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Shapes and distribution of air bubbles in an ice core from Åsgårdfonna, Spitsbergen

Takao KAMEDA[1], Toshiyuki KAWAMURA[1], Yoshiyuki FUJII[2] and Hiroyuki ENOMOTO[3]

1 Institute of Low Temperature Science, Hokkaido University, Sapporo, 060 Japan

2 National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo, 173 Japan

3 Geographisches Institute, ETH, Winterthurerstrasse 190, CH–8057, Zürich, Switzerland

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Abstract

Air bubbles were observed in an ice core from Åsgårdfonna, Spitsbergen. These were classified into four types by their shape and distribution pattern (uniform distribution type, bubble layer type, cylindrical type and cobwebbed type). Also parts which contained few air bubbles (clear type) were observed in the ice core. On the basis of this classification, distribution of each pattern of air bubbles was investigated through the entire ice core (85.5 m). Inhomogeneous distribution of each pattern with depth was observed, and was probably a result of differences of formation process or of stress condition in the ice body. From the observation of air bubbles and grains, it was found that clear parts which contain few air bubbles are composed of grains 2 to 4 times larger than those of the neighboring parts, and that "cobwebbed air bubble type" was observed only at grain boundaries. If this type of air bubbles was affected by solar radiation during the formation process, they probably reflect that a bare ice field existed at that time.

1. Introduction

Ice core drilling and *in–situ* core analyses were carried out in the northeastern part of Spitsbergen by Japanese Arctic Glaciological Expedition, 1987 (JAGE'87) with cooperative work by the Norwegian Polar Research Institute. The overall objective of JAGE, which is planned to continue until 1992, is to study the climatic and environmental changes of the last few hundreds years around the Arctic region (Watanabe and Fujii, 1988), and the primary objective of JAGE'87 was to clarify these changes in the Atlantic section of the Arctic cryosphere. From this point of view, field research was planned at the top of Høghetta ice dome on Åsgårdfonna, Spitsbergen (79° 16'N, 16°52'E; 1200m a.s.l.; Fig. 1) from May to June, 1987.

The firn layer was only 0.5 m thick at the drilling site and the rest was composed of glacier ice to the bedrock, with a depth of 85.5 m. Temperature at 0.5 m from the surface (top level of the glacier ice) was -10.3 °C (May 31, 1987; Izumi, personal communication), minimum temperature was −13.3°C at a depth of 4.3 m (June 4, 1987), and 10 m ice temperature was −11.0°C (June 4,1987). This glacier ice was most likely made by refreezing of melt water on the cold ice body, which is known as superimposed ice. Meteorological observations of this site in the period from May 26 to June 13, 1987, was already reported by Izumi *et al.* (1988).

Various air bubbles were observed in glacier ice. These air bubbles have several specific shapes ; round, cylindrical and cobwebbed (being connected with each other). If these different shapes are caused by different conditions, *e.g.* freezing rate of melt water, water content in snow, layered structure and texture of snow, and stress in ice body, the distribution of shapes of air bubbles in an ice core could reveal such information. Consequently it is important to investigate the shapes of air bubbles, and its relation to the formation conditions.

Gow and Langston (1977) indicated a relation between shapes of air bubbles and weather conditions for lake ice. However air bubbles of glacier ice have not been investigated in detail from the view point of

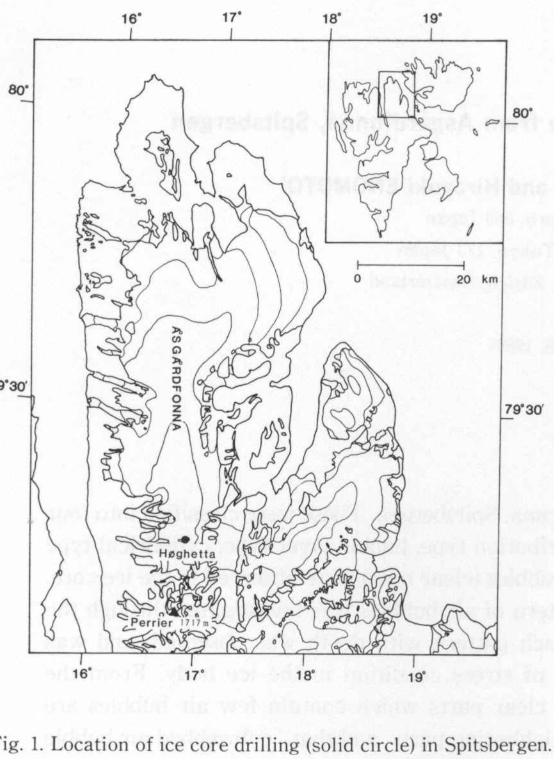


Fig. 1. Location of ice core drilling (solid circle) in Spitsbergen.

growth history, especially for superimposed glacier ice.

In this paper shapes and distribution of observed air bubbles are discussed. Thereafter relation between air bubbles and grains, and their formation process are described.

2. Method of observation

Air bubbles were observed just after recovering ice cores at the drilling site. We divided the cores into three parts along the vertical direction. Stratigraphy (shape and size of air bubbles, that of grains and distribution of dirt layers) was observed using one part, which was cut from the center with a width about 10 mm . This thickness enabled us to observe air bubbles and grains easily. The second part was used for chemical analyses ($\delta^{18}O$, major ions, trace elements, pH and electrical conductivity) and the third part was for physical analyses (density, grain size, bubble pressure and total gas content). Results of these studies will be published later.

Air bubbles and grains were observed, recorded, and photographed by transmitting light and polarlized light on a light table at the drilling site. Due to a logistic problem, only one eighth of all ice cores could be brought back to Japan. Detailed observations of air bubbles and grains were carried out in the cold laboratory of the Institute of Low Temperature Science.

3. Results and discussion

3.1 Shapes and distribution of air bubbles in the ice core

Various shapes of air bubbles were observed in the ice core. These air bubbles are classified according to their shape and distribution. Shapes of air bubbles are round, cylindrical and cobwebbed (being connected with each other). Round air bubbles were divided into two patterns according to their distribution type; with or without clear bands. In addition, clear parts which contain few air bubbles were observed. These parts were classified into two types according to their thickness. "Clear type" means that clear parts continue for more than 10 mm. "Bubble layer type" indicates that the thickness of clear parts is narrower than 10 mm, and many clear bands were observed. On the basis of shapes of air bubbles and their distribution patterns, air bubbles are divided into the following four patterns (Fig. 2) and one pattern which contains few air bubbles:

A) "uniform distribution type", that is nearly round air bubbles which are distributed almost uniformly.

B) "bubble layer type", that is nearly round air bubbles which contain several clear bands.

C) "cylindrical air bubble type", that is cylindrical air bubbles (major axis is about 5−20 mm, minor axis is 0.5−1 mm), and distributed in a nearly parallel way.

D) "cobwebbed air bubble type", that is bubbles which are connected with each other like a cobweb in ice.

E) "clear type" which contains few air bubbles

This classification of air bubbles was carried out by continuous photographs and records of stratigraphy. Distribution of air bubbles is shown in Fig. 3. Solid parts indicate that each pattern of air bubbles was observed at these depths. It was found that each pattern shows inhomogeneous depth distribution. Pattern A ("uniform distribution type") distributes sparsely at depths of 0.77 to 85.10 m except at 33.80 to 48.30 m, and was particularly observed at a depth of 48.30 to

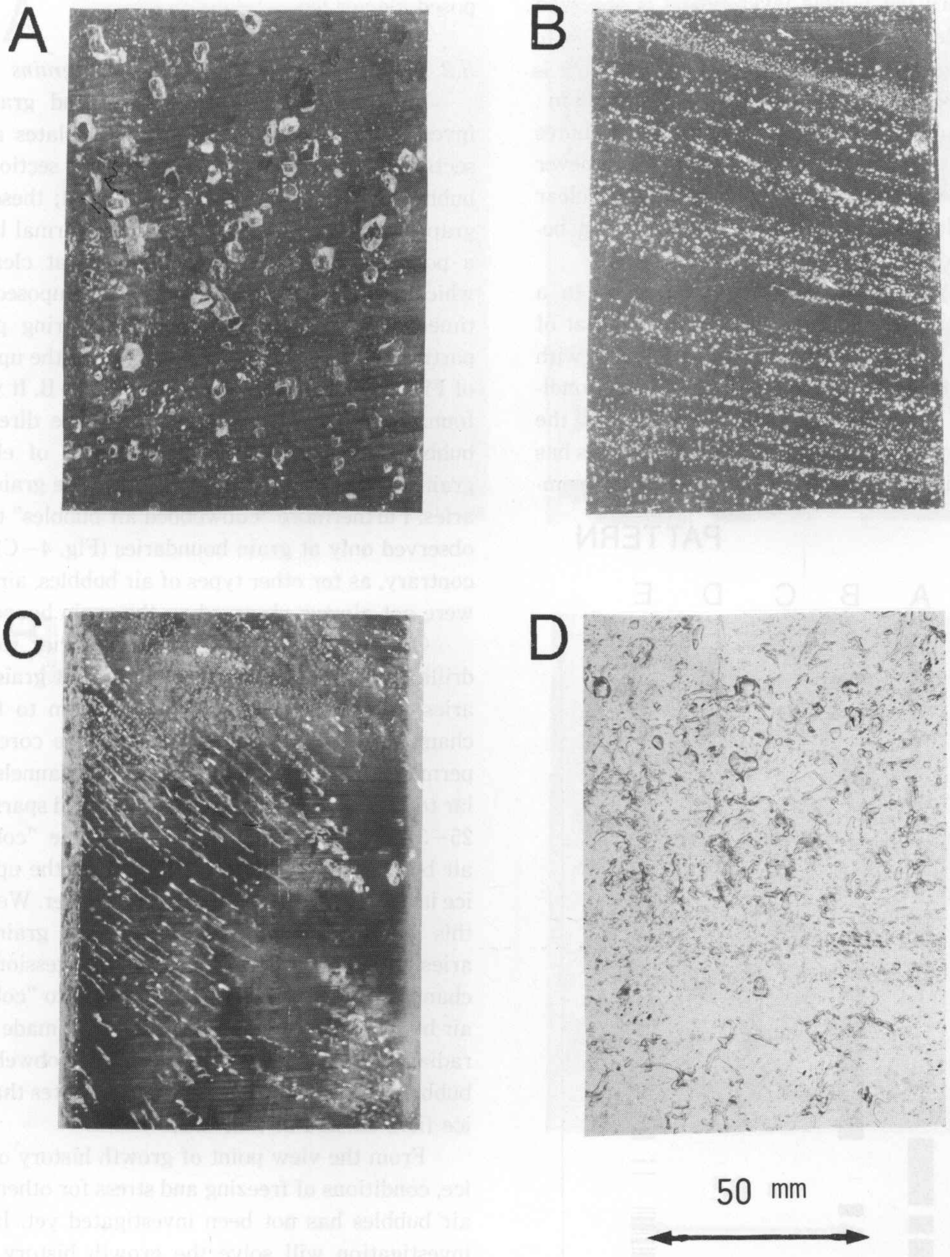


Fig. 2. Shapes of air bubbles in the ice core.
A "uniform distribution type" at 6.9 m depth.
B "bubble layer type" at 39.9 m depth.
C "cylindrical air bubble type" at 22.3 m depth.
D "cobwebbed air bubble type" at 5.3 m depth.

62.70 m. Pattern B ("bubble layer type") is observed mainly at a depth of 11.78 to 15.20 m and 30.68 to 48.30 m. Pattern C ("cylindrical air bubble type") is observed sparsely only at a depth of 22.80 to 38.78 m . Pattern D ("cobwebbed air bubble type") distributes sparsely at depths of 1.25 to 31.84 m and was never observed below the depth of 31.84 m. Pattern E ("clear type") is dominant all through the depth except between 12.50 to 14.60 m and 39.84 to 54.80 m.

If these types of air bubbles are related to a specific condition of refreezing melt water or that of glacier stress, the inhomogeneous distribution with depth should be caused by the change of such condition from the past to the present. Nevertheless, the formation process of various shapes of air bubbles has not been clarified in detail, especially for superimposed glacier ice.

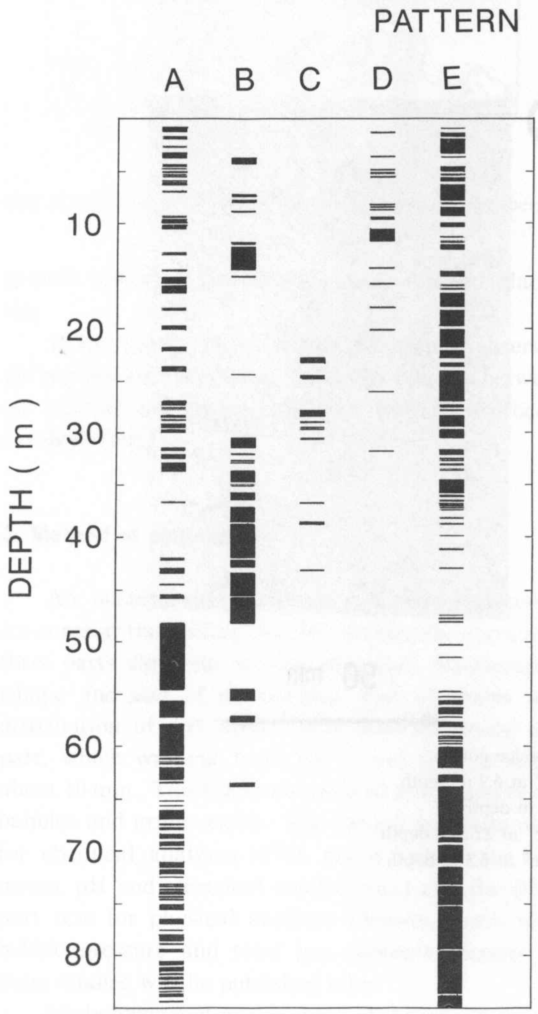


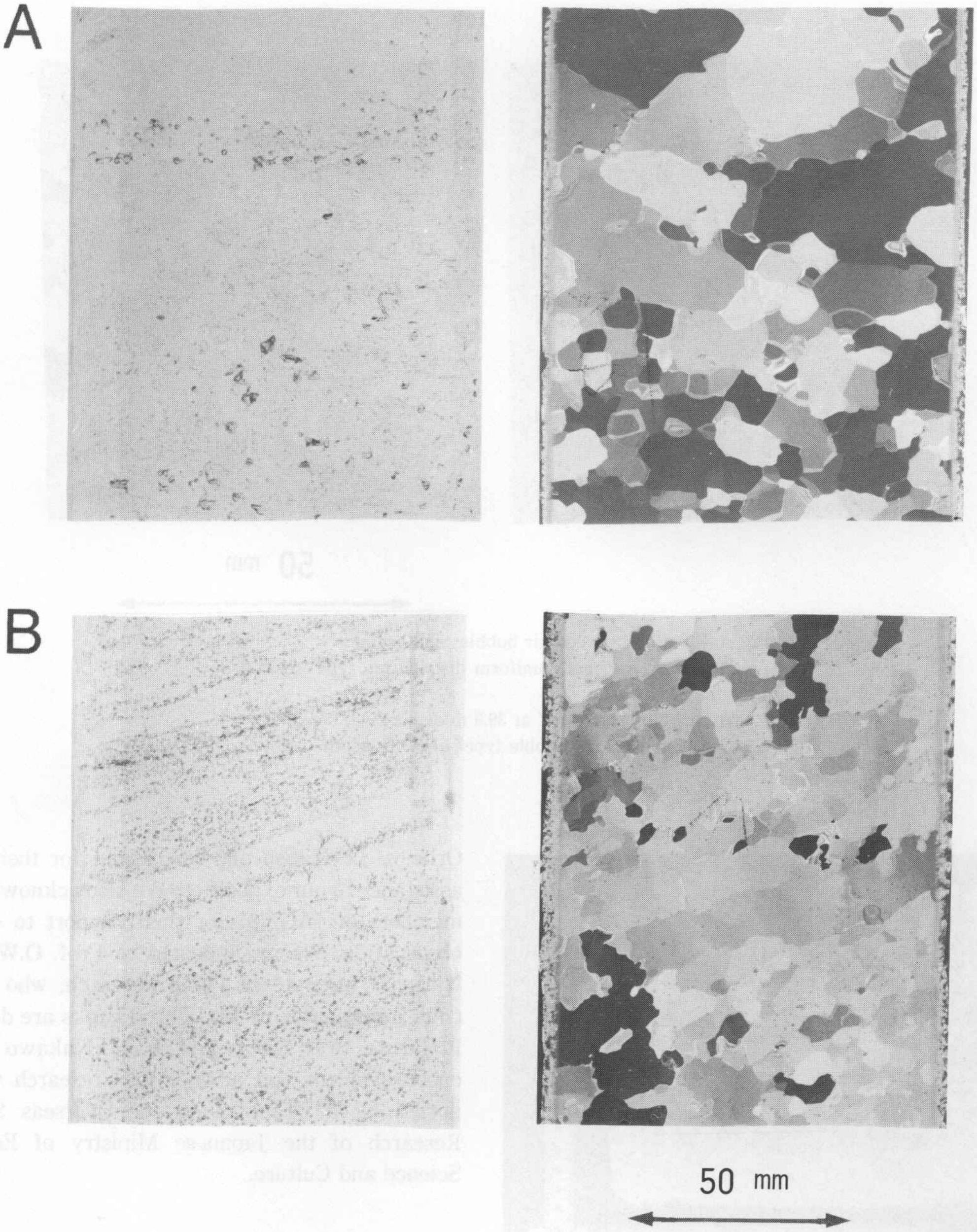
Fig. 3. Distribution of each pattern of air bubbles in the entire ice core (85.5 m).

3.2 Relation between air bubbles and grains

Relation between air bubbles and grains was investigated. We observed it on ice plates and thin sections cut from the ice cores. Vertical sections of air bubbles and grains are shown in Fig.4; these photographs were taken by a transmitted normal light and a polarized light. Figure 4 shows that clear parts which contain few air bubbles were composed of 2−4 times larger grains than the neighboring parts. In particular this is demonstrated both at the upper part of Fig. 4−A and middle part of Fig. 4−B. It was also found for "bubble layer type" that the direction of bubble layer was identical with that of elongated grains, and that air bubbles exist on the grain boundaries. Furthermore "cobwebbed air bubbles" type was observed only at grain boundaries (Fig. 4−C). On the contrary, as for other types of air bubbles, air bubbles were not always observed on the grain boundary.

On the very top level of the glacier ice at the drilling site, it is observed that voids at grain boundaries, about 0.1−0.5 mm in width, join to form air channels (Fig. 5). Thus this part of ice core has air permeability. The shape of these air channels is similar to "cobwebbed air bubbles" observed sparsely at 1.25−31.84 m in depth. Consequently the "cobwebbed air bubbles" were probably formed as the uppermost ice in the glacier by refreezing melt water. We observe this "cobwebbed air bubbles" only at grain boundaries, this observation supports the impression that air channels at the grain boundary turn into "cobwebbed air bubbles". If these air channels were made by solar radiation, the ice which contains "cobwebbed air bubbles" in the ice core probably indicates that a bare ice field existed at that time.

From the view point of growth history of glacier ice, conditions of freezing and stress for other types of air bubbles has not been investigated yet. If further investigation will solve the growth history of each shape of air bubbles, this work would probably contribute to clarify the paleoenvironment of Åsgårdfonna.


A
B
50 mm

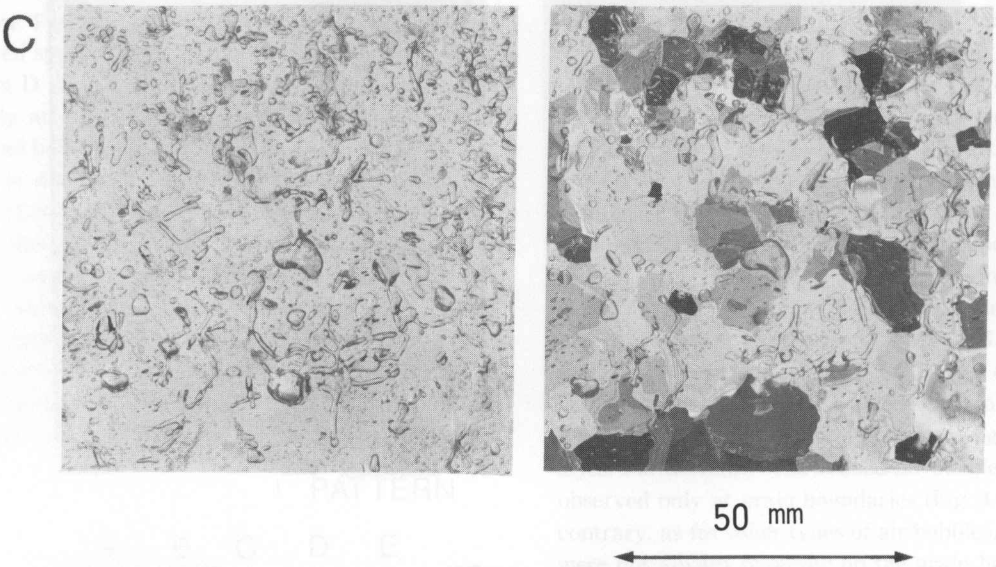


Fig. 4. Relation between air bubbles and grains.
A "clear type" and "uniform distribution type" at 77.0 m depth.
B "bubble layer type" at 39.9 m depth.
C "cobwebbed air bubble type" at 5.3 m depth.

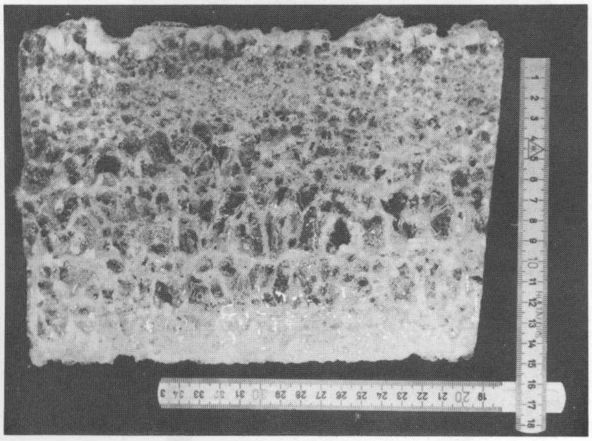


Fig. 5. Glacier ice observed at 0.5 to 0.8 m depth in the drilling site.

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