THE BASAL UNIT AT THE NORTH POLE OF MARS: AN AMAZONIAN RECORD OF MARS' POLAR AEOLIAN AND GLACIAL HISTORY S. Nerozzi[1], M. R. Ortiz[2], J. W. Holt[1] [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ (nerozzi@email.arizona.edu). [2]Jackson School of Geosciences, University of Texas at Austin, TX.

Introduction: The basal unit (BU) is a sedimentary deposit of water ice and lithic fines lying at the base of Planum Boreum 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:

How are the different geologic units within Planum Boreum related? What is the full extent and volume of the rupēs and the cavi units? What is the geometry of the erosional unconformity between them?

What do the characteristics of the lower north polar ice deposits reveal about their formation and evolution? Which geologic processes and climate events are recorded in the morphology of the BU?

Ref. [8] hypothesized that the cavi unit is made of alternated aeolian sand sheets and pure water ice remnants of former polar caps. How many of these sheets are contained within cavi, and what is their extent? How was cavi constructed through time? Was the rupēs unit similarly constructed and shaped by aeolian processes?

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

Radar sounding. SHARAD is an orbital sounding radar with a vertical resolution of ~8.4 m in water ice [9]. The comprehensive and dense coverage of Planum Boreum with over 3000 profiles 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]: "sharp" return, typically associated with rupēs unit materials; "diffuse" return, typical of the cavi unit and dune fields; "mixed" return, interpreted as rupēs unit material with abnormal surface roughness and/or a thin veneer of cavi unit material.

High-resolution imagery. We integrate the analysis of SHARAD profiles with images acquired by the High Resolution Imaging Science Experiment (HiRISE; [10]). 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 Planum Boreum, and establish the

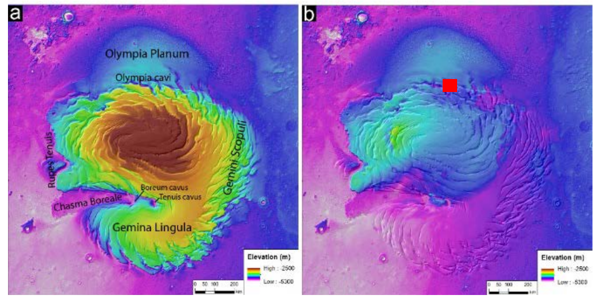

Figure 1: (a) MOLA elevation map of Planum Boreum. (b) MOLA and SHARAD elevation map of the basal unit and surrounding plains obtained in this study, with superimposed shaded relief of the modern Planum Boreum topography. The red box indicates the location of Fig. 2.

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.

BU lateral extent: Our mapping indicates that the BU extends over an area larger than that delineated by the most recent radar studies [3, 5, 7]. We detected radar diffuse returns extending from the western edge of Gemina Lingula to Gemini Scopuli, covering an area of ~120000 km^2. The diffuse return reflector is followed by a second, deeper reflector, which is continuous with the Vastitas Borealis interior unit. Based on detection of radar diffuse signals and the continuity with the adjacent cavi unit, we interpret this packet of material as a previously undetected lobe of cavi unit. Assuming a lithic-rich mixture for the cavi unit with a relative permittivity of ε' = 4.84 [8], we obtain an average thickness of ~50 m. In Gemini Scopuli, this lobe extends beyond the edge of the NPLD, where HiRISE images reveal flat lying terrains forming terraces and characterized by sinuous and arcuate forms reminiscent of aeolian cross strata. These aeolian cross strata may pertain to aeolian forms in the cavi unit or remnants of more recent forms on top of it. These observations suggest that cavi unit materials, or their recent equivalent, are exposed in this region, thus corroborating the proposed detection of the BU of ref. [2]. The newly mapped extent of the BU reaches 890000 km^2, 37% larger than the most recent estimate [7]. The cavi unit alone represents the largest dune field on Mars, although the vast majority of it is buried underneath the NPLD. 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 Planum Boreum. At its easternmost locations, the rupēs unit is characterized by sub-horizontal meter to decameter layering with eastward slopes of <0.1°. These observations suggest that the eastern half of the BU is made up exclusively of cavi unit materials.

BU stratigraphy: 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 Planum Boreum (Fig. 2).. 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.

BU morphology: 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. A series of elongated depressions tens to hundreds of meters deep appear along the edge of cavi unit. In some cases, the base of these depressions are flat and appear to continue as reflectors within and at the base of the cavi unit. The location and orientation of these depressions coincide with deepest reaches of a buried chasma observed within the NPLD [12]. 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.

Implications for future studies: Overall, the stratigraphy and morphology of the BU represent a record of climate variability and surface processes that dates back to the Late Hesperian-Early Amazonian. The cavi unit, in particular, likely records multiple episodes of polar ice growth and retreat from the Middle Amazonian to the first phases of NPLD accumulation. In addition, it also records the intimate interplay between water ice accumulation and aeolian processes in its ice and sand sheets and cross strata. Therefore, 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.

Acknowledgments: This work was supported by NASA MDAP grant NNX15AM52G. SHARAD is provided and operated by the Italian Space Agency. We thank the HiRISE team for their effort in providing excellent coverage of polar outcrops.

References: [1] Byrne S. and Murray B.C. (2002) *JGR, 107*, 11-1-11-2. [2] Fishbaugh K.E. and Head J.W. (2005) *Icarus, 174*, 444–474. [3] Putzig N.E. et al. (2009) Icarus, 204, 443-457. [4] Tanaka K.L. et al. (2008) *Icarus, 196*, 318–158. [5] Selvans M.M. et al. (2010) *JGR, 115*, E09003. [6] Tanaka K.L. and Fortezzo C.M. (2012) https://pubs.usgs.gov/sim/3177/ [7] Brothers T.C. et al. (2015) *JGR, 120*, 1357–1375. [8] Nerozzi S. and Holt J.W. (2019) *GRL, 46*, 7278-7286. [9] Seu R. et al. (2007) *JGR, 112*, E05S05. [10] McEwen, A.S. et al. (2007) *JGR*, 112, E05S02. [11] Kneissl et al. (2011) *Geol. Soc. London Spec. Pub., 356*, 257-279. [12] Holt J.W. et al. (2010), *Nature, 465*, 446-449. [13] Nerozzi, S. and Holt, J.W. (2018) *Icarus*, 308, 128-137.

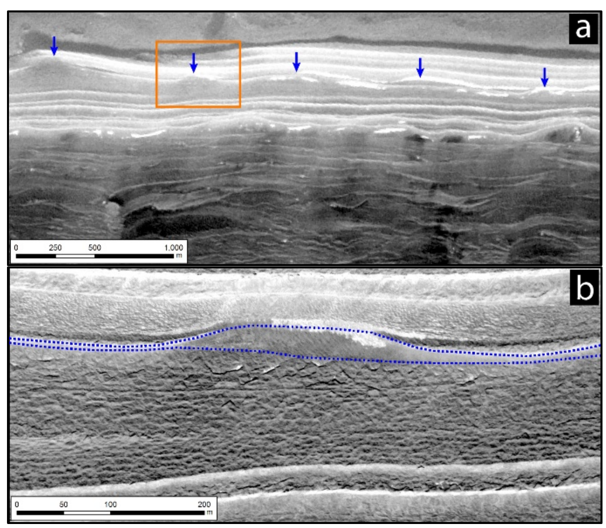

Figure 2: (a) Dune field within the NPLD in Olympia Cavi as seen in CTX image G22_026631_2650. The sand dunes, indicated by blue arrows, are a record of renewed siliciclastic material deposition long after the NPLD started to accumulate. (b) Details of a sand dune in HiRISE image ESP_026631_2650, location in orange box above.