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PRELIMINARY DISCUSSION OF PHYSICAL PROPERTIES OF THE DOME FUJI SHALLOW ICE CORE IN 1993, ANTARCTICA

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Abstract: To make a pilot-hole for deep core drilling at Dome Fuji Station, East Queen Maud Land, Antarctica, shallow ice core drilling was conducted to a depth of 112.59 m by electro-mechanical drill. Core logging, measurements of impermeability and bulk density were conducted in situ and most of another analysis was done in Japan. Much depth hoar developed at Dome Fuji Station. However, it did not influence the densification rate, which mainly depends on temperature. Air bubble close-off starts from about 90 m depth. Much accumulation at one time occurs during marine cyclones at Dome Fuji Station.

1. Introduction

In 1993, the 34th wintering party of the Japanese Antarctic Research Expedition (JARE-34) conducted shallow core drilling at Dome Fuji Station (77°19′01″S, 39°42′12″E), East Antarctica to make a pilot bore-hole for deep core drilling. Then, an ice core of 112.59 m depth was recovered by electro-mechanical drill. The core was brought to the National Institute of Polar Research (NIPR: Tokyo). In 1995, core analysis was started to determine: (1) the recent circumstance of deposition process at Dome Fuji Station, and (2) the formation process of stratigraphic structure and its characteristics in a shallow layer. Chronology, chemical and physical properties are examined.

Meteorological conditions were as follows: average wind speed was about 2.6 m/s (KAMEDA *et al*., 1997), annual mean temperature which was measured at snow depth of 10 m was −58.6°C and annual accumulation was between 2.5 and 3.0 cm of water equivalent/year (WATANABE *et al*., 1993a). The altitude of Dome Fuji Station is 3810 m, about 1000 km from the coast. Therefore, it is expected that marine lows hardly influence the Dome area, and furthermore, as wind speed is very weak, snow layer structures are simple without sastrugi. Also, depth hoar develops remarkably in the Dome Fuji area. Since the depth hoar has large compactive viscosity to vertical direction (KOJIMA, 1976), it is assumed the depth hoar has a delay-effect of densification rate and, as a result, the bubble close-off depth becomes deeper. This is important to interpret the result of gas analyses.

2. Physical Measurements and Results

After the core logging was carried out at Dome Fuji Station, bulk density and impermeability of the core were measured continuously in situ. Subsequent core analysis in Japan included the following:

Continuous measurements and sampling:

(1) Re-measurements of results *in situ* in the core logging, bulk density and impermeability.

(2) Visual stratigraphy and grain size investigation on the light table.

(3) DC electric conductivity measurement (ECM).

(4) Sampling for thin section analysis.

Other measurements:

(5) Accurate density.

(6) Total air bubble volume.

(7) Permeability.

The bulk density was obtained by measuring average diameter, length and weight of the core. After that, cores were cut as shown in Fig. 1. Core (A) was cut to make thin sections and used for measurements of fabrics and grain size from thin sections. Core (B) was used to examine the physical properties and cut in to a slabs. The physical samples for permeability, total of air bubble volume and mechanical tests etc. were sampled from slab core. Observations of stratigraphy, grain size and measurements of impermeability and ECM were conducted on the fresh slab core surface. Also, it is planned to use the slab core for analysis of gas and organic compounds. The half core (C) is used to measure chemical compositions, $\delta^{18}O$ and δD.

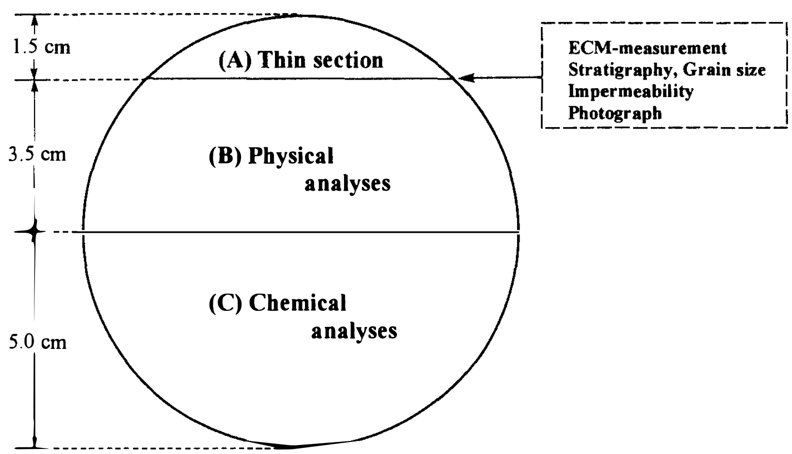

Fig. 1. Diagram of specimens cut for physical and chemical analyses for '93 Dome Fuji shallow core.

Depth hoar has developed very much in the Dome Fuji area. Fig. 2 shows the bulk density profile. The density was measured again in a cold room using a core which was cut at intervals of 20 cm to 50 cm. Open circles in Fig. 2 are the exact densities which were precisely obtained by measurement of total air bubble volume. There are parts with no data up to depth of about 16 m as shown in Fig 2. Cores of those parts were lost during drilling or core transportation, hence the core were a fragile depth hoar. After measuring the bulk density, the core was divided into three along the vertical direction by band-saw. Layer boundary, grain size, snow quality and impermeability were observed on the slab core surface. ECM-measurement was conducted on the fresh surface which was cut again at thickness of several mm by micro-tome. Figure 3 shows the distribution of thickness of unit layers through the shallow core. As shown in Fig. 3, each thickness is not uniform. The average thickness is 5.7 cm. A thicker layer exists continuously at depths in the vicinities of 30 m and 60 m. As the formation of unit layers originates from continuous deposition under the same weather/circumstance conditions, the duration for a continuous series of depositions was estimated from the thickness. Also, 101 thin ice layers are contained in the depth range from surface to 112.59 m. The inclination of most ice layers was less than 1 degree, as shown in Fig. 4, and it seems to deviate largely from 1 degree

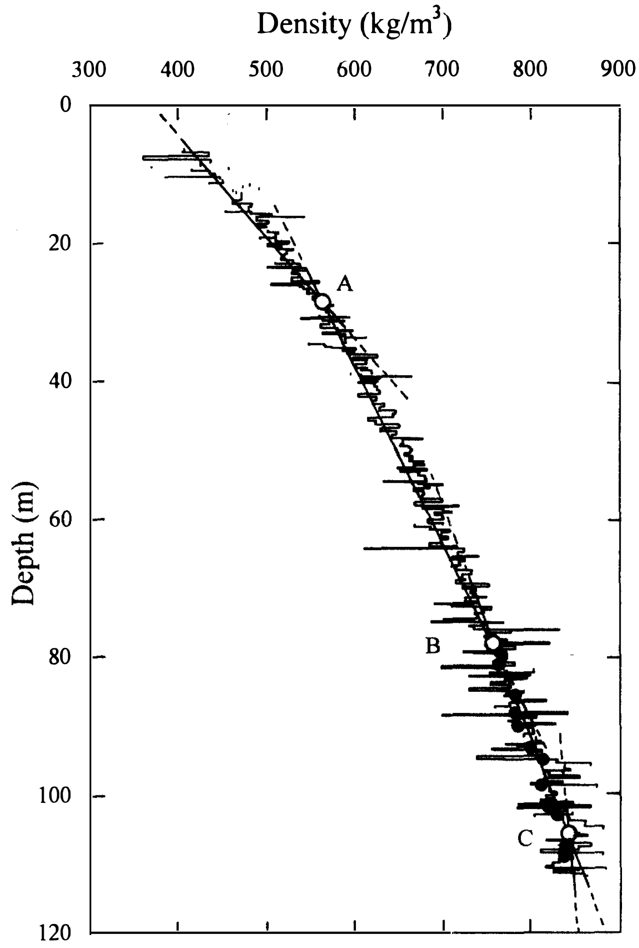

Fig. 2. Bulk density profile of Dome Fuji shallow core. Black dots are exact measured values.

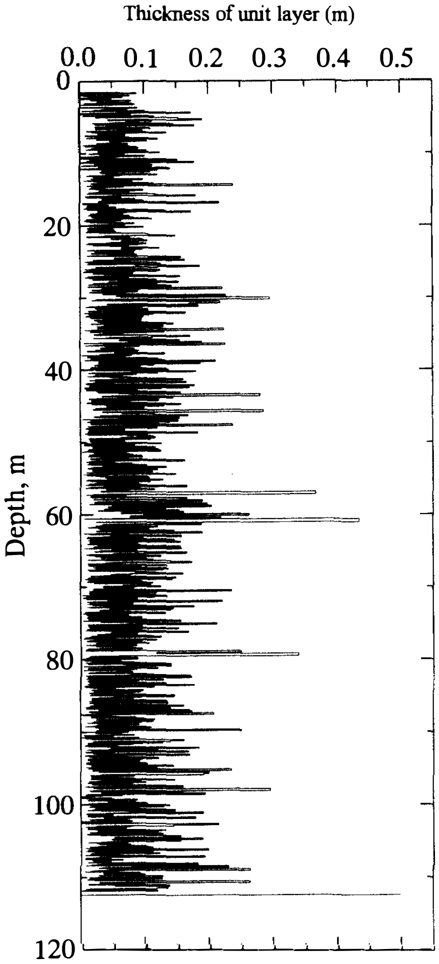

Fig. 3. Profile of thickness of unit layer obtained from observation of stratigraphy.

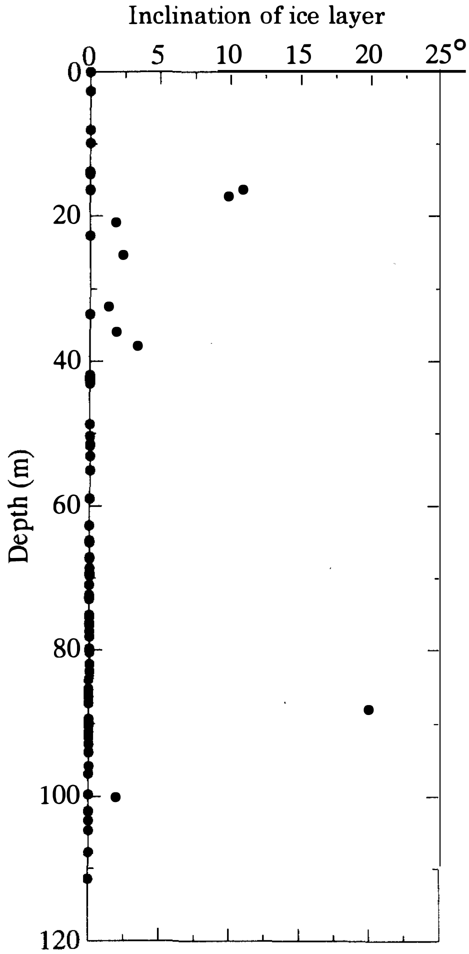

Fig. 4. Distribution of inclination of thin ice layers contained in shallow core.

between about 26 m and 36 m in depth. However, they are below 3 degrees. This means that snow deposition was done on almost flat snow without influence of wind, as average wind speed is 2.6 m/sec at Dome Fuji Station (KAMEDA *et al.*, 1997).

In general, there are three transitions in the densification process, namely around 550 $kg \cdot m^{-3}$, 730 $kg \cdot m^{-3}$ and 830 $kg \cdot m^{-3}$ (NARITA *et al.*, 1978). As shown in Fig. 2, they were marked A, B and C from smoothed lines in this profile. The corresponding density values to the transitions are 540 $kg \cdot m^{-3}$, 730 $kg \cdot m^{-3}$ and 840 $kg \cdot m^{-3}$, respectively. Those depths correspond to 22 m, 66 m, 101 m, respectively. The grain size was measured by use of a gauge which has black circles of various diameter as a series (HYOSHO DOME SAGYO IINKAI, 1995). The grain size has a tendency to decrease gradually with depth up to 80 m, although it fluctuates considerably at shallow depth, as shown in Fig. 5. Large grain size in the vicinity of the surface is caused by the developed depth hoar. Below 80 m, they begin to increase by pressure sintering.

The densification process is reflected in impermeability of firn which indicates a characteristic of the ice matrix. Figure 6 shows the impermeability profile. The imper-

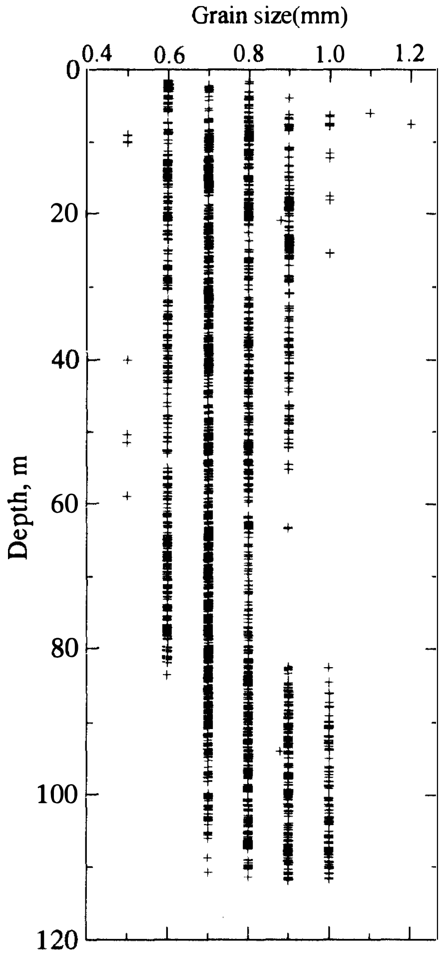

Fig. 5. Grain size distribution of Dome Fuji shallow core.

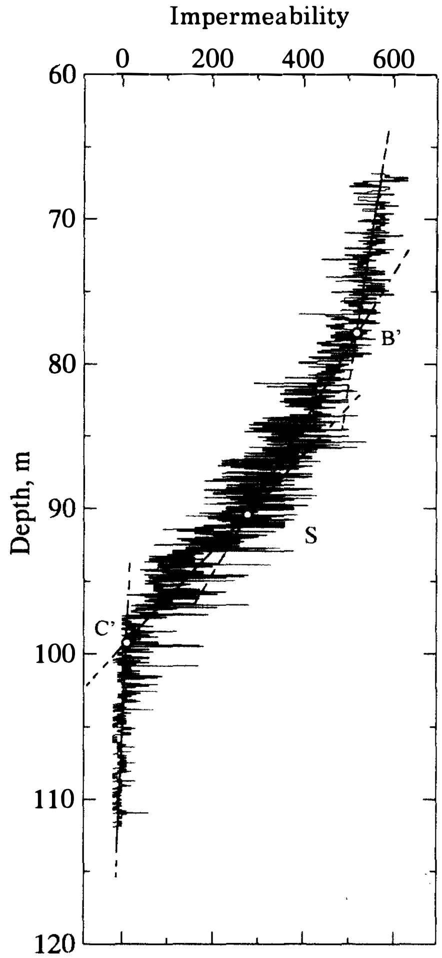

Fig. 6. Impermeability versus depth of Dome Fuji shallow core.

meability was measured by an air-sucking system (LANGWAY *et al*., 1993). The diameter of the top of the air-inlet is 12 mm. A rotary vacuum pump can intake 15 l/min. The non-permeable and free levels were 0 and 760 Torr, respectively. In Fig. 6, impermeability is indicated in units of Torr. Four smoothed lines can be draw on the profile as in Fig. 2. These intersections of B′ and C′ agree with B and C in Fig. 2, respectively. The point C′ corresponds to the bubble close-off depth. Simultaneously, bubble volume was measured by a method similar to that developed by SCHWANDER and STAUFFER (1984) based on the ideal gas law. According to those results (: Fig. 7a and b), the bubble begins to close from depth of about 90 m (: namely about 800 kg/m^3 density). The starting point corresponds to depth S in Fig. 5; not all voids became independent air bubbles even at a depth of 110 m. It is assumed that close-off is completed at depth between 110 m and 120 m. The thickness of range from the start of bubble close-off to the finish was about 20–25 m. This value is not different from other values which were measured by cores recovered at Mizuho plateau, East Antarctica.

The DC-ECM signal was measured at DC 1250 V and about −15°C. The data were corrected to values corresponding to −15°C by use of the Arrhenius law for temperature

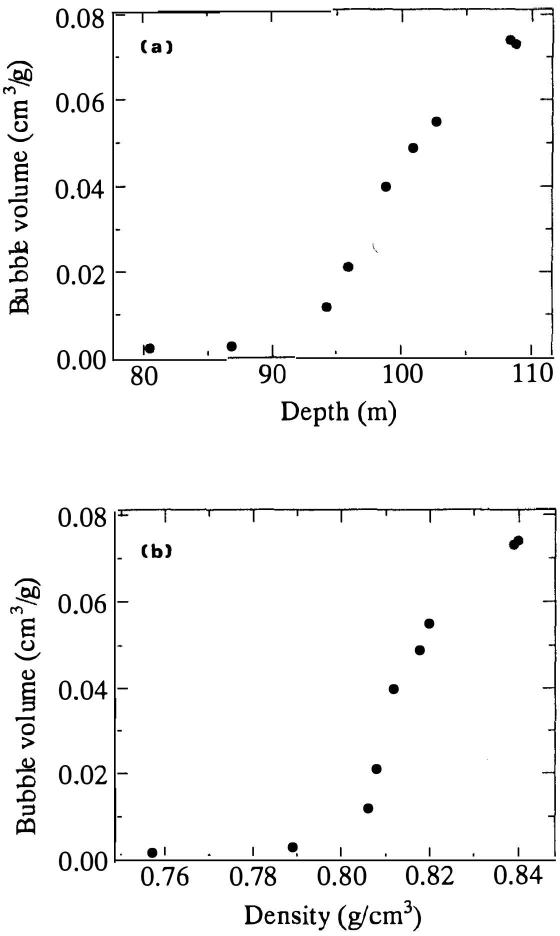

Fig. 7. (a) Relationship between air bubble volume and depth, (b) relationship between air bubble volume and density.

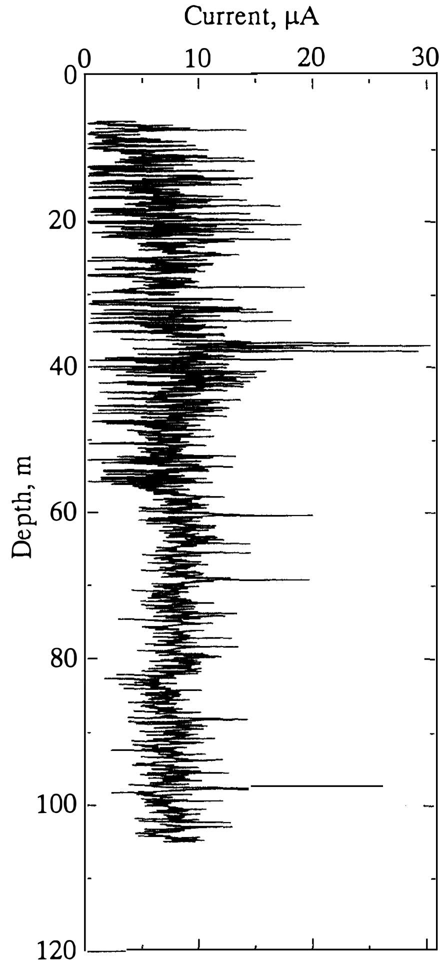

Fig. 8. ECM data of Dome Fuji shallow core.

dependence (NEFTEL, 1985). Density was also corrected by an equation: $A = A_{measured}(\rho_{ice}/\rho_{sample})$. Here, A is DC current (μA) and ρ is firn density. Analogue ECM data were digitized at 1 mm intervals. After taking the moving average of 10 data, Fig. 8 was obtained by sampling data at intervals of 1 cm. Peaks of 29.1, 37.8, 60.4, 69.2 and 97.8 m in depth are caused by volcanic events as described in detail by WATANABE *et al.* (1997a). They are identified as 1464AD, 1259AD, 865AD, 639AD and 346BC volcanic eruption signals, respectively.

3. Discussion

Very developed depth hoar exists to a depth of about 6 m, and firn metamorphosed from depth hoar, keeping the shape of vertical structure which is characteristic of the depth hoar, continues to about 40 m. They are strong mechanically in the vertical direction (KOJIMA, 1967). This slows the densification rate. However, three divisions in the general

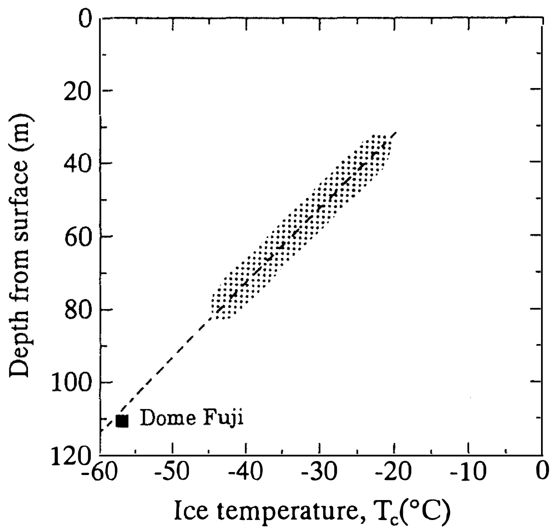

Fig. 9. Depth of the firn-ice transition layer versus ice temperature. The shaded portion shows the firn-ice transition layer at other places.

densification process were recognized as shown in Fig. 2. Furthermore, firn-ice transition layers are linearly interpolated between −43°C and −25°C as was reported by KAMEDA (1994). It is assumed from Fig. 6 that the transition layer is in the depth range from 110 m to 120 m. As ice temperature at depth is −58.6°C, the point on the Dome is located on the extended line of the shaded portion in the linear relation as shown in Fig. 9. It can be considered that there is no effect of depth hoar against the densification rate. Also, the bubble close-off thickness was similar to that at other places as described above.

Average wind speed is below 3 m/s at Dome Fuji Station (KAMEDA *et al.*, 1994). Therefore, it is assumed that hiatus is not made easily in Dome Fuji area and the annual accumulation rate is between 2.5 and 3.0 cm of water equivalent/year, which was obtained from major volcanic events by use of ECM-signals (WATANABE *et al.*, 1997a). In observation of the unit layer, we obtained that its thickness is about 6 cm on average as shown in Fig. 3. This value does not agree with the annual accumulation rate. Many unit layers above 15 cm in thickness were observed. In particular, layers above 20 cm exist continuously in the vicinities of 30 and 60 m depth. Namely, at the periods, much precipitation occurred continuously as described before. Much precipitation will need an air mass containing much water vapor. This will happen when a cyclone from the sea reaches to Dome Fuji area. According to chemical analysis and measurement of $\delta^{18}O$, chemical components of marine origin were contained much more in parts of those layers, and values of $\delta^{18}O$ are higher than in others (WATANABE *et al.*, 1997b).

4. Concluding Remarks

In 1993, shallow core drilling was conducted to a depth of 112.59 m. The results and physical analysis indicated as follows:

(1) Depth hoar had developed remarkably in the vicinity of the surface. It is assumed that this influenced the densification rate. However, the decrease of the rate caused by the depth hoar structure could not be clearly determined. The rate depends on the ice temperature.

(2) 101 thin ice layers were observed in this core. They were nearly horizontal. This means that deposition at Dome Fuji Station is stable over a long time without influence of wind etc..

(3) Snow deposition which determines the thickness of a unit layer is never constant. The average value was about 6 cm. However, much deposition seems to occur under the influence of marine cyclones.

Analysis of thin sections is still in progress.

Acknowledgments

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