A NEW VIEW OF PLANUM BOREUM EVOLUTION FROM RADAR STRATIGRAPHY.  J.W. Holt¹ and the SHARAD Team, ¹Institute for Geophysics, University of Texas, Austin, TX (jack@ig.utexas.edu)

**Introduction:** In the five years since the 4th Mars Polar conference, orbital radar sounders have acquired a wealth of data probing the interior of polar deposits on Mars. A few of the long-standing questions regarding Planum Boreum (reviewed in [1]) have now been answered and a new perspective on its long-term evolution is emerging. These advances have come about primarily from examining paleosurfaces and large-scale stratigraphic relationships previously hidden from view, combined with decades of previous studies making excellent use of the exposed geology. Here we attempt to integrate these findings into a holistic view. From this we conclude that the North Polar Layered Deposits (NPLD) have, to first order, been shaped by the same processes acting today, namely surface-atmosphere interactions that result in deposition and erosion, with aeolian forces playing a significant role. Glacial flow, basal melting and other catastrophic events are largely ruled out, making it more straightforward to interpret the stratigraphic record in terms of climate. This also provides important context for other investigations using complementary, high-resolution data.

**Initial Conditions:** Radar sounding by MARSIS on Mars Express [2] revealed that the base of Planum Boreum is flat and the lithosphere beneath is not deflected, implying a thicker and colder lithosphere than previously thought [3], while SHARAD on Mars Reconnaissance Orbiter [4] has enabled mapping of the base of the NPLD in detail [5,6]. Topography on the sand-and-ice-rich basal unit (BU; comprised of both the rupes tenuis and cavi units of [7] for our purposes) underlying the NPLD is highly nonuniform (Fig. 1a), indicating the possibility of two processes that have shaped the BU - one resulting in an elongate dome similar to that proposed by [8] and now shown to be smoothly contiguous with Olympia Planitia (Fig. 1a), and a second that resulted in a tilted, block-shaped, high-relief region offset from the pole (Fig. 1a). This is supported by the fact that MARSIS does not penetrate BU in this higher region [9], implying that the interface there is significantly different.

**Ice as a Sediment:** Radar has constrained bulk composition of the NPLD to be consistent with that of nearly pure water ice [3, 10]. One might expect this to affirm Planum Boreum as a strong analog to ice sheets on Earth, with similar processes impacting its overall morphology and stratigraphy. Indeed, ice flow has previously been proposed as a significant factor in shaping the morphology of Planum Boreum [11-13]. However, the analysis of internal radar stratigraphy including flow models and the presence of deep-seated unconformities contradicts this analogy [14,15]. Deformation by glacial flow therefore appears to not have impacted stratigraphy in a significant way. Likewise, there is no evidence yet identified in radar stratigraphy to support basal melting from increased geothermal flux or brittle deformation on large scales.

**Stratigraphy within the NPLD** is, in fact, far more consistent with a submarine sedimentary sequence than a terrestrial ice sheet. Far from invoking a marine origin, this indicates the dominance of processes that are sedimentary in nature - namely, deposition and erosion. Furthermore, sedimentary structures indicate that aeolian processes have played a major role throughout PB's history. This is clearly a dominant force at work both within the basal unit [16] and in the uppermost NPLD. To first order, the NPLD can be regarded from a sequence stratigraphy perspective, with the possibility of significant erosion in the form of sublimation.

Using large-scale stratigraphic unconformities to define the major sequence boundaries, at least three large-scale depositional sequences are preserved (Fig. 1b). The lower of these was mapped across Planum Boreum to reveal the early appearance of Chasma Boreale and another, equally large chasma [17]. A higher unconformity found in the saddle region east of Chasma Boreale indicates a later period of regional erosion (Fig. 1b). In both instances, the lateral extension of reflectors bounding these unconformities are conformal under the main lobe of Planum Boreum, indicating that these erosional epochs may have been relatively short-lived and limited in extent; however, evidence also exists for significant retreat of the NPLD margin in the region of Gemini Scopuli prior to the most recent episode of deposition, and possibly coeval with the erosional event that created the uppermost large-scale unconformity (Fig. 1c).

**Rise of the Troughs:** In the higher portions of the NPLD, stratigraphic structures began to take shape that indicate the first appearance of spiral troughs and their subsequent migration during deposition that continued to the present ([18], Fig. 1b). This finding and the unique inter-trough stratigraphy negates hypotheses relying on recent incision to create the troughs but supports a constructional hypothesis put forth invoking katabatic winds as a critical driver of the process [19]. Trough stratigraphy provides unique constraints for a model of cyclic steps in terrestrial marine settings modified for the aeolian case on Mars [20] and should result in new insights into surface/atmosphere interactions.

**Nonuniform accumulation:** During the bulk of NPLD history there is a high degree of nonuniform accumulation and with controls exerted from pre-existing topography. It is now clear that topography on the basal unit exerted significant influence on NPLD accumulation. Its major features persists in today's surface morphology in the high-relief BU region (Fig. 1a). The non-uniformity of accumulation is perhaps...
most dramatically apparent with the persistence of Chasma Boreale as a topographic low from early in NPLD history while another large chasma was completely filled in ([17], Fig. 1b). Feedbacks between topography and mass transport processes that impact net accumulation are demonstrated by the role of katabatic winds in shaping the spiral troughs [18].

**Climate signals:** Multiple types of climate signals are represented in the radar stratigraphy, beginning with the transition from the sand-rich basal unit to the NPLD. Within the NPLD’s major depositional sequences bounded by erosional periods, there are many sub-sequences represented by groupings of radar reflectors into “packets” that are quasi-periodic [5] as well as the reflectors themselves which often have very regular spacing (Figs. 1b, 1c). While the exact cause of radar reflectors is still being ascertained, they likely represent compositional variations such as dust content modulated by global dust storms [21].

Linking this sequence to high-resolution stratigraphy at outcrops [22,23] could provide a much more comprehensive stratigraphic sequence than has been previously available to interpret from an orbital forcing perspective. Finally, the 3-dimensional nature of the radar data enables spatially quantifiable geographic patterns of deposition and erosion with an evolving paleotopography that together can be used to further constrain climate models and, hopefully, the sequence of orbital parameters required to produce what is observed in the geologic record. Modeling specific processes such as the onset and migration of spiral troughs has the potential to provide tighter climatic constraints for specific points in the sequence [20].

**Conclusions:** The internal radar stratigraphy of Planum Boreum contains a rich record of deposition, erosion, aeolian processes and compositional variations that can be more readily linked to past climatic conditions through modeling than if internal, basal or exotic processes dominated. Significant challenges remain for such an effort, but the potential exists to find a unique correlation of this rich stratigraphic sequence to past orbital parameters in order to determine the age of the NPLD and better understand volatile exchanges between the north pole and other reservoirs.

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