# HIRISE HIGH-RESOLUTION, STEREO, AND COLOR PERSPECTIVES OF MARS NORTH POLAR BASAL STRATIGRAPHY AND EROSIONAL PROCESSES.

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**Introduction:** A distinct darker basal unit (BU) underlying the polar layered deposits (PLD) is described from 1.4-6 m/pxl-resolution MOC images [1,2]. HiRISE [3] has made several observations of scarps in the north polar deposits in which much of the stratigraphic section from the lower BU to the PLD surface is exposed. High resolution images (0.3-1.2 m/pxl), stereo anaglyphs, and 3-band color data (see [4] for Fig.) provide an unprecedented, exciting new perspective of Mars. Along with details that support or clarify previous observations, many new stratigraphic, sedimentary, and erosional features within the BU are apparent in HiRISE data.

**General Stratigraphic Overview:** At HiRISE scale, distinct PLD albedo layer contacts are difficult to identify, especially in the lower PLD which is disrupted by polygonal fracturing. Within the BU, the presence of competent brighter layers forming resistant structures amongst dark sandy material is corroborated by HiRISE (Fig. 1). Images initially may suggest a generalized outcrop profile of a smoothed stair-step pattern. In contrast to the PLD, bright layers in the BU may independently move towards and away from the scarp face when traced along strike. Dark material appears to favor the most stable areas within these geometries. The result is that high resolution data reveals apparently wavy, converging/diverging, discontinuous, and truncating layers (Fig. 2). Distinguishing which are true representations of bedding and which may be explained by variable erosion of originally horizontal layers on a slope, in conjunction with partial covering by blown or mass-wasted dark deposits, is a challenge yet crucial in determining the constituent fractions of dark sandy and bright ice-rich material in the stratigraphic column.

**Bright Layers:** Bright layer characteristics are consistent along layers, but vary from one layer to another. Outcrop expression varies from thin plates emerging from a dark background (Fig. 2), to dominating local cliffs irregularly separated by narrow, discontinuous stripes of dark material (Fig. 1), both of which indicate relatively resistant, competent material. Striations or laminations are visible within some bright layers (Fig. 1).

Most bright layers are cut by polygonal fractures or joints, delineating triangular, rhombahedral, or hexagonal shaped blocks, typically ~4->10 m across (Fig. 1). Fractures between blocks become wider and deeper towards the layer edge, and some blocks here have rotated slightly. Isolated clusters of loose blocks on shallower slopes below indicate that pieces of the layer edge eventually break off and fall away (Fig. 3). Similarities to the PLD in brightness, fracturing, erosion style, and competence suggest the bright layers within the BU are likewise ice rich.

**Dark Material:** Dark material is rippled with dune ridges (~3 m crest to crest) perpendicular to local strike (Fig. 1). Formation into dunes, an absence of large blocks, and gentle variations in surface slope all point to a uniform, relatively fine-grained, sandy material. This is consistent with previous conclusions identifying BU dark material as the sediment source for larger-scale polar dunes [1,2].

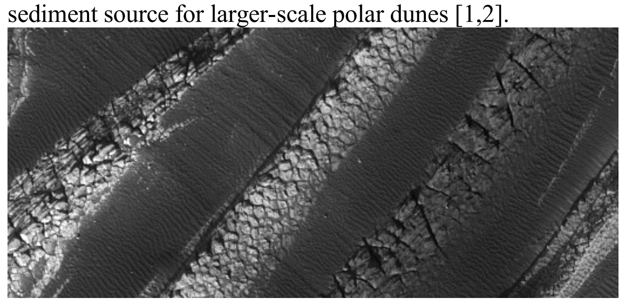

**Fig. 1:** Full resolution of basal unit stratigraphy and features. PSP_001334_2645. ~360 m across.

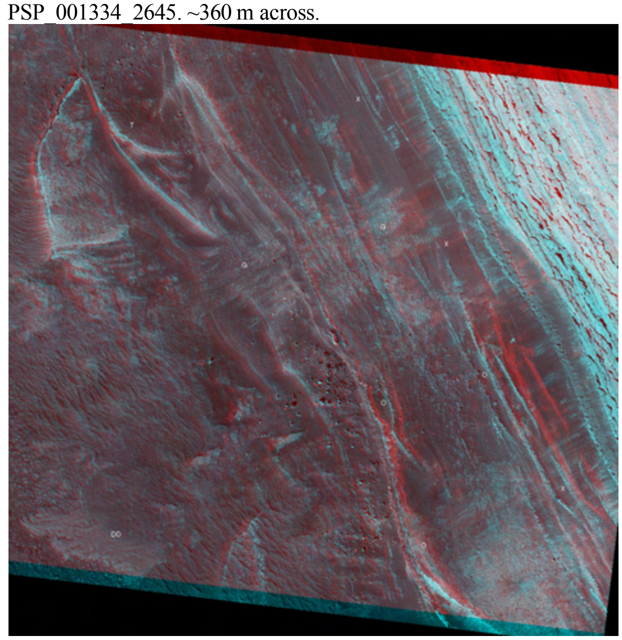

**Fig. 2:** Stereo anaglyph of irregular platy bedding. O=overhang; T=tilted layer; X=layers with most x-bedding, near potential instances; G=area of superposed grey deposit, DD=distal deposit. TRA_000863_2640. ~1500 m across.

**Basal Unit Stratigraphy:** Stereo analysis is wicked helpful in sorting out the mess that is the basal unit. In dramatic illustration of relative material strengths, overhanging bright layers not only exist, as hinted at in HiRISE images, but are common (Fig. 2). The presence of overhangs, in conjunction with saltation as the dark material's transport mechanism, argues strongly against the possibility that wind transport alone could be responsible for the prevalence of dark sandy material throughout the BU, adding confidence that the dark sand is eroding out of in situ layers.

Bedding orientation of platy bright layers is not limited to horizontal (Fig. 2). Dark layers or lenses with light streaks that appear straight and horizontal or fanning conformably are common. The irregular layering and outcrop expression of the BU make identification of true cross-bedding problematic. We have found several examples, particularly in a few near-horizontal beds of dark material (Fig. 2,4), of curving light streaks that converge asymptotically downwards and fan out as they curve upwards, truncating against what is most often a thicker light streak or thin bright layer marking the top of the dark bed (Fig. 4). Along with the sand-grain size of dark material, these cross-bedded structures suggest preservation of a paleo dune field in the stratigraphic section. The light streak material was either also saltating, was deposited as a thin veneer concurrently with dark sand eolian activity, or is simply frost highlighting bedding structures.

In conclusion, the major distinction between the similar BU bright layers and the lower PLD is the presence of dark sand amongst the former and their tilted and domed forms. Non-uniform layering is seen at many scales, from cross-bedded or truncated curving light streaks (<1 m thick, typically traceable up to 100 m) within dark deposits, to lenses of sediment covered by tilting bright layers (100-300 m across), to undulations of thinly veneered bright layer surfaces across the outcrop (e.g., 250 and 450 m crest to crest). Observations require processes that can lead to non-horizontal and non-parallel bedding; alternating regimes of sand abundance, mobility, and deposition, and temporary quiescence in which sand activity is replaced by dominantly ice deposition; some erosion to plane off sloping sand layers; but gentle enough transitions such that later ice-rich deposits may be draped over sandy lenses.

**Erosional Processes:** Several currently or recently active processes of scarp modification have been identified.

Mass wasting appears to play a major role in erosion of bright layers in the BU and fractured lower PLD. Given that the total surface area of a cluster of fallen blocks (as described above and in [4]) is greater than that of an intact layer or scarp, the combination of mass wasting and subsequent sublimation of fallen blocks may be more efficient in scarp erosion than retreat due to sublimation alone.

The layering discussed so far is occasionally overlain by aprons of light grey material on the order of 100 m wide and of variable thickness (Fig. 2). These can usually be traced high up the BU, occasionally to the base of the lower PLD. The intermediate color may be due to a combination of ice-rich debris falls from the PLD and blown sand. Surface characteristics and overall form suggest downslope movement has taken place but that the deposit may now be quite competent, perhaps re-cemented after an event or period of erosion. Depending on the outcrop, large volumes may be tied up in these secondary deposits. In contrast, more continuous but smaller-scale erosion is evidenced by dark and white aprons (up to 10 m wide) emanating from the base of bright layers, often funneled by the fractures.

Several features present around a break in slope within the BU are intriguing for their apparent indication of flow of material assisted by liquid water or possibly ice. Most striking are sinuous individual, distributary, or braided rille segments (up to ~350 m cumulative length) with uniform banks or levees (~2-3 m crest to crest) (Fig. 5). Beyond their cessations, some but not all rilles are associated with positive-relief deposits with lobate or fingered margins and flat tops standing above the level of, and overlying, the surrounding dark dunes. (Fig. 2 includes such a distal deposit, but without prominent rilles.) This set of features appears to indicate that highly fluidized debris flowed away from the polar scarp and was deposited a short distance after leaving the slopes of the steeper BU above. Lack of dune cover and stratigraphic position suggest a relatively young age. Distal deposits occasionally have fine polygonal fractures and may still be ice rich. Some rille segments emanate from the center of a pair of wider, taller, parallel (spacing ~20 m) or V-formed levees of light grey, markedly blocky material. They resemble lateral deposits associated with terrestrial glaciers or relatively dry debris avalanches, and may be related to the grey aprons mentioned above.

**Geologic History:** We suggest that during the period of BU accumulation, a plentiful supply of sand was available in the northern lowlands [5]. At high-obliquity, this sand was readily transported to the BU's location where surface sand sheets and/or larger individual dunes developed [2]. With a shift to low obliquity, any ice at low latitudes migrated poleward and was widely deposited at high latitudes, both cutting off the sand source and delivering the ice-rich layers of the BU. In the next transition to high obliquity, ice is removed from more equatorward regions first, allowing sand to migrate in over the BU ice before it becomes unstable. Several repetitions of this cycle formed the sequence of ice-rich bright layers and sand-rich dark layers and lenses comprised by the BU. When the sand supply ran out, continued deposition of successive ice layers occurred without intervening sand sheets, forming the lower PLD [2]. Today's intermediate obliquity favors deposition of the classical upper PLD.

**References:** [1] Byrne S. and Murray B. (2002) J. Geohys. Res., 107 E6. [2] Fishbaugh K.E. and Head J.W. (2005) Icarus, 174, 444-474. [3] McEwen A.S. et al. (2007) J. Geophys. Res., 111, in press. [4] Byrne S. et al. (2007) LPSC XXXVIII. [5] Tanaka K.L. and Kolb E.J. (2006) Mars Polar Sci. Conf. 4, #8098.

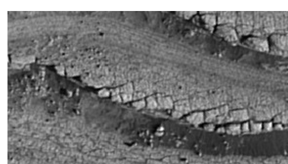

**Fig. 3:** Mass-wasting mode of ice-rich bright layers. ~200 m across. TRA_000845_2645.

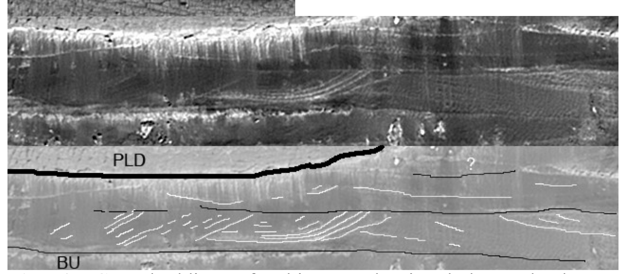


**Fig. 4:** Cross-bedding of white streaks in dark sandy layers. TRA_000863_2640. ~400 m across.

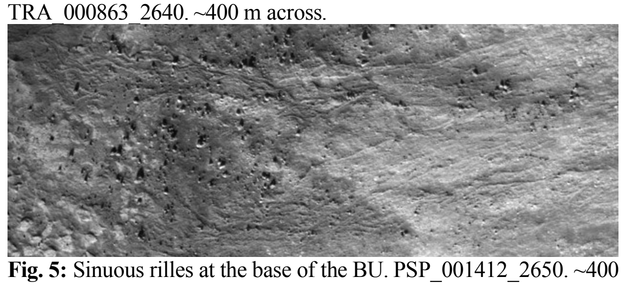

**Fig. 5:** Sinuous rilles at the base of the BU. PSP_001412_2650. ~400 m across.