REGIONAL GEOLOGIC HISTORY OF THE POLAR REGIONS OF MARS. K. L. Tanaka[1] and E. J. Kolb[1], [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, ktanaka@usgs.gov.

Introduction: Geologic mapping and topical studies of the martian polar regions based on Mariner 9 and Viking data have identified major geologic units and structures and their formational sequence [e.g., 1-3]. However, several fundamental questions remain poorly answered, such as: (1) What has been the history of ice and dust deposits at the poles and their subsequent modification over geologic time? (2) Is their a signature of melting and discharge from any polar deposits? (3) Can long-term or sporadic climatic and geologic changes of global significance be detected in the polar geologic records? (4) How have volcanism, tectonism, and impacts been involved in the geologic evolution of the polar regions?

Here we discuss how these questions are currently being re-examined with Mars Global Surveyor data and new geologic mapping of the polar regions.

History of ice and dust deposition: The south polar layered deposits (SPLD) make up Planum Australe as well as isolated outcrops within surrounding craters and local depressions out to 60° S. [2]. The timing of initial SPLD deposition is poorly constrained; the unit overlies middle Hesperian units of the Dorsa Argentea Formation (DAF) and younger cavi material [2]. SPLD are Late Amazonian, and recent crater counts using Viking images of frosted surfaces suggest that the mean surface age is <10 Ma [4]. In comparison, the north polar layered deposits (NPLD) also make up a large plateau, Planum Boreum, and local outliers out to about 73°N. The high-standing, rounded topography of Olympia Planitia suggests that its dune field overlies a large patch of NPLD. In turn, NPLD rest on Late Hesperian/Early Amazonian materials [2] and appear to be uncratered in Viking images, indicating surface ages of <100 Ka [4].

The older SPLD surface age may indicate that these higher-elevation surfaces largely ceased receiving deposits since the obliquity has been <40°, ~5 million years ago [4]. However, localized south polar (SP) deposition may account for mantles that cover (1) the residual ice cap, (2) broad, flat terrace surfaces on the planum, and (3) plains adjacent to Planum Australe (between ~330 to 30°W) [5]. It remains to be seen to what degree these young deposits may be layered.

Older polar deposits are preserved in the south polar (SP) region. The SP pitted material generally has been considered to be a deeply eroded, paleopolar dust and ice deposit [1,2,6]. The pitted material rises above the DAF, and the pits bottom out at about the surface level of the DAF. Thus the cavi material likely postdate or are coeval with the DAF and have an Late Hesperian crater density [6]. The pitting indicates local instabilities within the pitted material that might lead to collapse, such as concentrations of ice or more highly volatile ice mixtures. Pitted terrain underlies perhaps much of the SPLD adjacent to Cavi Angusti. Near the mouth of Chasma Australe, a 15-km crater having a pedestal ~100 km across overlies the DAF and is being exhumed from beneath SPLD. The crater apparently armors an intermediate, friable deposit. Plateaus at the mouth of Planum Boreale may form older polar deposits underlying NPLD, but this interpretation is highly conjectural.

No clear evidence for Noachian polar deposits has been discovered at either pole. This may be explained either by polar wandering or by perhaps climate conditions that did not promote concentrated polar ice-and-dust deposition. Noachian highland terrains across Mars appear to be ubiquitously layered and may in fact reflect highly voluminous but diffuse ice and dust deposition [7]. Alternatively, the SP Noachian terrain may include polar deposits that have been obscured by later activity.

Polar ice cap melting: Deposits with lobate flow margins and esker-like ridges surround both polar caps and have been interpreted in various ways, including melting of former ice caps [8-11]. Basal melting should occur if ice caps of sufficient thickness occur depending upon climate conditions and ice composition [12-13]. For example, sub-ice lakes may be present beneath Planum Australe if the SPLD is at least partly composed of CO_2 clathrate [12]. Water-ice layered deposits, however, may require thicknesses of several kilometers for basal melting to occur under present conditions.

If basal melting had occurred, the overlying layered deposits may have moved like warm-based glaciers on Earth. The sinuous ridges on the DAF have been interpreted as glacial eskers [11]; however, these features deviate in preservation and geomorphic associations in significant ways from terrestrial eskers. We find that the ridges also occur locally atop the pitted terrain. In any case, if the ridges are related to basal melting, then DAF actually may have formed by expulsion of water and sediment from beneath a former ice cap. The sinuous ridges mostly trend toward extant outcrops of pitted material and SPLD. Floods generated by ice-cap melting also have been proposed to explain the large chasma troughs that cut both polar plateaus [11, 14]. Sinuous ridges occur within Chasma Australe, but streamlined erosional landforms are not clearly observed in either chasma.

Long-term climate change: Like earth, the polar regions are the most sensitive regions of the planet to climate change. The polar layered deposits may record climate and atmospheric variations related to orbital changes, intense volcanic activity, impacts, and perhaps other phenomena. New MOC images show a great diversity in the characteristics of individual layers in the polar layered deposits. Also, angular unconformities and trough structures within the deposits may also relate to periods of erosion or deformation controlled ultimately by climate. These changes may occur over times scales ranging from thousands to tens of millions of years during the Late Amazonian.

Older polar deposits differ in significant ways from the SPLD, and thus may have different compositions. In Viking images, except perhaps for a resistant cap in places, the SP pitted materials do not show layering. Also, the margin of the pitted materials locally has a lobate form suggestive of flow. Therefore, the pitted material may have been melted and may have been relatively more volatile (CO_2-rich?). The DAF may also have been derived from a highly volatile source; locally, its surface is covered by small pits that may have developed via volatile release.

Other geologic activity: Impacts, volcanism, and tectonism have likely affected the development and modification of layered deposits at both poles. Large impacts (>10 km) superposed on polar deposits are rare or obscure and limited to the SP region. Two types occur: (1) Those with well-developed secondaries; one each on both SPLD and DAF. One might expect that impact into icy material should produce fluidized ejecta morphologies instead. Instead, laboratory experiments demonstrate that impacts into porous target material tends to be ejected in large clumps, resulting in large secondary craters [see 5]. (2) The 15-km pedestal crater at the mouth of Chasma Australe that presumably is armoring some former, perhaps largely eroded deposit.

Possible volcanoes have been proposed in the vicinity of both polar layered deposits [2,15], raising the possibility that sub-layered deposit (and thus sub-ice) volcanism may have occurred. However, stronger evidence such as suites of tuya- (table mountain) related features have yet to be recognized.

Tectonic sagging of the underlying lithosphere has been proposed for both polar plateaus, based on their loading [16, 17]. Estimates range up to a few hundred meters of sagging, depending on the actual thickness of the deposits, their densities, and lithospheric rheology. In addition, catastrophic deposition in the northern plains associated with a mud or water ocean may have caused as much as a kilometer of regional sagging in the north polar basin. [18]

Summary: Both polar regions, while having similar-sized plateaus of layered deposits, differ markedly in related recent and long-term geologic activity, including both polar and non-polar geologic processes. New studies involving geologic mapping and geomorphologic and topographic analysis using MGS data are providing significant advances in unraveling the geologic histories of the polar regions, yielding potential insights into the polar climate records. We expected to see enhanced analyses, new interpretations, and continued debate of these largely enigmatic regions.

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