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WEST-ANTARCTIC ICE STREAMS: ANALOG TO ICE FLOW IN CHANNELS ON MARS

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Sounding of the sea floor in front of the Ross Ice Shelf in Antarctica recently revealed large persistent patterns of longitudinal megaflutes and drumlinoid forms, which are interpreted to have formed at the base of ice streams during the last glacial advance [1]. The flutes bear remarkable resemblance to longitudinal grooves and highly elongated streamlined islands found on the floors of some large martian channels, called outflow channels. In addition, other similarities exist between Antarctic ice streams and outflow channels. Ice streams are 30 to 80 km wide and hundreds of kilometers long, as are the martian channels. Ice stream beds are below sea level [2]. Floors of many martian outflow channels lie below martian datum [3], which may have been close to or below past martian sea levels [4,5]. The Antarctic ice stream bed gradient is flat and locally may go uphill, and surface slopes are exceptionally low [6]. So are gradients of martian channels [7]. The depth to the bed in ice streams is 1 to 1.5 km [8]. At bankful stage, the depth of the fluid in outflow channels would have been 1 to 2 km. These similarities suggest that the martian outflow channels, whose origin is commonly attributed to gigantic catastrophic floods [9], were locally filled by ice that left a conspicuous morphologic imprint [10].

Unlike the West-Antarctic ice streams, which discharge ice from an ice sheet, ice in the martian channels came from water erupting from the ground. In the cold martian environment, this water, if of moderate volume, would eventually freeze. Thus it may have formed icings on springs [8], ice dams and jams on constrictions in the channel path [10], or frozen pools [11]. Given sufficient thickness and downhill surface gradient, these ice masses would have moved; and given the right conditions, they could have moved like Antarctic ice streams.

The Antarctic ice streams are thought to slide over longitudinally grooved, deforming till, where much of the movement is within the till [8,12]. The till is saturated with water at high pore pressures that nearly supports all of the weight of the ice [12,2]. For pore pressures to remain high, the ice streams have to act as a seal that blocks the flow of water through them, and the rock underneath has to be of low permeability to prevent the water from draining away. A similar mechanism of sliding may have applied to ice in martian channels. In situ rubble from weathering products may have served as the deformable layer. The channel ice forms the seal above the sliding horizon, the bedrock the seal below so that water could accumulate under high pore pressures. The water could have been derived from remaining liquids associated with the icings, ice jams and dams, or frozen pools.

However, if no such water remained in the liquid state, water had to be liberated by other means. Under current average equatorial surface temperatures on Mars of 218 K [13], a heatflow of 30 mWm^{-2} [13], and a thermal conductivity of ice of 2.6 $J\ m^{-1}\ s^{-1}\ K^{-1}$ (after Glen [14]), water ice would freeze to a depth of nearly 5 km and ice in the channels would be welded to the ground. Warmer climates in the past would have to be invoked to make the Antarctic ice-stream mechanism work. Most outflow channels, however, date from the martian mid-history [15], when the existence of warmer climates is conjectural.

On the other hand, heatflow in channel regions may have been elevated. Martian channel floors tend to be littered with dark, mafic [17] materials; some channels originate at grabens [16]; and channels are locally associated with volcanoes [18]. Assuming a heatflow of 90 mWm^{-2}, representative of some volcanic regions on earth [19], and using the other parameters given above, melting could have occurred at less than 2 km depth. Thus, in volcanic regions, water could have been liberated on the floor of ice-filled, 1- to 2-km-deep outflow channels.

Elevated heatflows also existed in the past. Schubert and Spohn's [20] model estimates mantle heatflows of about 40 mWm^{-2}, 1 b.y. ago; of about 70 mWm^{-2}, 2 b.y. ago; and of about 100 mWm^{-2}, 3 b.y. ago. Accordingly, 2 b.y. ago and earlier, melting could have occurred at depths of 1 to 2 km. Thus, at the time when many of the outflow channels formed, ice contained in the channels could have slid on rubble under high pore pressures like Antarctic ice streams.

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