RECENT GEOLOGIC MAPPING RESULTS FOR THE POLAR REGIONS OF MARS. K.L. Tanaka[1] and E.J. Kolb[2], [1]Astrogeology Team, U.S. Geological Survey, Flagstaff, AZ 86001, ktanaka@usgs.gov, [2]Google, Inc., Mountain View, CA 94043, ekolb@google.com.

Introduction: The polar regions of Mars include the densest data coverage for the planet because of the polar orbits of MGS, ODY, and MEX. Because the geology of the polar plateaus has been among the most dynamic on the planet in recent geologic time, the data enable the most detailed and complex geologic investigations of any regions on Mars, superseding previous, even recent, mapping efforts [e.g., 1-3]. Geologic mapping at regional and local scales is revealing that the stratigraphy and modificational histories of polar materials by various processes are highly complex at both poles. Here, we describe some of our recent results in polar geologic mapping and how they address the geologic processes involved and implications for polar climate history.

North polar stratigraphy: The exposed geologic record for the north polar region appears largely limited to the Amazonian Period, as redefined by [3]. The north polar plains are made up of the *Vastitas Borealis units*, perhaps emplaced as fluvial sediments and (or) periglacially reworked material at the beginning of the Amazonian following cessation of outflow-channel discharges from the Chryse region [3].

Thereafter, the *Scandia region unit* was emplaced in the form of circular plateaus and irregular hilly complexes of Scandia Tholi and Cavi and planar deposits that have since eroded into knobs and mesas, forming Scandia Colles. This unit may have once covered ~1.5 x 10^6 km^2 of the plains north of Alba Patera to Planum Boreum to an average thickness of 100 m. We interpret that the material represents deposits related to mud-diapir-like processes, possibly redistributed by wind. In this scenario, the north polar gypsum discovered by the OMEGA instrument [4] may relate to Alba Patera magmatism [5].

Possibly coeval with and following formation of the Scandia region unit was emplacement of evenly to wavy-bedded material forming the *Rupes Tenuis unit* (ABrt) [6-7]. This material forms the base of much of Planum Boreum. West of Chasma Boreale, along the Rupes Tenuis scarp, the unit includes more than 20 beds and is >1000 m thick. A number of large impact craters on the unit indicate that it is a fairly ancient polar deposit. In spite of the unit's great thickness, it appears to be completely eroded back to an abrupt margin. Possibly correlative is the mantle material that forms the bases of >1800 pedestal craters in surrounding plains [8].

Perhaps during much of the Amazonian, dark, (possibly made up of weathered basalt [9]) dune fields migrated across the circum-polar plains mainly north of 70ºN where dunes are presently common. We map the current dune fields as the *Olympia Undae unit*, after the largest dune field. Some of the present dune fields originate from steep scarps exposed on the margins of Abalos Mensa, from Boreum and Tenuis Cavi at the head of Chasma Boreale, and from reentrants of Olympia Cavi into Planum Boreum. The bases of the scarps include dark, cross-bedded bright and dark layered material mapped as the *Planum Boreum cavi unit* (ABb_c) [7, 10]. Some of the dunes of Olympia Undae are embayed by the young mid-latitude mantle [11] and the youngest polar layered deposits (Planum Boreum unit 2).

The Planum Boreum cavi unit grades upwards into *Planum Boreum 1 unit* (ABb_1), which forms the majority of what are commonly referred to as "polar layered deposits" (however, other polar deposits are also layered, thus the term is now ambiguous). The unit includes dozens of unconformities as seen in MOC images, which may be related to changing patterns of spiral-trough development and (or) local variations in topographically controlled depositional environments [12]. Correlation of layer sequences exposed in various troughs is challenging, but rhythmic sequences of layers ~30-m-thick have been detected [13]. Deformation within this unit is rarely observed, such as near Udzha crater [14].

Within Chasma Boreale and troughs and adjacent plains of Planum Boreum, several dark layers form a sequence as much as 200 m thick and forms the *Planum Boreum 2 unit* (ABb_2). This unit is sculpted with yardangs and within Chasma Boreale is embayed by dozens of bright layers of the *Chasma Boreale unit* (ABcb). This unit also includes yardangs. In turn, the youngest layered deposits, *Planum Boreum 3 unit* (ABb_3), consists of several layers as much as a few tens of meters thick that unconformably overlie older Planum Boreum units. On top, the residual ice cap forms the *Planum Boreum 4 unit* (ABb_4), which rests unconformably on underlying materials [15]. The Planum Boreum 2 unit appears to be made up of a sandy, dark layer, which is the source of veneers of material that appear to contribute to erosion of the spiral troughs and related undulations [16].

South polar stratigraphy: In contrast to the north polar region, the south polar region exposes a geologic record that extends into the Noachian Period [17]. Here, the oldest rocks form the *Noachis Terra unit* and consist of impact breccia and melt, volcanic materials, and eolian and other sediment of the southern cratered highlands. Many impact craters within the highland terrain have undergone degradation and removal, and some unusual remnants, perhaps modified by volcanism, form the rounded massifs of the *Sisyphi Montes unit* [18]. Also, outpourings of likely volcanic material during the Late Noachian through Early Hesperian formed the *Aonia Terra*, *Malea Planum*, and *Terra Cimmeria units*.

Throughout the Hesperian, the nearly circum-polar deposits of the Dorsa Argentea province were emplaced, forming a complex sequence consisting of lobate plains and superposed sinuous ridges, high-standing rugged terrain, and depressions. These unusual characteristics have led to various interpretations [see 2 and references therein]. We divide the Dorsa Argentea province into eight units that differ markedly from those mapped by [1]. The province includes: (1) a thick basal sequence of layered deposits exposed within the pits of Cavi Angusti and Sisyphi Cavi, (2) a high-standing rugged member that includes pitted cones and ridges, (3) five units of plains materials, and (4) a thick, fine-grained friable planar deposit that caps mesas and plateaus of Cavi Angusti. We suggest that the deposits and structures are best explained collectively by cryovolcanic eruptions and discharges of volatile-rich, fluidized slurries formed by the mixing of subsurface volatiles with fine-grained, unconsolidated crustal material and perhaps cryoclastic ash. This activity may have arisen from instabilities in Hesperian aquifers and triggering events caused by seismic shaking, fracturing, intrusions, and loading by polar deposition [2].

Some of the impact craters surrounding Planum Australe, including Richardson crater, are partly infilled by layered mound deposits capped in some cases by ripples that may be frozen dunes. In Richardson, the dunes appear to be buried by the Planum Australe 1 unit. These combined deposits form the *Richardson unit* (AAr).

The *Planum Australe 1 unit* (AAa_1) forms the majority of Planum Australe, the south polar plateau, reaching a maximum thickness of ~3 km within the plateau's thickest region, Australe Mensa. The unit is exposed along plateau margins and within canyons, and its basal layer sequences are perhaps Early Amazonian in age. A regional unconformity identified in the chasmata of Promethei Lingula and the curvilinear canyons of Australe Scopuli divides the Planum Australe 1 unit into the lower and upper members. The erosion associated with the unconformity was primarily wind and sublimation driven, and occurred after approximately one-third of the Planum Australe 1 unit stratigraphy was emplaced. The unconformity's orientation and outcrop expression indicates the chasmata formed by down-cutting of Planum Australe 1 unit surface depressions formed where the unit overlies uneven substrate [19] and marks the initiation of curvilinear canyon formation within Australe Scopuli [20]. The lowest 500 m of the Australe Mensa stratigraphy includes many local unconformities. In higher sequences, several layers that can be traced throughout most of Australe Mensa show unconformities that are up to 50 km long; they are seen at multiple exposure locations and indicate that regional erosive events punctuated emplacement of the relatively younger sequences of this region. The oldest regional unconformity in Australe Mensa occurs where this section of the plateau reaches 1 km thickness and thus may occur at the same stratigraphic position as the upper/lower member contact seen in other plateau regions; current mapping efforts will determine if such a correlation can be made.

The *Planum Australe 2 unit* (AAa_2) unconformably buries eroded Planum Australe 1 surfaces. The unit was emplaced after the canyons had largely reached their current form and after the plateau margins underwent extensive removal from Argentea, Promethei, and Parva Plana. The unit is <300 m thick and is comprised of layers that are slightly thicker than those of the Planum Australe 1 unit.

The *Planum Australe 3 unit* (AAa_3) crops out mostly in a series of narrow, shallow (<~200 m) curvilinear Australe Mensa canyons between 270°E and 30°E and on the floors of canyons that cut the southernmost sections of Australe Scopuli [21]. The unit is ~300 m thick and is comprised of 6-7 uniformly thick, conformable layers; 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 they are relatively dust rich. The unit unconformably overlies the Planum Australe 1 and 2 units.

The *Planum Australe 4 unit* (AAa_4) delineates the residual ice cap, the bright, <~10 m-thick veneer centered between 225°E through 45°E and poleward of ~82°S. The upper member consists of the high-albedo CO_2-dominated sections [22] of the residual ice cap and constitutes the majority of the deposit's areal extent. The lower member is a thin basal layer consisting of water ice [23-24] that forms the moderate-albedo margins of the residual ice cap. The unit unconformably overlies the Planum Australe 1 through 3 units.

Synthesis of polar geology: Polar deposits include atmospheric volatile and dust precipitates and aeolian dunes and sheets made up of basaltic fines that have undergone some moderate cementation and weathering and extensive aeolian reworking. Our mapping studies generally indicate that the availability of dust, sand, and volatiles controlled by climate conditions and geologic activity and the variable circum-polar wind patterns controlled by topography and weather conditions have resulted in a complex history of accumulation and erosion at Planum Boreum and Planum Australe. Both climate-related cycles operating at differing time scales as well as unique geologic and climatic events have driven these processes. However, we find no compelling evidence for glacial-like deformation and for basal melt-water discharge of polar deposits. First-order comparison of the polar stratigraphies indicates a plausible scenario for synchronous phases of deposition and erosion (Figure 1).

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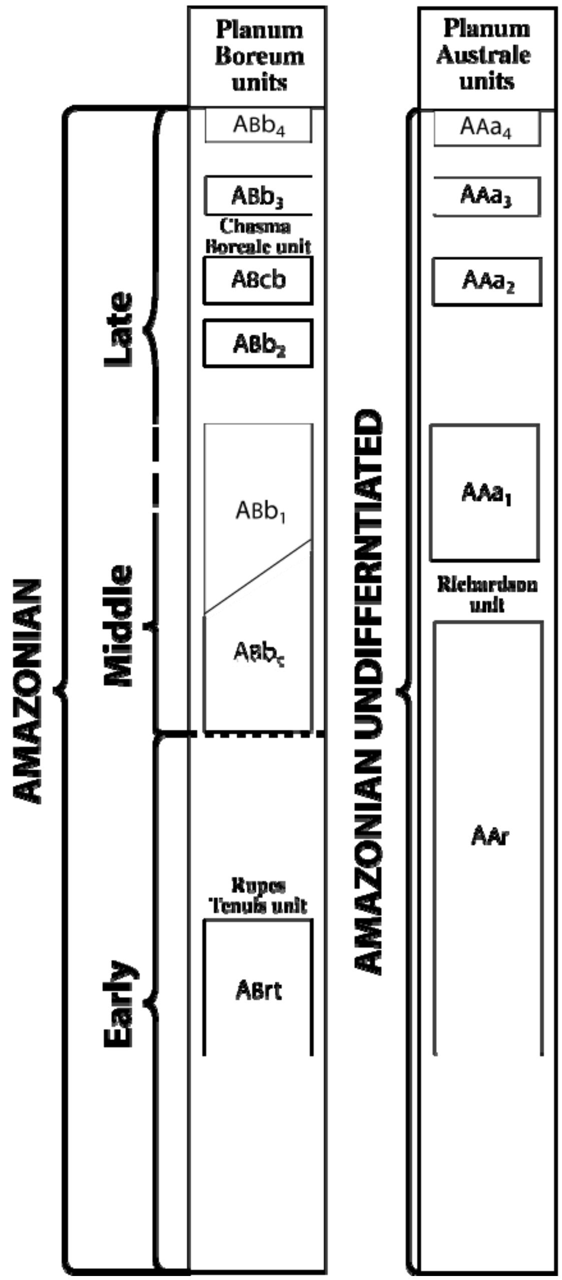

Figure 1. *Possible correlation of units making up Planum Boreum and Planum Australe. The relative ages of Planum Boreum units are approximately constrained by stratigraphic position and a few crater densities [7], whereas Planum Australe units are mainly constrained by stratigraphic relations thus far. Therefore, the vertical position of the Planum Australe unit boxes are aligned with Planum Boreum units based on the proposed correlations in [7] for illustrative purposes, but their correct positions are uncertain. See text for unit names associated with the symbols.*