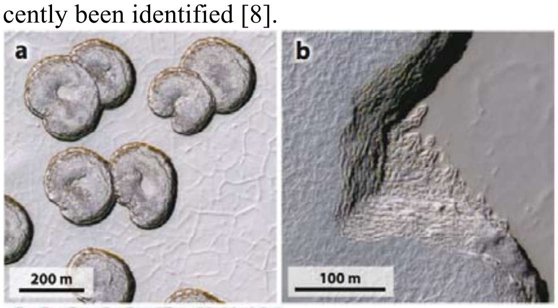
SIMULATING THE LANDSCAPE EVOLUTION OF THE MARTIAN RESIDUAL CO_2 ICE CAP.

S. Byrne[1], [1]Lunar Planetary Laboratory, University of Arizona. shane@lpl.arizona.edu

Introduction: The southern residual ice cap (SRC) is composed in-part of high-albedo solid CO_2 [1] that persists throughout the year. It is on the order of a few meters thick [2-6] and has areas at its margins and in its interior where underlying water ice shows through [4-6]. Under current conditions, the SRC exists in a precarious position, where its stability depends critically on its ability to maintain a high albedo [7]. If terrain at this latitude were to defrost then solar heat could be stored in the subsurface which would offset condensation of CO_2 frost the following winter. This solid reservoir of CO_2 ice currently buffers the seasonal atmospheric pressure cycle although larger buried reservoirs of CO_2 ice have recently been identified [8].



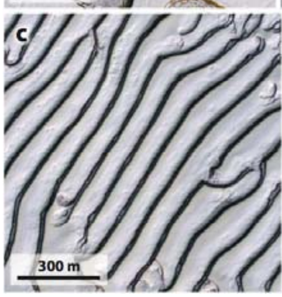


Figure 1. HiRISE views of the SRC showing (a) pits in an 8m-thick slab of CO_2 ice PSP_005517_0930, (b) layering in the CO_2 ice PSP_003882_0930 and (c) a linear sawtooth pattern indicating directional processes PSP_005954_0940.

Previous high-resolution imagery [9] revealed both linear grooved terrain (e.g. Fig. 1c) and flat-floored, quasi-circular pits (dubbed Swiss-cheese features) (e.g. Fig 1a). These pits come in a range of sizes and morphologies and are embedded in CO_2 ice slabs that vary in thickness from 2 to 10 meters [9-12]. Repeated observations have shown that the inclined walls of these quasi-circular pits retreat by several meters each year [10-12]. The expansion of these pits led [10] to suggest that the SRC is in the process of disappearing and that the Martian climate is changing. Indeed, when one looks at the spatial density of Swiss-cheese pits and the rates at which they are expanding, there should be nothing left of the SRC within a century or so. However, a changing climate on Mars is hard to understand as orbital elements of the planet change on timescales much longer than the time needed to ablate all the ice by expanding Swiss-cheese features. This begs the question (which this work aims to answer): *How can a residual CO_2 cap, with these pits, survive for us to observe?*

Here I report on model results of icy landscape evolution (incorporating results from analysis of historical and HiRISE imagery) that explain the observed behavior of the SRC without invoking climate change.

Further Constraints: One unusual deposition event occurred between the Mariner 9 (M9) (after the global 1971 dust storm) and Viking observations (3 martian years (MY) later) where areas of the cap that had appeared patchy were filled in with fresh ice. The overall change in the lateral extent of the cap since then has been minor with both small local expansions and contractions [13]. Cap brightnesses over several martian years (~20MY after M9) showed only small variations from year-to-year, although counterintuitively the brightest year was also immediately after the global dust strom of 2001 [14].

High-Resolution Science Experiment (HiRISE) [15] observations of these deposits have advanced our understanding of small scale processes considerably. These data reveal that the expansion of the Swiss-cheese pits is not a smooth process. In some cases, lower layers ablate faster (as they are generally darker in the late summer) and undercut the uppermost layer. This overhang results in small-scale mass-wasting leading to a 'jerky' retreat of the pit's rim. HiRISE images also reveal up to 15 layers. in many of the isolated (and shrinking) CO_2 ice mesas (Fig. 1b, each layer is about 60cm thick) that represent some form of environmental history. Interannual variability of the pit expansion rates related to dust storms has both been suggested [16] and refuted [12]. We are now acquiring a third year of HiRISE data and are in a position to expand on previous measurements [16] and test this.

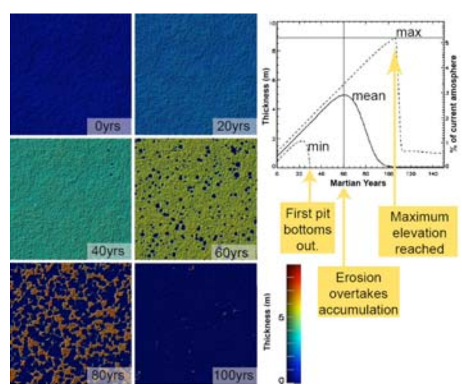


Figure 2: A typical model run of a CO_2 landscape. Panels on left are shaded elevation maps at times indicated. Plot on the right shows the minimum, mean and maximum CO_2 thicknesses as a function of time.

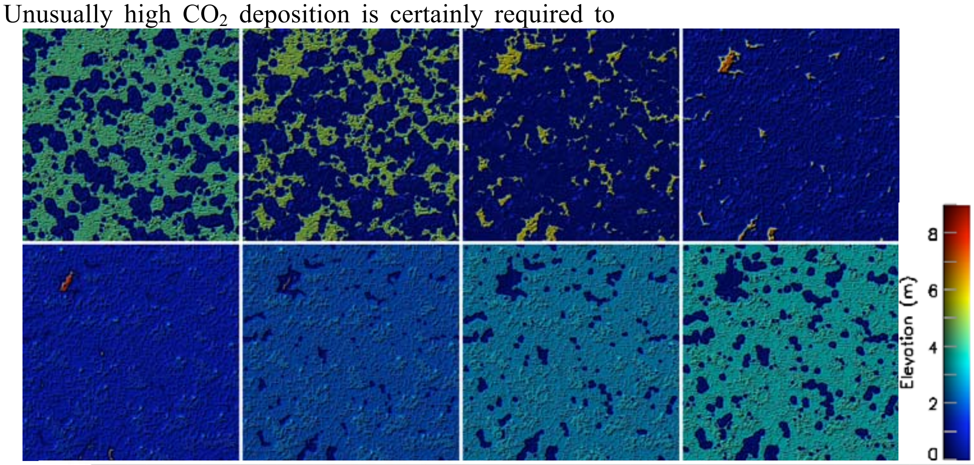
Model description: A landscape evolution model was developed to investigate the behavior of the SRC. We represent the topographic surface of the CO_2 landscape using a regularly spaced grid of triangles as facets with a cyclic boundary condition. The elevation of these CO_2 ice facets falls or rises via ablation or condensation due to imbalances in their energy budgets. Several approximations are employed that allow us to simulate large landscapes in reasonable times.

In a typical model run (Fig 2), we initiate the model with a randomly generated fractal surface with a thin CO_2 ice cover whose surface roughness is low. The surface begins accumulating mass as it has a high albedo and surface slopes are low; however, surface roughness also increases with time. After about 30 years, instabilities begin to occur in the locations with the highest slopes. Pits begin to form and quickly penetrate down to the water ice basement. Over the following decades these pits expand laterally even while the intervening flat surfaces continue to accumulate mass vertically. As the accumulation area (mesa-tops) shrinks, and the ablation areas (pit perimeters) grow, the landscape as a whole passes from a net accumulation to a net ablation regime. The right panel of figure 2 illustrates the behavior of the mean CO_2 thickness (which is a proxy for total volume). We can define a characteristic time for the evolution of the landscape as being when this transition to net ablation takes place. This timescale depends on the initial surface roughness; if one starts with a smoother surface then it will last longer before pits begin to form. Many SRC locations are close to the final state in this model, where only isolated (and shrinking) mesas remain as remnants of the original ice slab. This overall behavior is an inevitable consequence of starting with a surface that is not perfectly flat; CO_2 ice caps can never be stable indefinitely.

Understanding that surface roughness governs the lifespan of the ice cap allows us to answer the original question of how it is that the SRC persists to this day. Unusually high CO_2 deposition is certainly required to re-cover the exposed water ice, but extra deposition on its own does not reduce the surface roughness as it simply raises each point. However, if we allow this material to be mobile, and so be able to drift across the surface, filling in small-scale roughness (treated mathematically as a diffusion process) then these years of unusual deposition can smooth the surface. This behavior, illustrated in figure 3, where 40cm of loose material is added every 80 MY, allows CO_2 to begin recondensing, forming a new ice cap that may overlap in time with the old one, thus ensuring CO_2 ice is continually present. With each episode of unusual deposition another ice cap may form which is in-turn destroyed by expanding pits. Each generation of the residual cap formed like this differs in exact appearance, but is identical in behavior (lower panel of figure 3).

Results: No climate change is necessary to explain the current erosion of the SRC, expanding pits exist at all phases of its life cycle (Fig 3). Interannual variability in the form of unusual depositional events is required to explain a recurring SRC and the fact that different parts of the current SRC are at different stages of the life-cycle depicted in Fig 3. Historical data indicate that these unusual despoitional events are preceeded by global dust storms.

References: [1] Kieffer, H.H., (1979), JGR. [2] Byrne and Ingersoll (2003), Science. [3] Tokar et al. (2003) GRL. [4] Prettyman et al. (2004), JGR. [5] Titus, T.N., (2003) Science. [6] Bibring et al. (2004) Nature. [7] Jakosky and Haberle (1990), JGR. [8] Phillips et al. (2010) AGU. [9] Thomas et al. (2000), Nature. [10] Malin et al. (2001), Science. [11] Thomas et al. (2005), Icarus. [12] Thomas et al. (2009), Icarus. [13] Piqueux and Christensen (2008) JGR [14] Byrne et al. (2008), PSS. [15] McEwen et al. (2007), JGR. [16] Byrne et al. (2008) LPSC.



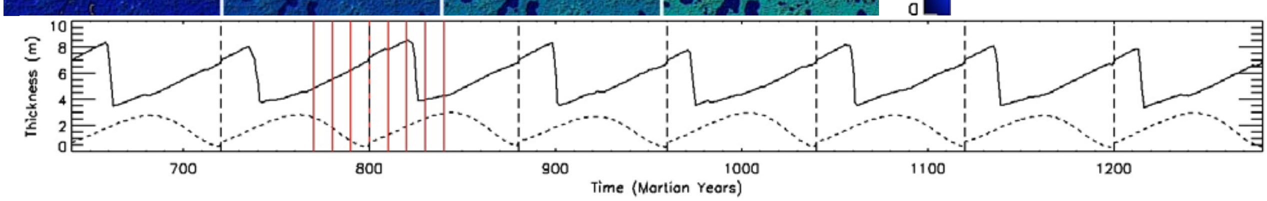


Figure 3. The model naturally generates a new CO_2 cap every smoothing event that is in-turn destroyed. The plot below shows several centuries of this evolution (maximum and mean CO_2 thicknesses plotted). DEMs every 10 years (red vertical lines) from one cycle are shown in images to the left (each 1km across).