THE BASAL UNIT AT THE NORTH POLE OF MARS: RECENT FINDINGS AND NEW OPPORTUNITIES

S. Nerozzi[1], M.S. Christoffersen[1], J. W. Holt[1] [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ (nerozzi@arizona.edu).

Introduction: The basal unit (BU) is a sedimentary deposit of water ice and lithic fines lying at the base of Planum Boreum (PB) on Mars [1-8]. It can be divided into two subunits, rupēs and cavi, on the basis of their stratigraphy and age [4, 6]. The BU lies between the Late Hesperian Vastitas Borealis interior unit and the Late Amazonian North Polar Layered Deposits (NPLD), and thus represents a record of polar geologic processes and climate events spanning most of the Amazonian Period [4, 6]. Despite the numerous recent studies, several key questions remain unanswered [9].

• *Structure and stratigraphy*: How are the different geologic units within PB related? What is the full extent and volume of the rupēs and the cavi units? What is the geometry of the erosional unconformity between the two units?

• *Surface processes*: What do the characteristics of the BU reveal about their formation and evolution? Are there periods, such as during higher obliquity, when the aeolian regime is more energetic, leading to erosion? How was cavi constructed through time?

• *Climate*: What major climate events are recorded in the BU? Ref. [8] hypothesized that the cavi unit is made of pure water ice remnants of former polar caps, and sand sheets. How many of these sheets are contained within cavi, and what is their extent?

Methods: In this study, we integrated Shallow Radar (SHARAD) observations, high-resolution visible imagery, and altimetry datasets to provide answer to the outstanding questions presented above.

Radar sounding. The comprehensive and dense Shallow Radar (SHARAD, [10]) coverage of PB enables high-detail mapping of the surface topography and internal stratigraphy of the BU. We mapped the upper surface of the BU distinguishing three distinct radar reflectivity facies, which allow us to separate rupēs and cavi unit detections [7, 9].

High-resolution imagery. We integrate our radar analysis with images acquired by the High Resolution Imaging Science Experiment (HiRISE; [11]). We use the nearly complete HiRISE coverage of BU visible outcrops to obtain a high-resolution (~32 cm/pixel) visual constraint of the BU topography and spatial distribution in PB, and establish the type of contact between the cavi unit and the NPLD, with special regard to aeolian stratigraphic structures that may indicate a gradual vs abrupt transition between the two units.

Results: The newly mapped extent of the BU reaches ~896,440 km^2, 35% larger than the most recent estimate [7]. However, the volume is ~351,400 km^3, ~7.5% smaller than the previous estimate [7]. Analysis of BU outcrops gives us a visible constraint on the lateral extent of the rupēs unit, which we detect only in the western half of PB. At its easternmost locations, the rupēs unit is characterized by sub-horizontal meter to decameter layering with eastward slopes of <0.1°, similar to previous measurements [12]. We also found a possible SHARAD detection of the contact between rupēs and cavi, characterized by slopes similar to those seen in visible outcrops. Together, these observations suggest that the eastern half of the BU is made up exclusively of cavi unit materials. In general, we found that radar profiles acquired by SHARAD can provide the necessary stratigraphic correlation to comprehensively study isolated BU outcrops with high-resolution imagery that would otherwise lack important context.

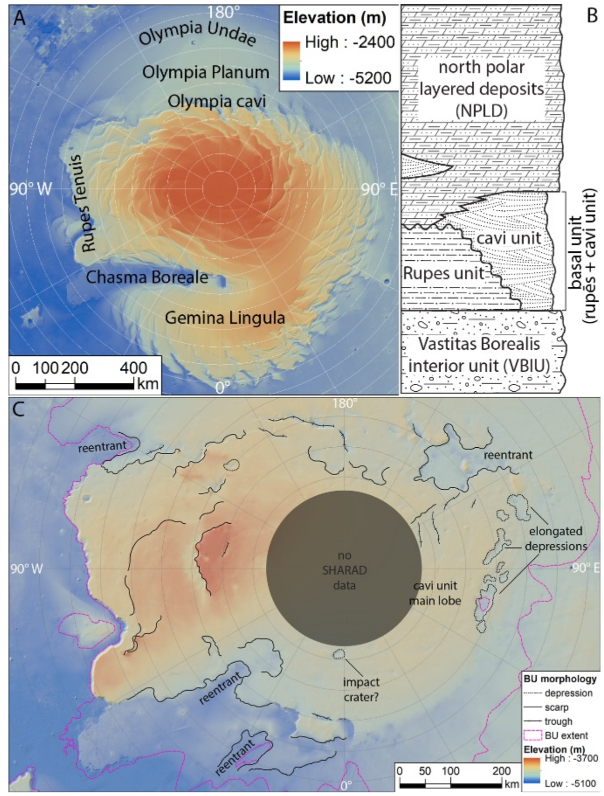

Fig. 1: (a) MOLA [15] topography map of PB and surrounding terrains. (b) Stratigraphy of PB units, modified after [4]. (c) Topography and morphology map of the BU obtained in this study by combining SHARAD and MOLA observations.

We obtained new constraints on the timing of rupēs and cavi unit formation and evolution. The initial rupēs unit accumulation in the Late Hesperian to Early Amazonian was likely followed by a depositional hiatus well into the Early Amazonian Period. A resurfacing event recorded in Hyperborea Lingula suggests that the widespread erosion that created the unconformity between the rupēs and cavi units may have peaked at 260^{+60}_{-50} Ma. This age may correspond to the initial phases of cavi unit accumulation.

Our detailed mapping of the BU surface morphology provides new insight on the erosional history of the rupēs and cavi units and suggest a more complex resurfacing history than previously thought. We identify several scarps in our BU morphology map. All but one scarp face southward, and some enclose low-lying reentrants. The two reentrants mapped by ref. [7] show significant morphologic al complexity that was not detected before. We hypothesize that the numerous southward-facing scarps carved into the rupēs unit formed thanks to a protective ice sheet that limited erosion to undercutting, implying that the scarps are a record of past ice sheet extent. SHARAD also reveals erosional bench forms in the cavi unit that provide new supporting observations of its hypothesized water ice and sand-sheet structure, confirming that it likely preserves remnants of former polar ice caps in its interior. Although SHARAD does not generally detect subtleties of the gradation between cavi and the NPLD, we did find evidence of a lens of isolated material located between the two units. The top of this deposit is a relatively sharp reflector, followed by a diffuse return and a reflection-free zone. This feature extends over an area of ~4000 km^2, and has a volume of over 300 km^3 assuming a water ice composition. We also found further evidence of the gradational and transgressive contact between the cavi unit and the NPLD at multiple outcrop sites. We interpret the lens of material located above cavi as a late episode of aeolian sand accumulation on top of cleaner water ice. Numerous occurrences of similar cavi-NPLD transitional features can be observed along visible outcrops in the outskirts of PB. This is the first detection of such transitional deposits in radar profiles and provides new information on the potential three-dimensional size and geographical distribution of these features.

A series of elongated depressions tens to hundreds of meters deep appear along the edge of cavi unit. The location and orientation of these depressions coincide with deepest reaches of a buried chasma previously observed within the NPLD [13]. SHARAD profiles crossing these features show a continuation of the angular unconformity from the NPLD to cavi materials, suggesting that the erosional event that carved the chasma is also responsible for the formation of the depressions. This morphological record gives us insight on the intensity of the erosional event that carved the chasma. Current age estimates and growth models for the NPLD favor a short duration of the erosional event, suggesting very intense resurfacing of PB that removed large amounts of water ice and lithic fines from the cavi unit in addition to carving a chasma in the NPLD.

New questions and opportunities: We argue that the long and intricate evolution of the BU complements the brief and detailed record of the overlying NPLD, and should be considered as a prime target for future studies that aim to reconstruct the Amazonian history of Mars from a climate and surface processes standpoint. Below we summarize some outstanding and new questions on the nature of the BU:

• What is the composition of the rupēs unit? What was the source of its materials? Is there any connection between its evolution and other global-scale events that occurred during its accumulation? Which and how many depositional and erosional processes and events contributed to the formation of the rupēs unit?

• What is the nature of the change in geologic processes between the formation of the rupēs and cavi unit? When did the cavi unit start to accumulate? Is the rupēs unit the main source of its lithic materials? Is the cavi unit still growing in the present day, sourced by icy layers of the NPLD and lithic sand sheets from the circumpolar dune fields?

The abundance of remote sensing observations over PB offer a unique opportunity to decipher the climate record contained within the BU. Although the resolution is an order of magnitude lower than SHARAD, MARSIS [14] is capable of penetrating through most of the BU, and could be the key to fully reconstruct the distribution of the rupēs and cavi units underneath PB.

Acknowledgments: This work was supported by NASA MDAP grant NNX15AM52G. SHARAD is provided and operated by the Italian Space Agency (ASI). We thank the HiRISE team for providing the excellent coverage of BU outcrops.

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