Ancient Glaciation on Mars J.S. Kargel and R.G. Strom, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

Photogeologic evidence for widespread ancient episodes of glaciation has been discovered in Viking spacecraft images of Mars. The principal image base used for this study consists of the USGS 1:2 million scale photomosaics of the MC-26 Quadrangle and the Viking Orbiter images obtained on orbits 349S, 352S, 567B, 568B, 569B, and 574A. We recognize that non-glacial mechanisms may adequately explain certain individual types of landforms discussed below. However, we believe that a glacial hypothesis provides a more acceptable unified explanation, and is consistent with the emerging outlines of a global hydrologic model [1].

Figure 1 is a glaciological map of a region the Charitum Montes and the adjoining Argyre Planitia. The most startling feature in this region is an anastomosing system of sinuous ridges, noted previously [2-5]. The plan of this ridge system (Viking Orbiter frames 352S34 and 567B30-35) is fluvial in character and must therefore have an underlying fluvial explanation (volcano-tectonic processes can not generate this pattern). The possibility that similar ridge systems elsewhere on Mars are glacial eskers has been previously noted [2](eskers are stream deposits of sand and gravel originally layed down on the surface of, within, or beneath stagnant, melting glaciers). The esker hypothesis is lent support by the similarity in length, height, width, overall structural plan, and detailed structure of the Martian features compared to large terrestrial eskers associated with the melting of Late Pleistocene and modern ice sheets on Earth [6, 7].

Figure 1 also shows the characteristic structure of the mountainous inner ring of Argyre, including numerous valleys separating sharp linear to semi-circular ridges. The characteristics of this mountain range, if considered with a terrestrial perspective, are diagnostic of alpine-type glacial erosion. The Charitum Montes appear to be a classic glacial assemblage of horns, cirques, and aretes, with intervening valleys mantled by lobate debris aprons. A prominent cirque near 54°30'S. Lat. 31°30'Long. is intimately associated with a region of fluvial deposition and erosion interpreted to be a glacial outwash deposit (sandur plain). Another region of fluvial erosion and deposition, near 54° S. Lat. 37° Long., emanates from a large glacially modified valley in the Charitum Montes and is interpreted as a glacio-lacustrine delta.

Large-scale glacial fluting was severe in Argyre Planitia during the height of the ancient ice age. The scouring of several large impact crater rims (e.g., frame 568B33) demonstrates that a considerable interval of time elapsed between the Argyre impact and the glacial epoch. In the area mapped in Figure 1 (450,000 km^2) there are seven fresh impact craters larger than 10 km in diameter displaying fresh ejecta and sharp rims and lacking any signs of glaciation, suggesting an early Amazonian termination of the glacial epoch. The extensive ejecta blanket of the large crater Galle (not one of the seven) covers about a third of Argyre Planitia, and clearly mantles many glacial grooves and ridges (e.g., frame 352S39). However, the delta-like fluvial system mentioned above erodes and elsewhere embays the ejecta blanket of Galle; further, smooth layered deposits, interpreted as glacio-lacustrine sediments associated with the esker system, embay Galle's ejecta blanket (frames 567B36 and 568B09); finally, a channel, either glacial or possibly fluvioglacial, incises the rim of Galle (frame 352S24). Hence, Galle dates from the glacial epoch (or an interglacial). Impact into an ice sheet is suggested by the extensive occurrence of ice disintegration features (e.g., kettle holes) on the ejecta blanket of Galle (frame 568B12). Possibly an underlying ice sheet, or perhaps anomalously large quantities of ice entrained in the ejecta itself, later melted or sublimated.

Kettle fields outside the area of Galle's ejecta testify to the retreat of the ice sheet and the stranding of large blocks of ice on Argyre Planitia (frame 568B53). Together with the eskers and outwash deposits these landforms record the melting of the Argyre ice sheet, *indicating a period of relatively warm climate even at moderately high elevations and latitudes*. However, the absence of super-imposed fluvial systems (other than those plausibly related to the melting of ice) indicates that *humid conditions following the ablation of the ice sheet were short-lived*. We note that the northern rim escarpment of Argyre has been fluvially modified and lacks evidence of glaciation, as if it rained there probably at the time that it snowed at higher latitudes.

We have made a preliminary search for possible glaciogenic landforms elsewhere on Mars. The single most diagnostic glaciogenic landform on Mars probably is the esker. Eskers are widespread in the Southern Hemisphere of Mars, often occurring in close association with polar layered deposits and etched (kettled and/or glacially scoured?) terrains; these probably indicate that a vast ice sheet once enveloped much of the Southern Hemisphere down to about 40° S. Lat. Eskers also occur more sparingly in the Northern Lowlands north of 26° in close association with the "thumbprint terrains" (recessional moraine fields?), and in one tropical location.

The final ablation of the southern ice sheet must have occurred under much warmer conditions and under a denser atmosphere than currently prevail. Glaciation and de-glaciation may have been two steps in a global hydrologic cycle. Possibly Oceanus Borealis [1] supplied the atmosphere with water vapor which then was cold-trapped as snow or frost in the high elevations of the Southern Hemisphere. As the climate warmed due to climatic perturbations related to the formation of Oceanus Borealis the ice sheet eventually melted, charging the cratered uplands with groundwater. Given sufficient permeability this groundwater may have flowed northward to re-charge the equatorial region. Volcanism-driven outbursts of groundwaters may have re-filled Oceanus Borealis, completing the cycle, possibly on a repeating basis [8, 9].

Finally, we suggest that the nature and significance of the lobate debris aprons at high- and mid-latitudes on Mars [10] should be re-evaluated. It is generally thought that these debris aprons are rock glaciers. The outstanding issue is whether they are purely periglacial rock glaciers where down-slope motion is generated by gelifluction (surficial freeze-thaw), or whether the debris aprons are ice-cored rock glaciers where a rocky lag has accumulated on the surfaces of old glaciers by processes of melting and/or sublimation [11]. Figure 1 shows that debris aprons are commonly associated with individual cirques, suggesting a glacial origin.

References. 1) V. Baker et al., 1990, *LPS XX*. 2) M.H. Carr et al., 1980, Viking Orbiter Views of Mars, U.S. Gov't. Printing Office, Washington, D.C., p. 136. 3) P.H. Schultz and D. Britt, 1986, *LPS XVII*, p.775. 4) T.J. Parker, 1989, *LPS XX*, p. 826. 5) C.A. Hodges, 1980, Geologic Map of the Argyre Quadrangle of Mars, USGS Map I-1181. 6) R.J. Price, 1973, *Glacial and Fluvioglacial Landforms*, Oliver & Boyd, Edinburgh, 242 pages. 7) H. Lee, 1965, *Geol. Surv. Can. Pap. 65-14*, 1-17. 8) V. Gulick and V. Baker, 1990, *LPS XXI*. 9) G. Komatsu and R.G. Strom, 1990, *LPS XXI*. 10) S.W. Squyres and M.H. Carr, 1986, *Science 231*, 249-252. 11) J.R. Giardino, J.F. Schroder, Jr., and J.D. Vitek (eds.), 1987, *Rock Glaciers*, Allen & Unwin, Boston, 355 pages.

Figure 1. Glaciological map of a portion of Argyre Planitia and the adjoining Charitum Montes.