SPATIAL AND GEOMORPHOLOGICAL EVOLUTION OF SWISS CHEESE TERRAINS IN THE MARTIAN SOUTH POLAR CAP. M. S. Fusco[1], K. Farnsworth[1], J. P. Knightly[1], A. Yazdani[1], and V. Chevrier[1]
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Introduction: Swiss Cheese Terrain, comprised of Swiss Cheese Features (SCFs), refers to groups of pit-like features in the south polar ice cap of Mars. These features were first observed in Thomas et al., (2000)[1]. Sizes (in surface area) vary from less than one square meter to hundreds of thousands of square meters. Depths vary from close to zero for newly formed features to the order of ten meters for mature SCFs. Typically, SCFs are flat bottomed depressions cut into an also flat CO_2 ice surface layer [1]. The sides of the SCF's are generally steep, such that the topology often resembles the inverse of a mesa or butte.

Changes in the sizes of SCFs are governed by sublimation and deposition processes and the environmental conditions affecting them [2,3,4]. The change in size of SCFs occurs on a few different time scales. There is strong evidence of year-over-year growth, implying a warming (not in equilibrium) state for the Martian South Pole over the course of nearly a martian decade. In addition, we find some indication of seasonal variability, as sublimation rates are highly temperature dependent. There are many other factors which might affect the sublimation rate of the CO_2 layer. These include but are not limited to albedo changes, local topology, and martian latitude/longitude.

Methods: The images chosen for our study were taken by the High Resolution Imaging Science Experiment (HiRISE) camera aboard the Mars Reconnaissance Orbiter [5].

We select 103 SCFs at 10 locations spread across the Martian South Pole. The sizes of the SCFs chosen span several orders of magnitude in area (from near one square meter to tens of thousands of square meters). Images are all in the southern hemisphere spring-fall with gaps during the southern winters. Areas are measured through the use of Photoshop or GIMP (see: figure 1). The outer edges of the SCF are manually selected and the number of pixels counted using the histogram tool. Pixel areas are transformed to square meters using the pixel scale available from the HIRISE images. It should be noted several options of different edge fitting algorithms might in the future be adapted to the automation of area measurement for Swiss Cheese features [6]. However, finding the appropriate parameter space for accurate measurement is nontrivial.

We also propose a possible classification scheme for the various SCF shapes, dividing them into simple (round, bean, concave), composite (donuts, cookies),

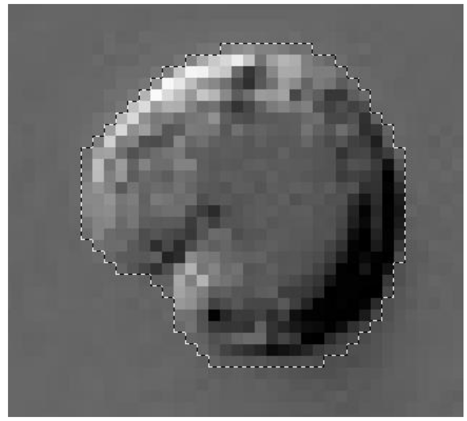

Figure 1: Area Measurement of a Swiss Cheese Feature using the Histogram tool in the photo editing software GIMP.

lineated (parallel, fingerprint terrain), merged, and irregular. For our sample we choose the more circular simple features and the edges of some donut shaped composite features. This was done to attempt to reduce scatter in measurement which might arise from morphological differences by using only the simplest shapes.

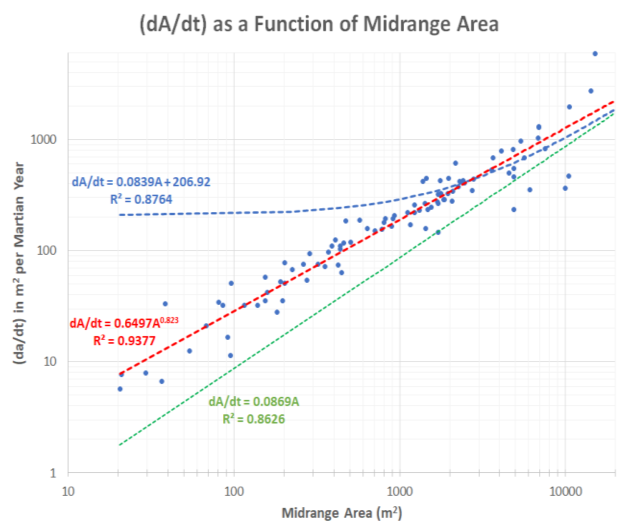

Figure 2: Linear through zero, Linear, and Power Law best fits for dA/dt as a function of A for our SCF dataset. Power law best fit is $\frac{dA}{dt} = 0.6497A^{0.823}$

Results: We find changes in the area of SCFs over more than five martian years. The SCFS are increasing in size from year to year, with lesser evidence of seasonal change within individual years. This observed pattern of growth of the swiss cheese features, due to excess interannual sublimation of CO_2 ice, is present across the entirety of the South Polar Cap. Most features and locations as a whole appear to show a reasonably smooth growth pattern, with no major spikes. A few locations, in contrast, show a local sharp spike in growth rate after years of slower growth. It does appear the whole South Polar Cap is, during the five martian year duration of our data sampling, experiencing a warm period where more CO_2 ice is being sublimated than deposited.

Discussion: The growth of the SCFs is measured in terms of a linearized change in surface area over time, with the slope dA/dt being the least squares linear fit to the full time range of the area data. The value of dA/dt in our data somewhat unexpectedly follows a power law with respect to the area of the feature (see: fig. 2). In the simplest (assume circular SCF) case, this suggests a nonlinear increase in the radius of the Swiss Cheese based on its size. Small SCFS grow rapidly in terms of percent change in area but slowly in terms of absolute change in area, while large SCFS grow slowly in terms of percent change in area but rapidly in absolute terms. This may partially arise from the geometry. If the SCFs may be described as changing mainly along its sloped edges (ring of radial change dr added to the existing radius per year), the size of the shell (with constant dr) compared to the total area becomes smaller as the area gets larger. However, our data appear to show dr increases as a function of r, which remains unclear for now. From the empirical power law relationship between dA/dt and A, we may derive an equation (see: eq. 1) describing A(t), where t is the age of a feature assuming the environmental conditions governing its growth have not changed.

Equation 1: $\frac{dA}{dt} = mA^n$, A(t)= $(1-n)(C+mt)^{\frac{1}{1-n}}$

Conclusions:

Swiss Cheese Features across several different latitudes and longitudes of the Martian South Polar Cap are measured in terms of surface area and are shown to be growing in size over the time period sampled. This growth is the result of excess sublimation versus deposition over the course of each Martian year. The entirety of the pole is consistent with this finding, though it remains to be seen whether rates vary on smaller spatial scales (latitude, longitude, etc.).

From our data, we are able to formulate an Age Function (see: Figure 3) for SCFs of different sizes based on the best fit average growth rate over the time period of our observations. While the assumption of the entire Martian South Pole following the same growth function for several decades (extrapolated age of largest features) is probably not totally valid, this function gives an estimate of the relative and absolute ages of SCFs across several orders of magnitude difference in surface area. If growth rates were constant over the lifetimes of the SCFs, this function gives a good approximation for their age and a mechanism for predicting future growth should environmental conditions remain constant.

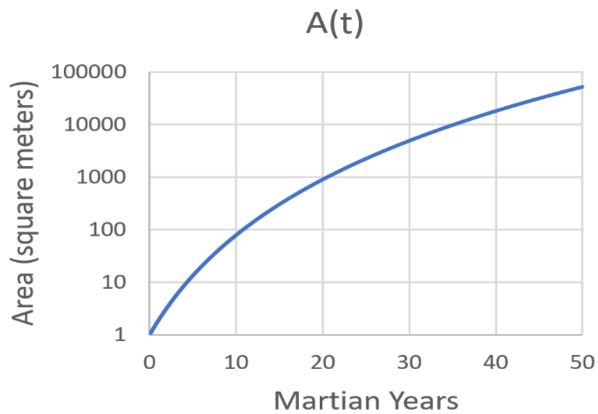

Figure 3: Fit to our data, and defining time since one square meter, this empirical description of the SCF behavior gives A(t)= $(0.0000564)(5.65 + 0.660t)^{5.65}$.

Our data provides interesting results for broad behavior of SCFs across the entire Martian South Pole. It remains to explore the many parameters which govern the sublimation of these SCFs on a finer spatial scale. Candidates for data mining include latitude/longitude dependence, the effects of morphological differences on growth rates, and a closer look at the intraseasonal change. Albedo is likely an important contributing factor to local changes [7], and local mineralogy and changes in dust are probably important in governing SCF growth.

More efficient measurement of SCF size could possibly be done algorithmically with optimized edge-finding. It would significantly further understanding if Digital Elevation Maps (DEMs) of the same locations over several years could be extracted, and measurements done in Volume rather than Area.

References:

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