BASAL SUBLIMATION OF THE SEASONAL CAPS AND SUB-ICE GAS FLOW: A MAJOR GEOMORPHOLOGICAL AGENT IN THE MARTIAN POLAR REGIONS. Sylvain Piqueux and Philip R. Christensen, School of Earth and Space Exploration, Mars Space Flight Facility, Arizona State University, Tempe AZ 85287, USA, sylvain.piqueux@asu.edu.

Introduction Every winter, a layer of CO_2 frost condenses from the atmosphere and covers the polar regions of Mars forming the seasonal caps. During the spring, seasonal features form on and beneath the cap as it sublimes. They include spots, fans, spiders and also seasonal polygons.

Spots, Fans and Spiders Formation Model In [1] and [2] models, the seasonal cap is opaque to the solar radiation before ~Ls 190. During the spring (Ls 190 to ~Ls 240), a self cleaning process [3] removes the dust trapped in the CO_2 frost which becomes "Cryptic" in some parts, i.e. translucent. The solar rays reach the top of the Polar Layered Deposits (PLD) which are also in contact with the base of the cap. As the PLD warm up, the adjacent CO_2 ice sublimes, forming pockets of pressurized gas trapped between the basement and the slab. The confined gas will converge toward the lower pressures, e.g. under cracks within the cap connected to the atmosphere. The flowing gas scours the surface of the PLD and entrains dust and sand size particles, forming the spiders. At the surface, the gas is violently ejected into the atmosphere. The dust settles on the seasonal cap following the direction of the wind forming the spots and fans. In the summer, when all of the seasonal frost has sublimed away, only the spiders remain.

South Observations Figure 1A is a portion of the seasonal cap at Ls 199 when the cap sublimes. It shows three units. The right unit is covered with dark fans originating from point sources and oriented toward the upper right direction. The size of these fans is ~600m by ~200m. Between the fans, the seasonal cap is slightly darker than the pristine ice visible on the left. The intermediate part of Figure 1A displays a 750m wide network of polygonal patterns. Each polygon has four or five ~50 to ~80 m long dark edges. On the left side of this field of polygons, most of the features are incomplete, missing one or several edges. The edges of the polygons vary from relatively thin and straight (near the resolution of the image) to large and blurry (up to 30m). These wide edges present a gradient from very dark (near the edge) to grey farther away (30m away). In the upper part of Figure 1A, this grey gradient is not symmetrical to the center of the edge but is elongated toward the upper right corner of the scene, in a similar fashion as the fans but at a much smaller scale.

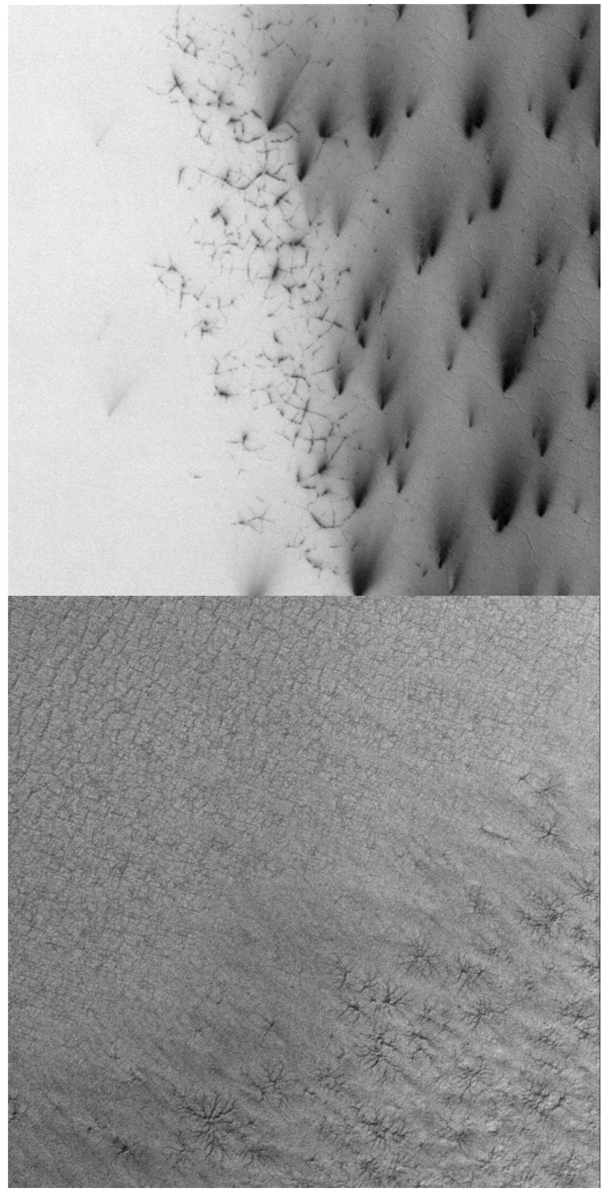

Figure 1A (top) MOC R0600398 and **1B** (bottom) MOC R1301400. 3 km by 3 km.

The left side of the Figure 1A shows the pristine seasonal cap with no dark fans and polygons. This unit is the brightest. Typical spiders are visible in the lower right corner of the Figure 1B. They are ~250m to ~370m large, with numerous merging and branching troughs radiating from the center depressions. Right next to the field of spiders, after 400m of transition where no specific feature is visible, the PLD are covered by a field of ground patterns. These polygons are characterized by 12m large troughs or more and ~50 to ~100m long edges. The troughs are not linear and are not well-defined, with diffuse edges. These polygons have not been specifically categorized in published classifications [4] [5] [6]. Figure 2 is a higher resolution view of this type of polygonal terrain, which we call “etched”. They differ from other ground patterns by the extremely irregular shape of their wide edges, which are rugged troughs, connected to smaller converging elongated ~4 m deep depressions.

Model We present a model of formation of the spots, fans, polygons on the seasonal cap, spiders and ground patterns presented above. It is largely inspired by [3] with an emphasis on the formation of the polygons on the seasonal cap. In the winter, the atmosphere condenses on the surface. The thickness of the caps is 1-2m from MOLA and GRS data [7] [8] [9]. During the spring, the sun rises and a small fraction of the solar energy is absorbed by the seasonal cap [10]. This energy contributes to the “self cleaning” process described by [1] [2] [3] [11]. The slab becomes translucent and the solar rays warm up the top of the PLD underlying the cap. The CO_2 ice cannot stay in contact with the warmer substrate and a fraction sublimates immediately. The gas confined between the basement and the cap is pressurized and the seasonal cap levitates above the PLD [3]. Where the pressure exceeds the mechanical resistance of the seasonal cap, the gas flows from under the cap to the atmosphere via cracks. While it migrates, the gas loads with dust scoured from the basement. The gas migrating radially toward the points of lower pressure forms the spiders. When the gas and the dust reach the open atmosphere, they form geysers. The larger particles settle, dragged by the wind, forming the spots and fans (Figure 1A). The finer particles take longer to reach the ground and diffuse near the surface. As a result, the seasonal cap is covered with fine dark dust where the fans are active (Figure 1A). This is consistent with OMEGA data [12]. The slab may not always be punctured and the gas has to migrate laterally toward lower pressures, confined between the seasonal cap and the substrate. In this case, no fans or spots can form at the surface where the CO_2 ice sublimates. The gas is forced to flow laterally and it may erode the substrate along its path. The repetition of this process over many years may lead to the formation of a network of troughs used by the gas as a preferential path during its migration.

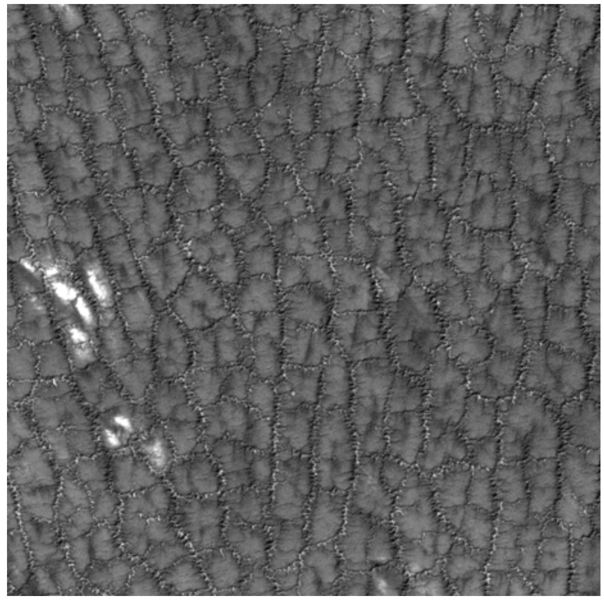

Figure 2. MOC R1004356. 1.5 km by 1.5 km.

Ultimately, this network may evolve to a field of etched polygons. Also during the gas migration, vertical cracks in the seasonal cap can reach the surface, somewhat reflecting the etched polygonal network used by the flowing gas as a preferred path during the lateral migration.The dust carried by the gas escaping to the atmosphere coats the vents and re-deposits near the fracture forming the dark fuzzy outline of the polygons on the seasonal cap (Figure 1A). Later, when the cap has sublimed, these seasonal polygons no longer exist because they correspond to a network of fractures highlighted by the contrast between the dark dust and the surrounding bright pristine cap in the CO_2 ice, which has sublimed away. A fraction of the polygons mapped by [5] has been mistakenly mapped as ground pattern whereas they are polygons only visible on the seasonal cap. The class LPC in particular concerns images near the pole occurring well before the seasonal cap has been removed. The polygons on the seasonal cap may reflect the pattern of the underlying etched polygons network and the polygons on the seasonal cap are expected to be similar (but not necessarily identical) during two consecutive summers.

Where the basal sublimation of the cap becomes prevalent but before the repetition of the process has led to the formation of etched polygons, the gas may be following random surface patterns which may not be re-used over time. In this case, the polygons on the seasonal cap may be completely different from one year to the next. The dark changing polygonal pattern observed by [13] may be an example of polygons forming on the seasonal cap before underlying mature etched polygons are formed.

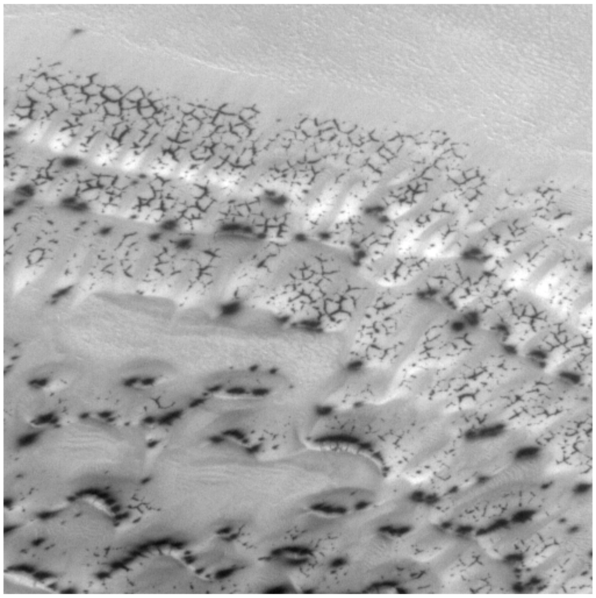

Figure 3. MOC E2000185. 1.7 km by 1.7 km.

North Observations Spiders have not been observed in the northern hemisphere whereas seasonal polygons, fans and spots have. We present additional observations of seasonal features visible on MOC im ages and we show that we can apply the formation model developed for the South to the North. Figure 3 shows a portion of the North polar seasonal cap that may be compared with Figure 1A: the field of view is composed of three units. On the first one, at the top, the cap is uniformly bright. The second unit, in the middle corresponds to a 550m large field of dark polygons compared to the bright background. On this image, they are ~40m long. Their edges are straight and blurry but their widths vary as do their southern counterparts. These polygons are accompanied by a few spots. The lower part of the image is covered with a field of 35m large dark spots forming at the crest of sand dunes. Smaller elongated spots are present and seem to be aligned, possibly forming a polygonal network of the same nature as the one presented just above. Figure 4A shows a field of spots forming preferentially at the top of sand dunes. Most of them are ~40m large but there is also a family of smaller features whose size is near the resolution of the image (3.1m per pixel). On this illustration, the spots are not perfectly round but are all elongated toward the right side of the image. On the same MOC image, a few typical fans formed (Figure 4A). They have similar characteristics (size, shape and tone contrast with the surrounding terrains) as the southern fans. On Figure 4B, they are up to 430m long and 120m large. A few spots are present but they seem much smaller than on Figure 4A (~20m in diameters). Some of these smaller features can be characterized as elon

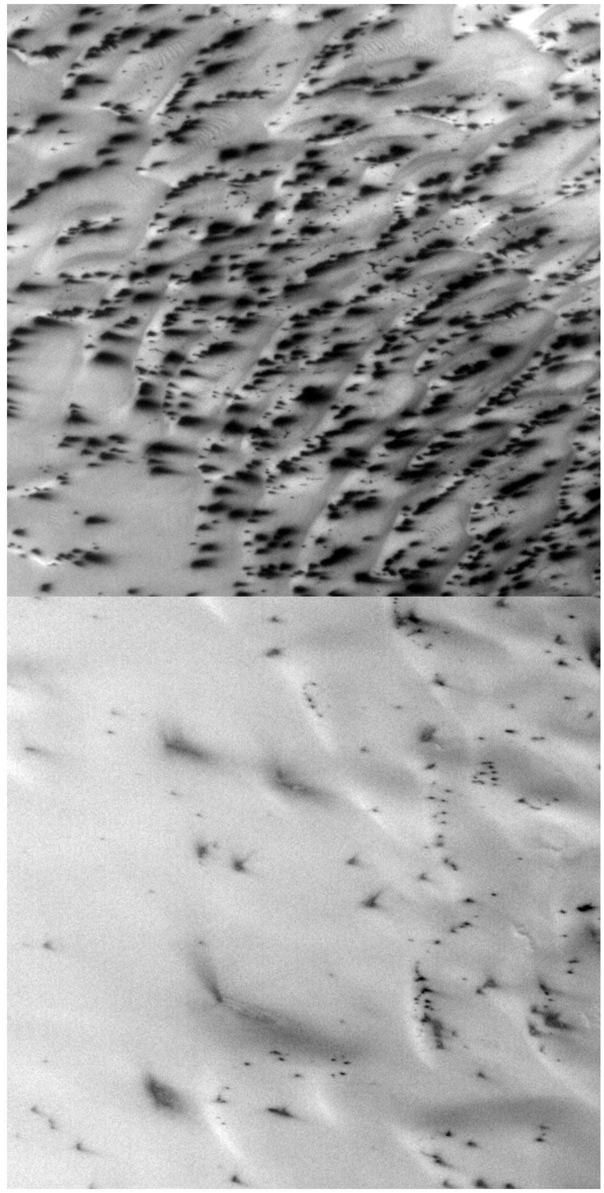

Figure 4A (top) and **4B** (bottom) E2000185. 1.7 km by 1.7 km

gated spots or fans (size of small spots but elliptic shape and color gradient from the center point to the periphery). Few fans occur on flat terrains whereas the spots are visible near the crest of dunes. Fans are less common in the North than in the South. Figure 5 shows a dark dendritic pattern on the North PLD, with thinbranches converging and merging toward larger branches. Its overall size is 500m. The width of the dark branches varies from 10 to 40m. On the same MOC image, several other identical groups of features are visible. This object is typically 2-4 times larger than usual spiders observed in the South. It is not clear if this object is a depression and if it has been formed by the scouring action of the confined gas subliming

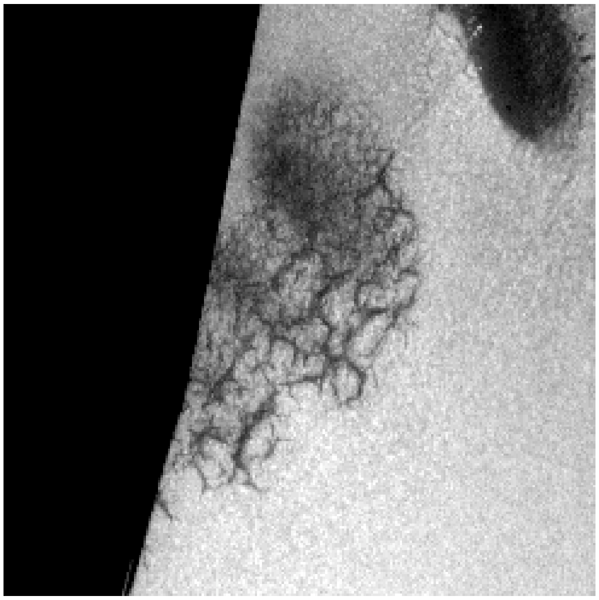

Figure 5. Example of possible spider near the North Pole. 1.2 km by 1.2 km.

from the seasonal cap, but its numerous branches merging toward a larger segment is suggestive of spiders similar to those common near the South Pole. Spots, fans and spiders form in the South as the consequence of the basal sublimation of the seasonal cap.
We have shown that polygons forming on the southern seasonal cap are also a type of seasonal feature that can be expected from these processes. Observations of similar objects (e.g. spots, fans, polygons on the seasonal cap and maybe spiders) in the North occurring under similar circumstances (during the spring, on the seasonal cap) suggest that a part of the seasonal cap is subliming from its base and shapes the North PLD the same way it does in the South.

Limits Spiders and etched polygons are rare in the northern hemisphere compared to the South, whereas the seasonal features are roughly as common near both Poles. [14] have shown that the nature of the surface is a key factor for the formation of spiders. The conditions may not be met in the North for the formation of perennial features. The North Polar Region is populated with sand dunes, some of which are made of loose material [15] which may not be able to maintain the topography created by the eroding flowing gas. Second, no Cryptic Region has been identified in the North, yet our model requires the slab to be translucent. Some regions may be cryptic but at a small scale (under TES resolution). In the South, a fraction of the spiders form outside of the Cryptic Region, suggesting that some undetected small patches of cryptic terrain exist.

Conclusions Spots, fans and polygonal features on the seasonal cap are all formed by the deposition of dust entrained by CO_2 gas on the cap. The gas scours the PLD and forms the spiders and the etched polygons after many years. The troughs of the etched polygons are preferential paths for the gas to flow under the cap. When the formation of the etched polygons is not mature, the gas may flow randomly under the seasonal cap and the surface seasonal polygonal network that results may be unique and not reproduced during the subsequent years. Our work suggests that the basal sublimation of the seasonal cap has numerous effects on the polar landforms and is a prevalent process in both Polar Regions. The stratigraphy may be extremely disrupted locally. Part of the stratigraphic record may have been lost by this seasonal gardening.

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