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MEASUREMENTS OF TOTAL GAS CONTENT OF AN ICE CORE FROM MIZUHO STATION, ANTARCTICA

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Abstract: Total gas content of an ice core, 700 m long drilled at Mizuho Station, East Antarctica (Mizuho core), has been measured by two methods. One method is the so called "melting method", in which entrapped gas in an ice sample was collected in a gas burette by melting the sample in liquid. The other method, the "dry extraction method", was also employed to measure gas content for small samples; gas was introduced into an evacuated container by crushing a sample. It was found that the total gas content of the Mizuho core increased almost linearly with decrease of depth from 600 to 180 m below the surface. Above 180 m, however, total gas content was much larger than the lower part of the ice core. This probably indicates that the ice sheet thickness has decreased since the gas was incorporated into the ice matrix located at about 180 m depth.

1. Introduction

Polar glacier ice is characterized by widespread air bubbles which are trapped during the transformation of snow to ice. Below a certain depth, pores in firn become isolated and turn into air bubbles, where no air permeability is achieved. This densification process of snow is one of the most important and fundamental phenomena in polar regions, and intensive work on the process, has been carried out in the past (LANGWAY, 1967; GOW, 1968, 1969; NARITA *et al.*, 1978; MAENO, 1982).

Attention has been given to total gas content of ice core (amount of air per unit mass of ice), since LORIUS *et al.* (1968) suggested that it could be an indicator for past ice sheet thickness. RAYNAUD and LEBEL (1979) showed the relation between total gas content and the surface elevation of ice sheets. The relation has been used to construct the past variation of the surface elevation of ice sheets (RAYNAUD and WHILLANS, 1979; JENSSEN and RADOK, 1982; HERRON and LANGWAY, 1987).

A 700 m long ice core was recovered at Mizuho Station (70°42′S, 44°20′E; 2260 m a.s.l.; Fig. 1) by the 24th and 25th Japanese Antarctic Research Expeditions (JARE-

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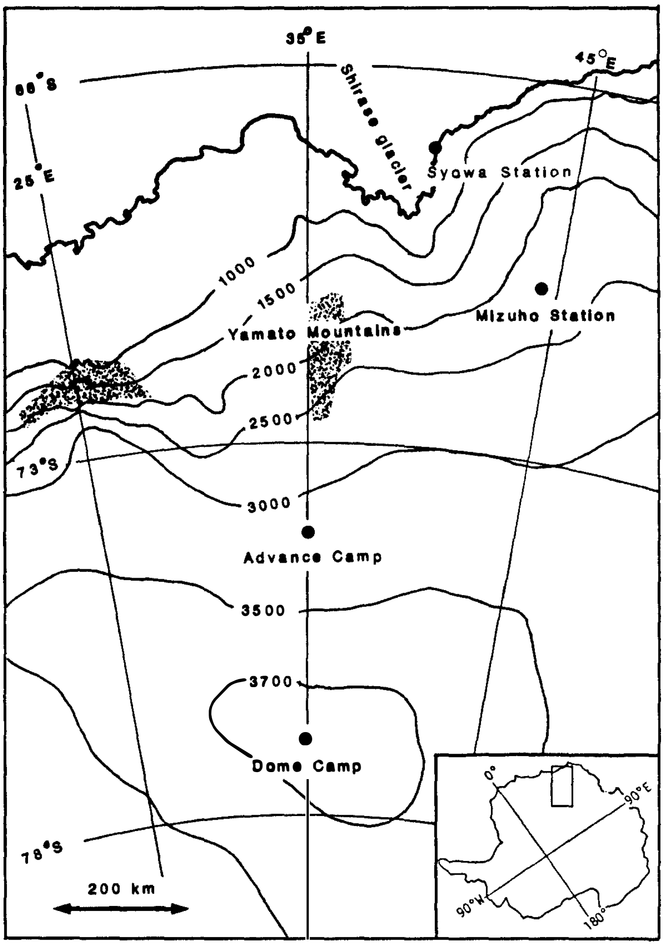

Fig. 1. Location of Mizuho Station, East Antarctica.

24, 25) in 1983–1984. This ice core (Mizuho core) is considered to cover about 9400 years (NAKAWO *et al.*, 1989) and a variety of analyses have been carried out to extract a variety of information in that period (FUJII and WATANABE, 1988; HIGASHI *et al.*, 1988; NAKAWO and NARITA, 1985; NARITA *et al.*, 1986; FUJITA *et al.*, 1987).

For measuring total gas content, successive sampling, or at least, sample of a certain volume covering an annual layer, is preferable, since significant seasonal variation of gas content was reported (RAYNAUD and LEBEL, 1979; HERRON and LANGWAY, 1987). It was possible, for the Mizuho core, to prepare relatively large samples near the surface (above 110 m in depth) and to measure gas content by a conventional method. At lower depths of the core, however, there existed fine cracks at intervals of 10 mm or less, presumably caused by a thermal shock during drilling (NAKAWO and NARITA, 1985). Hence, only a small sample (less than 20 g), which does not cover the mean annual thickness, had to be used for the gas content measurements, avoiding any cracks. It is considered that the conventional method is not accurate enough to measure total gas content with these small samples. An alternative method was hence developed for the measurements.

In this paper we present a vertical profile of total gas content of Mizuho core, in addition to a detailed description of the methods.

2. Experimental Procedure

2.1. *"Melting method"*

Air in a sample was extracted by melting the sample in a liquid and introducing the air into a gas burette. The procedure was described by LANGWAY (1958) in detail. This method is relatively easy to perform, and the experimental setup is rather cheap. Many workers have measured total gas content with this conventional method. The experimental error, however, was considered as much as approximately 5% (LANGWAY, 1958), mainly attributed to the uncertain assessment of the amount of air dissolved in the melt water, and vapor pressure of the liquid used. We have employed, hence, air and water saturated dimethyl silicone (1.5×10^{-2} St or 1.5×10^{-6} m^2/s) oil as the liquid, because of its low vapor pressure, small solubility in water and pure composition, although previous workers mostly used kerosene as the liquid.

The amount of air dissolved in the melt water was analyzed by the polarograph method and a modified Winkler method. It was found by both methods, that 92–98% of oxygen saturation was established in the melt water. A similar value was obtained when pure glacier ice (containing no air bubbles) was subjected to complete melting in dimethyl silicone oil. This suggests that the amount of dissolved air in melt water is much less than the result by LANGWAY (1958) with kerosene.

Overall errors of the measurements were estimated by the following experiments. Blocks of pure ice were prepared and holes (0.1–0.5 mm in diameter) were made with a drill from one side of each block. The holes were covered by a piece of ice so as to keep air in the block. Density determination of the block allowed us to calculate the entrapped air volume. The block was then subjected to the gas content measurement by the "melting method". By comparing these two results, it was found that the error of the melting method was 1% of total gas content for about 80 g ice samples and 4% of that for 20 g samples. This method was used for rather large samples (80 g to 200 g) obtained at depths shallower than 110 m of the Mizuho core.

2.2. *"Dry extraction method"*

Air contained in an ice was extracted by crushing a sample under vacuum in a vessel and introducing it into a pre-evacuated vessel. All these procedure were carried out in a cold room (−20°C). Total gas content is given by the temperature and pressure of extracted air in the vessel. Various crushing methods have been tried, *e.g.* "needle matrix crusher" (ZUMBRUNN *et al.*, 1982), "milling cutter method" (MOOR and STAUFFER, 1984; ETHERIDGE *et al.*, 1988), "ball mill method" (RAYNAUD *et al.*, 1982); we employed the "ball mill method".

The system, made of 316 stainless steel, is shown schematically in Fig. 2. The procedures for the measurements are as follows. 1) An ice sample (about 6 to 10 mm in width) was cut from the ice core with a bandsaw, and its surface was microtomed in a cold room. Its weight (M) and surface area were measured with an accuracy of 0.01 g and 1%, respectively. The ice sample was placed in a vessel (V_1) together with 12 stainless balls, ranging from 5.6 mm to 22.4 mm in diameter. 2) Vessel (V_1) was connected to a vacuum line (below 0.01 Torr or 1.3 Pa in SI units) and was evacuated for a few minutes. Valve 1 was then closed and vessel (V_1) was disconnected from the

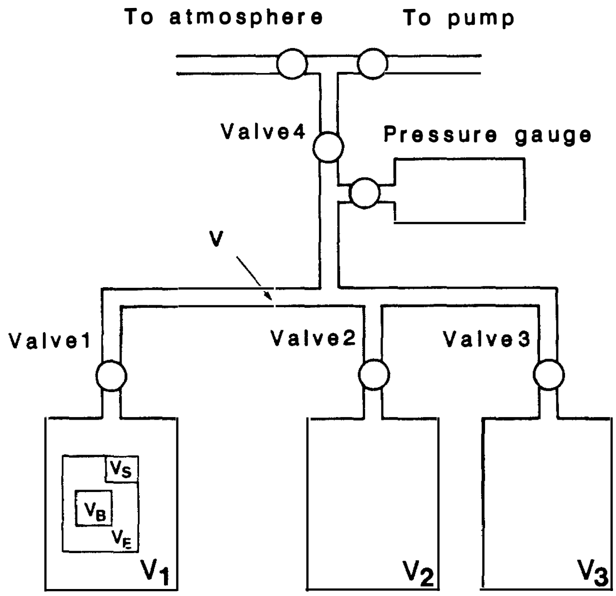

Fig. 2. Measuring device for total gas content ("Dry extraction method").

line 3) Vessel (V_1) was shaken by hand for a few minutes, resulting in the ice sample being crushed coarsely. It was then subjected to a self-operating crushing apparatus (Yokoyama Co. Ltd., Model 0-61, Type C-0112), which imparted an up-and-down motion (several hundred cycles per minute) to the vessel. The sample became powdered by this procedure; the diameter of the crushed powder was less than 0.1 mm. The size of the powder was considered to be fine enough for measuring accurate total gas content, since the mean diameter of air bubbles of the ice core was on the order of 0.1–0.2 mm (NARITA and NAKAWO, 1985). 4) After completion of the crushing, vessel (V_1) was connected to the vacuum line (v). 5) After the line and vessels (V_2) and (V_3) were evacuated to below 0.01 Torr, valves 3 and 4 were closed and valve 1 was opened. Extracted gas from the samples (V_B) diffused gradually into the system. 6) The pressure P_1 and temperature T_1 of the gas were measured using a digital manometer (Tukasa Sokken Co. Ltd., Model PH-22, $\pm$0.01 Torr) and a thermocouple ($\pm$0.1°C), respectively, when the equilibrium state was reached. 7) Valve 3 was opened; then the pressure P_2 and temperature T_2 of the gas were measured.

Total gas content (R) was then calculated based on the Law of Boyle-Mariotte for ideal gases, *i.e.*,

$$R=\frac{1}{M}\cdot\frac{T_0}{P_0}\cdot\frac{P_1P_2}{P_1T_2-P_2T_1}V_3$$

where P_0=standard pressure (1 atm)

T_0=standard temperature (0°C)

The values of P_1 and P_2 are the corrected values for vapor pressure of ice at temperature T_1 and T_2, respectively.

During the measurements, sublimation could occur at the sample surface, which could lead to errors in the measurements. Examining the changes in weight of samples before and after the measurement, we have confirmed that the error was about 0.5%

of gas content. The reading error of temperature and pressure was considered to be 0.3%. Overall measurement error, hence, was less than 1%.

2.3. Surface effect correction

The total gas content thus obtained underestimate real values, since gas in half-cut bubbles at the sample surface was not captured. Assuming all bubbles to be spherical, measured values of total gas content were corrected for this surface effect using density data by the hydrostatic method (BUTKOVICH, 1953; LANGWAY, 1958; NAKAWO, 1980) and bubble concentration data.

3. Results and Discussion

The "melting method" was used mainly for samples taken from depths above 110 m, while the "dry extraction method" was employed for small samples at lower depths. Figure 3 shows the measurement results. Circles and triangles show the data measured by the dry extraction method and melting method, respectively. Open symbols indicate that contained bubbles were not spherical. When the bubble shape is intricate, surface correction has to be much larger than the correction made (NAKAWO and NARITA, 1985). The data with open symbols are hence only for reference.

The following two tendencies can be seen in the results of total gas content of Mizuho core in Fig. 3.

1. 600–180 m: total gas content increases gradually with decreasing depth.
2. 110–90 m: total gas content is much larger than the values obtained at depths below 180 m.

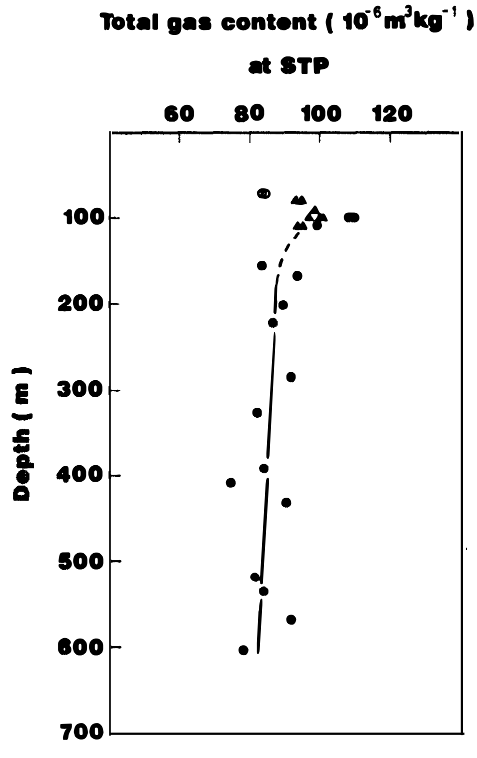

Fig. 3. Vertical profile of total gas content of Mizuho core.

The scatter of the data from the linear regression (straight line) in a range of 600–180 m is as large as 10×10^{-6} ($m^3\ kg^{-1}$). This scatter may be caused by the seasonal variation of total gas content. A similar order of scatter was reported as the seasonal variation by RAYNAUD and LEBEL (1979) and HERRON and LANGWAY (1987). The general trend at 600–180 m depth is mainly due to downslope movement of the ice sheet, since Mizuho Station is located midstream in the ice sheet. Much larger values of total gas content at the top level (dashed line at 110–90 m depth) would probably indicate that the surface level of the ice sheet has decreased since the gas was incorporated into an ice matrix located at about 180 m depth.

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