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INSTRUMENTS AND METHODS

HOAR-CRYSTAL METHOD FOR ICE FABRICS

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ABSTRACT. A new method has been developed for the observation of crystal axes orientation in fine-grained polycrystalline ice (grain-size approximately one millimetre). A two per cent ethylene dichloride solution of polyvinyl formal (Formvar) is applied to the surface of a sample. This solution produces adequate density of small holes in the Formvar coating and subsequently the nucleation sites for hoar crystal growth. The geometrical shape of each hoar crystal reveals both the *c*-axis and *a*-axes orientations using an optical microscope.

RÉSUMÉ. *Une méthode pour l'observation de la "fabrique" d'un cristal de givre.* On a mis au point une nouvelle méthode pour l'observation des orientations des axes cristallins dans une glace polycristalline à grains fins (taille des grains environ 1 mm). Une solution à 2% de formol de polyvinile (Formvar) dans du bichlorure d'éthylene est préparée et appliquée à la surface de l'échantillon. Cette concentration de la solution permet de contrôler la densité des petites cavités dans le revêtement de Formvar et par conséquent les sites de nucléation pour la croissance du cristal de givre. La forme cristalline de chaque dépôt de givre révèle géométriquement l'orientation des axes *c* et *a* grâce à un microscope optique.

ZUSAMMENFASSUNG. *Die Methode der Reif-Kristalle für Eisgefüge.* Zur Beobachtung der Kristallachsenorientierung in feinkörnigem polykristallinem Eis (Korngrösse etwa 1 mm) wurde eine neue Methode entwickelt. Eine 2-prozentige Lösung von Polyvinyl-Formal (Formvar) wird in Äthylendichlorid gelöst und auf die Oberfläche einer Probe aufgebracht. Diese Lösungskonzentration regelt die Dichte kleiner Löcher in der Formvar-Haut und folglich die Lage der Ansatzpunkte für das Wachstum von Reif-Kristallen. Die Kristallform jeder Reifablagerung lässt unter einem optischen Mikroskop die Orientierungen sowohl der *c*-Achsen wie der *a*-Achsen geometrisch erkennen.

INTRODUCTION

Several methods have been used for the determination of crystal orientation in ice, depending upon which crystal axes are to be measured and the size of the sample. The optical method (Langway, 1958) and X-ray diffraction techniques are well known and useful methods with thin section samples of a thickness around 1 mm. The evaporation pit technique developed by Higuchi (1958) is especially useful with much thicker samples (of the order of 1 cm) because it requires only one surface. Another method was developed by Nakaya (1956) who grew hoar crystals on the surface of a single crystal of ice to determine the *a*-axis direction as well as *c*-axis direction of the sample. However, in the latter case the high density of nucleation sites causes the hoar crystals to overlap.

During the 1980 field season of the Greenland Ice Sheet Program (GISP) at Dye-3 (lat. 65° 12′ N., long. 43° 47′ W.) we developed a reliable technique for forming distinct hoar crystals with a single unique orientation.

The low density of hoar crystals was achieved by covering the sample surface with a polyvinyl formal (Formvar) film. The Formvar technique is the essential difference between this method and Nakaya's described above.

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The work was conducted in a trench room 5 m below the surface of the ice sheet; the air temperature inside the room (where all experiments were carried out) was approximately −10 °C. The firn wall of the room is the source of the water vapor for the hoar-crystal growth.

2. Sample preparation

Samples were cut from the deep ice core using a band-saw to a size of $2 \times 3 \times 6\ cm^3$ and the surface was finished with a microtome. Samples were then allowed to sublimate for several hours in a relatively warmer location (approximately −9 °C). After obtaining a good flat surface, a 2% solution of polyvinyl formal (Formvar) dissolved in ethylene dichloride was applied to the surface. Samples were then placed in a slightly colder (approximately −11 °C) location overnight to permit hoar-crystal growth through small holes in the Formvar film.

3. Hoar crystal

Figure 1 shows the hoar crystals grown on the surface of a section of a sample. Each crystal keeps its sharp edge lines for at least 30 min under the usual illumination for microscopic observation; this is long enough to photograph the sample for a more precise measurement. The

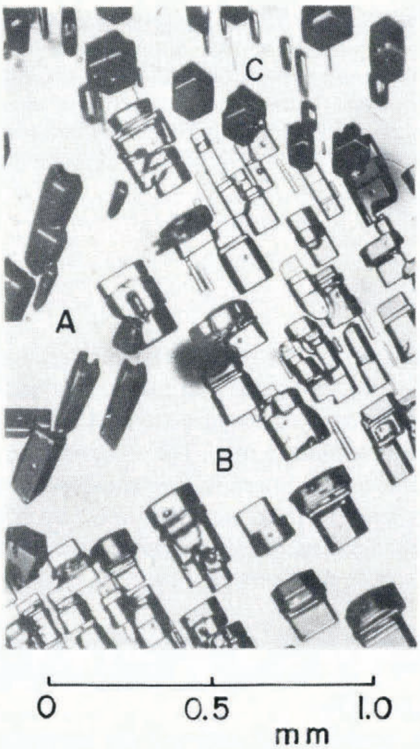

Fig. 1. Hoar crystals developed on the surface of an ice core sample obtained from the 708 m depth at Dye-3, Greenland.

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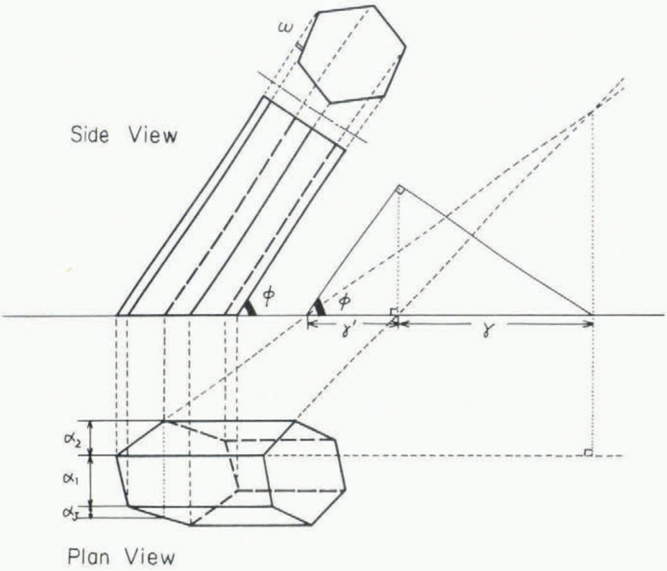

Fig. 2. Geometric configuration of hoar crystal for calculation of crystal orientation.

columnar shape of the hoar deposit makes it simple to find the c-axis and then the a-axis. The geometrical configuration may be visualized three-dimensionally when the focusing position is changed slightly under the microscope. It is also possible to calculate crystal orientations from the photographs by a similar method used in evaporation-pit studies (Matsuda, 1979). One should bear in mind that hoar crystal deposits are positive (real) while an evaporation pit is a negative crystal. Figure 2 shows one example of a geometric configuration of a hoar deposit. The microscope picture (Fig. 1) corresponds to a plan view in Figure 2. Each set of lengths (α_1, α_2, α_3) and (γ, γ') has a simple relationship as described in Matsuda's paper (1979):

$$\alpha_1 \tan \omega + \alpha_2 \tan (\omega + 120°) + \alpha_3 \tan (\omega + 60°) = 0$$

$$\gamma - \gamma' \tan^2 \phi = 0$$

where ω and ϕ are the rotation angle of a-axes and the inclination angle of the c-axis respectively as shown in Figure 2. Calculated directions of grains A, B, and C in Figure 1 are shown on a Wülff net projection in Figure 3. One α-axis direction of grain B lying almost horizontally is very close to that of grain C, which is clearly to be seen in Figure 1. The accuracy of this analysis is estimated to be 5°, certainly as good as a universal-stage measurement.

4. Discussion

The hoar-crystal method reported here is essentially the same as Nakaya's (1956) except for a decrease in the density of nucleation sites of crystal growth by a plastic film. Such a low density of hoar crystals enables us to determine the crystallographic orientations of polycrystalline ice even when the grain size is as small as a few millimeters.

These experiments were made in a trench where the air was always ice saturated. From the

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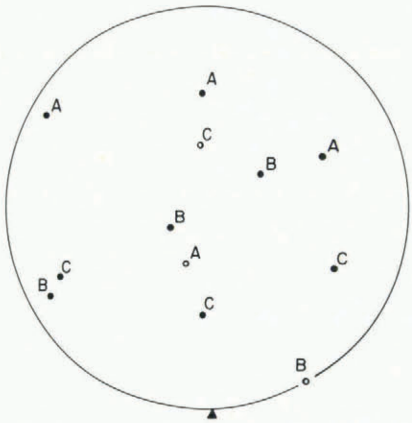

Fig. 3. Results obtained of crystal orientation for grain A, B, *and* C *in Fig. 1.* ○ *and* ● *show* c-*axis and* a-*axis directions respectively.*

crystal shape shown in Figure 1, we estimate that supersaturation in the colder location in the room is from 0 to 10% relative to ice as shown in the growth habit diagram reported by Kobayashi (1961). Under such experimental conditions the hoar-crystal method is more efficient than the evaporation-pit method which only produces a dull-shaped image.

In a laboratory cold room where the humidity is generally lower than that for supersaturation, an apparatus similar to a cloud chamber would be required to ensure an adequate supply of water vapor.

Using the hoar-crystal method we observed crystal orientation to depend on various features such as bubble shape, impurities, and grain boundaries in fresh core samples; these results will be reported separately.

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