EXPLAINING THE PERSISTENCE OF THE SOUTHERN RESIDUAL CAP OF MARS: HiRISE DATA AND LANDSCAPE EVOLUTION MODELS. S. Byrne[1], P. Russell[2], K. Fishbaugh[3], C. Hansen[4], K.E. Herkenhoff[5], A. McEwen[1] and the HiRISE Team, [1]LPL, University of Arizona, [2]Universität Bern, [3]CEPS, Smithsonian Institution, [4]JPL, [5]USGS. Correspondence: shane@lpl.arizona.edu

Introduction: The southern residual ice cap (SRC) is composed of high-albedo solid CO_2 [1]. It is on the order of a few meters thick [2-4] and has areas at its margins and in its interior where the underlying water ice of the layered deposits 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 become defrosted then solar heat could be stored in the subsurface which would offset condensation of CO_2 frost the following winter.

Previous high-resolution imagery [8] revealed flat-floored, quasi-circular pits (dubbed Swiss-cheese features). 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. Repeated observations have shown that the inclined walls of these quasi-circular pits retreat by several meters each year [9, 10]. The expansion of these pits led [9] 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 inferred time needed to ablate all the ice by expanding Swiss-cheese features.

This begs the question: *How can a residual CO_2 cap, with these pits, survive for us to observe?*

Here we report both on analysis of the HiRISE imagery and model results of icy landscape evolution. Our model results, constrained by these HiRISE data, allow us to explain the observed behavior of the SRC without invoking climate change.

HiRISE Observations: The High-Resolution Science Experiment (HiRISE) camera has been observing Mars in its mapping orbit since late 2006. HiRISE [11] acquires images in three bands centered on the near-infrared (874 nm), red (694 nm) and blue/green (536 nm) portions of the spectrum. The typical pixel scale in the south polar region is ~25cm.

HiRISE observations of these deposits have advanced our understanding of small scale processes considerably. These data reveal that the expansion of these pits is not a smooth process. In some cases, lower layers ablate faster (as they are generally darker) and undercut the uppermost layer. This overhang results in small-scale mass-wasting (Figure 1) leading to a 'jerky' retreat of the pit's rim.

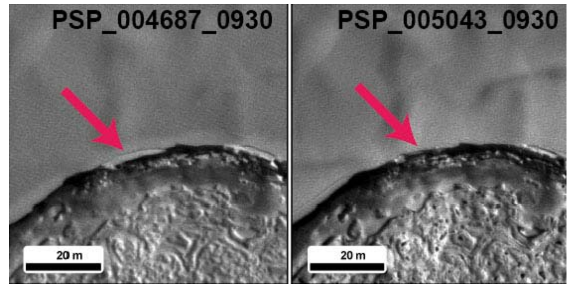

Figure 1. Arrows show mass wasting of 2m wide blocks. Images are separated by 30 days and illuminated from the lower left.

To better quantify the mean expansion rates we outline pits imaged at several times as polygons in GIS software. The amount of wall-retreat is given by the change in the area of the polygon divided by the mean perimeter. Calculating expansion in this way is more accurate as hundreds of points are used to create each polygon. The results for one such pit are given by:

Image	Year	AREA (m^2)	PERIMETER (m)	Expansion rate (m/yr)
M0900609	2	39032.717	742.329	2.265
R0903548	4	42424.394	755.385	1.036
PSP_003738_0930	6	44009.146	774.167	

The first period contains the global dust storm of 2001 while the second period contains no global dust storm. In the period with the storm, the pit expansion was more than double that of the other period. Our measurements of the most recent year's expansion (which also contained a global dust storm) show the walls again retreated by large amounts (~2m).

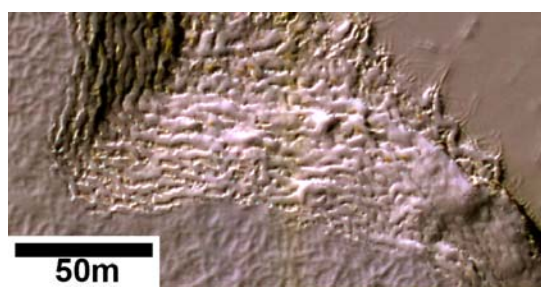

Figure 2. Part of HiRISE frame PSP_003382_0930, illumination from the lower right.

These expansion-rate data show that this CO_2 ice deposit responds sensitively to variations in the current climate. HiRISE data show that a record of these variations may exist in this ice. Figure 2 shows the edge of a CO_2 ice mesa containing up to 15 layers over a relief of ~9m (i.e. each layer is about 60cm thick). Previously, only ~4 layers could be recognized [10].

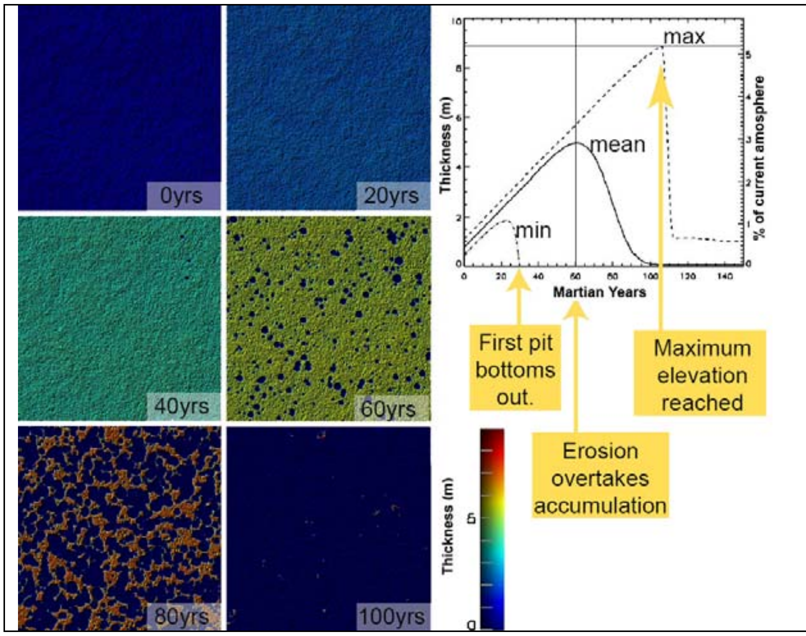

Figure 3: A typical model run of a CO_2 landscape. The six color panels on the left represent shaded elevation maps of the model domain at the times indicated. The plot on the right shows the minimum, mean and maximum CO_2 thicknesses as a function of time. Mean thickness can be combined with the SRC area to be used as a proxy for total volume, expressed as a fraction of the current atmosphere on the right axis.

Model Results: To explain the continued existence of the SRC, we have developed a landscape evolution model to investigate its behavior. We represent the topographic surface of the CO_2 landscape using a regularly spaced grid of triangles as facets with a cyclic boundary condition. We allow the elevation of these CO_2 ice facets to fall or rise 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 (figure 3), 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 3 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 locations on the SRC 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 an ice surface that is not perfectly flat; in this picture 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 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. We will use historical data to argue that it is the winters immediately after global dust storms that receive this unusual deposition.

Summary: The HiRISE observations are used to constrain the input parameters of the modeling. The model described explains the continued existence of the SRC, is consistent with the new HiRISE data and need not invoke climate change. We find good agreement between features in the SRC and models that have characteristic timescales of 60 years, implying that each layer visible in figure 2 represents a few martian years. Meaning (as we suggested above) that each layer could be related to individual 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] Thomas et al. (2000), Nature. [9] Malin et al. (2001), Science. [10] Thomas et al. (2005), Icarus. [11] McEwen et al. (2007), JGR.