**OBLIQUITY-DRIVEN PERIODS OF EXTENDED EROSION AND DEPOSITION IN THE GEOLOGIC RECORD OF PLANUM BOREUM, MARS.** K.L. Tanaka[1], J.A.P. Rodriguez[2], C.M. Fortezzo[1], and F. Seelos[3].. [1]U.S. Geological Survey, Flagstaff, AZ (ktanaka@usgs.gov), [2]Planetary Science Institute, Tucson, AZ, [3]JHU Applied Physics Laboratory, Laurel, MD.

**Introduction:** Unconformities in the stratigraphic record signify hiatuses in deposition, which are most readily observed when accompanied by obvious erosion as shown by angular unconformities. Observations of the deposits making up Planum Boreum, the north polar plateau of Mars (based primarily on MOLA altimetry and THEMIS VIS, CTX, MOC narrow-angle, and HiRISE images) reveal common, local unconformities in layered deposits mapped as the Planum Boreum 1 (PB1) unit (also known as "lower layered deposits") and the Planum Boreum 3 unit (also known as "upper layered deposits") [1-3]. Only two major, regional unconformities in north polar deposits have been identified [3]. Here, we describe erosional features, timing, and possible implications of the only two major, regional unconformities in north polar deposits that have been identified [3]. We propose that these unconformities formed due to transitions from primarily depositional to primarily erosional environments in Planum Boreum. These transitions appear to have occurred during major excursions to higher obliquity when increased polar insolation may have resulted in a denser atmosphere and highly erosional wind regimes. Conversely, periods of deposition may correspond to lower and transitional obliquity episodes and desiccation of lower-latitude water reservoirs.

**The Tenuis Hiatus:** An older unconformity is defined by the highly eroded surface features of the Rupes Tenuis (RT) unit making up a sequence of tens-of-meters-thick layers forming the base of the main lobe of Planum Boreum (that excludes the Gemina Lingula lobe). Erosional relief of the RT unit approaches 1400 m [3]. The RT unit apparently has moderate ice content (CRISM observation FRT0000C58F). This surface is locally overlain by the Planum Boreum cavi unit (PBc*)* and more extensively by the PB1 unit. These respectively consist of (1) ~meter-thick layers expressing horizontal, wavy, and cross-bedding structures that are dominantly dark and presumably lithic sand-rich, with bright, ice-rich interbeds [3, 4], and (2) ~meter-thick, horizontal, ice-rich beds banded by variations in albedo and texture [2, 3].

An increasing number of pedestal craters are recognized on the RT unit's surface in CTX and HiRISE images. These features indicate that impact ejecta somehow armored the unit from subsequent erosion. These are found at various stratigraphic levels of the RT unit, indicating that either unit thickness varied, the deposition and erosion of the unit occurred over an extended period of time, and/or erosion rates of the unit were highly variable.

**The Olympia Hiatus:** This hiatus is largely defined by the eroded surface of the PB1 unit. The hiatus was followed by deposition of the dark, poorly expressed, meters-thick layers of the Planum Boreum 2 unit (PB2; also known as the "intermediate deposit" [5]) and the extensive, meters-thick layers (tens of meters total thickness) of the PB3 unit.

Erosion of PB1 has been extensive and diverse. The PB1 unit exposures locally attain 1000 m in erosional relief in Chasma Boreale and in eastern Gemina Lingula. On western Gemina Lingula and on Planum Boreum above central and western Rupes Tenuis, extensive surface undulations evident on the PB3 unit appear to represent draping of the PB3 unit over swales initially carved into PB1 unit [5]. Surfaces of Planum Boreum upslope of Boreum and Tenuis Cavi at the head of Chasma Boreale appear fluted into broad troughs a few kilometers wide

Initial deposition following erosion of PB1 consists of the dark PB2 unit. This unit is extensive in Olympia Cavi and atop much of Olympia Planum, underlying the Olympia Undae erg (e.g., Fig. 1; previously identified as the PBc unit [3]). Following emplacement of the PB2 unit, sand was likely eroded mostly from the PBc unit, though other sources are possible (e.g., the RT, PB1, and PB2 units). Eroded material then appears to have accumulated in the circumpolar erg [3]. Apparently, the dunes then became frozen and were partly buried by the PB3 unit (Fig. 1).

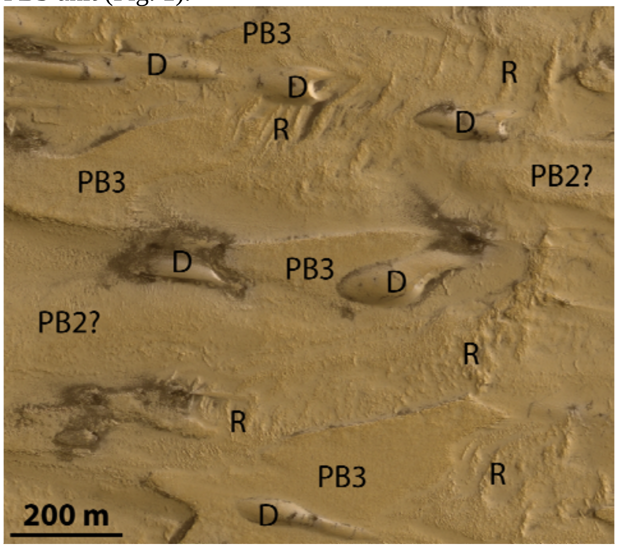

*Figure 1. Northern margin of Olympia Undae dunes on top of Olympia Planum (~82.8°N., 140.5°E.). Sequence from oldest to youngest: Planum Boreum 2 unit (PB2?), ripples (R), dunes (D), and Planum Boreum 3 unit (PB3). (Part of HiRISE color springtime image PSP_007368_263, north at bottom, illumination from right. )*

**Relating the recent polar insolation history to polar geology:** The conclusion of the Olympia Hiatus, about 3.6±2.5 Myr ago [2], coincides roughly with the transition to a lower mean obliquity from ~35° to 25° at about 4-5 Myr [6]. Assuming that polar geologic history is driven by orbitally-governed climate conditions, we propose that the Olympia Hiatus was primarily a result of high obliquity. Thus, it may be that during the period when mean obliquity was ~35°, relatively elevated insolation in the polar regions increased surface modification due to higher ice sublimation rates and wind stress at the surface. This would lead to a net transfer of ice from polar to lower latitudes [7]. Higher winds could also remove unconsolidated surface lags and expose underlying ice and ice-cemented sediment, at least where insolation and wind stress were particularly intense. Thus, small to large topographic irregularities in Planum Boreum may have served as precursors to the plateau's various erosional landforms [8]. Silt and sand eroded from the polar deposits could provide agents for heat absorption and saltation, increasing the rate of erosion.

When the mean obliquity transitioned to 25°, overall polar insolation decreased. This would imply decreased wind strengths and thus less aeolian mobilization of sedimentary particles at the poles. Insolation at lower latitudes would increase, thereby gradually sublimating near-surface ground ice. The released water vapor would then condense at the poles. This may explain the build up of the PB3 unit. (Individual layers of the PB1, PB3, and other polar units may be indicative of shorter-term, cyclic obliquity and eccentricity oscillations [9].) The volume of the unit (~$10^4$ $km^3$) represents a ~10-cm-thick global layer. The deposition rate of PB3 may have initially increased for about a million years during the transition to lower mean obliquity. However, PB3 unit margins are presently deflating (as in Fig. 1), suggesting that the deposition rate of the unit peaked and then waned. Near Chasma Boreale, decameter-wide grooves that may be yardangs [3] were carved into the PB3 unit. Bright, ~decimeter-thick residual ice superposed on the PB3 unit seems to be a thin active layer that likely responds to minor, perhaps cyclic transfer of water ice that is engaged by orbital insolation fluctuations [e.g., 10]. The PB3 unit appears to be incised by shallow, spiral troughs near the pole, which contain dark lag deposits. Steep cavi walls made up of units PBc and PB1, continue to erode back by mass wasting and sublimation [4].

**Duration of Olympia Hiatus:** Obliquity calculations are reliable only for about 10 to 20 Myr in the past for Mars due to uncertainty in the precession rate; these results yield a mean obliquity of ~35° during the 5-20 Myr interval [6]. Calculations extending back to 250 Myr within permissible values of precession rate result in a wide range of scenarios for obliquity history prior to 20 Myr, including maintenance of a high obliquity through that entire interval [6]. Perhaps, however, the south polar layered deposits provide a constraint on the hiatus, as much of Planum Australe has a crater age of ~30 to 100 Myr [11]. The south polar region has much less dark deposits and dunes, suggesting that they may have contributed to a much lower rate of erosion, such that craters were largely preserved. If so, then the period of ~100 to 5 Myr may be the span of the Olympia Hiatus.

**Other possible obliquity changes:** Accumulation of the PBc and PB1 units may reflect a similar history as that proposed for the PB2 and PB3 units--a decrease in obliquity, but incorporating about two orders of magnitude more ice. This might mean that much more water was available during that time, perhaps from sources at lower latitudes. Mars demonstrates a record of generally decreasing, but perhaps episodic, volcanism and fluvial discharges that may have accounted for this more substantial reservoir [e.g., 12].

The RT unit may represent redistributed water and lithic fines from northern plains sediments [2]. Possibly, the RT unit accumulated during relatively low obliquity. Subsequently, during higher obliquity, its margin may have retreated toward the pole. Given the thousands of recognized middle-latitude Amazonian pedestal craters on Mars [13], ice-rich mantles may have accumulated during such periods at these latitudes, with the removed portions of the RT unit serving as a polar ice source for them. Evidence of repeated pedestal crater development [13] implies that the Tenuis Hiatus (~3 to <1 Gyr [3]) may include pronounced oscillations in the long-term obliquity record.

**Conclusion:** Polar geology provides valuable constraints for the climate history of Mars. If the end of the Olympia Hiatus in the north polar geologic record indeed correlates with the significant decrease in obliquity at 5 Myr, then long-term episodes of high vs. low obliquity may govern the timing of major phases of polar ice deposition and removal. This would coincide with the formation of polar landforms and the movement of aeolian sediments. In addition, lower-latitude volcanism and fluvial discharges were likely required to provide near-surface sources of water for the accumulation of polar deposits.

**References:** [1] Malin M.C. and Edgett K.S. (2001) *JGR*, *106*, 23,429-23,570. [2] Tanaka K.L. (2005) *Nature*, *437*, 991-994. [3] Tanaka K.L. et al. (2008) *Icarus*, *196*, 318-358. [4] Herkenhoff K.E. et al. (2007) *Science*, *317*, 1711-1715. [5] Rodriguez J.A.P. et al. (2007) *Mars 3*, 29-41. [6] Laskar et al. (2004) *Icarus*, *170*, 343-364. [7] Mellon M.T. and Jakosky B.M. (1995) *JGR*, *100*, 11,781-11,799. [8] Rodriguez J.A.P et al. (this volume). [9] Laskar et al. (2002) *Nature*, *419*, 375-377. [10] Montmessin F. et al. (2007) *JGR*, *112*, E08S17. [11] Koutnik M. et al. (2002) *JGR*, *107*, 5100-5112. [12] Greeley R. (1987) *Science*, *236*, 1653-1654. [13] Kadish et al. (2008) *GRL*, *35*, L16104.