnants of polar material and kettle-like features, respectively. In profile, in addition to the kettles and prominent remnants, some mapped bright patches exhibit a flat topography and are thus probably frost patches. Viking images also show some bright outliers to be associated with the bowls and rims of craters. We propose that the mapped [1,2] high albedo patches represent a mix of: 1) frost and/or residual ice - filled craters, 2) frost patches, 3) polar material remnants, and 4) kettles.

The Olympia Lobe and the previous extent of the polar cap

Olympia Planitia (situated poleward of and concentric to the polar material remnants and kettles) is dune-covered and not flat as previously thought. It has a positive, convex topography, contiguous with the polar cap as shown in Fig. 1. On the basis of this topography, we propose that Olympia Planitia represents an extension of the polar cap, now covered by dunes.

We suggest that, together, Olympia Planitia and the polar material outliers and kettles represent remnant morphology of a once larger northern cap (Fig. 2). We have termed this former extension the Olympia Lobe. Assuming cone shapes delineated by the slope from the top of the cap to the furthest extent of Olympia Planitia and by the slope from the top of the cap to 77°N (see Fig. 2), we have estimated the minimum missing volume of polar material. This volume estimate of 3x10⁶ km³ constitutes 25% of the minimum volume estimate of the entire current cap [4]. Assuming 40% sediment content in the layered terrain [5], this yields 250 times the amount of sediment estimated [6] to be in the north polar ergs. Thus, ablation of the cap could easily provide enough material for the dunes covering Olympia Planitia and for part if not all of the surrounding Amazonian mantling [1,2] deposits. This may imply that the current estimations [e.g. 5] of the volume percentage of dust in the north polar layered deposits need to be revised.

Though the evidence presented points towards an asymmetrical retreat of the polar cap in that it has occurred predominantly from the 180°W direction, Howard et al. [8] have noted ridges parallel to the cap and visible in Viking images up to 20 km beyond the cap edge in the 300-360°W direction which may represent a former cap extent.

The topography of Olympia Planitia and the presence of remnants of polar material and depressions interpreted to be kettles concentric to and just south of this region suggest that the cap has retreated and that this retreat has been predominantly from the 180°W direction. The configuration of the formerly larger cap is illustrated in Fig. 2. There are several possible causes for retreat of the cap, and these may have acted in some combination.

Possible causes of retreat

1) Decrease in accumulation: This could cause an imbalance between accumulation and ablation. The decrease could be caused by a number of factors, including: a) a decrease in H₂O supply due to inclusion of surface water into the regolith or due to low obliquity [e.g. 7,9] or b) a decrease in dust supply available for nucleation due to high obliquity [e.g. 7,9].

2) An increase in the ablation rates: This could be caused by, among other possibilities, a) an increase in obliquity, b) polar wander [10] and consequent movement of parts of the cap to more southerly latitudes, or c) deposition of volcanic ash from Alba Patera.

3) Melting of polar materials: The best evidence of melting exists in the form of chasmas in the 40-90°W direction. While these chasmas do not lie within the former Olympia Lobe, their presence strongly suggests melting in the past history of the cap.

Evidence of melting

Several origins have been proposed for the formation of Chasma Boreale. Howard [11] proposed that the chasma was carved by concentration of katabatic winds created by cold air flowing from the top of the cap down a topographic low. Evidence for this included the presence of yardangs, dunes, and erosional scarps within the Chasma. Zuber et al. [4] have supported this conclusion.

Other authors [e.g. 12,13] have proposed formation by catastrophic outflow of meltwater, analogous to a terrestrial jokulhlaup, citing similarities with a Martian outflow channel, Ravi Valles [12], and the presence of fluvial bedforms [13].

New high-resolution topography from MOLA allows us to better characterize the morphology of Chasma Boreale. It shows that the floor is relatively flat and lies close to the elevation of the surrounding plains. We propose that Chasma Boreale was formed initially by outflow of meltwater in sub/englacial tunnels and subsequent collapse of the polar materials. Eolian processes (including katabatic winds) and sublimation, the principle agents of ablation at this time, have since modified the
chasma.
In our analysis [14,15] we interpret the data to mean that the flow began near the deep, enclosed depression at the beginning of the chasma. The meltwater then tunneled through or beneath the ice (and was thus able at some points to flow upslope) until it broke out at the cap periphery. Polar materials then collapsed as a result of the flow and removal of material, forming a reentrant. During the outflow, layered material sediments and ice were deposited in the form of the lobate, delta-like structure at the chasma mouth, subduing the underlying polygonal terrain. Channel-like topographic lows were also carved beyond the lobate deposits.

As the outflow waned, the flow followed the lowest floor topography, eroding the eastern side of the lobe, following the earlier carved channels, and depositing a few meters of sediment in the lowest parts of the adjacent north polar basin.

Two smaller chasmae to the west of Chasma Boreale also showed evidence of channel-like features carved at their mouths. These chasmae have opposing curvature, arguing against a genetic relationship with the nearby polar cap troughs.

**Summary and future work**

We have presented evidence (in the form of recessional morphology, including polar material remnants and kettles) for asymmetric retreat of the north polar cap of Mars. This missing portion of the cap, termed the Olympia Lobe, has a volume sufficient to provide more than enough sediment (assuming 40 volume% sediment content) for the north polar ergs and part if not all of the surrounding mantling deposits. Retreat may be caused by several factors, including melting (which we propose formed Chasma Boreale).

Future work will include further investigation into the causes of retreat, using MOC and MOLA data, the timing of retreat, and similarities with terrestrial ice sheet retreat. We also plan to investigate the relative ages of the chasmas, polar cap troughs, and the portion of the Olympia Lobe still in existence.

**References:**

**Fig. 1** Topographic map enhanced to show details of Olympia Planitia and the remnant arc region. Black is low and, white is high. The large depression in the middle box is about 250 m deep.

**Fig. 2** The figure on the left shows the configuration of the once larger cap. The dotted line shows the extent of the kettles and polar material remnants and extends out to about 77°N. Topographic profiles show the relationships of the distal deposits (interpreted to be proglacial deposits and structures), the Olympia Lobe (interpreted to be a large-scale equivalent of an ice-cored moraine), and the main cap (residual ice and layered terrain).