CLIMATE HISTORY OF THE POLAR REGIONS OF MARS DEDUCED FROM GEOLOGIC MAPPING RESULTS.

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Introduction: New detailed geologic mapping of the polar regions of Mars reveals their history of dust deposition and erosion and other geologic processes and events. We propose a climate history for the polar regions of Mars, based on our mapping results combined with previous crater density studies and orbitally driven climate modeling.

Our geologic mapping includes the northern plains of Mars at 1:15M scale [1], the south polar region (60-90ºS) at 1:5M [2], and the polar layered deposits at 1:1.5M [3]. We primarily use MOLA topography at 460, 230, and 114 m/pixel resolutions respectively at progressively higher latitudes as MOLA shot density increases, hundreds of THEMIS VIS images at 19 m/pixel, and hundreds of MOC images at meters/pixel.

South polar region geologic mapping results:

Noachian and Hesperian units. We have mapped Noachian cratered materials and seven primarily Hesperian Dorsa Argentea units, formerly mapped as two members of the Dorsa Argentea Formation [2]. Interpretations for the Dorsa Argentea units include glacial outwash deposits [4] and slurries erupted from groundwater saturated, poorly consolidated substrate [2]. The units are marked by sinuous ridges previously interpreted as eskers [4] or inverted channel features [2].

Late Amazonian Australe units. The layered deposits of Planum Australe consist of two major units: (1) a thick, relatively smooth, flat-lying lower layer sequence that buries underlying Noachian and Hesperian materials, and (2) a thinner sequence of moderately to heavily pitted and knobby layers draped over the eroded topography of the lower sequence [3]. We named these units the Australe 1 and 2 units, respectively. Australe 1 unit displays local layer unconformities along the margins of Chasma Australe and Ultima Lingula (informally known as Ultimi lobe). It appears that soon following emplacement, most erosion of the Australe 1 unit took place, including formation of the spiral troughs and chasmata [3]. Next equatorward-facing scarps and perhaps other surfaces of the unit hardened, possibly due to the incorporation of salts or to other weathering processes. Further scarp retreat ensued, resulting in layer margins that developed into ridges where the deposits had hardened. During this hiatus, low-albedo dune fields within craters apparently formed on the margins of the Ultimi Scopuli area, perhaps made up of material reworked from the Dorsa Argentea Formation.

Later, Australe 2 unit was emplaced as a series of even-thickness mantles draped over the Planum Australe topography. It appears most likely that Australe 2 unit deposited where residual ice had been present on flat and poleward-facing scarps [5]. Crater counts completed for part of Planum Australe indicate a mean surface age of 30-100 Ma [6] but includes a diverse surface of flat-lying Australe 2 material west of Australe Scopuli, troughed Australe 1 unit of Australe Lingula and Scopuli, and windswept mainly Australe 2 unit on Promethei Lingula. The flat-lying area appears to have the highest crater density, whereas Promethei Lingula shows the fewest. In addition, we observe several mounds amongst Australe Sulci (the wirebrush terrain ridges) on Promethei Lingula that may be pedestal crater relicts. Thus the flat-lying area, which has about twice the crater density, has a 60-200 Ma age; other areas likely have been progressively stripped and thus have younger exposure ages.

The thick sequence of layers of Australe Mensa are capped by residual, uncratered [6] CO_2 ice that may represent recent and perhaps ongoing deposition.

North polar region geologic mapping results:

Early Amazonian units. The Vastitas Borealis Formation has been remapped as the Vastitas Borealis interior and marginal units based on current data sets [1]. In addition, the Vastitas Borealis units are proposed to define the beginning of the Amazonian Period [1]. They embay the floors of the outflow channels in Chryse Planitia, indicating that their formation followed the latest Chryse floods. Possibly, the Vastitas Borealis units could be outflow-related, lacustrine deposits that underwent a period of intense cryoturbation, mud volcanism, and other volatile-related processes to account for their associated morphologies (including arcuate chains of pitted cones, troughs with medial ridges, and polygonal graben networks), their post-dating of the outflow-channel floors, and their abundance of ghost craters (yet lack of moderately degraded craters).

The Scandia unit is superposed on the Vastitas Borealis units. The unit is highly degraded into knobs and may even be completely removed across much of the plain south of Chasma Boreale, wherein a continuous outcrop of the unit occurs. We suggest that the unit is composed partly of material erupted by mud volcanism due to high heatflow, hydraulic gradients, and tectonic fabrics associated with magmatic activity at Alba Patera. The Scandia Cavi in particular have the form of mud volcanoes with peripheral moats that may reflect subsidence due to the removal of volatile-rich substrate. At the mouth of Chasma Boreale, the unit is layered and may consist of deposits distal to source areas that may have been reworked and emplaced by lacustrine or eolian processes.

Boreum 1 unit includes low-albedo, irregularly layered deposits superposed on the Vastitas Borealis units and forming the lower to middle sections of Planum Boreum. It reaches hundreds of meters to perhaps a kilometer in thickness west of Chasma Boreale, depending on how much of the Scandia unit underlies Planum Boreum. The unit has been interpreted to be a sand deposit [7] and may be primarily the result of erosion of the Scandia unit.

Pedestal crater mantles and sinuous ridges. A large proportion of craters, perhaps even the majority larger than a few kilometers in diameter in some areas, dot the surface of Vastitas Borealis north of ~70ºN. Many of the thicker pedestals are ~100 m high. A few scattered sinuous ridges similar in form to those of the south polar Dorsa Argentea occur in the plains and Scandia Cavi region surrounding Planum Boreum. One example at 20.3ºE, 75.4ºN is 60 km long, several km wide and up to 130 m high. The ages of these features is poorly constrained and may span most of the Amazonian following emplacement of the Vastitas Borealis units.

Late Amazonian Boreum 2 units. Like the south polar Australe units, the Planum Boreum layered deposits can be divided into stacks of (a) fairly smooth layered deposits (Boreum 2a unit) exposed in equatorward-facing scarps and windswept surfaces in Chasma Boreale covered by (b) pitted layers (Boreum 2b unit) up to ~150 m thick mantling the flat and poleward-facing surfaces of the 2a unit. Planum Boreum overall is unmarked by craters >300 m in diameter, resulting in an inferred surface age of <100 Ka [8].

Proposed polar climate history: The geologic record provides a starting point for interpreting the climate history of Mars, particularly where geologic materials are deposited, eroded, reworked, or otherwise modified due to changing climate conditions. Generally, the farther back in time, the less certain interpretations become. Overall, our observations indicate that climate histories at the poles have been remarkably diverse.

Noachian and Hesperian Periods (~4.5 to ~3.0 Ga). The Noachian and Hesperian geologic record for the north polar region was largely obscured by Amazonian activity. In the south polar region, Noachian surfaces exposed as far south as 83ºS do not display any obvious extant polar geologic signatures such as layered deposits. During the Hesperian, the deposits and ridges of the Dorsa Argentea Formation point to volatile-driven activity, including fluvial action. Such activity appears to have been long-lived, at least periodically, over as much as the entire Hesperian [2], ~700 million years. The south polar region also includes local pedestal craters indicative of mantles of possible Hesperian age.

Early to Late Amazonian (~3.0 to ~0.4 Ga). The emplacement and modification of the Vastitas Borealis, Scandia, and Boreum 1 units at the beginning of the Amazonian appear to require the activity of water and ice at and near the surface. Widespread preservation of pedestal craters atop Vastitas Borealis units and south polar surfaces indicates polar mantles were common. This may indicate sufficiently low insolation to promote expansive deposits of polar ice and entrained dust.

Late Amazonian, Australe 1 and 2 stages (~400 to ~60 Ma). Layered deposition of Australe 1 and 2 units occur, possibly due to a decrease in obliquity-driven insolation. Episodes of wind erosion during and after deposition of Australe 1 unit carved Planum Australe into its overall, current shape. Australe 2 unit suggests residual ice was present across much of Planum Australe to fix the dust.

Late Amazonian, Australe 3 stage. (~60 to ~5 Ma). During this phase, polar insolation likely increased, leading to wind erosion of the Australe units, including formation of Australe Sulci. Some depositon may have occurred on Australe Mensa, the high point of Planum Australe, where residual ice is currently observed

Late Amazonian, Boreale stage (~5 Ma to ~75 Ka). Significant decrease in polar insolation [9] drives emplacement of Boreum unit 2a [10]. Hiatuses, perhaps driven by the obliquity cycle, results in erosion and layer unconformities within the unit. At some point, the layers are eroded dramatically to form spiral troughs and Chasma Boreale. They subsequently harden and experience more gradual erosion.

Late Amazonian, Olympia stage (<75? Ka). Boreum unit 2b is deposited following the latest peaks in the obliquity cycle at ~20 and ~75 Ka [9].

Implications. Widespread, dust-rich polar mantles 10s of m thick have been common during the Hesperian and Amazonian; their development may be related to the presence of residual ice during moderately low obliquity. The current polar plateaus may be the result of rapid dust deposition during relatively recent episodes of unusually low obliquity.

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