TENSION CRACKING ALONG HELICAL GLIDE LINES AS ORIGIN OF MARTIAN NORTH POLAR CAP SPIRALS A. A. Kostrikov[1] and I. A. Garagash[2], [1]Laboratory for Comparative Planetology, Vernadsky Institute, 19, Kosygin St, 117975, Moscow, Russia (kostrikov@geokhi.ru), [2]Institute of Earth Physics, Moscow, Russia.

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).

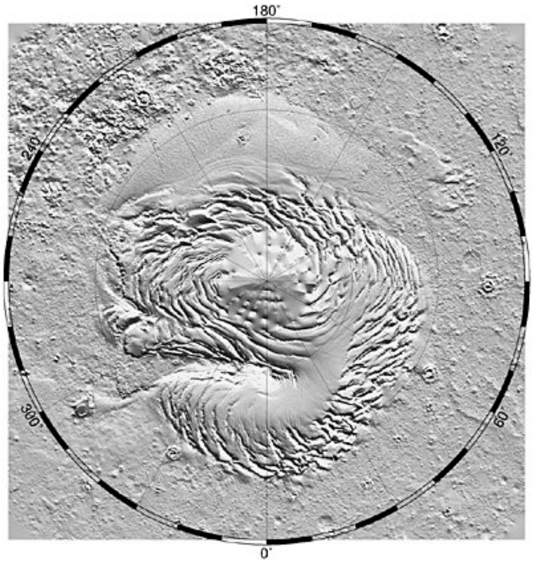

Fig. 1. The north polar cap of Mars.

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 by Fishbaugh and Head [9] suggests that Chasma Boreale - the greatest trough of the north pole ice sheet - is a giant scour generated by subglacial water outflow. This mass of water can arise in consequence of a number of reasons, such as intensive ice sheet melting provided by geothermal flux increasing. It is natural that water lubrication decreases bed friction. In view of this the ice sheet will spread radially with high speed. Augmentation of radial stress over the breaking point generated ice that fractured entirety. The last takes place in the zones of maximal shear strength, which look like as helical glide lines, producing a helical system of crevasses.

Basing of hypothesis: theoretical investigation: Start from the assumption that a stationary plane stress state of an axisymmetric elasto-plastic body (with no bed friction) satisfies the equation of equilibrium of the tension and gravitational forces and Mizes yielding condition.

In the present epoch, it seems, the parabola is the best approximation for the profile of the Martian north pole ice dome [10]. Thus, under a parabolic profile the gravitational force that causes the ice sheet to widen, increases proportionally with increasing radius. Under our statement of this problem, the central part of the ice sheet remains elastic whereas the outside is in the state of plastic yielding (Fig. 2).

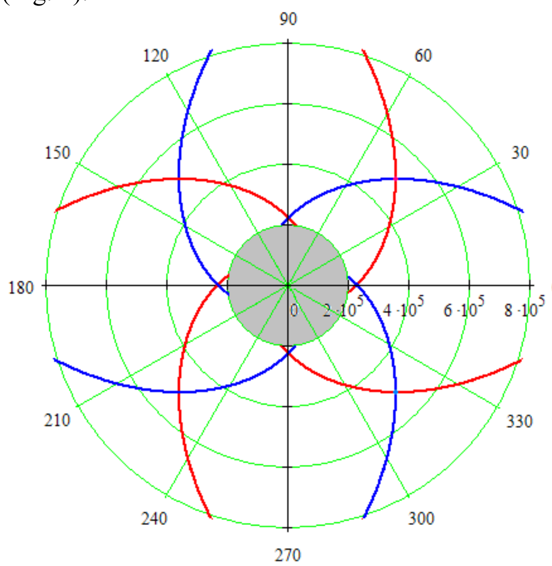

Fig. 2. Logarithmic glide lines.
Elastic kernel is in a grey.

The formula for the boundary radius between elastic and plastic region is the following

$$r_s = \sqrt{\frac{2\tau_s}{gH\rho(1+\nu)}}R \qquad (1)$$

where ν is Poisson ratio. (For the first time the solution for uniformly strained axisymmetric elasto-plastic body has been found in [11,12].) Experimental values of a limit shear stress lie within the limits 0,1-1 MPa [13]. Providing τ_s = 0.1 MPa and g = 4 m/sec2, H = 2800 m, ρ =10^3 kg/m3, $\nu = 0.3$, and R = 6 10^5 m, the radius of elastic kernel is equal to 73 km (~ 0.1 R). Providing τ_s = 1 MPa it reaches 227 km (~ 0.3 R). One can see that the plastic zone occupies the larger part of the ice sheet for the whole range of the limit shear stresses. It is worth noting that its percentage increases along with rising of ice temperature.

For many materials an erratic behavior of plastic yielding, driving to the localization of deformation bands, is observed nearly always on reaching a critical level of irreversible deformation. Laboratory rock testing [14] shows that the deformation is accompanied by evolution of initial microcracks and pores, leading to formation of new faults and modification of material properties. This process depends on both the level of actual tension, and the interaction of crack banks. This leads to dilatation, which is an irreversible expansion of the volume, caused by expansion of pores and exposure of cracks. The most powerful change of material structure proceeds in the vicinity of peak tension, before formation of the narrow fissured macroscopic abnormalities containing an abundance of microdefects. These abnormalities, referred to as “slip/glide lines/bands”, represent localized bands of plastic deformation. Their origin is concerned with an internal instability of material, i.e. with qualitative changes in the damage accumulation. The last reduces to a bifurcation of an initially uniform deformation process [15].

Under plastic flow, as opposed to brittle failure, cracking takes place along glide lines oriented at an angle to the tension axis [16]. Elementary theory of plane stress in a point (under the static balance of forces and moments) gives the value of angle φ with the maximum tangential stress. It is ±45°. For the axisymmetric plastic body these glide lines/bands look like as two families of logarithmic lines (Fig. 2).

The resemblance of these lines/bands and the Martian north pole trough structure is undoubted. As Mars (as well the Earth) rotates from the west to the east, in the north Martian hemisphere the cracking took place just in the glide bands bending clockwise. To prove the influence of planet rotation on trajectories of crack propagation look at the following scheme (Fig. 3).

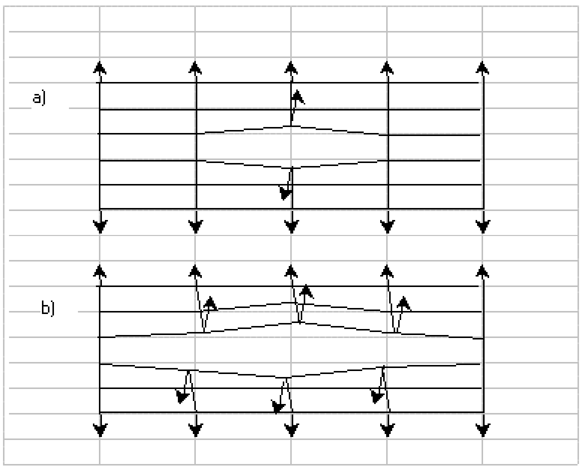

Fig. 3. Influence of Coriolis force on crack trajectory.

As known, the role of the Coriolis force reduces to a deviation of a moving particle trajectory (to the right in the north hemispheres of the Earth and Mars). In consequence of slight moving of the every particle on the crack bank to the right during cracking, its left part is rather more stretched that its right one. This drives the crack vertex trajectory to the right. Thus, under all other conditions being equal, in the north Martian hemisphere the cracking took place mainly in the glide bands, which are bending clockwise.

Conclusions: This investigation shows that after its bed thawed, the Martian north pole ice sheet began to transform to an ice body resembling an ice shelf (no basal traction). This transformation was accompanied by drastic amplification of radial tension that fractured ice entirely with formation of crevasses along helical glide lines. After bed temperature fell and ice sheet collapse ceased, the cracked bands began to undergo a smoothing owing to continuous slow ice spreading and mass transfer from the north crack slope warmed by the sun to the shady south slope. This process transformed the helical structure of crevasses into the helical structure of troughs.

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