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SHORT NOTES

CORRELATION BETWEEN CRYSTALLOGRAPHIC AXES AND THE SHAPE OF A SINGLE CRYSTAL IN GLACIERS

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ABSTRACT. Studies were made of the correlation between the crystallographic axes and the shape of an individual single crystal of a crystalline aggregate in a temperate glacier and an Antarctic deep core, both of which have the typical fabric pattern of the four-maxima type, by approximating the crystal shape to an ellipsoid and then measuring misorientations between the axes of the ellipsoid and the crystallographic axes of the crystal. The result shows that the crystallographic axes are correlated with the axes of the ellipsoid; that is, in most cases the longest and the shortest axis of the ellipsoid are coincident with one of the *a*-axes and the *c*-axis of a crystal, respectively.

RÉSUMÉ. *Corrélation entre les axes cristallographiques et la taille d'un monocristal dans les glaciers.* On a étudié la corrélation entre les axes cristallographiques et la taille d'un monocristal provenant d'un agrégat cristallin prélevé dans un glacier tempéré et d'un autre prélevé dans une carotte profonde de l'Antarctique. Ces deux agrégates présentent une fabrique typique à quatre maximums. L'étude a été faite en assimilant la forme du cristal à un ellipsoïde et en mesurant l'écart d'orientation entre les axes de l'ellipsoïde et les axes cristallographiques du cristal. Les résultats indiquent que les axes cristallographiques sont correlés à ceux de l'ellipsoïde: dans la majorité des cas le grand et le petit axe de l'ellipsoïde: coïncident respectivement avec l'un des axes *a* et l'axe *c* du cristal.

ZUSAMMENFASSUNG. *Beziehung zwischen den kristallographischen Achsen und der Form eines Einkristalls im Gletscher.* Es wurde untersucht, ob zwischen den kristallographischen Achsen und der Form eines einzelnen Einkristalles aus einem kristallinen Aggregat in einem temperierten Gletscher und aus dem Kern einer Tiefbohrung in der Antarktis eine Korrelation besteht, wobei das typische Gefügemuster mit vier Maxima vorliegt. Die Kristalle wurden durch ein Ellipsoid angenähert, von dessen Achsen die Länge und die kristallographische Orientierung gemessen wurden. Das Ergebnis zeigt, dass die kristallographischen Achsen mit den Ellipsoidachsen korreliert sind, und zwar so, dass meist die längste und die kürzeste Achse des Ellipsoids mit einer der *a*-Achsen bzw. der *c*-Achse des Kristalls zusammenfällt.

INTRODUCTION

The few studies which have been made on shapes of crystals from crystalline aggregates in a glacier include the following: Bader (1951) observed that crystals collected from a glacier had markedly complicated shapes. Rigsby (1968) proposed a quantitative method of analysing the shape of crystals. Kizaki (1969) showed that polygonal ice crystals located up-stream in a glacier grew and underwent deformation to have irregular shapes as it moved down-glacier. Narita and others (1979) introduced a stereological method in their analysis of a core from Antarctica. Most of these studies were concerned, however, with the crystal shape itself, devoting little attention to the discussion of any correlation between the orientations of crystallographic axes and the shape of a single crystal. The present study aims to look into the existence of such a correlation.

METHOD OF MEASUREMENT AND RESULTS

Single crystals of ice were brought back by HU-AGE '75 (Hokkaido University Alaska Glacier Expedition 1975) from Mendenhall Glacier, Alaska, U.S.A. (Higashi and others, unpublished), after collection from veins of large crystals in icebergs which had been calved from the terminus of the glacier

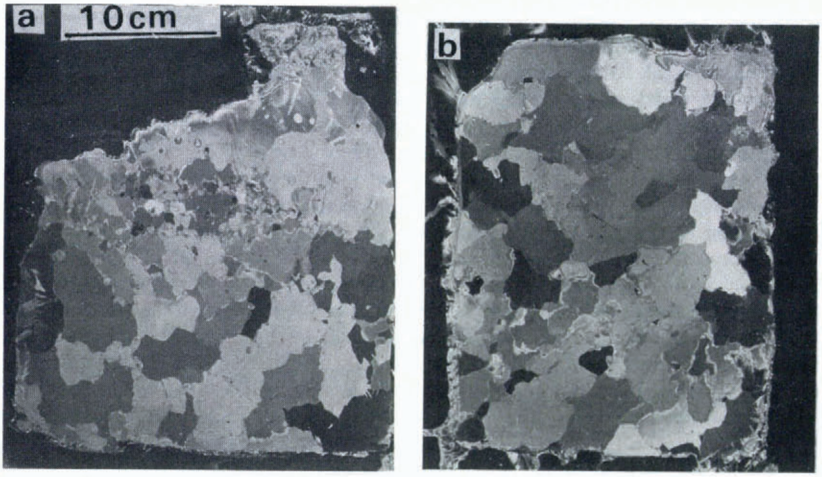

Fig. 1. Polarized photographs of thin sections of a Mendenhall Glacier ice sample cut out from an iceberg where large-sized crystals were collected. The two sections intersected at right angles; a: face A; b: face D.

floating on the glacier lake. The icebergs were exposed to the Sun, which melted the grain boundaries of individual single crystals, making it easy to identify each of them. Consequently, large-sized single crystals could be identified and collected with hardly any damage to their exterior surface, thus enabling them to

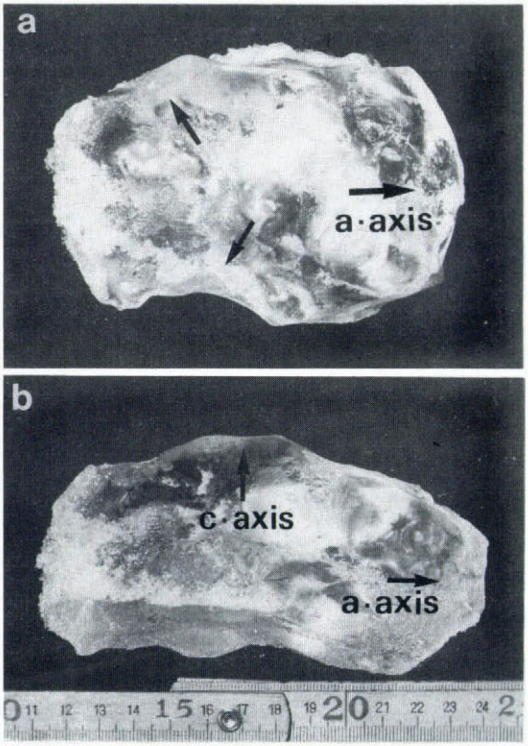

Fig. 2. Photographs of a large-sized single crystal of ice from Mendenhall Glacier with the crystallographic axes denoted by arrows; a: view from above; b: side view.

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preserve their original shape. Meanwhile, an aggregate of single crystals, which constituted a block, was also collected from a vein of an iceberg; thin sections of this block, which are shown in Figure 1, had the fabric pattern of the typical four-maxima type (Higashi and others, unpublished). Crystallographic orientations of the large-sized single crystal were determined to within $\pm 3°$ by the method of optical reflection by crystallographic surfaces namely the $\{10\bar{1}0\}$ and $\{0001\}$ planes, utilizing a piece of hoar which was condensed on the surface of the ice sample. Figure 2 shows one of the single crystals with the crystallographic axes indicated. As shown here, most of them had both the flattened and the elongated shape. Though the crystals had a somewhat interlocked shape as indicated in Figure 2, the correlation between the orientation of crystallographic axes and the shape of a single crystal was investigated by approximating the crystal shape to an ellipsoid in order to obtain a quantitative expression of the orientation of its elongation. That is, the orientation of three axes of the ellipsoid was estimated by fitting an ellipsoid by eye to the shape of the crystal within an error of $\pm 10°$; then the lengths of the three axes and their misorientations relative to the crystallographic axes of the crystal (i.e. c-axis and a-axis) were measured. Figure 3 gives a correlation between the axes of the ellipsoid and the crystallographic axes of the crystal in a stereographic projection with the shortest axis of the ellipsoid at the centre of the projection circle. Solid circles and open circles of the figure show c-axes and a-axes of the crystal respectively. It appears from the figure that most of them had a flattened shape in directions close to the c-axis and an elongated shape in the direction of one of the a-axes. The mean ratio of the length of the shortest axis of the ellipsoid to that of the longest axis was 0.44, and the mean ratio of the length of the middle axis to the longest axis was 0.63.

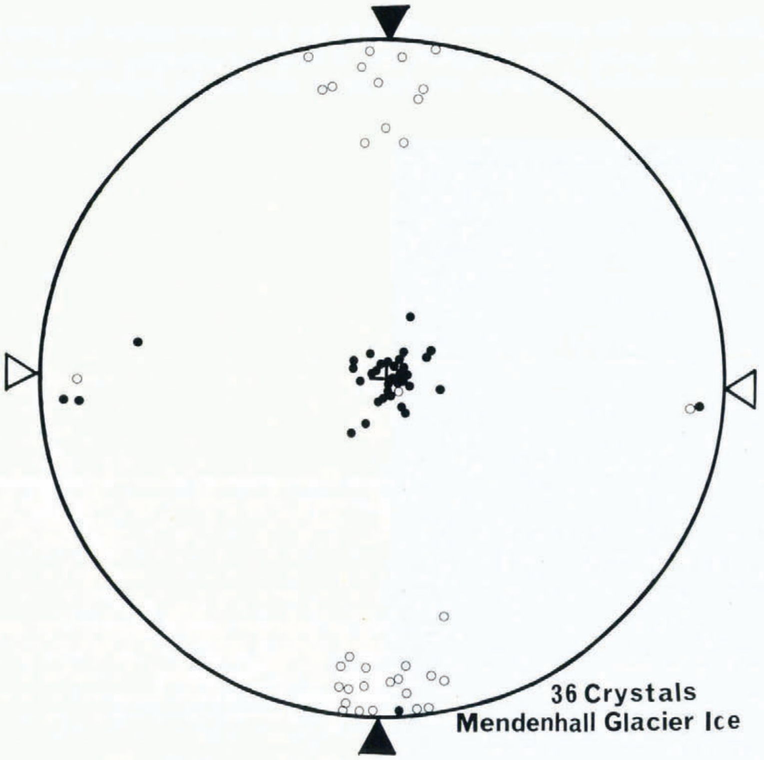

Fig. 3. Orientation relation between axes of an ellipsoid fitted to the shape of a crystal and its crystallographic axes in a stereographic projection with the shortest axis of the ellipsoid as centre. ▲*: direction of the longest axis of the ellipsoid.* △*: direction of the middle axis of the ellipsoid.* ●*: orientation of the c-axis of the crystal.* ○*: orientation of one of the a-axes of the crystal.*

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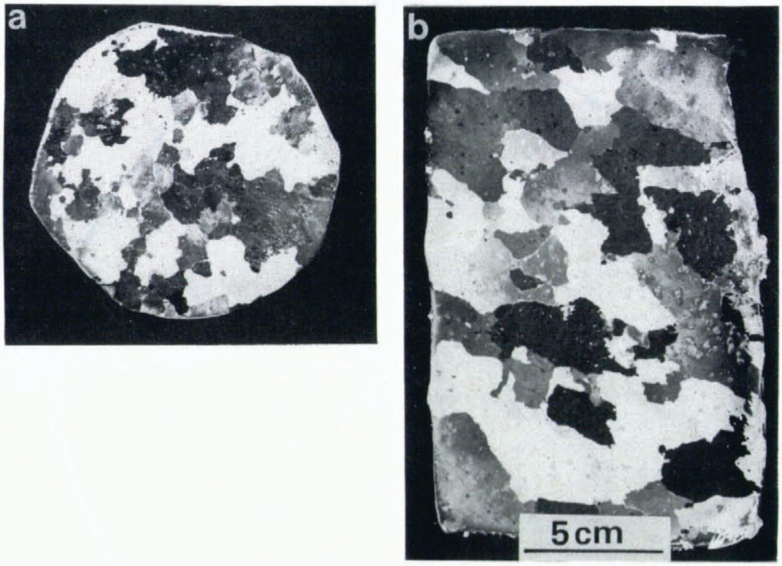

Fig. 4. Photographs of thin sections of a Cape Folger core ice sample at a depth of 324 m taken under crossed polaroids; a: horizontal thin section; b: vertical thin section.

Meanwhile, ice-core samples were drilled at Amery Ice Shelf and Cape Folger by ANARE as part of its project led by Dr W. F. Budd of the Antarctic Division, Australia. Budd (1966) and Wakahama (1974) reported the results of dynamical and textural studies using the data obtained from the ice-core samples. The present authors also analysed a core from a depth of 324 m at Cape Folger by preparing serial thin sections made at an interval of 5 mm to obtain shapes and sizes of randomly selected crystals. According to Wakahama (1974) the mean crystal size at this depth is the largest of all the core samples from Cape Folger. Figure 4 shows photographs of horizontal and vertical thin sections taken under crossed polaroids. Crystallographic orientation was determined by the transmission Laue technique. The fabric pattern of the core sample also showed the typical four-maxima type (Wakahama, 1974). The individual single crystals of the crystalline aggregate from the Cape Folger core were approximated to an ellipsoid in the same way as for the single crystals from Mendenhall Glacier. A similar result was obtained for them as for the Mendenhall Glacier ice as given in Figure 5; that is, the individual crystals were flattened in a direction close to the *c*-axis and elongated to the direction of one of the *a*-axes. The mean ratio of the length of the shortest axis of the ellipsoid to that of the longest axis was 0.46, and the mean ratio of the length of the middle axis to the longest axis was 0.64.

A stereological analysis was made following the method of Underwood (1970, p. 48–79) to examine a possible relation between the flow direction of a glacier and the shape of its single crystals. Two sections intersecting at right angles in each of Figures 1 and 4 have been used to obtain rose diagrams, as shown in Figure 6. A rose diagram gives a visible indication of a stereologically oriented structure by recording on a polar plot the number of intersections between grain boundaries in the thin section and the constant length of a test line which is rotated around its centre. The diagrams reveal that the Mendenhall Glacier sample has no preferred elongations in any specific direction in space since the diagrams are rather isometric (Fig. 6a, b). In the case of the Cape Folger sample the horizontal section also shows a stereologically randomly oriented structure in the horizontal section (Fig. 6c). However, the rose diagram for the vertical section shows that the shapes of the crystals are elongated in the direction X–Y (Fig. 6d) since there is a decrease in the number of intersections in this direction. This implies that the shapes are preferentially elongated in a specific plane with an inclination of 30° to the horizontal as given in Figure 6d. Since the sample is derived from a core whose horizontal orientation is unknown, the relation between this direction X–Y and the flow direction is unknown.

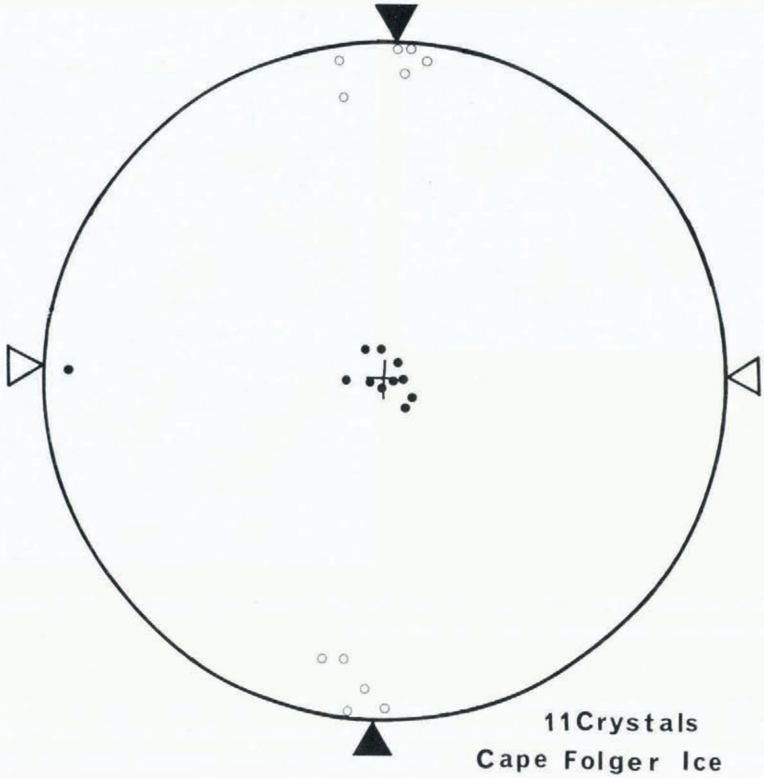

Fig. 5. Orientation relation between axes of an ellipsoid fitted to the shape of a crystal and its crystallographic axes in a stereographic projection with the shortest axis of the ellipsoid as centre. ▲: *direction of the longest axis of the ellipsoid.* △: *direction of the middle axis of the ellipsoid.* ●: *orientation of the c-axis of the crystal.* ○: *orientation of one of the a-axes of the crystal.*

Concluding remarks

As shown by these two results, single crystals in glaciers which had the four-maxima type of fabric pattern, showed a correlation between the crystallographic axes and the shape. This correlation is thought to originate from anisotropy in growth rate in the glacier, since both samples analysed in this study had large crystals, as mentioned above.

Acknowledgement

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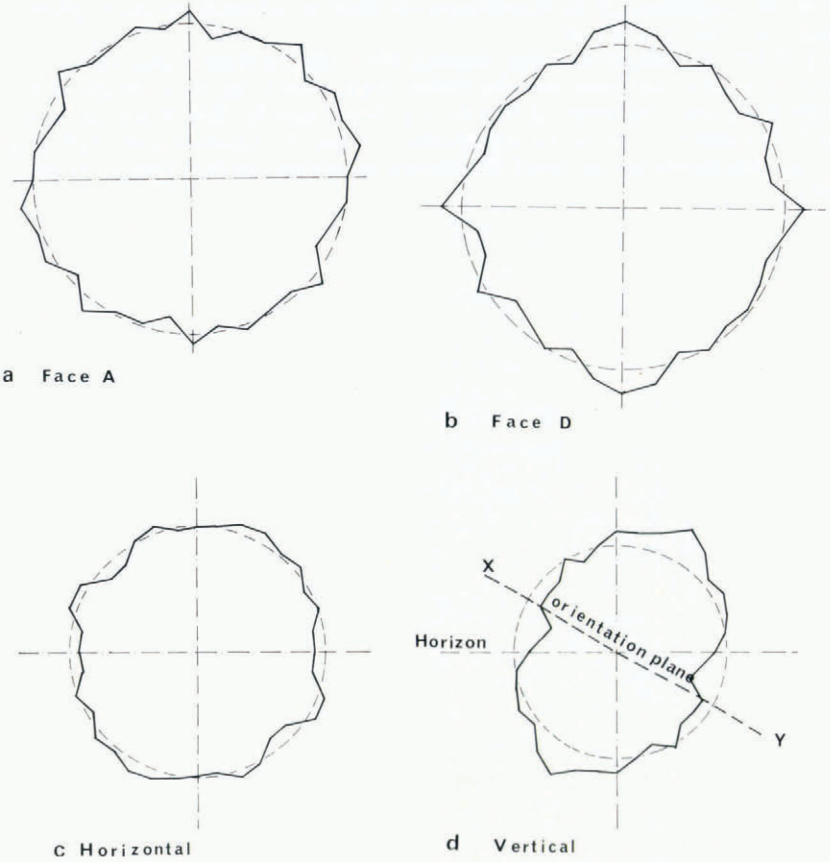

Fig. 6. Rose diagram of a stereologically oriented structure in a polar plot. Solid line shows the number of intersections between grain boundaries in the section and the constant length of a test line rotated around the centre at intervals of 10°. Broken line gives the mean value of intersections. a: face A of Mendenhall Glacier ice. b: face D of Mendenhall Glacier ice. c: horizontal section of Cape Folger core ice. d: vertical section of Cape Folger core ice; the line X–Y indicates the orientation at which crystals are elongated in vertical section.

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