# STRATIGRAPHIC ANALYSES OF FIRN AND ICE AT MIZUHO STATION

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***Abstract:*** Stratigraphy of the 150-m core from Mizuho Station, Antarctica, is studied with visual observation as well as with analysis of density and oxygen isotope profiles. Stratigraphic structures are well preserved to a depth of 70 m. Considerably deviated values of density from the average depth-density curve serve as one of good indicators of the texture of initially deposited snow. From stratigraphic interpretation about 10.6 g/cm$^2$ is estimated as the mean annual accumulation. With this value the age of the lowermost part of the 150-m core is estimated to be some 1100 years B.P. excluding the periods of hiatus of annual layers.

In the $\delta\,^{18}O$ profile to the depth of 60 m, the smallest peak indicating the coldest climate is seen at a depth of 32 m which is dated back to some 200 years B.P. Comparison of the $\delta\,^{18}O$ profile in the Mizuho core with that in the Camp Century core indicates that the period of hiatus of annual layers is about one-third of the real duration of the core formation and the mean annual accumulation is about two-thirds of 10.6 g/cm$^2$ at Mizuho Station in the past 300 years.

## 1. Introduction

As is well known, deep ice cores from both Greenland and Antarctic ice sheets provide important information about climatic changes in the late Cenozoic ages.

Objectives of the core drilling operations conducted at Mizuho Station, Antarctica, from 1970 to 1976 were to obtain the information about climatic changes on Mizuho Plateau and also to complement the glaciological and geophysical measurements of the surface carried out as a field research project from 1968 to 1976. Two core holes were drilled to the depth of about 150 m, whereby various observations and analyses were made using the holes as well as the cores obtained.

In the present paper, results on a long-term variation of surface condition on Mizuho Plateau are derived from various stratigraphic analyses. The data on structure and texture, and physical and geochemical properties of the cores are described in Appendix of this volume.

## 2. Glaciological Conditions of the Drilling Site

### *2.1. Geographical situation*

Mizuho Station was established by the 11th Japanese Antarctic Research Expedition (JARE-11) in July 1970 as an intended site of deep drilling operations. This inland station is located at 70° 41.9′S and 44°19.9′E, and lies at an elevation of 2230 m. It is situated on the slope in the moderate katabatic wind region (0.05 in slope ratio), 220 km from the edge of the Shirase Glacier and 300 km from Syowa Station.

### *2.2. Climatic conditions*

From the compiled data of meteorological observation since 1971 (INOUE *et al.*, 1978), climatic conditions at Mizuho Station are as follows: The annual air temperature ranges from −57°C to −4°C with the mean of −32°C. The 10 m snow temperature was −33°C (SATOW, 1977, 1978). The direction of prevailing wind is around E-ESE with annual mean velocity of 10 m/s.

Climatic characteristics of the region around Mizuho Station are highly influenced by the stationary katabatic wind and the cyclonic disturbance.

From the measurements of snow accumulation with snow stakes, the mean value of annual accumulation after 1971 is estimated to be about 45 mm in water equivalent (OKUHIRA and NARITA, 1978). However, the glazed surface with hiatus of annual layers overspread the stake farm at Mizuho Station. Therefore, the condition of snow accumulation should be considered to be more complicated.

Seasonal variations and regional characteristics of oxygen isotopic composition ($\delta^{18}O$) of drifting snow collected at Mizuho Station were reported by KATO (1977) and KATO *et al.* (1978). According to these reports, the range of $\delta^{18}O$ of drifting snow from January 1974 to February 1975 is between −28.4 and −44.1‰ against the range between −11.3 and −36.8‰ of fallen snow at Syowa Station (KATO, 1977, 1978a; KATO *et al.*, 1978).

### *2.3. Recent surface conditions*

In the region of drilling site, dunes representing typical depositional form are brought about by cyclonic disturbance and occur in the predominant direction deviated at 15–45 degrees (averaging 30 degrees) northward from the direction of sastrugi representing an erosional form. The katabatic wind as an erosional agent of dunes has the stationary direction deviated at 30 degrees to the left from the direction of the maximum slope (WATANABE, 1978a).

Frequent occurrences of glazed surface as well as dunes and sastrugi are the most characteristic surface feature in this region. The glazed surface is occasionally exposed over one year, resulting in hiatus of annual layer(s). Most part of the surface around Mizuho Station was glazed, except for the deposition of snow caused by the installation of the station facilities. The detailed observation of the surface around the station was made by WATANABE and YOSHIMURA (1972).

Observations of surface features in Mizuho Plateau (WATANABE, 1978a) show that glazed surface occurred in the region between 1800 and 3000–3200 m in elevation and highly developed glazed surface was found in the region between 2500 and 3100 m in elevation. The occurrence of highly developed glazed surface near the station may be due to the local topography of the ice sheet.

In the estimate of the annual accumulation with the stratigraphic method, the existence of hiatus should be considered.

## 3. Stratigraphic Analyses of the Core

### *3.1. Scheme of pit and core studies*

A 70-m core and two 150-m cores were obtained from Mizuho Station during the period between 1970 and 1976. However, it was very difficult to obtain cores from the upper subsurface layer, because this part was highly metamorphosed and brittle. So two pits, 4-m and 20-m deep respectively, were dug at Mizuho Station during the period of 1970–1972, in addition to the three deep cores.

Scheme of pit and core studies is shown in Fig. 1. The cores used for this study were obtained in 1971–1972 and 1972–1973 by JARE-12 and JARE-13, respectively. Another deep core obtained in 1974–1976 by JARE-15 and JARE-16 was not used in this study.

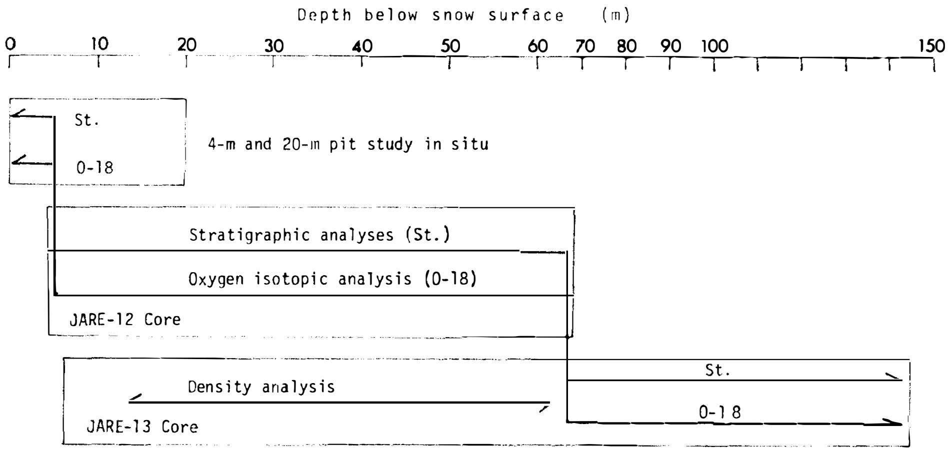


*Fig. 1. Scheme of pit and core studies.*

### *3.2. Basic elements of the core stratigraphy*

#### 3.2.1. Layer boundary

Surface conditions of the ice sheet are in various stages of deposition-erosion process.

When a surface condition attains to the equilibrium stage in deposition-erosion process, a difference between the deposited and eroded amounts corresponds to the net accumulation. This snow accumulation should remain as a unit of snow stratification, which is superimposed upon the previous surface. This unit of stratification is called as a unit layer (WATANABE, 1978b). So an annual layer is composed of unit layer(s).

Layer boundary and snow texture are the basic elements in the study of visible stratigraphic structures of a core.

When a surface is exposed to the ambient air, the surface is subjected to mechanical processes (wind packing) and thermal processes (sublimation, condensation and radiation melting). Therefore, the surface reflects these various processes, resulting in the formation of specific textures in connection with the duration of exposure and the related season.

Layer boundaries can be classified into the following three categories:

(1) layer boundary without ice crust
(2) ice crust
(3) multi-layered ice crust.

Some examples photographed by NARITA (unpublished data) are shown in Fig. 2.

A layer boundary without ice crust is presumed to be formed in a relatively short interval of the time before it is covered with the upper layer. Such boundary is distinguished as a contact line between different textures of snow without any continuous ice crust.

A microscopic examination of ice crusts discloses two types of ice crust structures. The one has a structure formed by sintering of snow particles. The other has a continuous single- or multi-layered ice structure resulted from the frozen snow, which was melted once at the surface as suggested by spherical air bubbles in the crust (NARITA and WATANABE, 1977).

A glazed surface is presumed as a kind of multi-layered ice crust formed due to a long-period exposure of the surface. As seen in Fig. 2, the uppermost layer of the core has a multi-layered ice crust and a highly developed depth hoar layer below the ice crust. Such formation of large numbers of layered crust and highly metamorphosed layer must be brought about by a long-period exposure of the same surface.

#### 3.2.2. Snow texture

Texture of Antarctic snow layer, particularly in the dry snow zone, is characterized by depth hoar development. Air temperature fluctuations create temperature gradients in the upper 10 m of subsurface layer, which cause vapor transfer in it.

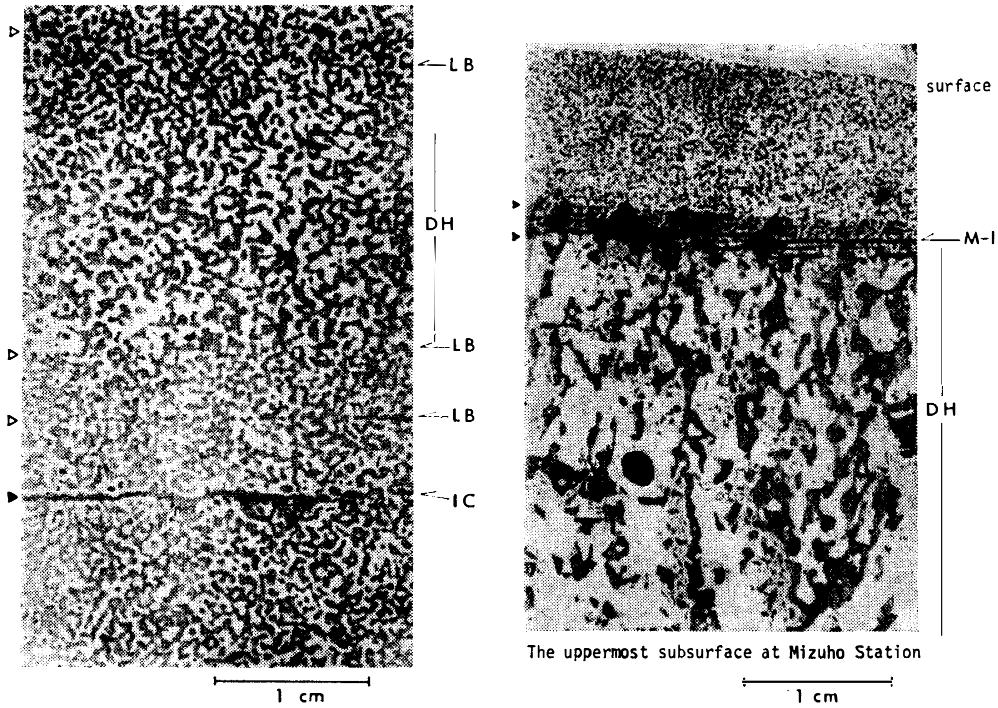


*Fig. 2. Various structures and textures of firn. ▷, LB: layer boundary without ice crust. ▶, IC: ice crust. ⧗, M-IC: multi-layered ice crust. DH: well-developed depth hoar.*

Two types of depth hoar, loose type and hard type, were generally seen in the snow cover of Mizuho Plateau (WATANABE, 1978b). Their formations depend largely on density and thickness of deposition in the initial stage of layer formation.

Various conditions of the depth hoar development are seen in the core from Mizuho Station, as shown in Fig. 3. As the parameters indicating the process and degree of depth hoar development, the morphological elements such as shape of grain, shape of pore space, texture of grain aggregation and packing are important in addition to the basic physical properties such as grain size, density, hardness and so on.

A continuous grading for depth hoar development was used as an index in visual analysis of a sliced core plate on the light table. Standard levels for the grading are follows: level 0 indicates the texture in the least-developed depth hoar or in hard depth hoar, the highest development corresponds to level II, and the intermediate texture is indicated by level I. Some examples of this description in the core are shown in Fig. 3.

### *3.3. Characteristics of unit layer distribution*

#### 3.3.1. Vertical distribution of unit layer in the core

Unit layers of 1283 were found in the core from the surface of the depth of 106.46 m. The weight of every unit layer is calculated by multiplying its thickness

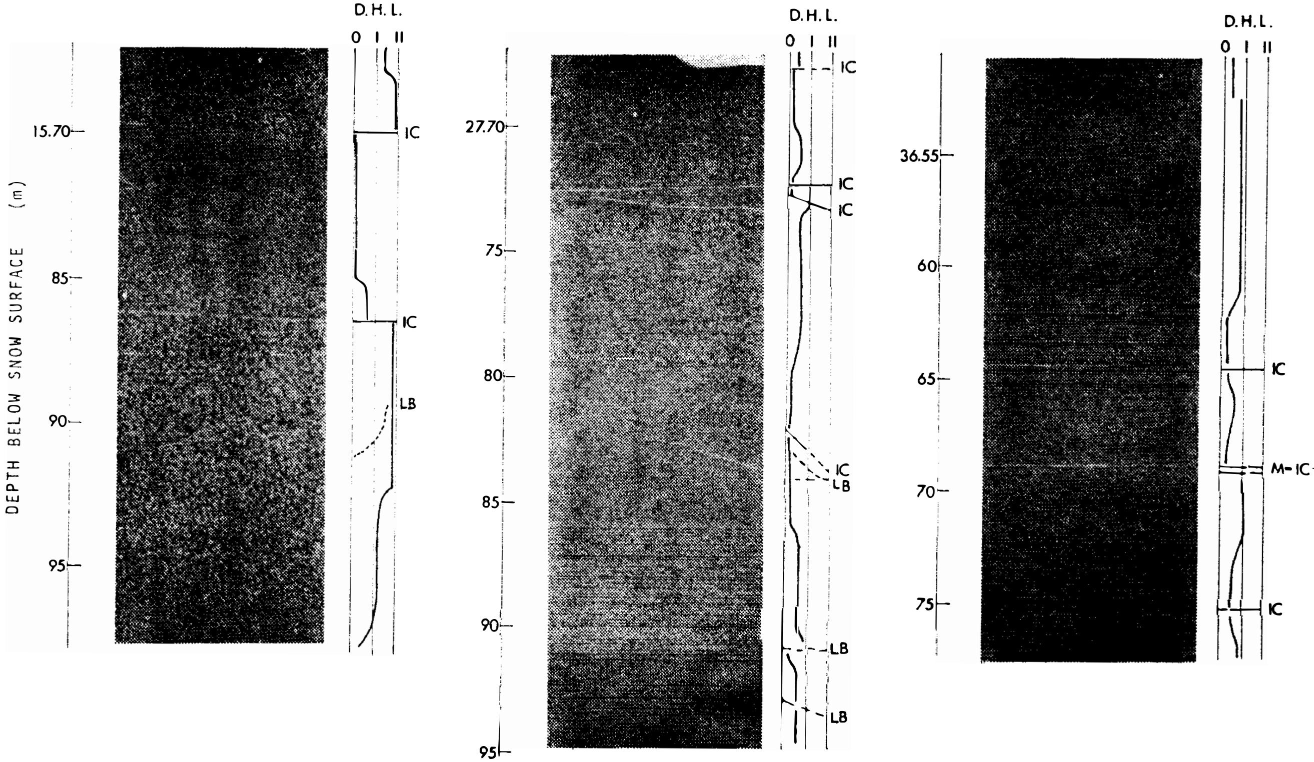


*Fig. 3. Examples of continuous grading of depth hoar development using the standard depth hoar level (D.H.L.). LB: layer boundary. IC: ice crust. M-IC: multi-layered ice crust.*

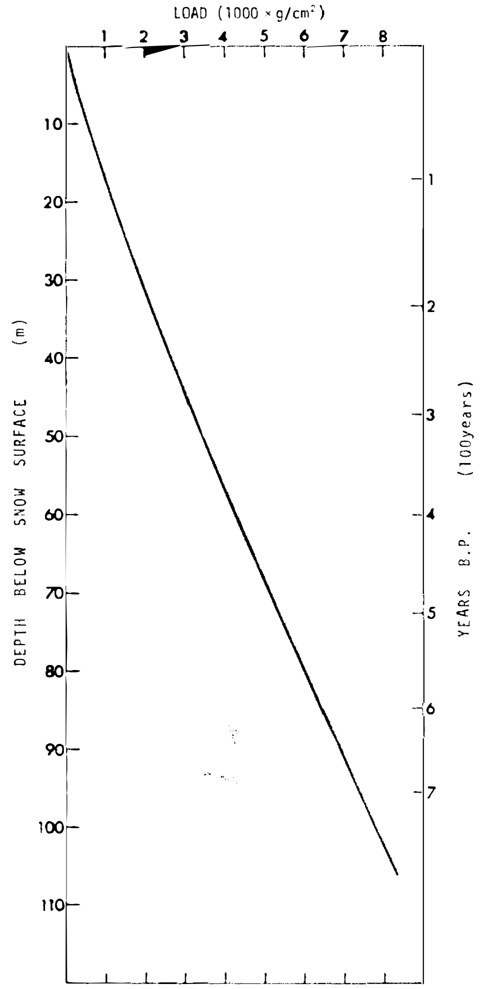


*Fig. 4. Curve of cumulative load in the core from the surface to the depth of 106.46 m with the time scale estimated from the mean annual accumulation of 10.6 g/cm².*

by its density. The total load of 1283 unit layers is 8093 g/cm², as shown in Fig. 4. The mean weight of one unit layer averages 6.5 g/cm².

Fig. 5 shows the histogram of weight of unit layer in the core from the surface to the depth of 106.46 m. Weight distribution of unit layers shows a Poisson one. Weight of a unit layer extends to 37–38 g/cm² in the maximum and the largest number of unit layers occurs in the range of 2–3 g/cm².

Similar histograms in every 10 m interval from the surface to the depth of 106.46 m are shown in Fig. 6. As seen in these histograms, the weight distribution of unit layers below the depth of 70 m is fairly different from that above 70 m.

Mean weight of unit layer and standard and relative deviations of weight of unit layer for every 10 m interval of depth are given in Table 1. The values of standard deviation are in the range of 4–6 g/cm² in the core above the depth of 70 m,

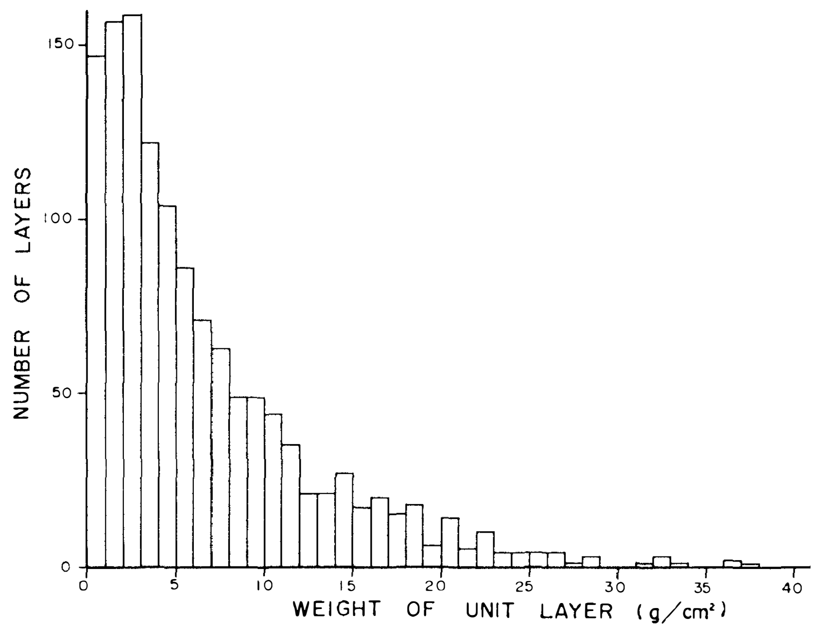


*Fig. 5. Histogram of weight of unit layer in the core from the surface to the depth of 106.46 m.*

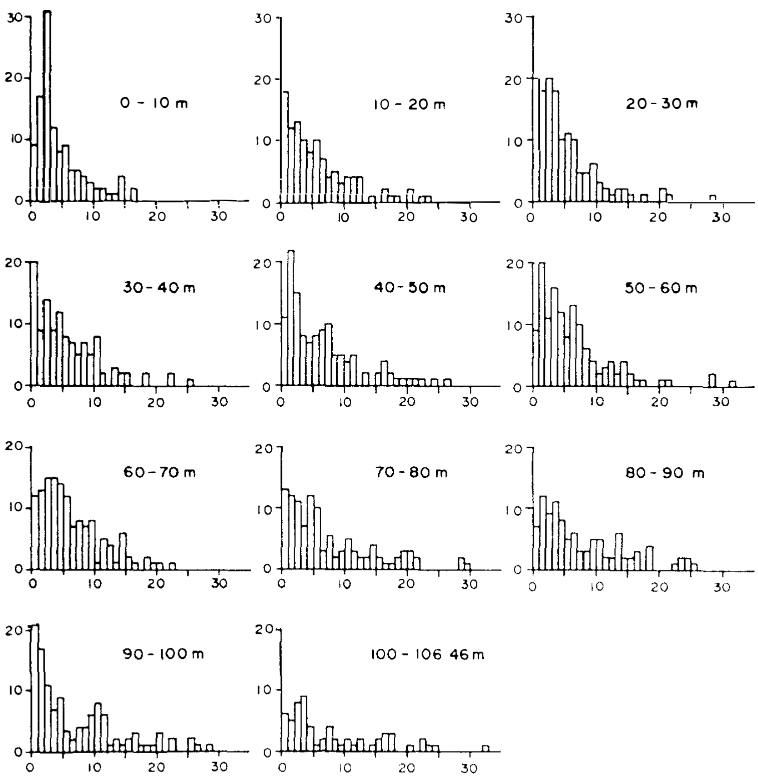


*Fig. 6. Histograms of weight of unit layer for every 10 m interval in the core from the surface to the depth of 106.46 m. Vertical axis: number of unit layers. Horizontal axis: weight of unit layer in g/cm².*

*Table 1. Distribution of unit layers for every 10 m interval of depth in the core.*

| Depth (m) | N | L | A | $\sigma$ | $\sigma/A$ |
|---|---|---|---|---|---|
| 0– 10 | 115 | 521.0 | 4.53 | 3.75 | 0.83 |
| 10– 20 | 111 | 638.1 | 5.75 | 5.21 | 0.91 |
| 20– 30 | 138 | 724.0 | 5.25 | 5.78 | 1.10 |
| 30– 40 | 120 | 737.5 | 6.15 | 6.02 | 0.98 |
| 40– 50 | 126 | 801.2 | 6.36 | 5.71 | 0.90 |
| 50– 60 | 133 | 844.1 | 6.35 | 5.62 | 0.89 |
| 60– 70 | 138 | 858.9 | 6.22 | 4.81 | 0.77 |
| 70– 80 | 112 | 850.3 | 7.58 | 7.14 | 0.94 |
| 80– 90 | 103 | 878.4 | 8.53 | 8.43 | 0.99 |
| 90–100 | 121 | 889.2 | 7.35 | 7.32 | 1.00 |
| 100–106.46 | 63 | 550.6 | 8.74 | 8.74 | 1.00 |

N : Number of layers.
L : Cumulative load (g/cm$^2$).
A : Mean weight of one unit layer (g/cm$^2$).
$\sigma$ : Standard deviation of weight of a unit layer (g/cm$^2$).
$\sigma/A$ : Relative deviation of weight of a unit layer.

below which they become larger. This fact may be attributed to disappearance of some boundary structures below a depth of 70 m of the core, hence difficulties in identifying unit layers.

It is concluded from these results that the visual stratigraphic analyses may be effective only to a depth of 70 m of the core.

3.3.2. Locality of characteristics of unit layer distribution

Vertical distributions of weight of unit layer in the 10-m cores obtained from various stations in Mizuho Plateau shown in Fig. 7 were examined. The results in the cores from W46, H128, Z30, Y200 and I355 as well as Mizuho Station are shown in Fig. 8. The corresponding cumulative curves are shown in Fig. 9.

It is seen from Figs. 8 and 9 that the surface condition at Mizuho Station is similar to those at Z30 and Y200. These three stations belong to a stationary katabatic wind region (SHIMIZU *et al.*, 1978). The surface condition at W46, which has markedly higher snow accumulation than the other stations (WATANABE, 1978b), is considerably different from those at the other stations.

### *3.4. Stratigraphic interpretation of annual layer*

If annual units are determined in the sequence of unit layers, annual accumulations are also determined.

Stratigraphic profiles in the four different depth intervals of the core from Mizuho Station are shown in Fig. 10. The profiles in these intervals were selected from among those in all the intervals, considering the existence and good preser-

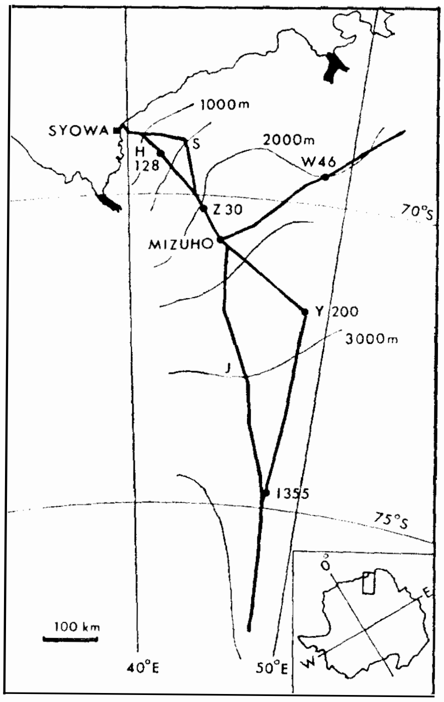


*Fig. 7. Map showing the boring stations in Mizuho Plateau, East Antarctica.*

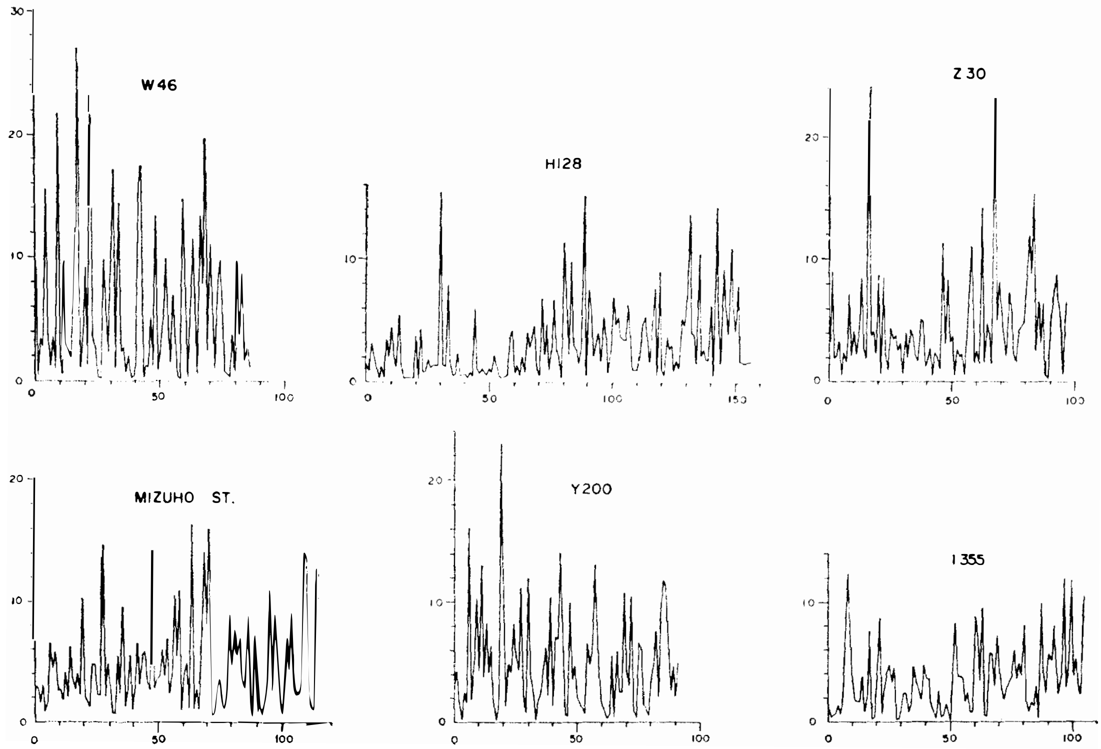


*Fig. 8. Vertical distribution of weight of unit layer in the 10-m cores from W46, H128, Z30, Mizuho Station, Y200 and 1355. Vertical axis: weight of unit layer in g/cm². Horizontal axis: number of unit layers.*

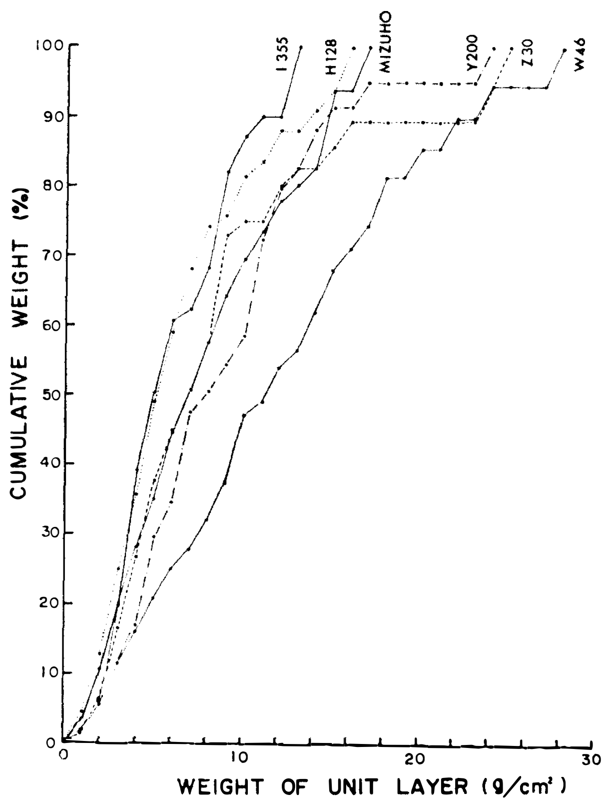


*Fig. 9. Cumulative curves of weight of unit layer in the 10-m cores from W46, H128, Z30, Mizuho Station, Y200 and I355.*

vation of all structures observed in the core. These depth intervals are 20.50–23.40, 32.60–35.60, 41.50–44.30 and 62.50–65.50 m.

Thick ice crusts are seen in the first three profiles. Oxygen isotope profile in the uppermost depth interval is shown in Fig. 10. The profiles of depth hoar development are also shown in the right of the stratigraphic diagram. The profiles of grain size and density were omitted because of their less variation than depth hoar development.

In the katabatic wind region of the ice sheet, a cycle of seasonal accumulation or a similar sequence of layer formation is rarely observed (WATANABE, 1978b). Therefore, such classical stratigraphic interpretation as high density and finer-grained layer correspond to winter and low density and coarser-grained layer to the warmer season (LANGWAY, 1970), is not always applicable to the present stratigraphic study.

Consequently, the criterion for interpretation of annual layers was derived from the stratigraphic study of surface layers in Mizuho Plateau (WATANABE, 1978b): Surface leveling occurs generally in summer, during which a thick ice crust develops occasionally. A large deposition with the homogeneous or wind-packed texture occurs in the colder season. On the other hand, a relatively thin layer with the

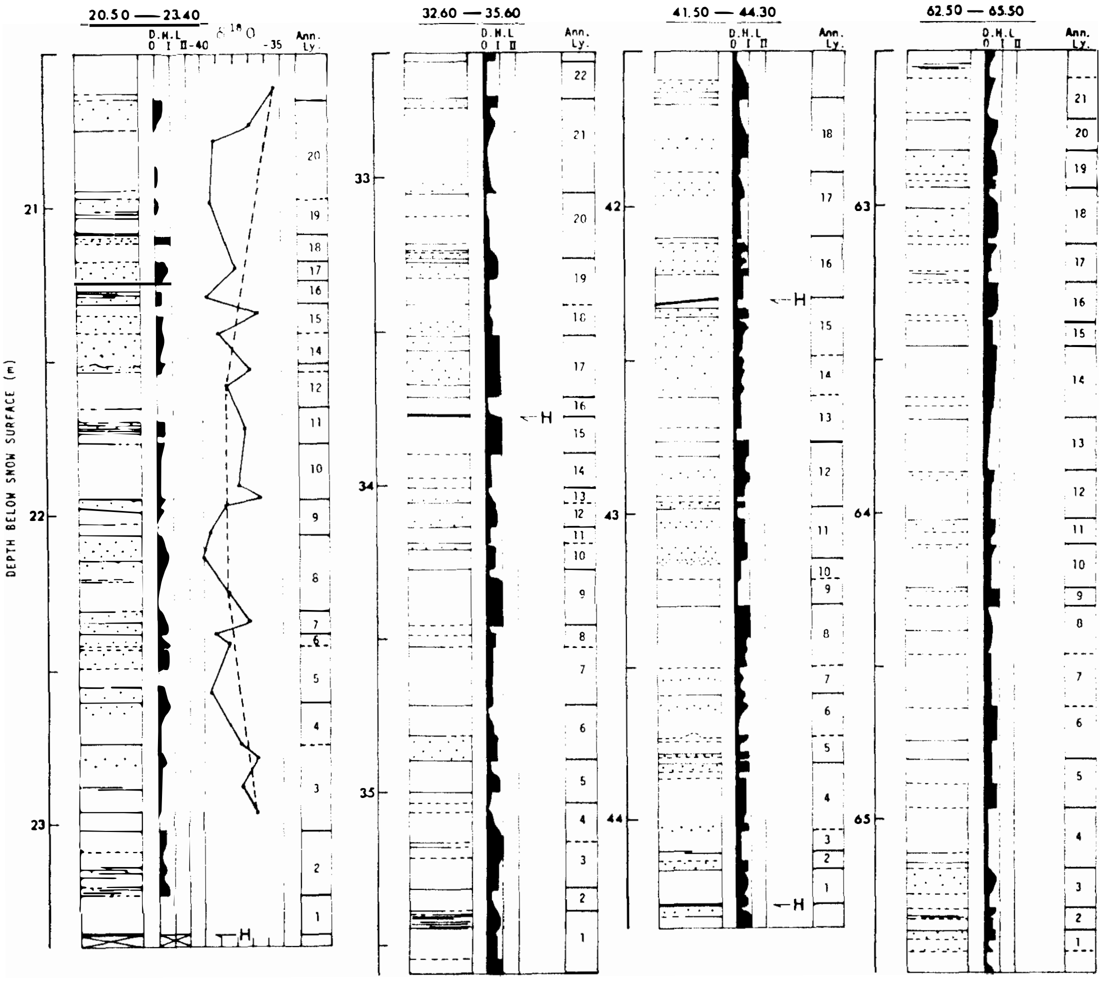

*Fig. 10. Stratigraphic diagrams at various depth of the core. D.H.L.: depth hoar level. $\delta^{18}O$: oxygen isotopic composition in ‰. Ann. Ly.: interpreted annual layer in sequence (solid line: probable, broken line: possible). H: hiatus.*

loose texture is formed in the warmer season. Depth hoar develops in a high degree in the layer deposited in late summer or autumn, as found at Byrd Station by BENSON (1971).

Using this criterion, annual layers of the core were interpreted. The results are shown in Table 2 and Fig. 10. The average accumulations of annual layers in the four depth intervals range from 9.1 to 11.8 g/cm$^2$, the mean value being 10.6 g/cm$^2$.

This mean value of annual accumulation of 10.6 g/cm$^2$ was applied to the dating of the core from Mizuho Station. The results are shown in Fig. 4. The age of the lowermost part of the 150-m core was determined as about 1100 years B.P. excluding the periods of haitus of annual layers.

*Table 2. Estimation of annual accumulation at various depths of the core.*

| Depth range (m) | Depth interval (cm) | Number of layers | Average thickness of an annual layer (cm) | Average density in the depth interval ($g/cm^3$) | Average accumulation of annual layer ($g/cm^2$) |
|---|---|---|---|---|---|
| 20.50–23.40 | 270 | 20 | 13.5 | 0.67 | 9.05 |
| 32.60–35.60 | 297 | 22 | 13.5 | 0.75 | 10.13 |
| 41.50–44.30 | 263 | 18 | 14.6 | 0.79 | 11.54 |
| 62.50–65.50 | 277 | 20 | 13.9 | 0.85 | 11.77 |
| Total average | | 20 | 13.9 | | 10.62 |

## 4. Stratigraphic Analyses of Density Profile

### *4.1. Density profiles as a stratigraphic indicator*

Fig. 11 shows a density profile between the depths of 13 and 63 m of the core from Mizuho Station.

The magnitude of density indicates the compactness of the snow texture. However, the absolute value of density of a layer can not serve as an indicator of its compactness, because the density increases with depth as seen in Fig. 11.

Therefore, a line shown in Fig. 11 was obtained by the least squares method. The line is given by the following equation

$$\rho_0 = 0.361 \log Z + 0.198 \quad (13 \leqq Z \leqq 63), \tag{1}$$

where $Z$ is the depth in m and $\rho_0$ is the density in $g/cm^3$. Here, the deviation $\delta\rho$ of observed density $\rho$ from $\rho_0$ is introduced to be defined by the following equation,

$$\delta\rho = \rho - \rho_0. \tag{2}$$

A vertical profile of $\delta\rho$ is shown in Fig. 12.

A high density ($\delta\rho > 0$) should indicate a densely packed texture, whereas a low density ($\delta\rho < 0$) a loosely packed one. So, the correlation was examined between the value of $\delta\rho$ and the layer texture determined by a visual analysis. Taking the accuracy of measurement into account, the values of $\delta\rho$ for $|\delta\rho| > 0.01$ $g/cm^3$ were used.

It was found that 92% of 209 sample layers between the depths of 13 and 63 m show good correlations, but the good correlations rapidly decrease in the layers below a depth of 50 m. The initial textures formed at the surface may be considered to have been preserved fairly well in the layers above a depth of 50 m.

### *4.2. Periodic variations in $\delta\rho$ profile*

Periodic variations in the $\delta\rho$ profile should indicate environmental changes at the surface such as annual or longer variation in climatic conditions.

The analytical procedure for the periodic variations in the $\delta\rho$ profile consists

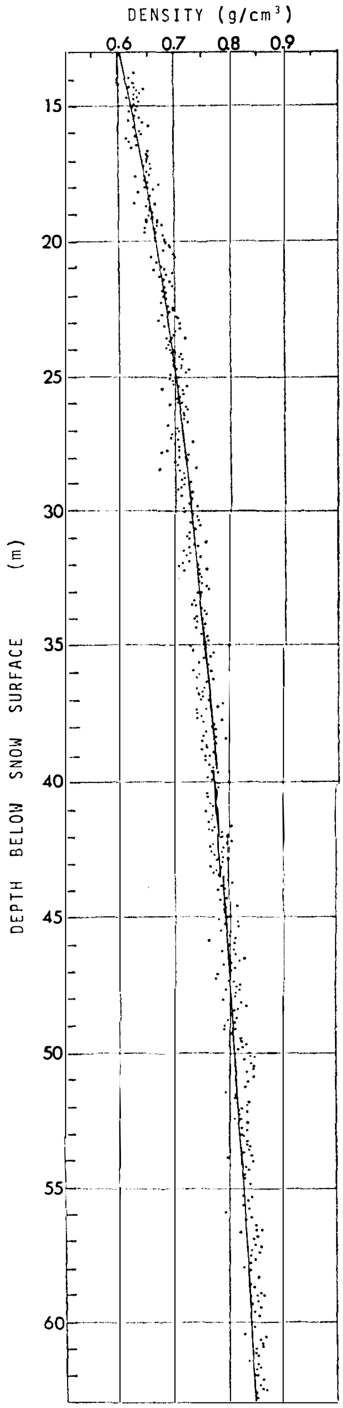


*Fig. 11. Density profile in the depth of 13 to 63 m of the core. A solid line shows the curve obtained by the least squares method.*

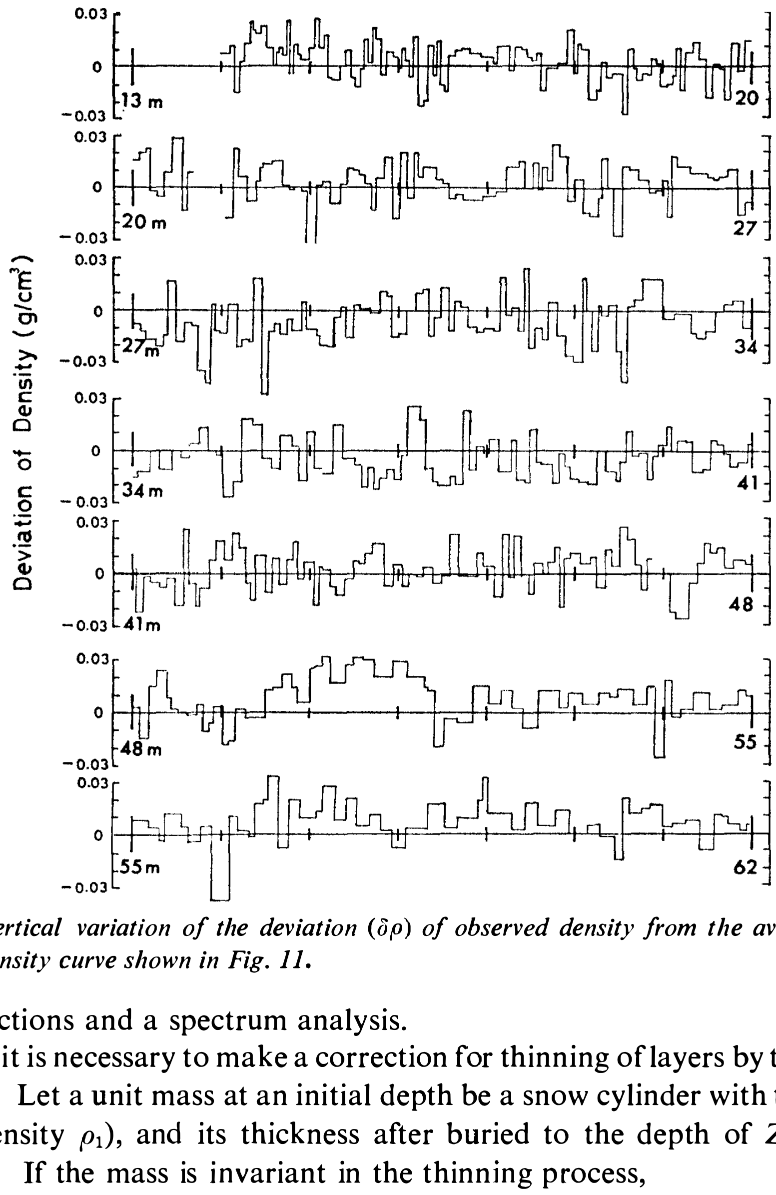


*Fig. 12. Vertical variation of the deviation ($\delta\rho$) of observed density from the average depth-density curve shown in Fig. 11.*

of two corrections and a spectrum analysis.

At first, it is necessary to make a correction for thinning of layers by the following calculation. Let a unit mass at an initial depth be a snow cylinder with the thickness of $A$ cm (density $\rho_1$), and its thickness after buried to the depth of $Z$ m be $B$ cm (density $\rho_2$). If the mass is invariant in the thinning process,

$$\rho_1 A = \rho_2 B. \tag{3}$$

Therefore, if the line in Fig. 11 can be assumed as a curve of densification, we can substitute $\rho_2$ as $\rho_0(Z)$.

$$\frac{A}{B} = \frac{\rho_2}{\rho_1} = \frac{0.361 \log Z + 1.198}{\rho_1}. \tag{4}$$

Let the initial depth be 14 m, for convenience. Then $\rho_1$ is equivalent to 0.611 g/cm$^3$. The thickness of the layer in each depth is covertible into the thickness at the depth of 14 m by eq. (4). Thus, using a standard depth interval at the depth of 14 m, the rearranged depth interval is prepared for analysis of variations in $\delta\rho$ profile. Next, a correction is made for the change of $\delta\rho$ when the density of a sample approaches to the ice density of 0.917 g/cm$^3$, as given by the following equation

$$\delta\rho'_Z = \delta\rho_Z \times \frac{\rho_Z}{\rho_{14}}, \tag{5}$$

where $\delta\rho'_Z$ is the corrected value of $\delta\rho_Z$ at the depth of $Z$ m, and $\rho_Z$ and $\rho_{14}$ are the densities at the depth of $Z$ m and 14 m, respectively.

Finally, a spectrum analysis of $\delta\rho$ was made, in which the depth interval $\Delta Z$ was 5 cm, the maximum lag number $M$ was 90, and the total number of data $Z$ was 1120. The result is shown in Fig. 13. When the level of significance is 5%,

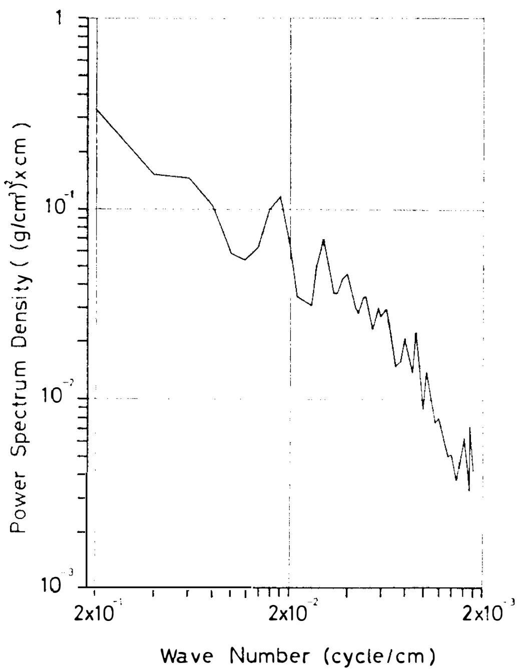


*Fig. 13. Fourier power spectrum density of step curve shown in Fig. 12 of the deviation ($\delta\rho$) of observed density from the average depth-density curve.*

the power spectrum density is significant and has the lag number $M$ equal to 9 and 89. Therefore, the predominant cycles of the periodic variation in the $\delta\rho$ profile are found to have the wave lengths of 45 cm and 445 cm, which may correspond to the oscillations of deposition-erosion process and climate, respectively.

## 5. Oxygen Isotope Profile in the Core

### 5.1. Oxygen isotope determination

Oxygen isotopic composition in the core from the Antarctic and Greenland ice sheets provides paleoclimatic records (DANSGAARD *et al.*, 1969; EPSTEIN *et al.*, 1970; JOHNSEN *et al.*, 1972). A report on the oxygen isotopic composition in the core from Mizuho Station is presented here.

The experimental procedures for the oxygen isotope determination of water samples are essentially the same as those described by EPSTEIN and MAYEDA (1953). The $^{18}O/^{16}O$ ratio of $CO_2$ equilibrated isotopically with a water sample was measured with a double collector mass spectrometer (Varian Mat CH-7) at Department of Earth Sciences, Nagoya University. Analytical results are given in $\delta^{18}O$ notation (CRAIG, 1961) as follows,

$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 1000\ (‰)$$

SMOW: Standard Mean Ocean Water

and analytical error is $\pm 0.2‰$.

For study of the seasonal variation of $\delta^{18}O$ of drifting snow at Mizuho Station, samples were collected on different dates in January 1974—February 1975. For study of the oxygen isotope profile in surface snow cover at Mizuho Station, samples were collected from a pit. All the samples were kept in polyethylene bottles, transported in a frozen state to the refrigerator at Water Research Institute, Nagoya University and melted only just before the oxygen isotope determination.

### 5.2. Oxygen isotope profile in the pit

Fig. 14 shows the snow stratigraphy and the oxygen isotope profile in the pit. The annual range of $\delta^{18}O$ of drifting snow sampled at Mizuho Station in 1974 (KATO, 1977; KATO *et al.*, 1978) is also shown in Fig. 14. Annual layer boundaries (summer surface of every year) after 1970 were determined by artificial marks. The annual accumulation in 1972 was extremely larger than those in the other years.

Every annual layer contains only a few unit layers except for 1972. The patterns of $\delta^{18}O$ profiles in those annual layers differ from each other, as seen in the lower part of Fig. 14. This fact means that a mode of snow accumulation depends largely on the surface condition (WATANABE, 1978a) and snow can accumulate in all seasons under the surface condition favorable to snow accumulation.

Obvious seasonal variation of $\delta^{18}O$ is seen in the firn accumulated in 1972. The amplitude of the seasonal variation of $\delta^{18}O$ is almost the same as that of drifting snow sampled at the surface in 1974, though the annual range of $\delta^{18}O$ in the firn differs, to some extent, from that of drifting snow. This fact supports that snow can accumulate in all seasons under the surface condition favorable to snow accumulation. Since snow accumulation occurred in every season of 1972, the annual

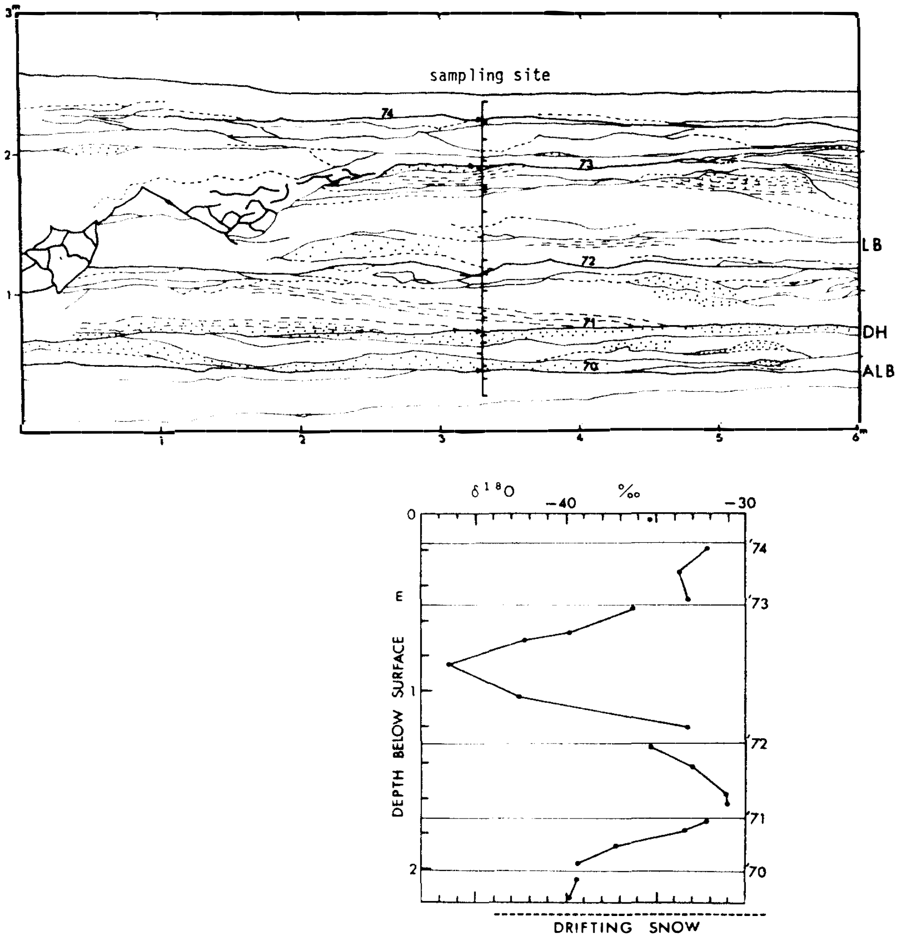


*Fig. 14. Snow stratigraphy and oxygen isotope profile in the pit dug at Mizuho Station. ALB: Annual layer boundary. LB: layer boundary. DH: well-developed depth hoar. A broken line shows the annual range of $\delta^{18}O$ of drifting snow sampled at Mizuho Station in January 1974–February 1975.*

accumulation in 1972 was extremely larger than those in the other years.

*5.3. Characteristics of oxygen isotopic composition in the core*

For study of the oxygen isotope profile in the core, appropriate samples were collected from the cores. All the samples in a liquid state were brought to the laboratory of Water Research Institute, Nagoya University.

The $\delta^{18}O$ values in the depths of 20.60–23.30 m (KATO, 1978b) are shown in Fig. 10. Water vapor diffuses in snow layers during depth hoar formation under a considerable temperature gradient. Diffusion of water vapor contributes to the mass exchange. Accordingly, depth hoar formation causes some change in $\delta^{18}O$ of accumulated snow. Taking the depth hoar formation into consideration, the whole trend of vertical variation of $\delta^{18}O$ can be shown by the vertical variation of

$\delta^{18}O$ of the thick and fine-grained layers with little-developed depth hoar. The vertical variation of $\delta^{18}O$ such layers (KATO, 1978b) is shown as the oxygen isotope profile in the core in Fig. 15, which shows also profiles of stratigraphic elements.

The variation of $\delta^{18}O$ range from $-30.3$ to $-41.2‰$ with a difference of 11‰. The mean value of $\delta^{18}O$ is $-35.7‰$. The $\delta^{18}O$ values larger than $-33‰$ are seen only in the core above a depth of 10 m. In the core below this depth, fairly large fluctuations of $\delta^{18}O$ are seen, which may indicate a climatic change in Mizuho Plateau. The colder the climate, the smaller the $\delta^{18}O$ of snow, and vice versa.

## 6. Long-term Variation in Glaciological Conditions Estimated from Core Analysis

### 6.1. *Periodic variation in climatic and surface conditions in the region around Mizuho Station*

Vertical profiles in the core of frequencies of ice crust and layer boundary without ice crust in each 1 m interval of depth, and the moving average of weights of 11 unit layers are shown in I and II of Fig. 15, respectively. Vertical profiles of $\delta\rho$ and $\delta^{18}O$ are also shown in Fig. 15.

The peaks indicating a cold climate in the $\delta^{18}O$ profile are seen at depths of 17 m (C1), 22 m (C2), 32 m (C3) and 43 m (C4). The smallest values among them is $-41.2‰$, which is less by 5.5‰ than the mean, at the depth of 31.78 m. On the other hand, the peaks indicating a warm climate are found at depths of 10 m (W1), 20 m (W2), 28 m (W3), 37 m (W4) and 53 m (W5). Except for the $\delta^{18}O$ of W1, the other peaks represent the larger values by 2–2.5‰ than the mean.

The pattern of fluctuations in the profile of $\delta^{18}O$ as an indicator of climatic conditions is fairly different from those in the profile of stratigraphic elements as indicators of surface conditions, as seen in Fig. 15. No obvious correlation is seen between the climatic condition and the weight of unit layer or the frequency of ice crust in 1 m interval of depth.

However, the frequency of layer boundary without ice crust and $\delta\rho$ tend to increase under the warm climate and decrease under the cold climate. These facts indicate that the surface condition under the cold climate is more favorable to the formation of ice crust and the depth hoar development than under the warm climate. The $\delta\rho$ oscillation with the wave length of 445 cm shown in Fig. 13 may correspond to a climatic oscillation.

### 6.2. *Periods of hiatus of annual layers*

For a comparison of climatic changes shown in $\delta^{18}O$ profile in the core from Mizuho Station with the world-wide climatic changes, the $\delta^{18}O$ profiles in the cores from both Mizuho Station and Camp Century, Greenland (JOHNSEN *et al.*, 1970) are shown in Fig. 16. As seen in the figure, the profile in the Camp Century core also has several peaks indicating the cold and the warm climate to the depth of 280 m

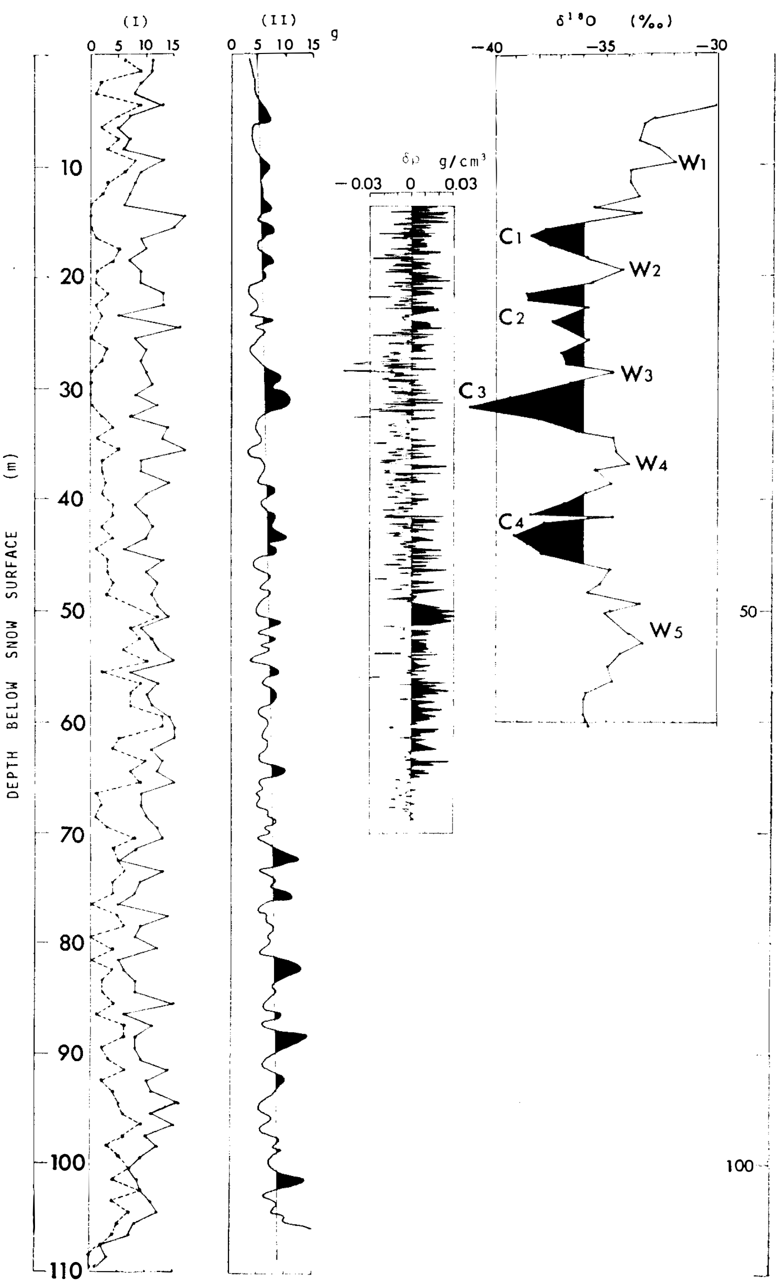


*Fig. 15. Profiles in the core of numbers of ice crust (solid line in I) and layer boundary without ice crust (broken line in I) in each 1 m interval of depth, moving average of weights of 11 unit layers (II), $\delta\rho$ and $\delta^{18}O$.*

estimated to be some 800 years B.P.

A general trend is fairly similar between these two profiles. This means that the $\delta^{18}O$ profiles in the both cores reflect the world-wide climatic change. However, the corresponding peaks in the both profiles are not synchronized. The peaks

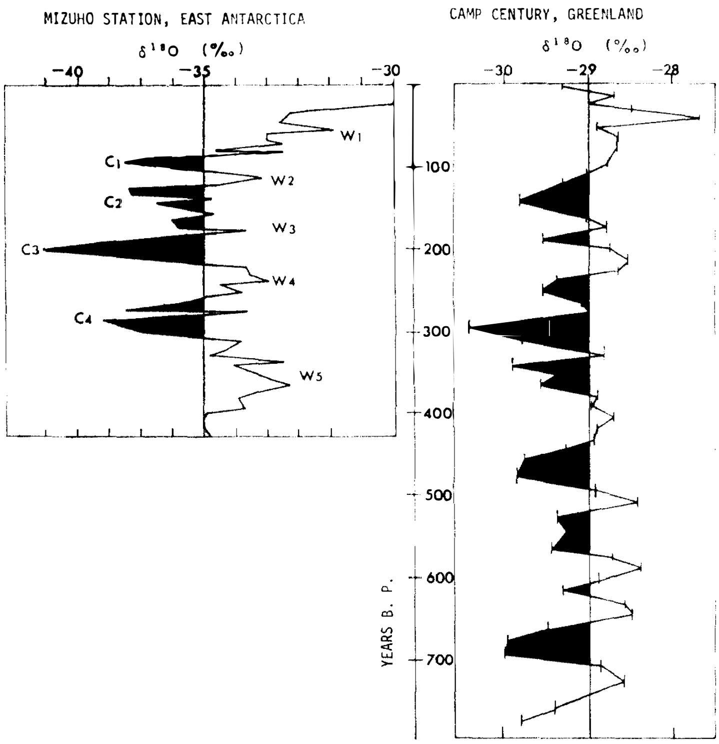


*Fig. 16. Oxygen isotope profiles in the cores from Mizuho Station, East Antarctica and Camp Century, Greenland.*

in the profile of the Mizuho core always lag behind the corresponding those of Camp Century core.

In the Camp Century core was found that the obvious seasonal cycles of $\delta^{18}O$ are preserved to a depth of 1000 m. Therefore, dating of the core by counting the annual layers determined from seasonal cycles of $\delta^{18}O$ is possible to a depth of 1000 m. Furthermore, counting of annual layers in the core is hardly missed, because the annual layers are extremely thick and have many unit layers showing various $\delta^{18}O$ values. So, the dating shown in the Camp Century core is reliable because of the absence of hiatus of annual layers.

In the Mizuho core was found no obvious seasonal cycles of $\delta^{18}O$. Mean annual accumulation of 10.6 g/cm$^2$ estimated from the stratigraphic interpretation was applied to dating of the Mizuho core. Therefore, the determined age is younger by the period of hiatus of annual layers than the real age.

Now, the smallest peak of $\delta^{18}O$ (C3) in the Mizuho core is seen at a depth of 32 m estimated to be some 200 years B.P., while that of Camp Century core is seen at the depth corresponding to some 300 years B.P. The difference of some 100 years between these datings may be due to the occurrence of hiatus of annual layers at Mizuho Station.

If so, the periods of hiatus of annual layers are about one third of the real duration of the core formation and the mean annual accumulation is about two-thirds of 10.6 g/cm$^2$, at Mizuho Station in the past 300 years.

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