VISCOUS FLOWS FROM POLEWARD-FACING WALLS OF IMPACT CRATERS IN MIDDLE LATITUDES OF THE ALBA PATERA AREA.

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Introduction: A statistical analysis of the Mars Orbiter Laser Altimeter (MOLA) data shows that steep slopes (>20°) are less abundant in poleward-facing slopes than equatorward-facing slopes in middle latitudes in the both hemisphere [1]. The preferential flattening of poleward-facing slopes might be explained by melting of near-surface ground ice which is expected only on poleward-facing slopes in middle latitudes during periods of high obliquity [1]. This is consistent with the fact that recent Martian gullies associated with fluid flows are also frequently observed on poleward-facing slopes in middle latitudes [2], since gully formations might have played certain roles in the slope flattening processes. However, whether or not the near-surface melting of snow and/or ground ice happens at geologically recent times includes complicated problems; for example, it would also depend on the amount of trapped CO_2 on the open reservoirs such as the regolith at high latitude and the south residual polar cap [3]. In middle latitudes, tongue-shaped ridges (morphologically similar to terrestrial protalus ramparts or terminal moraines) are also dominantly observed at the base of poleward-facing walls of some impact craters [4]. It is suggested that tongue-shaped ridges would have some relation with viscous flows of ice-rich deposits [5, 6]. In this study, we identify whether the preferential slope flattening of poleward-facing slopes had or have continued through Amazonian, because it is generally considered that erosion rates on Mars would rapidly drop at the end of Noachian. We also discuss the formation of the north-south asymmetry of steep slopes on the basis of observations of MOC images and MOLA topographic profiles.

Methods: We study 77 impact craters in the Alba Patera area (25° N-60° N, 90° W-120° W) whose diameters are greater than 7 km. Since the most part of the Alba Patera area had been resurfaced during the periods from late Hesperian to early Amazonian [7], impact craters in the Alba Patera area would have formed after this period. Using the MOLA track data, we measure the maximum inclinations of both poleward-facing and equatorward-facing inner walls for each investigated impact craters. The maximum inclinations are measured for one MOLA shot spacing (about 0.3 km) and averaged in 3-5 MOLA tracks which pass near the center of impact craters.

Results: As shown in Figure 1a and 1b, the maximum inclinations of poleward-facing walls are generally smaller than those of equatorward-facing walls from around 30° N to 55° N, which is consistent with the previous statistical analysis (see Figure 5 in [1]). Inclinations of equatorward-facing walls below 45° N keep relatively high values of around 30°, which might reflect the angle of repose on Mars, and gradually decline with the increase of latitude (Figure 1a). On the other hand, inclinations of poleward-facing walls begin to decrease from 35° N (Figure 1a). In particular, an impact crater at 29.6° N shows an extraordinary low inclination of 20.6° (Figure 1a). These results indicate that the preferential flattening of poleward-facing slopes had occurred though Amazonian and might still continue today.

Figure 1c shows relative degrees of crater degradations. The degradation degree is defined as $R = (H - h)/H$, where H is initial crater depth which is altitudinal difference between the average rim height and the depth of the lowest point of crater floor, and h is actual crater depth [8]. H is calculated from an empirical equation for the aspect ratios (diameter:depth) of complex craters assembled by [9]. Most craters below 40° N have R-values of under 0.4, although R-values of most craters above 50° N are more than 0.4. The positive correlation between the R-value and the latitude may indicate preferential crater degradations in the higher latitudes.

Crater flattening by viscous flows of ice-rich materials: The processes involved in crater degradations would include dry mass wasting, fluvial incision and deposition, glacial and periglacial activities, lava filling, and dust and volcanic ash deposition. However, the systematical flattening of poleward-facing slopes in middle latitudes is difficult to be explained by most of these processes. Here we propose that slope flattening would be strongly influenced by stability of near-surface volatiles, that are ultimately controlled by solar insolation. Figure 2 shows a fresh crater with tongue-shaped deposits at the base of the poleward-facing (north-facing) wall. Tongue-shaped deposits are considered to have formed by viscous flows of ice-rich materials and contributed to crater degradations in middle latitudes [6]. We also consider that viscous flows of ice-rich materials from poleward-facing walls would mostly dominate flattening of craters, because almost all of degraded craters in middle latitudes in the Alba Patera area display flat floors, which are slightly inclined toward poleward (Figure 3, 4). We consider that floors of fresh craters such as Figure 2 might have been gradually filled by viscous flows of ice-rich materials to form flattened floors as shown in Figure 3. With the further progress of crater degradations, impact craters might be changed into almost flat, even floors such as Figure 4. Inclinations shown figure 4c suggest that viscous flows may be able to transport materials even under extremely low gradients of slope (<1°). As such, the preferential flattening of poleward-facing slopes can be formed by filling of crater cavities and/or erosions of rims by viscous flows of ice-rich materials which dominantly occur on poleward-facing walls in middle latitudes.

"Cold trap effect" of a CO_2 ice covering on poleward-facing slopes: In the above, we discuss the possibility of the repeated fillings of ice-rich materials for the crater flattening. Here we discuss how an ice-rich layer is formed only on poleward-facing slopes. We pay attention to a CO_2 ice covering which keeps ground surface temperature much below condensation point of water. Slope orientation would strongly affect near-surface CO_2 frost stability, and cold poleward-facing slopes would be covered with CO_2 ice for longer periods than other orientation [10]. If the surrounding atmosphere contains some moisture, CO_2 ice would continue to absorb the moisture, as if water vapor condenses on cold windows in a room during winter season. The "cold trap effect" of a CO_2 ice covering might develop an ice-sheet and/or permafrost layer only on cold poleward-facing slopes in middle latitudes.

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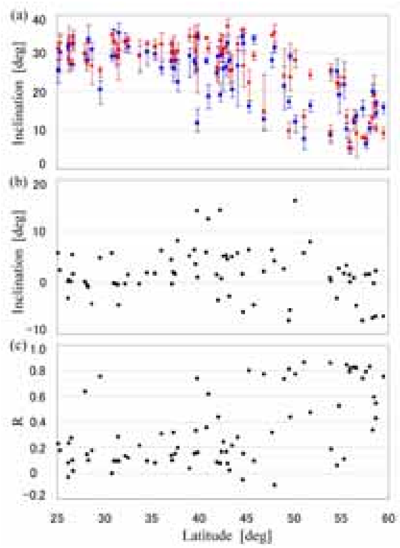

Figure 1: (a) The maximum inclinations of both equatorward-facing (red) and poleward-facing slopes (blue). Error bars show the upper or lower values of the maximum inclinations among 3-5 selected MOLA tracks. (b) Inclination differentials between equatorward-facing and poleward-facing slopes. (c) R-value.

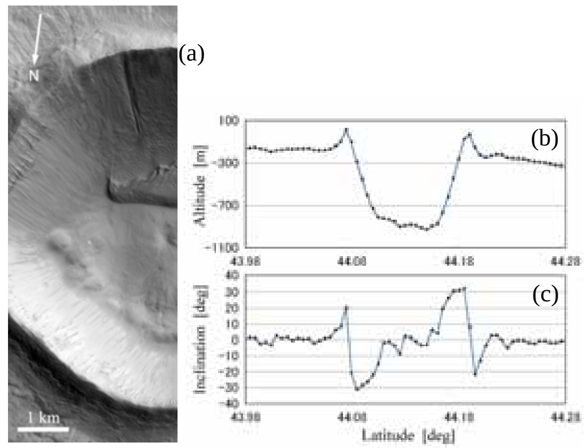

Figure 2: **(a)** A portion of MOC image R03-01123 near 44.1 °N, 91.1 °W (illuminated from the upper right). The diameter and R-value of the impact crater are about 6.95 km and 0.095, respectively. **(b)** Topographic profile of the crater shown in (a). **(c)** Inclinations between adjacent two MOLA shots. Positive value shows an equatorward-facing gradient and negative value shows a poleward gradient.

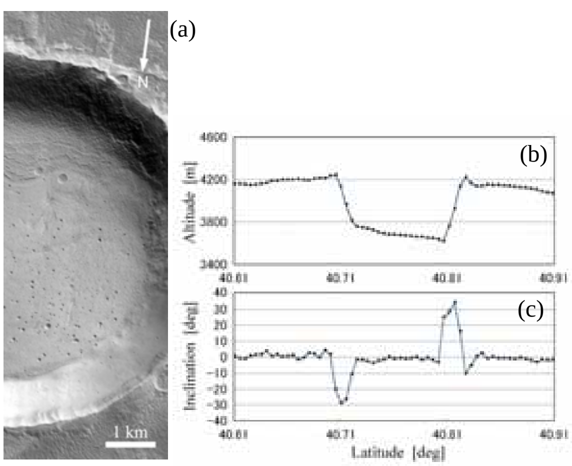

Figure 3: A portion of MOC image R15-02631 near 40.8 °N, 105.4 °W (illuminated from the upper right). The diameter and R-value of the impact crater are about 7.31 km and 0.36, respectively.

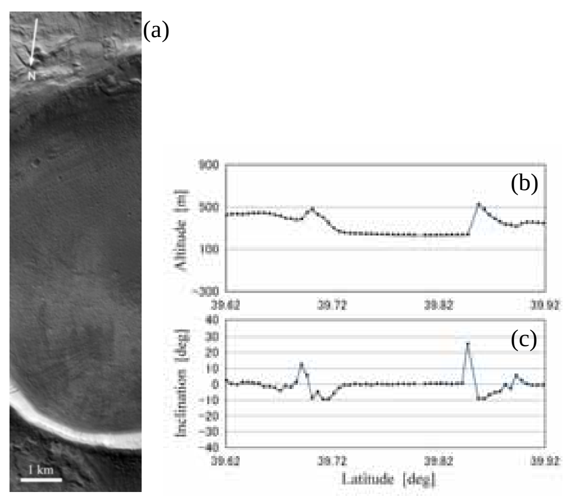

Figure 4: A portion of MOC image R09-01882 near 39.8 °N, 94.2 °W (illuminated from the upper right). The diameter and R-value of the impact crater are about 9.67 km and 0.74, respectively.