A type of plastic deformation of ice in glacier sheets

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ABSTRACT The results of experimental investigation of ice structure and texture were analyzed. The authors came to the conclusion that a scheme of the strained state of ice can be defined on the basis of the analysis. The types of processes leading to variations in the spatial structure of ice were also defined.

Investigation of the strain and deformation fields in the glacier stratum are of special importance for understanding its rheology. Attention should be drawn to the fact that much experimental information on ice texture is not properly used. The texture here is understood as a preferential orientation of crystals (Shubnikov, 1975). The paper analyzes the main results of the ice texture study of Antarctic ice sheet.

Texture formation process was analyzed from symmetry positions having great eureka possibilities. Using the accumulated knowledge about the symmetry of physical environments and fields of action we have found, in accordance with Curie principle (Shubnikov, 1975), the resultant symmetry of the environment suffered from physical action. The solution of an opposite task is also possible.

An analysis of the orientation of the ice grains' optical axes investigated by Barkov (1973), Barkov et al. (1987), Dmitriev & Vostretsov, 1979, Korotkevich et al. (1978), Portnov (1975), Chashchinov (1977) was performed with the help of the symmetry approach. We also treated this data by the semiquantitative method of texture description (Borodkina & Spektor, 1981).

The reliability of application of the symmetry principle can be established on the basis of experimental results of ice aggregate deformation. The work by Brace (1960) was chosen with this aim. In this work, the untextured ice aggregates (texture symmetry $\omega/\omega\ m$ - sphere symmetry) were deformed under different stress conditions. Some results of the study are given in Fig. 1.

According to Curie principle, the texture symmetry of a deformed aggregate must agree with resultant symmetry of extrinsic mechanical impact on a quasi-isotropic polycrystal aggregate. The deformation field texture is
characterized by symmetry of suitable tensor. The axial symmetry (m \(\omega/m\)) tensor corresponds to the stress indicated in Figs 1a and 1b. The symmetry (mmm) tensor corresponds to the stress given in Fig. 1b. As a result of integration of the above symmetry groups, the deformed aggregates must in such case possess a texture symmetry equal to the symmetry of the action field. Actually the stereograms (Figs 1a, 1b) have symmetry (m \(\omega/m\)) and in Fig. 1c - symmetry (mmm). Hence the next conclusion can be made as follows:

(a) Curie principle is right for description of ice rocks deformation;
(b) the stereogramme symmetry of optical axes of ice grains make possible to obtain data on symmetry and thus on the type of deformation field.

\[\text{FIG. 1 Optical axes orientation of the ice grains for different fields of stress.} \ P_1, P_2 \text{ and } P_3 \text{ are the general stresses; (a) - uniaxial compression, (b) uniaxial tensile stress, (c) compression.}\]

Ice grain orientations considered in this work are demonstrated in Fig. 2. A detailed analysis was made of stereograms for Antarctic ice sheet in the area of Vostok Station. It was found that each stereogramme had its own statistical symmetry. Stereograms of surface untextured layers have a sphere symmetry (\(\omega/\omega\ m\)), the others - symmetry group of general ellipsoid (mmm) (one symmetry plane is horizontal, the other two are vertical). Most distinctly this feature is seen on stereograms obtained by Portnov (1975).

Texture symmetry of surface layers of the glacier is explained by chaotic orientation of original snow crystals. The texture symmetry will change according to Curie principle with plunge down the section. Since in the area of the Vostok Station ice rocks have symmetry group (mmm) of texture in the range between 300 and 1400 m, it is concluded that a pure shear deformation is under way in the region. This deformation is described by tensor having the above symmetry group. The tensor may be established in the following way:
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FIG. 2 The stereograms of optical axes of ice grains. In the area of Vostok Station: (a) the depth of 104.5 m; (b) the depth of 383 m; (c) the depth of 879 m (Barkov et al., 1987); (d) the depth of 32.8 m; (e) the depth of 96 m; (f) the depth of 638 m (Portnov, 1975). In the area of Mirnyi Station: (g) the depth of 15 m; (h) the depth of 95 m; (i) the depth of 249 m (Chashchinov, 1977). In the south-east of Greenland: (j) the depth of 100 m; (k) the depth of 695 m; (l) the depth of 1065 m (Herron et al., 1985). The borehole axis coincides with axis C. If axis C is not shown in the figure, it appears at the projection center.
The pure shear may be examined as double deformation: contraction in vertical direction and strain in horizontal direction.

The marked regularity is characteristic also of ice division region of Greenland ice sheet in range of depths between 200 and 1800 m (Figs 2j-2l) and of the area of Mirnyi Station in the range of depths between 100 and 250 m (Figs 2g-2i).

Patterson (1984) pointed out that the combination of pure and simple shear stresses affect the ice sheet. The degree of their development depends on the glacier region. The results of our work show that the role of pure shear stress is prevalent.

It was found that in the upper part of Antarctic ice sheet the specific volume of texture reaches 75%.

The texture formation of ice can be associated with the processes of recrystallization and plastic deformation.

For the identification of the contribution of each process, data on the change of structure parameters (form and size of grains, degree of boundary surface orientation) were used. The data are interpreted in terms of the following conditions: each grain changes the form like the whole volume of ice does. According to the structure and texture parameters of ice rock in the area of Vostok Station, the conclusion is made that their change in the depth from 0 to 650 m was due as much to the plastic deformation as to recrystallization. Further down, the process of plastic deformation is predominant.

**REFERENCES**


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