REGIONAL MID-LATITUDE GLACIATION ON MARS: EVIDENCE FOR MARGINAL GLACIAL DEPOSITS ADJACENT TO LINEATED VALLEY FILL.

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Introduction: Recent analysis of the orbital parameters of Mars [1] leads to the conclusion that chaotic diffusion prevails; analytical assessment of the density function of different orbital parameters leads to the prediction that the mean obliquity over geological time is ~38^o, and that the probability is 63% that it exceeded 60^o in the past Ga. Thus, Mars is currently in a period of anomalously low obliquity (~23^o), and typical obliquity values in the history of Mars (and thus climate zones and the distribution of surface and near-surface water ice [2]) are likely to be much different than now. Indeed, synthesis of recent observational data suggest that Mars underwent an ice age in the last few million years from which it is currently emerging, during which time obliquity exceeded 30^o and polar ice was mobilized and transported equatorward and deposited down to latitudes of ~30^o in both hemispheres [3]. What happens when obliquity exceeds 30^o for extended periods of time? Where is water deposited, in what volumes, and how is it manifested in terms of geological processes? Geological evidence suggests that extensive water ice was deposited at mid-latitudes in the past associated with lineated valley fill and lobate debris aprons [4,5] and the case has been presented for extensive past tropical mountain glaciation [6,7]. Recent general circulation model analyses provide evidence for significant mobilization of polar ice during periods of high obliquity and redeposition equatorward in the form of low to mid-latitude ice deposits [8-11].

What might such ice deposits look like and how might they behave? We have been focusing on analysis of mid-latitude bands of lobate debris aprons and lineated valley fill and find evidence in the landforms for significant accumulations of snow and ice and glacial-like flow [12-13] earlier in the Amazonian. Of particular interest is the lineated valley fill in the Deuteronilus region, which has numerous features that are interpreted to be formed during extensive valley glaciation [13].

Evidence for widespread valley glaciation has led us to further consider GCM models suggesting significant ice deposition at high obliquity [8-11] by assessing the behavior of such deposits in terms of regions of accumulation and subsequent flow [e.g., 14], for example the highland region north of 30^o up to the dichotomy boundary. Among the predictions from these analyses are: 1) deposition is likely to be altitude-dependent, as well as latitude-dependent, and thus to be widespread across the upland plateau; 2) ice accumulation and flow will be influenced by micro-environments (e.g., local topographic and cold-traps, such as local craters and valleys); 3) regional accumulations will form ice sheets and will flow into adjacent valleys much in the manner that marginal valley glaciers form adjacent to ice sheets on Earth; 4) the viscosity of ice under martian conditions combined with martian gravity means the shallow valleys will often overflow and form marginal ridges on plateaus adjacent to valley glaciers; 5) during periods of deglaciation, sublimation occurs on the plateaus and produces deposits from contained debris, and flow retreats to the trunks and valley floors.; 6) as these ice sheets are likely to be cold-based, the debris content of the ice sheets on the plateaus is likely to be low, and to consist predominantly of dust nucleated on falling snow or dust captured by the ice sheet from atmospheric circulation; 7) in contrast, debris content of the valley glaciers is likely to be high due to the abundant and nearby debris source provided by the valley walls, as is the case with terrestrial glaciated valley landsystems [15].

On the basis of these analyses, we are examining regions of predicted ice accumulation for deposits and structures that might represent evidence of ice sheet accumulation and flow in the past history of Mars. Here we report on evidence for plateau deposits adjacent to regions of lineated valley fill (LVF) that appear to represent remnants of 1) valley-marginal ice lobes that extended away from the valleys at a time when they were filled with ice and overflowed into surrounding terrain, and 2) plateau deposits that are interpreted to represent the sublimation and wasting of previously widespread ice deposits.

Description and Interpretation: The broad dichotomy boundary region above ~30^o N latitude is an area of fretted terrain and includes abundant examples of lineated valley fill, lobate debris aprons, and mantled and softened terrain [e.g., 4,5]. Carr [5] identified scabby remnants of a stippled unit on an uplands plateau adjacent to lineated valley fill at 33.9^{o}N 296.5^{o}W (Fig. 1), and interpreted these to be remnants of a deposit emplaced as ice-rich, and partly removed by sublimation and deflation. Our analysis [13] in the Deuteronilus region supports a glacial origin for LVF there. If the LVF in Fig. 1 originated in the same manner as in Deuteronilus [e.g., 13], how might it be related to the scabby plateau deposits interpreted by Carr to be a water-ice rich veneer?

Figure 1 shows a valley containing LVF (center) and the adjacent relatively smooth walls of the valley. The flat bounding plateaus to the north and south are characterized by ridged and lobate deposits extending away from the valley margin. Ridges and lobes commonly face outward away from the valley (Fig. 1, insets C, D), indicating that they were emplaced outward from the direction of the valley. On the plateau just to the north of the LVF, the terrain is rough and hummocky and is somewhat lower than the adjacent plateau surface (Fig. 1, inset E). In agreement with Carr [5], we interpret these deposits to be volatile-rich materials now undergoing sublimation. In this particular case, we interpret these to have originated as glacial deposits from ice that once filled the valley floor and flowed out into the surrounding terrain and then underwent deglaciation to produce sublimation tills and moraines, much in the same manner as observed in the Antarctic Dry Valleys (ADV), when valley glaciers rise and spill over into adjacent topography and then retreat [16]. Similar examples of overfilled valleys, marginal moraine deposits, and lowering of the valley floor during deglaciation are seen in the Arsia Mons tropical mountain glacier [17], and elsewhere in the study region. The pitted and hummocky deposits at the north edge of the plateau are interpreted to be the residue of more pure ice (closer to the source), and are thus downwasted to negative topography during deglaciation.

Summary: 1) If lineated valley fill forms as glacial deposits, as proposed in the Deuteronilus area [13], then there are likely to be times when the valleys filled with ice such that the ice overflows and extends out into adjacent terrain, as seen at Arsia Mons [17] and in the ADV. 2) We identify several types of structures and terrains (moraines, sublimation tills, wastage zones, etc.) that are consistent with valleys filled with ice and the overflow of ice into the surrounding plateaus. 3) The Antarctic Dry Valleys provide plausible models for this process, with ice from valley glaciers overflowing onto adjacent plateaus and cirques and leaving remnant moraines and tills after deglaciation [16]. 4) Modeling of ice accumulation at mid latitudes on Mars [14] strongly suggests that ice will accumulate regionally and flow into existing valleys, often filling them and extending out over the margins. 5) These features and their deposits imply the possibility of filled valleys and more regional ice deposits during the Amazonian in the mid-latitude regions of Mars.

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Figure 1. A) Portion of MOC SP2-43104. 33.9° N 296.5° W. B) Sketch map showing main units and relationships. C) Enlargement of portion of lobate flows and moraine-like features on the S plateau rim. D) Enlargement of portion of lobate flows and moraine-like features on the N plateau rim. E) Enlargement of portion of pitted and hummocky terrain on the N plateau rim. Locations of C, D, E in A.