Fabric Studies on a 1 Meter-Deep Snow Core from Mizuho Plateau, East Antarctica*

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南極みずほ高原で採取された1m深積雪コアーの結晶主軸方位分布解析*

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要旨: 南極大陸みずほ高原の「S100」地点（南緯 69°38.1′, 東径 42°51′, 標高 1,630 m）から採取された深さ 1 m の積雪コアについて雪の結晶 *c* 軸方位分布を測定した．方位分布図を作成するとともに「鉛直集中度」を定義し，深さに対するその変化を調べた．

表面近くでは *c* 軸の卓越方位は水平方向であるが，それが，鉛直方向，水平方向と，周期的に変化しながら次第に鉛直方向集中の傾向が強まっている．上記の周期変動は霜ざらめ層あるいは年層とかなり良い一致を示している．

Abstract: Petrofabric analyses were carried out on a snow core from the surface to a depth of one meter obtained at S100 (69°38.1′S; 42°51′E; 1,630 m above sea level) in Mizuho Plateau, East Antarctica. In order that the distribution of *c*-axes of snow crystals was examined, the concept of the value of χ^2 was introduced and "the degree of vertical *c*-axis concentration" was defined.

Although the predominance is in the horizontal direction as regards the degree of *c*-axis concentration in snow layers near the surface, this predominance periodically alternates between the horizontal and the vertical direction as the depth increases, gradually strengthening a trend for the increasing degree of vertical *c*-axis concentration. This periodicity shows a fairly good correlation with the positions of autumn layers or depth-hoar layers.

1. Introduction

In high polar regions such as the interior of Antarctica, the transformation from snow into glacier ice primarily proceeds by the mechanical densification of dry snow.

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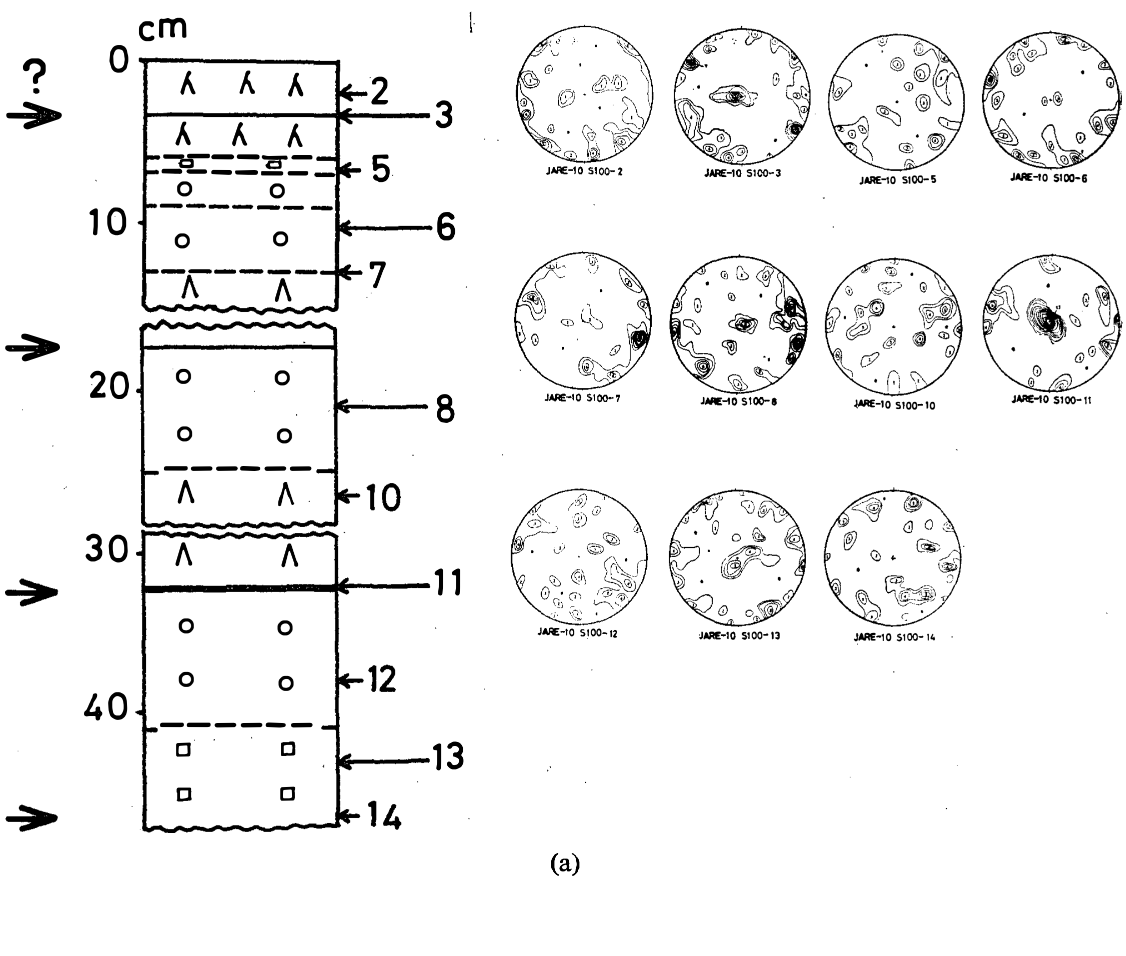
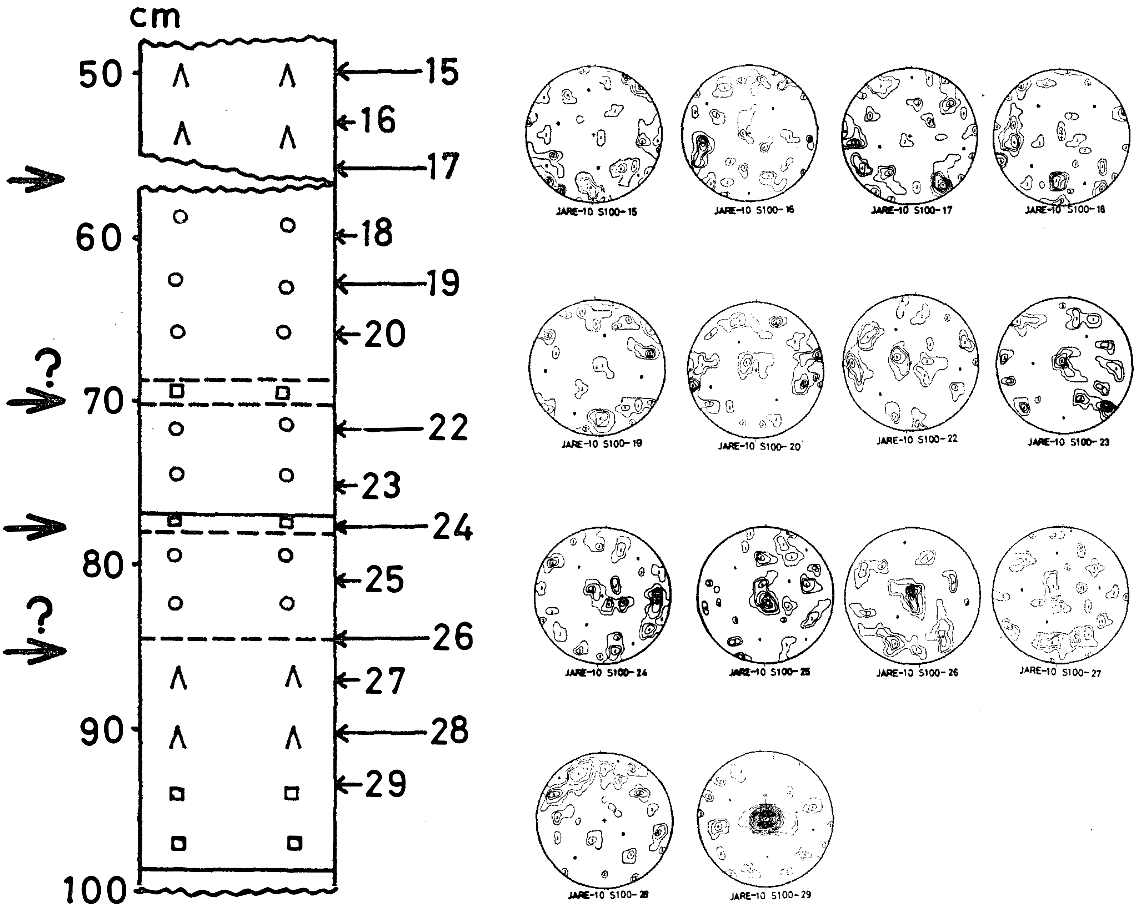
During the process of densification of snow, depth-hoar crystals are formed in snow layers near the snow surface. In conjunction with the densification and the sublimation perecrystallization of snow (SHUMSKII, 1964), the present author made petrofabric studies of snow collected from various depths of a borehole at Mizuho Camp (70°42.1'S; 44°17.5'E), and found most of the *c*-axes of ice crystals composing snow layers at the depth of 2.8 m to 33.3 m were vertically oriented (NAKAWO, 1974). He concluded that the strong vertical concentration of *c*-axes of ice crystals may be attributed to the formation of depth-hoar crystals.

For the purpose of clarifying the detailed processes of vertical concentration of *c*-axes in connection with the densification of snow and depth-hoar formation in snow, fabric analyses of snow obtained from a 1 m-long snow core were conducted at intervals of several centimeters from the surface down to a depth of 1 m at site S 100 (69°38.1'S; 42°51'E) located near Mizuho Camp. Observation of stratigraphic features and measurements of hardness, grain size, density and specific surface of snow were also carried out on the same core (NARUSE *et al.*, 1972).



(a)



(b)

Fig. 1. Stratigraphic sketch and fabric diagrams (The skech is after NARUSE *et al., 1972).*

2. Analysis and Results

Twenty-five horizontal thin sections of snow were cut out of snow layers at intervals of several centimeters from the snow surface down to a depth of 1 m. The crystallographic *c*-axis orientations of 100 ice crystals in each thin section were measured under a polarizing microscope and plotted on a Schmidt net. The obtained fabric diagrams and their locations in the stratigraphic structure of snow are shown in Fig. 1. The contours in the fabric diagrams show the concentration of 1 %, 2 %, 3 %, . . . per 1 % area. The center of each diagram coincides with the vertical direction. The arrows labelled at the left side of the stratigraphic sketch indicate summer layers.

It is seen that the diagrams of the upper snow layers above a depth of approximately 50 cm generally show the horizontal concentration of *c*-axes. Exceptions are two diagrams, Nos. 3 and 11 obtained from wind crust layers; these show a strong vertical concentration of *c*-axes. The fact that the diagrams obtained from wind crust layers have a vertical concentration is in agreement with the observed result obtained by STEPHENSON (1966). A fairly strong single vertical maximum pattern is also seen in diagrams Nos. 8 and 13.

In the lower snow layers, on the other hand, many of the diagrams show a comparatively vertical concentration pattern, except Nos. 15, 17, 24 and 28 which show a horizontal (or equatorial) pattern.

It should be noted that most of the *c*-axes are oriented to either the vertical or the horizontal direction in any layer of snow, and there are few crystals whose *c*-axes are oriented to intermediate directions between the vertical and the horizontal.

3. Discussion

Most of falling or drifting snow crystals observed at Mizuho Camp were needle-type crystals formed at very low temperatures (NARITA and NAKAWO, in preparation). Needle-type snow crystals generally tend to lie horizontally in the settling process of snow even though they are deposited at random orientations (KOJIMA, 1960). The equatorial fabric patterns obtained at or near the snow surface are, therefore, considered to be a "depositional pattern" caused by the re-orientation of the long axis (*c*-axis) of needle-type snow crystals to the horizontal direction during the settling process of snow.

This horizontal concentration of *c*-axes, however, seems to disappear gradually with an increase in the depth of snow, having some periodic variations in concentration. In order that the degree of vertical (or horizontal) concentration of *c*-axes, i.e. *c*-axis concentration was clarified quantitatively in each diagram, the value of χ^2, an index commonly used in stochastics, was introduced here; this value gives the degree of fluctuation or deviation from a reference distribution.

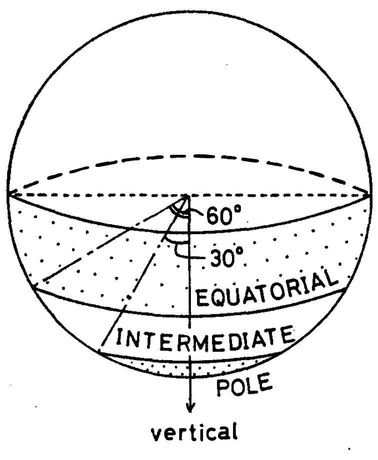


Fig. 2 Three areas on the lower hemisphere of orientation.

In this paper, χ^2 is defined as

$$\chi^2 = \sum_i^N \frac{(K_i - E_i)^2}{E_i},$$

where K_i is the *i*-th observed value, and E_i is the *i*-th expected value in the random distribution of *c*-axis orientations, when the lower hemisphere in the reference sphere is divided into *N* parts. The degree of freedom is (N–1). For the sake of convenience, the lower hemisphere is divided into three areas, a polar circle (between a vertical and a zenithal angle of 30°), an intermediate band area (between 30° and 60°) and an equatorial band area (between 60° and 90°, i.e. horizontal), as shown in Fig. 2.

Two values of χ^2, namely, χ_p^2 and χ_E^2, were computed, since the value of χ^2 is dependent on the way in which the hemisphere is divided. The value of χ_p^2 is the one for the hemisphere which is divided into a polar circle and the remainder, and χ_E^2 is the one for the hemisphere which is divided into an equatorial band and the remainder. The sign of χ_p^2 is taken as positive (or negative) when the observed value is larger (or smaller) than the expected one. Reversely, χ_E^2 is taken as negative (or positive) when the observed value is larger (or smaller) than the expected one. The value of χ^2 becomes algebraically larger with the increase of vertical c-axis concentration. Thus, the value of χ^2 gives the degree of vertical c-axis concentration.

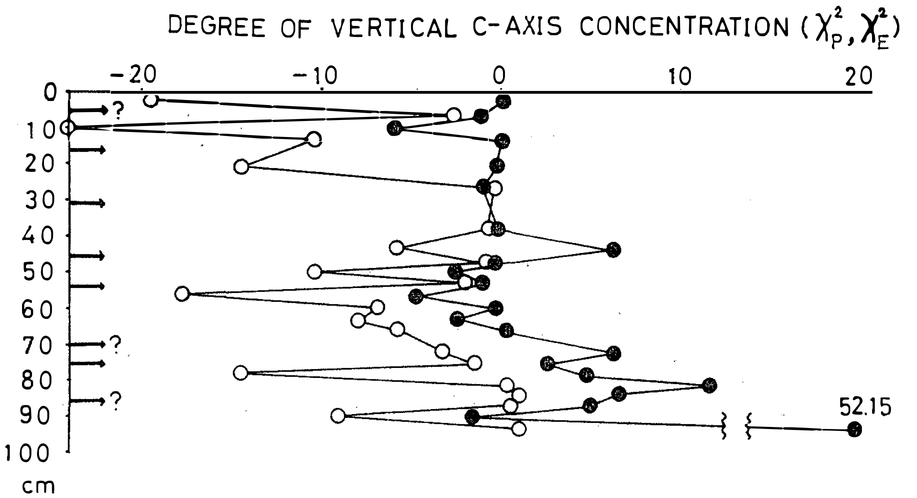


Fig. 3. Variations of degree of vertical c-axis concentration.

The values of χ_p^2 and χ_E^2 obtained from each fabric diagram are plotted in Fig. 3 with dark and open circles, respectively. It is seen that the degree of vertical c-axis concentration generally becomes larger with an increase in depth of snow, as was described qualitatively before. Some periodic variations in the value of χ^2 are also seen in this figure. Maximum values of χ^2 which represent the higher vertical c-axis concentration, are found at the depth of autumn snow layers in which depth-hoar crystals were observed (NARUSE *et al.*, 1972). The transition from the original horizontal concentration to the vertical concentration is, therefore, accompanied by the formation of depth-hoar crystals in autumn. GOW (1965) also reported that the depth-hoar is developed in autumn at the South Pole. It was verified, therefore, that the original horizontal *c*-axis concentration is converted to the vertical one by the formation of depth-hoar crystals in snow layers. This transition in orientation proceeds mostly in autumn under a strong temperature gradient. Since this process is repeated every autumn, the vertical *c*-axis concentration becomes more predominant in deeper snow layers, as was found in the previous fabric analyses of deep core samples from layers 2.8 m to 33.3 m in depth (NAKAWO, 1974).

Table 1. χ_I^2 *of each fabric diagram.*

Sample No.	2	3	5	6	7	8	10	11	12
χ_I^2	−22.01	−18.29	−0.91	−11.37	−11.88	−14.91	−0.25	−22.01	−0.11
Sample No.	13	14	15	16	17	18	19	20	22
χ_I^2	−18.29	−0.29	−4.84	−0.56	−7.97	−5.80	−3.19	−7.97	−13.35
Sample No.	23	24	25	26	27	28	29		
χ_I^2	−5.80	−28.24	−2.74	−0.56	−0.56	−4.84	−16.56		

As was mentioned before, there are few crystals whose *c*-axes are oriented to intermediate directions. In order that this was shown quantitatively, another kind of the value of χ^2, namely χ_I^2, was computed. In this case the hemisphere is divided into an intermediate band and the remainder. The degree of freedom equals 1. The obtained values of χ_I^2 are tabulated in Table 1. The 95% value of the distribution of χ^2 is 3.84, and many of the values in the table are much larger than 3.84. Therefore, it can be said with a 5% level of significance that the orientation of crystals is seldom distributed between the inclinations of 30° and 60°.

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