RECENT ADVANCES IN THE STRATIGRAPHY OF THE POLAR REGIONS OF MARS. K. L. Tanaka¹, E. J. Kolb², and C. Fortezzo³, ¹U.S. Geological Survey, Flagstaff, AZ (ktanaka @usgs.gov), ² Arizona State U., Tempe, AZ, ³Northern Arizona U., Flagstaff, AZ

Introduction. We have completed preliminary geologic maps of the polar plateaus (Planum Boreum and Planum Australe) of Mars at 1:1.5M scale based on Mars Global Surveyor (MGS), Mars Odyssey (ODY), and Mars Express (MEX) image and topographic datasets. These data permit more detailed results than recent maps based mainly on MGS Mars Orbiter Laser Altimeter (MOLA) digital elevation models and Mars Orbiter Camera (MOC) data and at smaller scale [1-3]. Our analysis is preliminary, as we have not had full opportunity to scrutinize all of the pertinent, released image data. Moreover, additional High Resolution Imaging Science Experiment (HiRISE) and Context Camera (CTX) image data sets from Mars Reconnaissance Orbiter (MRO) are enabling even closer scrutiny of the polar plateaus. Because the polar plateaus are extensively dissected by troughs and scarps that are mostly cleanly exposed, the opportunities to analyze stratigraphy are extensive.

We are focusing on the units and layer sequences that can be divided primarily based on unconformities and significant disconformities expressed geomorphically. Many other avenues for polar geologic studies are available with the new data sets. As reported at LPSC 38, other workers are engaged in (a) scrutinizing finely-layered sequences and marker beds [4-5], (b) interpreting MEX Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) and MRO Shallow Subsurface Radar (SHARAD) radar soundings of polar materials [6-8], (c) studying recent surficial processes and features [9-10], and (d) conducting various other analyses involving the polar plateaus and surroundings.

Planum Boreum region stratigraphy. We describe here the geologic units of Planum Boreum from oldest to youngest. This stratigraphy has been refined over recent iterations [e.g., 11-12] as more data are viewed, digested, and used in the mapping. The mapping of these units is shown in Fig. 1.

Early Amazonian materials. Planum Boreum is surrounded by plains made up of Early Amazonian materials of the Vastitas Borealis interior (ABvi) and the Scandia region (ABS) units. The oldest part of Planum Boreum mapped as the Rupes Tenuis unit (ABrt) crops out along Rupes Tenuis and forms Hyperborea Lingula within Chasma Boreale, as well as along some steep scarps and trough floors of outer Planum Boreum along its margin with Olympia Planum. This unit in ODY Thermal Emission Imaging System (THEMIS) visual (VIS) images (18-36 m/pixel) displays upwards of 20 layers along Rupes Tenuis, each tens to perhaps ~100 m in thickness. The edge of the Hyperborea Lingula plateau displays ~10 layers in THEMIS VIS images. The unit likely forms the Escorial crater plateau and perhaps makes up Abalos Colles, which are pitted cones that could be elevated, degraded impact craters armoring the unit.

Early to Late Amazonian materials. Many of the impact craters surrounding Planum Boreum appear to have ejecta deposits on platforms elevated tens of meters above adjacent plains. These crater forms have been referred to as “pedestal craters” and apparently armor once-extensive mantle deposits. The history of such deposits is uncertain; there may have been one to many episodes throughout the Amazonian of thick mantling and subsequent exhumation of the Vastitas Borealis surface. The present mantle appears to be meters thick [13]. We tentatively call this material the Vastitas Borealis pedestal unit, but its outcrops are too small to map at 1:1.5M scale.

Late Amazonian materials. Planum Boreum enlarged and surrounding dune fields accumulated to their present extents during this epoch. Prior to this, Planum Boreum was smaller and made of the eroding Rupes Tenuis unit. The more prominent exposures form basal pedestals beneath the ejecta of larger craters, including Boola (17 km in diameter), Crotone (6.4 km), and a largely buried crater at 81.6°N., 295.4°E. (~22 km) above Rupes Tenuis. Escorial crater (23 km) south of Hyperborea Lingula and a 13.2 km, partly buried crater on the northwest flank of Chasma Boreale (82.8°N., 304.5°E.) also appear to have pedestals made up of the Rupes Tenuis unit. Smaller pedestal craters occur on the Chasma Boreale/Hyperborea Lingula surface, including a 4.5 km crater at 80.3°N., 308.9°E. that is partly surrounded by a ~100 m tall pedestal.

The stratigraphically lowest Late Amazonian unit we have identified thus far is the Planum Boreum cavi unit (ABbc), which was first recognized as a basal, platy unit of Planum Boreum made up of possibly cross-bedded light and dark layers [14]. Later, Tanaka et al. [11], after recognizing the Rupes Tenuis unit, suggested that the platy unit has a spotty occurrence in the depressions of Olympia Cavi at the base of outer parts of Planum Boreum and at the head of Chasma Boreale, from which dark dune fields appear sourced. HiRISE images confirm that this unit is the source of active dune-forming sands and is cross-bedded. The
brighter layers are intensely fractured by a polygonal network of joints spaced apart a few meters and less.

Overlying the Vastitas Borealis interior, Rupes Tenuis, and Planum Boreum cavi units, Planum Boreum 1 unit (ABb1) forms finely layered materials that appear flat-lying and continuous in MOC images yet deformed and degraded in higher-resolution HiRISE images. The unit locally exceeds 1000 m in thickness and includes hundreds of layers and dozens of local unconformities [2]. It appears to be unconformable with the Planum Boreum cavi unit, as the top layers of unit ABb1 commonly pinch out, indicating they were eroded prior to deposition of unit ABb1.

The Chasma Boreale unit (Atcb; not shown in Fig. 1) includes upwards of 47 layers exposed in the western part of Tenuis Cavus as seen in CTX-8 and overlies what may be the Rupes Tenuis or Vastitas Borealis interior unit; the Olympia Cavi unit, exposed on the east side of Tenuis Cavus, is not observed on the west side. The layers are wind-sculpted and show little development of layer-controlled terraces. The unit is thus morphologically distinct from Planum Boreum 1 unit. The Chasma Boreale unit may include multiple unconformable sequences, as displayed by complex stratigraphic and structural relations in northern Tenuis Cavus. Also, along the northern wall of Tenuis Cavus, unit Atcb appears to embay the eroded margin of the Olympia Cavi unit. It may also embay unit ABb1 along the southern wall of Tenuis Cavus, but the relationship is unclear. A similar deposit may form the broad, elongate mound that covers the southwestern part of Boreum Cavus and much of eastern Chasma Boreale. However, imaging data thus far are not adequate to verify this possibility.

Planum Boreum 2 unit (ABb2) forms at least several layers that rest unconformably atop units ABb1, ABoc, Atcb, ABrt, and ABV. It mostly is preserved on plateau tops and poleward-facing scarps of Planum Boreum and locally on adjacent plains. Planum Boreum 3 unit (ABb3) forms the residual ice atop Planum Boreum and outlying plateaus and crater-fill deposits and can be viewed as a surficial material (Fig. 2). It mostly is underlain by units ABb1, ABb2 and locally rests unconformably on them along plateau margins.

Surficial materials. In addition to the residual ice cap, additional surficial deposits include what appear to be unconsolidated, transient materials that coat the more long-lived, consolidated deposits. Not all of these materials have been mapped yet, and some are too limited in extent or diffuse to justify formal mapping of them. The broader units can be defined by their color and are mapped in Fig. 2, based on the MRO Mars Color Imager image mosaic MARCI2-4.

Covering much of Vastitas Borealis, including the Scandia region, is a meters-thick mantle having a pebbly texture [13]. The mantle obscures the underlying rock units and their geomorphic features. Its light reddish color (LM in Fig. 2) arises from oxidized iron and is interpreted to be made up of dust. In places, it appears that dust may thinly veil the residual ice (unit ABb3) resulting in an intermediate color (DI in Fig. 2).

Extensive, dark dune fields (unit DS in Fig. 2) occur in plains areas immediately surrounding Planum Boreum and on some low-lying parts of Planum Boreum, such as within Chasma Boreale. The dunes appear to be recently active, although some appear embayed by the light-colored mantle deposits. Some of the dune fields originate from exposures of the Planum Boreum cavi unit within Olympia Cavi, Chasma Boreale, and Abalos Mensa. The dunes are commonly surrounded by rippled material that likely constitutes a thin sand sheet that noticeably subdues underlying landforms. Locally, dunes interact completely with Planum Boreum units and possible yardangs suggestive of varying wind direction (e.g., MOC images R19-01291 and R20-00214). Some of the dunes are associated with moderately dark low mounds, perhaps loess deposits (e.g., MOC image E03-01735). The extent of polar dune material and aspects of their morphologies and orientation have been mapped previously [e.g., 1, 15]; however, higher resolution mapping datasets such as MEX High-Resolution Stereo Color Camera (HRSC) and THEMIS VIS images as well as higher resolution MOC and HiRISE spot images have yet to be tapped for comprehensive and more detailed mapping of dunes and ripples and their morphologies and orientations. The color mapping in Fig. 2 indicates more extensive surficial dark sand than can be inferred from detectable MOLA topographic effects of the dunes and sand sheets as mapped in Fig. 1.

HiRISE images reveal rock falls and avalanches on steep scarps of Planum Boreum [9] made up of the Planum Boreum cavi and 1 units. Boulders are generally less than a few meters across. The finer material of the avalanches generally is brighter and rarely darker than adjacent materials. Some of the avalanche deposits display flow features [9] and are fractured, indicating reconsolidation after emplacement.

Planum Australe region stratigraphy. The Noachis Terra unit (Nn in Fig. 3) comprises the oldest materials of the south polar region and consists of both intact and degraded impact craters and associated terrains emplaced and formed during the Early and Middle Noachian and later extensively resurfaced during the Late Noachian. The Hesperian circum-polar materials of the Dorsa Argentea province (unit Hdp) consist of volatile-rich deposits [7] that make up lobate plains
and cavi terrain marked by sinuous, anastomosing ridges. Early Amazonian deposits of the Richardson unit (unit Ar; named after its type locality in Richardson crater) are commonly a few hundred meters to as much as 1.5 km thick within impact craters and low areas especially between 150° and 240°E. The deposits are covered by perennial frosts and frozen linear dunes and are perhaps remnants of an Early Amazonian polar deposit or may be re-deposited material originating from deflation of unit Hd. Finally, our recent mapping of Planum Australe [12, 16-18] divides its Late Amazonian layered deposits into the Planum Australe 1 to 4 units (Aa1-4; Fig. 3), as described in detail below.

Planum Australe 1 unit (Aa1). This unit comprises the majority of the south polar plateau, accounting for most of the south polar layered deposits (SPLD) that crop out within canyon and margin scarps and reaches a maximum thicknesses of >3.5 km within the plateau’s thickest region, Australe Mensa. The unit is characterized by evenly-bedded planar layers. Our mapping of SPLD sequences exposed in the chasmata of Promethei Lingula [16] and the curvilinear Australe Mensa canyons between 270° and 240°E, mostly in a series of narrow, shallow (<~200 m deep) and cavi terrain marked by sinuous, anastomosing ridges. Early Amazonian deposits of the Richardson unit (unit Ar; named after its type locality in Richardson crater) are commonly a few hundred meters to as much as 1.5 km thick within impact craters and low areas especially between 150° and 240°E. The deposits are covered by perennial frosts and frozen linear dunes and are perhaps remnants of an Early Amazonian polar deposit or may be re-deposited material originating from deflation of unit Hd. Finally, our recent mapping of Planum Australe [12, 16-18] divides its Late Amazonian layered deposits into the Planum Australe 1 to 4 units (Aa1-4; Fig. 3), as described in detail below.

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Our mapping of SPLD sequences exposed in the chasmata of Promethei Lingula [16] and the curvilinear canyons of Australe Scopuli [18] identifies an unconformity in the Planum Australe 1 unit that subdivides the unit into the lower and upper members (units Aa1b and Aa1a respectively). We interpret the unconformity to be the result of plateau-wide, wind-driven processes. Associated preferential downcutting of uneven plateau surfaces (whose layers were deposited over uneven relief substrate) resulted in chasmata formation. The initiation of chasmata and Australe Scopuli canyon formation was coeval and the apparent thickness of the lower member (~1.1 km) indicates the structures began forming relatively early in plateau history.

Planum Australe 2 unit (Aa2). This unit also consists of evenly-bedded planar SPLD sequences but in places individual layers appear somewhat thicker than those of unit Aa1. Total thickness of the unit is ~300 m. The Planum Australe 2 unit unconformably overlies most plateau surfaces of unit Aa1 including sculpted sequences that form the scarps and floors of the chasmata and curvilinear canyons, and low-lying sections within Promethei Planum and Argentea Planum. The unconformable contact relationship between units Aa1 and Aa2 indicates a second period of plateau-wide erosion, including completion of chasmata and curvilinear canyon formation, occurred after Aa1b emplacement but prior to unit Aa2 emplacement.

Planum Australe 3 unit (Aa3). This unit’s extent appears to be limited to the summit area, cropping out mostly in a series of narrow, shallow (<~200 m deep) curvilinear Australe Mensa canyons between 270°E and 30°E and on the floors of canyons that cut the southernmost sections of Australe Scopuli [17]. The Planum Australe 3 unit is ~300 m thick and is comprised of 6-7 uniformly thick, conformable layers. Within canyon outcrops and along unit margins, contacts are traceable for 10s to ~200 km and individual layers have undergone differential erosion, resulting in an outcrop profile of cliffs and terraces. The characteristic low-to-intermediate albedo of the individual layers suggests their surfaces are dust rich. The unit unconformably overlies units Aa1 and Aa2.

Planum Australe 4 unit (Aa4). This unit delineates the residual ice cap, the bright, ~10 m-thick veneer centered between 225°E through 45°E and poleward of ~82°S. MGS, ODY, and MEX datasets indicate the Planum Australe 4 unit is a mixture of CO2 and H2O ice [19-21] that unconformably overlies units Aa1-3. Modeling of the OMEGA spectra dataset [21] indicates the high-albedo CO2-dominated sections of unit Aa4 which constitutes the majority of the deposit’s areal extent, contains a 15 wt% intimate mixture of H2O ice and confirms the THEMIS-based observations by Titus et al. [20] of a water-ice composition for the thin basal layer that forms the moderate-albedo margins of the unit. We assign the residual ice cap’s basal H2O ice layer to the Planum Australe 4 lower member (unit Aa4b) and the CO2-dominated component to the Planum Australe 4 upper member (unit Aa4a).

Fig. 1. Geologic map of Planum Boreum region, Mars. See text for discussion of map units. OC, Olympia Cavi; RT, Rupes Tenuis; AM, Abalos Mensa; HL, Hyperborea Lingula; CB, Chasma Boreale; BC, Boreum Cavus; TC, Tenuis Cavus. (MOLA shaded-relief base in polar stereographic projection.)

Fig. 2. Color-unit map of Planum Boreum, Mars. A\textsuperscript{3}b\textsubscript{3} = residual ice cap, DI = dust and ice, LM = lighter material, DS = dark sand. (MOLA shaded-relief base in polar stereographic projection.)

Fig. 3. Geologic map of the Planum Australe region, Mars. See text for discussion of map units. (MOLA shaded-relief base in polar stereographic projection.)