the layered deposits appears to consist mainly of bright red dust, with small amounts of dark dust. Dark dust, perhaps similar to the magnetic material found at the Viking Lander sites, may preferentially form filamentary residue particles upon weathering of the deposits. Once eroded, these particles may saltate to form the dark dunes found in both polar regions. This scenario for the origin and evolution of the dark material within the polar layered deposits is consistent with the available imaging and thermal data. Further experimental measurements of the thermophysical properties of magnetite and maghemite under martian conditions are needed to better test this hypothesis.

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THE MARS WATER CYCLE AT OTHER EPOCHS: RECENT HISTORY OF THE POLAR CAPS AND LAYERED TERRAIN. Bruce M. Jakosky, Bradley G. Henderson, and Michael T. Mellon, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO 80309-0392, USA.

The martian polar caps and layered terrain presumably evolve by the deposition and removal of small amounts of water and dust each year, the current cap attributes therefore represent the incremental transport during a single year as integrated over long periods of time. We have investigated the role of condensation and sublimation of water ice in this process by examining the seasonal water cycle during the last 10^7 yr. In our model, axial obliquity, eccentricity, and L_s of perihelion vary according to dynamical models. At each epoch we calculate the seasonal variations in temperature at the two poles, keeping track of the seasonal CO_2 cap and the summertime sublimation of water vapor into the atmosphere; net exchange of water between the two caps is calculated based on the difference in the summertime sublimation between the two caps (or on the sublimation from one cap if the other is covered with CO_2 frost all year). Despite the simple nature of our model and the tremendous complexity of the martian climate system, our results suggest two significant conclusions: (1) Only a relatively small amount of water vapor actually cycles between the poles on these timescales, such that it is to some extent the same water molecules moving back and forth between the two caps. (2) The difference in elevation between the two caps results in different seasonal behavior, such that there is a net transport of water from south to north averaged over long timescales. These results can help explain (1) the apparent inconsistency between the timescales inferred for layer formation and the much older crater retention age of the cap and (2) the difference in sizes of the two residual caps, with the south being smaller than the north.

N93-19812 p.4

POSSIBLE RECENT AND ANCIENT GLACIAL ICE FLOW IN THE SOUTH POLAR REGION OF MARS. J. S. Kargel, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff AZ, USA.

Martian polar science began almost as soon as small telescopes were trained on the planet. The seasonal expansion and contraction of the polar caps and their high albedos led most astronomers to think that water ice is the dominant constituent. In 1911 Lowell [1] perceived a bluish band around the retreating edge of the polar caps, and he interpreted it as water from melting polar ice and seasonal snow. An alternative idea in Lowell's time was that the polar caps consist of frozen carbonic acid. Lowell rejected the carbonic acid hypothesis primarily on account of his blue band. To complete his refutation, Lowell pointed out that carbonic acid would sublimate rather than melt at confining pressures near and below one bar; hence, carbonic acid could not account for the blue watery band. Some of the many ironies in comparing Lowell's theories with today's knowledge are that we now recognize that (1) sublimation is mainly responsible for the growth and contraction of Mars' polar caps, (2) carbon dioxide is a major component of the southern polar cap, and (3) Lowell's blue band was probably seasonal dust and/or clouds.

Melting of water ice certainly is not a significant extant polar process.

It has been eight decades since Lowell [1] discussed the composition of Mars' polar caps, and considered the roles of glaciers (moving ice) and seasonal snow or frost (static ice) as contributors to the polar caps. Although we now have a far better observational base to consider these matters, and have made considerable progress in understanding the polar caps, these basic issues remain largely unresolved.

This abstract presents geomorphic evidence that glacial ice and glacial melt waters once flowed over broad areas of the southern polar region. Earlier reports by the author and co-workers have suggested similar processes and associated hydrologic phenomena across many other areas of the martian surface [2,3]. Two aspects of the south polar region suggest possible glacial processes during two distinct eras in Mars' history. First, the lobate marginal form of polar layered deposits is consistent with geologically recent glacial flow; this is considered weak evidence because purely sublimational processes might produce the same structure. Stronger evidence, in the writer's view, is the observation that landforms in regions surrounding the polar layered deposits seem to bear the imprint of ancient but far more extensive glacial processes. Some geomorphologic evidence is presented below.

The great sinuous ridges of Dorsa Argentea and nearby "etched plains" in the south polar region (Figs. 1 and 2) were interpreted by Howard [4] as having formed by basal melting of ground ice. He thought that the ridges may have formed by deposition of fluvial sediment between large blocks of ground ice. If the ice had been active at some time (i.e., moving), such features would be termed *kame moraines*, a truly glacial landform. However, it seems that Howard had in mind more static bodies of ice-rich soil or rock that would not be considered glacial. Howard [4] also considered a more strictly glacial interpretation that the ridges of Dorsa Argentea are eskers, but he did not favor this hypothesis on account of a perceived absence of associated glacial landforms.

Kargel and Strom [3,5,6] have examined the glacial esker model for the formation of Dorsa Argentea and similar sinuous ridges elsewhere on Mars. They found that terrestrial eskers bear many geomorphic aspects in common with martian sinuous ridges, and, furthermore, identified a host of associated landforms that are plausibly explained by glaciation. Other researchers also have explored the possible genesis of sinuous ridges on Mars [7–13]. All these workers have considered glacial esker or eskerlike hypotheses as acceptable purely on the basis of the characteristics of the ridges. However, every group of researchers has come to a different conclusion concerning what they "probably" are! Proposed analogues include longitudinal sand dunes, inverted stream beds, lacustrine spits or bars, clastic dikes, wrinkle ridges, igneous dikes, and volcanic flows, in addition to the eskers favored here. On the basis of present data it would be fruitless for anyone to try to prove one model to the exclusion of others. This abstract simply shows that other glacial-appearing features do exist in the southern polar region of Mars in association with Dorsa Argentea.

Figure 2 shows part of Dorsa Argentea adjacent to an area of higher ground. The high ground exhibits many elongate depressions, including some in a conspicuous radial pattern. Generally, these depressions are sharp-edged pits 10 to 100 km long and several hundred meters deep (based on shadow measurements). This terrain is part of the south polar etched terrain, which is generally regarded as the result of either (1) eolian deflation or (2) sublimation or melting of massive ground ice. A third hypothesis is that these depressions were eroded by active glacial ice and melt water. In this case, they would be roughly analogous in scale, form,

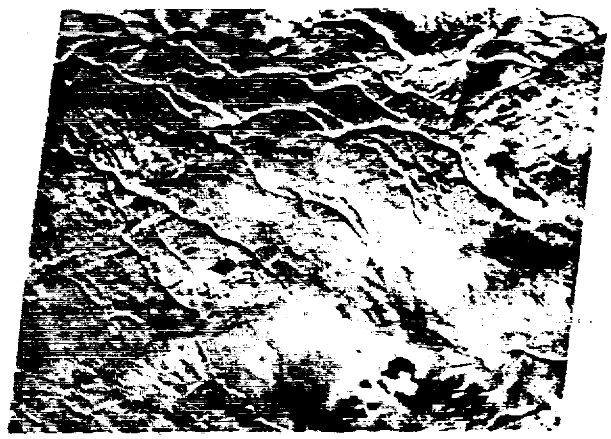

Fig. 1. Part of Dorsa Argentea, near latitude 78°S, longitude 40°. Scene width 213 km. Solar illumination from top 12° above horizon. VO image 421B53.

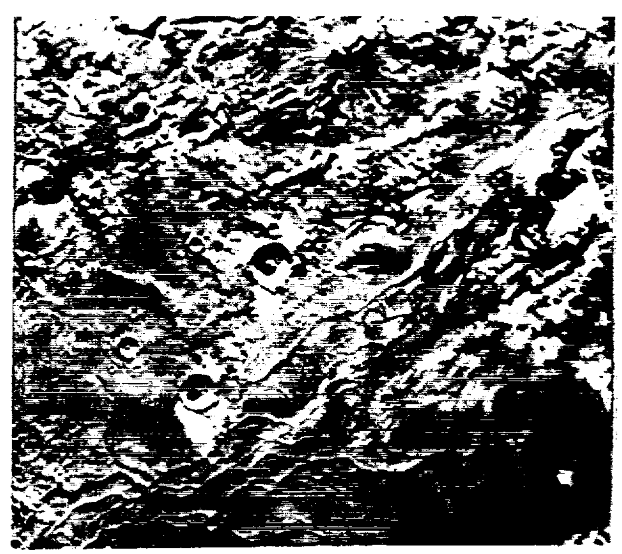

Fig. 2. Another view of Dorsa Argentea, showing also adjoining areas of etched terrain near latitude 76°S, longitude 30°. Solar illumination from top. Scene width 357 km. VO 421B16.

and origin to the fjord lakes of British Columbia and Scotland and the finger lakes of New York. Some of these terrestrial features, such as the New York finger lakes, tend to have smoothly rounded edges, while others, including many of the fjord lakes of British Columbia and Scotland, have fairly sharp edges. All of these terrestrial features were eroded by glacial ice streams and catastrophic glacial melt water releases late in the Pleistocene when climatic amelioration destabilized the continental ice sheets.

Figure 3 shows an area roughly 400 km southeast of the nearest parts of Dorsa Argentea. The rugged area near the center of the image is one of the highest regions in the southern hemisphere of Mars. The scalloped form of the mountains is similar to terrestrial mountain ranges modified by alpine glaciation. The scalloped embayments, some compound, resemble terrestrial glacial cirques and glacial valleys. Figure 4 is a Landsat image of the Sentinel Range, Antarctica, seen at a resolution similar to the Viking scene. The Sentinel Mountains are dominated by simple and compound cirques ("cirque-in-cirque" structure). The Mars scene exhibits a similar morphology. The smooth plains in the Mars scene and the smooth glacial ice sheet in Antarctica both possess faint lineations streaming away from the mountains. In the Antarctic scene (Fig. 4) the lineations are lateral and medial moraines and pressure ridges in the ice closely approximate glacial flow lines. While one cannot prove it with present data, thoroughly moraine-mantled glacial ice with glacial flow lines or ground moraine retaining former ice-flow structures are reasonable interpretations of the Mars scene (Fig. 3). A working hypothesis is that the high mountains in Fig. 3 served as a major source of ice ultimately responsible for the formation of the Dorsa Argentea ridges. Another source may have been the etched plains to the northeast of Dorsa Argentea (Fig. 2).

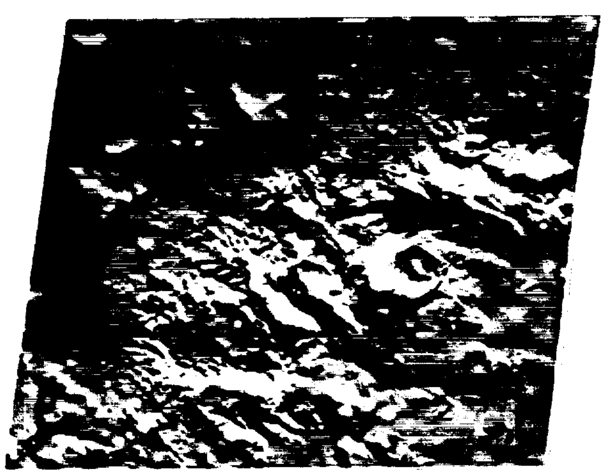

Fig. 3. Mountainous region and adjoining lineated plains ~400 km southeast of Dorsa Argentea, near latitude 81°S, longitude 347°. Solar illumination from top. Scene width 172 km. VO 421B83.

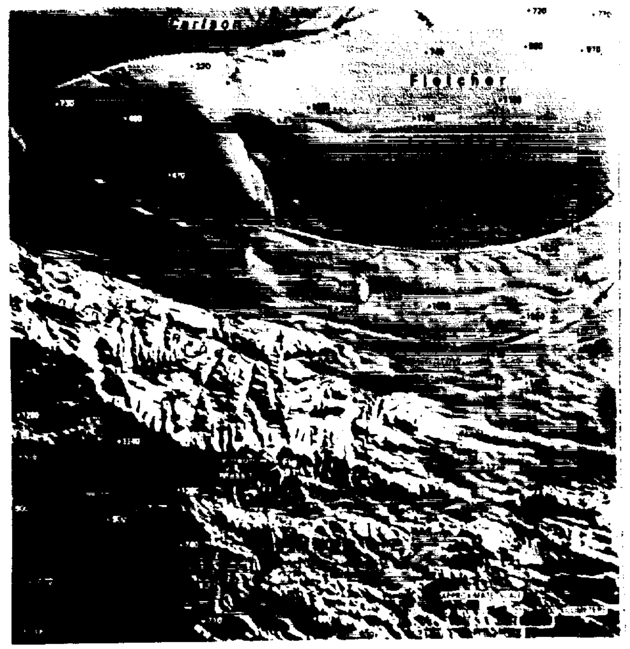

Fig. 4. Landsat image of Sentinel Mountains, Antarctica. Solar illumination from top. Scene width ~200 km. Courtesy of Baerbel Lucchitta and the Flagstaff Image Processing Facility, U.S. Geological Survey.

Mars Observer will have the capabilities to address the glacial and competing hypotheses. For instance, glacial erratics, if they exist, should be visible in narrow-angle images as randomly distributed bright spots one to several pixels wide with long shadows. These images may reveal abundant moraines, some containing resolvable boulders, in some areas. Fluting, roches moutonnées, rock drumlins, and true drumlins should be readily visible on some glacially sculptured plains and alpine valleys. Narrow-angle images of eskers may reveal layering and cross-bedding and probably will show thermokarstic features. Images of ice-sculptured basins should show small-scale sculptural forms such as fluting and roches moutonnées and may reveal glaciolacustrine deltas and eskers. Mars Observer infrared observations of plains containing many eskers and covered by ground moraines should indicate abundant gravel-, cobble-, and boulder-sized material, while thermal infrared data for large glacial lake plains should indicate mainly very fine-grained sediment. Laser altimetry should reveal characteristic U-shaped transverse profiles of many glacial valleys. In combination with imagery, laser altimetry may indicate ice-flow directions opposing the topographic gradient of the rock surface in some cases and may indicate longitudinal gradient reversals of eskers.

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N93-19813

IS CO_2 ICE PERMANENT? Bernhard Lee Lindner, Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge MA 02139, USA.

Carbon dioxide ice has been inferred to exist at the south pole in summertime [1,2], but Earth-based measurements in 1969 of water vapor in the martian atmosphere suggest that all CO_2 ice sublimed from the southern polar cap and exposed underlying water ice [3]. This implies that the observed summertime CO_2 ice is of recent origin.

However, Fig. 1 shows that theoretical models of the energy budget of the surface that simulate the formation and dissipation of CO_2 ice have been unable to preserve seasonal CO_2 ice at the south pole and still obtain agreement with observations of the polar cap regression and the annual cycle in atmospheric pressure [4–10]. This implies that either these models improperly treat the energy budget or that CO_2 ice from an earlier time is exposed in summer.

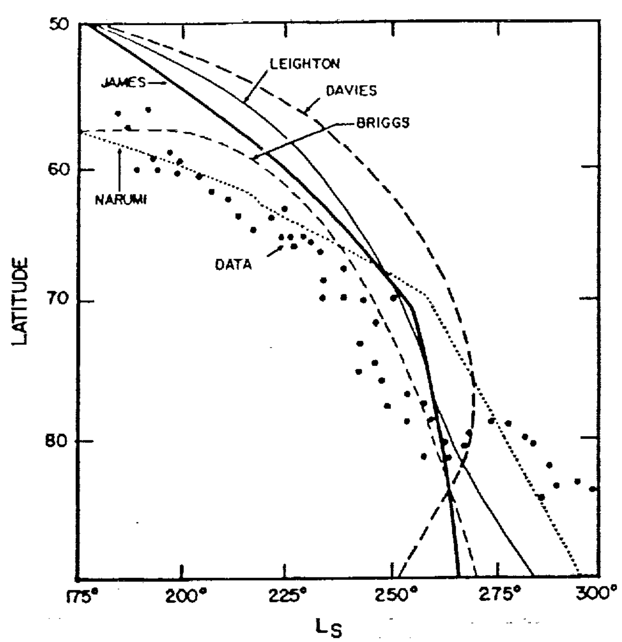

Fig. 1. The seasonal recession of the south polar cap as observed over the last 20 years [22] and as predicted by models [4,6–9]. (The aerocentric longitude of the Sun, L_s, is the seasonal index; L_s = 0°, 90°, 180°, and 270° correspond to northern spring equinox, summer solstice, autumnal equinox, and winter solstice respectively.)

An exact comparison to data is difficult, considering that the edge of the polar cap is usually patchy and ill defined [18,19], in large part due to terrain that is not included in any polar cap model. The edge of the polar cap is also diurnally variable since ice frequently forms at night and sublimes during the day. There is also some year-to-year variability in polar cap regression [20,21].

Several processes have been examined that might retain the good agreement to observations of the annual cycle in atmospheric pressure and to overall polar cap regression, and yet allow for better agreement at the south pole, without requiring old CO_2 ice. The radiative effects of ozone were suggested as important [11], but were shown numerically to be unimportant [12,13]. However, the radiative effects of clouds and dust [12] and the dependence of frost albedo on solar zenith angle [14,15] do allow for better agreement at the pole while maintaining good agreement to overall polar cap regression and the atmospheric pressure cycle [16]. Penetration of sunlight through the seasonal ice also has a marginal positive effect on CO_2 ice stability at the pole itself because it allows some solar radiation that would otherwise sublime overlying CO_2 seasonal ice to sublime ice within the residual polar cap [17].

Figures 2 and 3 show my model predictions for polar cap regression compared to observations. Before solar longitude of 250°, south polar cap regression is predicted to be similar to that predicted by earlier models (compare to Fig. 1). However, the new model retains CO_2 ice year round at the

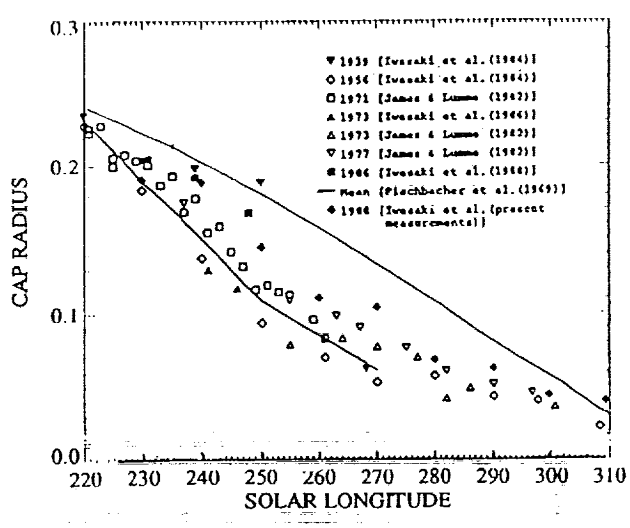

Fig. 2. The regression of the south polar cap, as observed for various years (taken from [23]) and as simulated by my model (thin line), as a function of the aerocentric longitude of the Sun (L_s). The cap radius is that which would be measured on a polar stereographic projection of the south polar region; the units of the radius are fractions of the planetary radius of Mars.