RADAR STRATIGRAPHY OF PLANUM BOREUM, MARS: A RICH HISTORY OF ACCUMULATION AND EROSION PRESERVED BY A LACK OF FLOW. J.W. Holt¹, I.B. Smith¹, S. Christian², T.C. Brothers¹, and R.J. Phillips³, ¹University of Texas Institute for Geophysics, University of Texas, Austin, TX (jack@ig.utexas.edu) ³Bryn Mawr College, Bryn Mawr, PA 19010, ³Southwest Research Institute, Boulder, CO

Introduction: Studies of outcrops in the polar layered deposits (NPLD) of Mars using morphological and topographic methods from high-resolution optical data have attempted to link compositional layering to climate with the primary objective of correlating observed patterns with orbital forcing parameters [1-4]. Although hampered by the limitations of outcrops, questions of large-scale continuity of layering and the variability of accumulation patterns has been addressed through similar means (reviewed by [3]).

Likewise, answering the question of whether the NPLD flowed in the past is important for constraining paleoclimate and the possibility that the NPLD have survived through warmer periods. This question has been examined primarily through morphological analysis combined with modeling [5-7] without the benefit of 3-dimensional internal stratigraphy.

Orbital radar has provided a new way to address these questions by probing the subsurface to depths of kilometers and detecting compositional boundaries. Previous radar studies have focused on broad stratigraphic characteristics and structure [8-10], a single, unconformity-defined horizon related to the formation of Chasma Boreale [11], and shallow stratigraphy related to the spiral troughs [12].

Here we focus on radar stratigraphic relationships found throughout the NPLD that provide new insights into the geologic processes that have (or have not) shaped Planum Boreum throughout its history.

Methods: The Shallow Radar (SHARAD) instrument on Mars Reconnaissance Orbiter (MRO) is a chirped radar operating at a 20 MHz center frequency. Its 10 MHz bandwidth yields a theoretical vertical resolution of ~9 m in water ice. Horizontal resolution is 0.3 – 1 km along-track and 3 – 6 km across track [13].

Data from SHARAD passes were processed with a focused synthetic aperture radar (SAR) technique in order to reduce along-track surface clutter and resolve reflectors with relatively steep slopes. Interpretation is performed in seismic analysis software that allows the tracing of individual reflectors over many intersecting lines.

Radar stratigraphy of the NPLD: At first glance, Planum Boreum’s radar stratigraphy seems quite uniform. Many radar reflectors exist, and some extend across the entire NPLD [10,13]; however we have found that internal stratigraphy of the north polar layered deposits (NPLD) exhibits great complexity including prominent unconformities (Fig. 1). In any stratigraphic sequence, the presence of angular unconformities signifies changes in accumulation (e.g., depositional hiatuses accompanied by erosion). The presence of pervasive unconformities within the NPLD points to a fundamental problem with attempts to correlate sequences of layers with orbital parameters since the presence of a continuous layer sequence appears to be unlikely.

Figure 1. Examples of stratigraphic unconformities in the NPLD. (a) SHARAD observation 5297_01 showing deep unconformities (red dashed lines) and significant thickness variations between reflectors. Red arrows indicate structures related to trough migration [12]. VB = Vastitas Borealis Fm. (b) Observation 7616_02 showing an extensive unconformity near the margin of PB. (c) Multiple reflectors near base of NPLD that pinch out against the BU, defining an outer edge of accumulation. (d) Smaller, possibly local, unconformities near outer margin of PB. (e) CTX imagery showing visible layer unconformity near SHARAD observation (d). Location map for all data in lower right. (1 µs = ~168 m vertical thickness in ice.)
No evidence for flow: Previous work has suggested that the overall morphology of Planum Boreum [5,6] or Gemina Lingula alone [7] is consistent with an ice sheet undergoing viscous flow. The presence of prominent angular unconformities throughout the NPLD, especially at deep levels (Fig. 1a and [11]), indicates that ice flow has not significantly influenced NPLD stratigraphy. Given significant flow, these structures would have been erased over time as both vertical and lateral shear dominated the geometry of layering.

Another powerful test of the flow hypothesis is the geometry of internal layers [14, 5]. Comparisons of internal layers in Gemina Lingula with those predicted by a 3-dimensional ice flow model [15] show a major discrepancy, especially towards the margins where an ablation zone was required by a balanced ice-sheet model [7].

Furthermore, the stratigraphy associated with spiral troughs [12] does not match that predicted by a flow model which maintained the existence of the troughs [5]. Basal sliding has also been invoked [16] but again, the internal stratigraphy does not match that predicted when the comparison is performed (as we have done) by tracking individual reflector horizons that represent isochrones across the NPLD.

Patterns of accumulation and erosion: The lack of significant flow modification allows for the interpretation of radar reflectors as representing virtually undeformed paleosurfaces (other than a small degree of vertical compaction). As demonstrated by [11], these paleosurfaces can indicate important stages in the evolution of Planum Boreum including the early development of Chasma Boreale and a second chasma that was completely filled in. Furthermore, difference maps between paleosurfaces show net accumulation patterns (Fig. 2). These are important, new constraints for climate models and when combined with elevation data, can be used to evaluate processes such as topographic feedbacks between deposition, insolation, katabatic winds, and erosion.

New mapping is underway to characterize these accumulation patterns in finer detail and map erosional surfaces throughout the NPLD by tracking individual reflectors. Approximately a half-dozen regional erosional events have been identified and are being mapped to reveal the geographic patterns of ice loss. This effort will provide a sequence of depositional and erosional events describing the long-term evolution of the NPLD. Accumulation and erosion events are directly attributable to climate processes and could perhaps be linked to orbital forcing parameters as has been attempted for individual layer sequences.

As constructional features resulting from aeolian transport combined with deposition, the spiral troughs are in themselves unique constraints on atmospheric processes [12] that complement the large-scale accumulation patterns.

Conclusions: While the lack of a continuous sequence is challenging for correlations with orbital forcing parameters, the complex internal stratigraphy of Planum Boreum as revealed by SHARAD is a rich record of deposition, erosion and aeolian transport exhibiting strong evidence of polar landscape evolution dominated by atmospheric processes rather than englacial flow or sub-ice processes. We find no evidence that either internal deformation or basal sliding has been significant in the history of the NPLD.

This provides both a unique opportunity to constrain fundamental climate processes through time and an important constraint on physical conditions that the polar ice has experienced. Hence, the internal radar stratigraphy of Planum Boreum holds the potential to reveal a great deal of new, quantifiable information about Mars paleoclimate.

Acknowledgements: This work was supported by the MRO project through a JPL contract to JWH, and NASA grants NNX10AO26G and NNX09AV95G.