ARE MARTIAN NORTH POLAR CAP SPIRALS TRACES OF ANCIENT ICE SHEET COLLAPSE?

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Introduction: The surface of north polar cap of Mars is essentially heterogeneous unlike flat terrestrial ice sheets [1]. Troughs up to one kilometer deep with gently (no more 10-15°) sloping are seen all over the ice cap. The unique feature of the trough system is its helical appearance (Fig. 1).

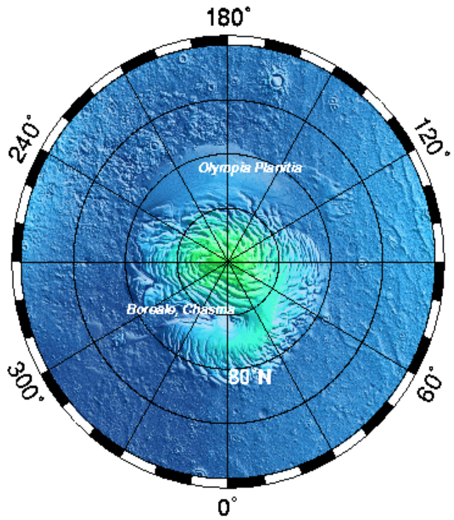

Fig. 1. The north polar cap of Mars.

Analogs of ice spiral structures are not known. The troughs have been attributed to the action of aeolian erosion [2-3], sublimation [4] or to "accublation" hypothesis (glacial flow + sublimation + accumulation) [5-7]. It is supposed that an ice mass transfer occurs by sublimation from equatorward-facing slopes and subsequent accumulation on pole-facing slopes. No ideas on origin of spiral pattern have been moved forward with the exception of an attempt to explain trough revolving by combined effects of accublation and ice movement [8].

Hypothesis: Analysis made in [9-10] suggests that Chasma Boreale - the greatest trough of north pole ice sheet is a giant scour generated by subglacial outflow. This mass of water (maybe subglacial lake) can arise in consequence of a number of reasons, as a result of intensive ice sheet melting provided geothermal flux increasing, for example.

It is natural that water lubrication comes to sufficient decreasing of bed friction. In view of this cause the ice sheet will spread radially with high speed. Augmentation of radial stress over breaking point generated ice entirety breaking, came to emergence of crevasses. Its trajectories depended on physical characteristics of ice and Coriolis force.

Laboratory experiment: A simple laboratory experiment has been run to prove the hypothesis.

A disk made of wet clay that measures 14 centimeters across and two tenths of a centimeter at the center (tapering down to 0 at the outer edge) had been thrown counter clockwise. In two minutes of rotating and subsequent drying spiral cracks made their appearance (see Fig. 2). There is a long crack on the right part of the figure, a shorter and S-like cracks in the center. Every crack has a clockwise cockling. One can see a qualitative resemblance of the spiral structure of Martian north polar cap and this clay model.

Fig. 2.

Cracks in the clay disk in two minutes of counter clockwise rotating (high contrast picture).

Model: A simple model of crack progression in viscous ice sheet on rotating planet has been developed. Model crack trajectory depends on Coriolis parameter f, initial coordinates, initial velocity (u_0, v_0) and ice resistance coefficient c.

Results: An example of model trajectory for x_0=0, y_0=600 km, u_0=60 m/sec, v_0=0 m/sec, f=10^{-4} sec^{-1} c=2 10^{-5} sec^{-1}, visualized on Fig.3. One can see the model

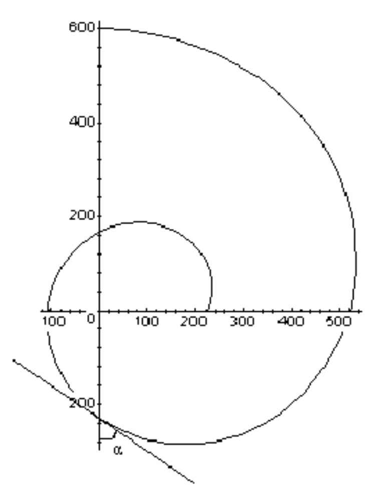

Fig.3. Model spiral

crevasse looks like a spiral, coiling around center. Qualitative resemblance of helical troughs is evident. It makes sense to verify if they fit quantitatively. An analysis of trough pattern (Fig.1) has been made in order to take angles (α) between its tangent directions and local meridian lines – “spiral inclines” (see Fig.3).

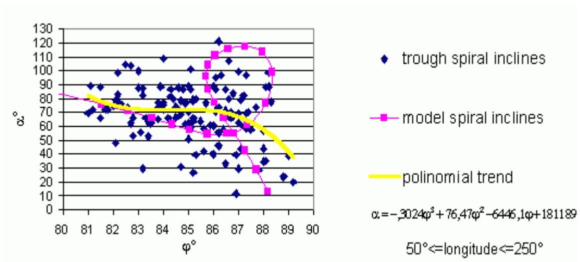

Fig.4. Dependence of spiral inclines α on latitude ***φ***.

Fig.4 shows these data, lines of polynomial interpolation and modeling dependency ***α(φ)***. One can see the scatter of points is sufficiently large at first sight. Trend line says that spiral inclines are above mean (67°) on the sheet periphery, approaching 90°. They diminish near pole and close to 70° in the wide enough latitude range (82,5°-86°). It is interesting that the model line loops a sufficient large loop.

Discussion: Model curve behavior is defined by starting conditions and parameters of the problem.

Suppose angular rotation velocity of Mars practically did not change since hypothetical collapse of polar sheet, and so used value of Coriolis parameter deserves credit. As a matter of fact the size of ice sheet could be different, though, one can hope, its distinction from present one is a little. The used values of initial speed and resistance coefficient ***c***, for their parts, depend on value of ultimate stress, kinematic coefficient of ice viscosity and ice density. Terristrial ice investigations show, that ice density varies in sufficiently close limits and only a little smaller of the used value 10^3 kg/m^3, but the ranges of ultimate stress and kinematic coefficient of ice viscosity are wide [11]. Mean values have been used in this research. Generally speaking, on account of faint maturity of the cracking dynamics theory application of simple models seems justified.

Being examined trough pattern closely, one can notice that no trough traces from sheet margin to the pole continuously, that they, as rule, consist of several sections. This says that cracking happened step by step. Continued spread of ice sheet resulted in a rise of stretching stress at crack vertex that, in its turn, sooner or later, set going spasmodic initiation of a new crack.

Flatness of trough slopes denotes that collapse accompanied by creation of immense crevasses, took place a long time ago. After reduction of geothermal flux to the previous level bed friction rose, ice sheet spreading dropped down, cracking stopped, and accumblation began to play a key role in sheet surface modification. Thus, regardless of the fact that the ice spreads away slowly (order of speed magnitude is mm/year [7]) smoothing irregularities of its surface, accumblation process drives helical troughs irrepressiblly north. If accumblation process did not start up, deep troughs would close in 10^5-10^6 years [7].

By the way, absences of spiral troughs on the surface of terrestrial ice sheets can stands for remoteness or lack of their collapses. However one can think that being disappeared to the end of last glacial period Laurentian and Fennoscandian ice sheets could left footprints (moraineas?) of their helical structure. One must take into account that underlying topography could disfigure this structure substantially.

Conclusions: Thus, it follows from this investigation that being defreezed at bed the Martian north pole ice sheet began to transform, as a matter of fact, to an ice body resembling ice shelf. This transformation was accompanied by drastic amplification of radial tension that came to breaking of ice entirety, to emergence of deep crevasses all over the sheet. This planetary scale process was so intensive that being influenced by Coriolis force crack trajectories deviated to the right, forming spirals. After bed temperature fell down and sheet collapse ceased, obtained relief began to undergo a smoothing owing to continuous slow ice spreading and mass transfer from the warmed by sun north crack slope to the shady south one. This process transformed the helical structure of crevasses to the helical structure of troughs.

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