
In a previous report, Lucchitta and Anderson (1) discussed the possibility that martian outflow channels were sculptured by glaciers. They compared martian channel morphologies with similar features of terrestrial glacial valleys and Antarctic ice streams. Among these morphologies are: a) U-shaped valley cross-profiles, b) hanging valleys, c) long, even scour marks on valley sides and floors, d) anastomosing patterns, e) valleys tens of kilometers wide, and e) precipitous scarps thousands of meters high.

The formation of streamlined islands in the martian outflow channels was addressed by Baker and Kochel (2), who compared them with catastrophic-flood islands in the scablands of Washington. In this paper the streamlined islands are compared with Antarctic ice-rises, which are sculptured by ice-streams, and the ice-rise dimensions are plotted on the same graph that contains Baker and Kochel's data for the scabland islands and those of Kasei Vallis (Fig. 1). The ice-rises are as large as the largest martian islands; their plotted dimensions fall near Baker and Kochel's regression line, and agree with a tendency for large islands on Mars to lie above this line. The lemniscate K-factors for streamlined islands in the scablands and Kasei Vallis and for Antarctic ice-rises also agree reasonably well. Additionally, Baker and Kochel calculated average elongations (length/width ratio) of islands. The average of 2.7 for Kasei Vallis islands agrees exactly with the value calculated by the author for 26 islands near the mouth of Tiu Vallis. They found that small scabland islands (1 km long) have an elongation of 3.0 and large islands (100 km long) an elongation of 4.1. Thus scabland islands appear to diverge from the elongation of martian islands as they approach the martian features in size. By contrast, Antarctic ice-rises, which are similar in size to the largest martian islands, have an average elongation of 2.5. This average agrees well with the martian values. The above mentioned data concerning channel islands support the hypothesis that the martian outflow channels were sculptured by ice.

Glacial ice that may have moved through martian outflow channels could have been cold based or warm based. Cold-based glaciers are frozen to the ground; shear movement takes place within the ice and occurs when the basal shear stress lies between 0.5 and 1.5 bars (3). The basal shear stress depends on the ice surface gradient and the ice thickness. On Mars, we can measure only ground gradients which, for the channels, range from less than 0.1° to 0.25° (4). Very low ground gradients, however, are no deterrent to ice movement, as can be seen in Antarctica, where an overall gradient of 0° exists for a distance of 1900 km in the Wilkes subglacial basin (5). Indeed, given appropriate ice surface gradients, ice will move even if the ground gradient is reversed. For Mars, the author calculated that an ice thickness of 4 km is required in order to move cold-based ice, given an ice surface gradient of 0.2° and a basal shear stress of 0.5 bars. Ice domes as thick as 4 km could have existed if the region of channel origin was under artesian pressure with heads of 4 to 5 km as suggested by Carr (6).

On the other hand, ice in the martian channels may have been warm based. Warm-based glaciers, at the pressure melting point at their bases, may be supported by a thin layer of liquid water and can erode powerfully (3). The longitudinal scour marks on martian channel walls and floors suggest that erosion was indeed effective, and that ice in the channels was warm based and possibly laden with debris. Perhaps the ice formed rock glaciers rather than true glaciers, as has been suggested for the material in the fretted channels.
Martian Outflow Channels

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The author calculated the depth for pure ice on Mars to the 273° K isotherm, which is the depth to a warm glacier base. This depth is 4 km at the equator and 5 km at 30° lat, using Toksöz and Hsui's (8) heatflow, Leighton and Murray's (9) mean annual surface temperatures, and Glen's (10) thermal conductivity for ice, and disregarding complicating factors such as changes of state. For ice loaded with debris, the depth to liquid water would be less, and would approach Fanale's (11) depth to the 273° K isotherm in ice-charged ground of 1 km at the equator and 2 km at 30° N lat. The depth to the bottom of warm-based glaciers would further lessen if increased speed owing to steepened gradients or converging flow added frictional heat. Thus, warm-based ice in martian channels may have been as thin as 2 km. This figure agrees with ice thickness estimates for the martian channels that the author obtained by measuring the relief between scoured surfaces above and below scarps.

Ice in the martian channels may have flowed from ice accumulations in their source region. Such accumulations may have originated from atmospheric precipitates, wind deposits, or springs. The disturbed appearance of the ground in the chaotic terrain, where most channels originate, suggests that water emerging from the ground is the most likely source. This water could have come from artesian springs (6), or may have been liberated from ground ice by geothermal heating (12,13). Artesian water may have formed ice domes from which glaciers flowed; river water may have formed ice caps (14) that eventually consolidated into glacial masses. In any case, available evidence indicates that sculpturing by glaciers could have given the martian channels their distinctive morphology.

REFERENCES

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Fig. 1. Dimensions of Antarctic ice rises and channel islands in the scablands and Kasei Vallis, Mars. Scabland and Mars data from Kochel and Baker (2).