Martian Climactic Events Inferred from South Polar Geomorphology on Timescales of Centuries.

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Introduction: The solid CO_2 reservoir at the southern pole of Mars, which survives the entire summer, has been known to exist for decades [1,2]. Mars Global Surveyor data have revealed this residual deposit to contain a rich variety of geomorphic features [3]. One of the most ubiquitous classes of features on the residual cap are the flat-floored quasi-circular pits with steep walls (see Fig. 1), dubbed Swiss-cheese features.

In this work we report on statistical properties of different Swiss-cheese populations within the residual cap. We use results from a model we have developed [4] to attempt to infer the recent history from such properties as the size distribution and other measured geomorphic parameters.

We find evidence of changing environmental conditions on the residual cap over timescales of Martian centuries.

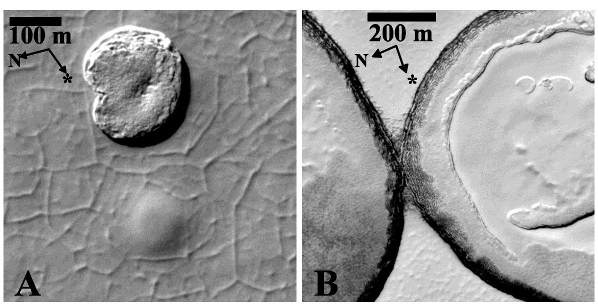

Figure 1. A) Typical depression in the polar CO_2 ice (“Swiss-cheese feature”) within the study area shown in Fig. 2. Just below and to the right is a slight depression, which may be the progenitor of a future Swiss-cheese feature. The ‘elephant hide’ appearance of the surrounding terrain is commonly observed near these features in this area. Sub-frame of MOC narrow angle image M09/00609, taken at 87° S, 353° E, and L_s 237°. **B)** Larger Swiss-cheese features show moats with a raised central island, also visible here is layering within the walls. Sub-frame of MOC narrow angle image M12/01995, taken at 86.9° S, 17 E°, and L_s 305°. In this and subsequent figures arrows denote the direction to the sun (*) and north (N).

Feature Description: These features are strictly confined to the southern residual CO_2 cap. Within that restriction they occur in all areas, usually right up to the border between the residual cap and the layered deposits. Swiss-cheese features have a number of distinctive characteristics (see Fig. 1), although not all features share all these characteristics.

- Flat Floored
- Steep Walls
- Depth ~8m (from shadows and MOLA)
- Size range from a few hundred meters to ~1 km
- Layers exposed in walls
- Asymmetric cusp (smaller ones only)
- Interior moat and island (larger ones only)
- Equatorward facing walls slightly steeper

Swiss-cheese features do not change shape or size over the course of a single year [3,5], however observations from two sequential Martian years show that the depressions are expanding [6]. The observed rate of retreat for individual walls is 1-3 m/yr [6]. The flat floors and growth of these features has been successfully modeled as a depression in CO_2 ice underlain by water ice [4]; modeled retreat rates (0.5-2.5 m/yr) were close to the observed rates and depended mostly upon the subsurface albedo profile.

Seasonal changes in the albedo characteristics of the depressions do occur [4,5]. The walls and moats (in the case of the larger depressions) darken considerably when the seasonal frost is removed. The surrounding upper surfaces and raised central islands (in the case of the larger depressions) do not darken in this way.

Observations and Model: Following previous work [4, 7]. We choose several study regions on the residual cap spanning latitude, longitude, elevation and distance to residual cap edge. Among the measured parameters we will report on are:

- Size
- Orientation (where visible)
- Moat widths
- Wall slopes (poleward and equatorward)

In work so far we have used the developed model to interpret the size distribution in terms of age [4, 7]. However other parameters such as the wall slopes can provide constraints on the subsurface albedo profile when compared to model results for different situations.

An example of one region studied is shown on Fig 2. This region has a unique population of Swiss-cheese features, which show a remarkable consistency in size and orientation [7].

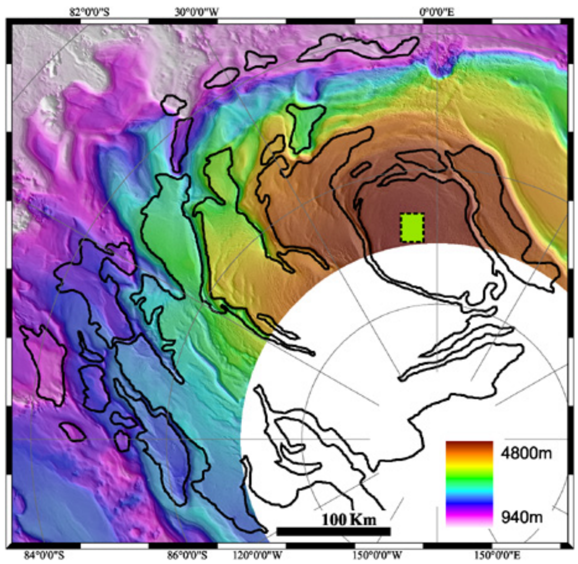

Figure 2. Shaded topographic map of the southern residual cap (outlined in black). Data poleward of 87° S (white areas) is very sparse and not shown here. The region of interest discussed here (400 km^2) is outlined by the dashed square near 87° S 355° E. Other regions will be similarly analyzed.

The model used is described elsewhere in more detail [4,7]. Briefly it accounts for all orders of incident and scattered long and short wave radiation within an arbitrarily shaped depression. The depression is embedded within CO_2 ice and can change size and shape in response to sublimation/condensation of CO_2 in different areas. The CO_2 ice is underlain by water ice which is assumed to be involatile within this temperature range but which is free to heat up and conduct heat into the subsurface if exposed to insolation.

Preliminary results: These features are fast growing and provide information on the last few centuries of Martian history. Although this work is still in the initial phases some preliminary results show the promise of this approach.

The model concept of a thin CO_2 layer on top of water ice was validated with THEMIS data [4,7]. This led to an estimate of the total amount of CO_2 in the residual cap reservoir (about 5% of the atmospheric reservoir [4]). This estimate is likely an upper limit as the 8 meters thick CO_2 layer is very patchy over most of the residual cap.

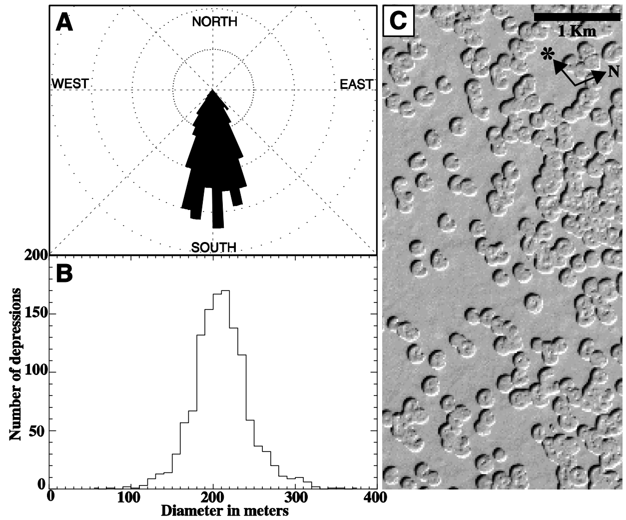

Figure 3. A) Rose diagram of Swiss-cheese feature orientations. Azimuth refers to the direction from the cusp to the opposite wall, through the center of the depression. The total number of features measured was 370, the mean azimuth was within 0.2° of south and the standard deviation was ~17°. Concentric circles indicate number in increments of 10. **B)** Histogram of sizes of identifiable Swiss-cheese features. Diameter here refers to the longest axis for non-circular features. The total number of features measured is 1263, the mean size was 217m and the standard deviation was ~35m. **C)** Many Swiss-cheese features destroying the upper 8m thick layer in a sample view of our study area. Sub-frame of MOC narrow angle image M07/04167, taken at 86.8° S, 355° E, and L_s 211°.

The narrow size distribution observed in the area shown on Fig. 2 (see Fig. 3) points toward a common formation period for these features. Comparing model results to the observations the age of this population could range anywhere from ~43 ± 7 to ~217 ± 35 Martian years (or 81 ± 13 to 408 ± 66 terrestrial years) [7]. The ± numbers quoted correspond to the error in the age of the population not the period over which these features were forming. The width of the distribution (measured by the interquartile scale of 40m) can be used to estimate the length of time these features were forming. This corresponds to a period of 8 to 40 Martian years (15 to 75 terrestrial years) [7].

The large spread in ages and length of formation period is due to the large spread in expansion rates. One fact which is independent of this is that the length of formation period is ~18% of the mean lifetime of the population.

The mapped positions of the asymmetric cusps indicate they occur without exception on south facing walls. This lends further credence to the insolation-based model that we have adopted. The cusp position is more difficult to record than the feature size since cusps are only visible in the highest resolution images.

Discussion: The narrowness of the size distribution combined with the size cutoff at smaller and larger sizes points toward a period in the history of this area of the residual cap where Swiss-cheese features were forming. It is hard to imagine what may be varying on timescales of centuries to control whether environmental conditions are suitable for Swiss-cheese formation or not. Orbital change cannot be playing a significant role over such short timescales and the atmosphere generally has no memory from one year to the next. One possibility is perhaps the slow redistribution of dust on a planet wide scale into preferred areas, which changes the albedo pattern with respect to the (by comparison) invariable elevation pattern. This could possibly switch the climate and circulation patterns into some other mode leading to differing conditions on the residual cap and a resetting of dust to its original configuration. This dust redistribution action may also act on more regional or local scales, changing the environment only in the near polar areas.

Each part of the residual cap has its own story to tell (although these stories should overlap). We will report on the extension of this geomorphic mapping to other areas. A more complete history of the polar environment over the last few Martian centuries should be forthcoming. In parallel we are improving our modeling methods to adequately characterize more geometrically complicated features such as the large Swiss-cheese features that contain moats and central islands. Finally, improvements to our estimates of the total amount of CO_2 in the residual cap reservoir are continuing and will be greatly helped by the detailed geomorphologic cataloging now underway.

References: [1] Leighton, R. B., and B. C. Murray, *Science* (1966) *153*, 136-144. [2] Kieffer, H. H. (1976) *JGR*, *84*, 8263-8288. [3] Thomas P. C. et al. (2000) *Nature*, *404*, 161-164. [4] Byrne, S., and A. P. Ingersoll (2003) *Science*, *299*, 1051-1053. [5] Malin, M. C., and K. S. Edgett (2001) *JGR*, *106*, 23429-23570. [6] Malin, M. C. et al. (2001) *Science*, *294*, 2146-2148. [7] Byrne, S., and A. P. Ingersoll (2003) *GRL, submitted*.