OXYGEN ISOTOPE PROFILES IN ADJACENT CORES FROM MIZUHO STATION, EAST ANTARCTICA

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Abstract: Oxygen isotopic composition ($\delta^{18}O$) in the cores from the Antarctic and Greenland ice sheets provides important information about paleoclimatic records. However, the interpretation of the $\delta^{18}O$ values in the cores is not always easy.

Mizuho Station is under the influence of a stationary katabatic wind. Periods of erosion, deposition and neither occur on the snow surface around Mizuho Station. Therefore, the interpretation of $\delta^{18}O$ values in the cores from the station are more complicated. In the present study was discussed how to obtain information about paleoclimatic records from $\delta^{18}O$ in the cores.

$\delta^{18}O$ values of thick and fine-grained layers with little-developed depth hoar were considered to provide the best information about paleo-temperature records, taking into consideration the following factors: 1) Snow does not always accumulate in every season. 2) A glazed surface is occasionally exposed over one year, resulting in an interruption in the annual layer(s). Subsequent movement of water vapor in firn occurs during depth hoar formation under a large temperature gradient. 3) The variation in annual air temperature is best shown by the air temperature in winter. The profile of $\delta^{18}O$ of such layers of one core agrees well with the profile of $\delta^{18}O$ of the long depth interval of another core, which is considered to provide information about the trend of variation of mean air temperature in the long term.

1. Introduction

Oxygen isotopic composition ($\delta^{18}O$) in the cores from the Antarctic and Greenland ice sheets provides important information about paleoclimatic records (DANSGAARD *et al.*, 1969, 1973; EPSTEIN *et al.*, 1970; JOHNSEN *et al.*, 1972). However, the interpretation of $\delta^{18}O$ values in the cores is not always easy (PICCIOTTO *et al.*, 1968; HAMMER *et al.*, 1978; KATO and WATANABE, 1977).

At Mizuho Station core drilling operations were conducted by the Japanese Antarctic Research Expedition during the period between 1970 and 1975. Four core holes were drilled to the depths of about 40 m, 75 m, 145 m and 150 m. Various observations and analyses were made by using the holes as well as the cores obtained (KUSUNOKI and SUZUKI, 1978).

Mizuho Station is under the influence of a katabatic wind. As pointed out by

KATO and WATANABE (1977), $\delta^{18}O$ in a core is controlled by the following factors: 1) Snow does not always accumulate in every season. 2) A glazed surface is occasionally exposed over one year and subsequent movement of water vapor in firn occurs during depth hoar formation. Therefore, interpretation of $\delta^{18}O$ values in the Mizuho Station cores becomes more complicated. In the present study we discuss how to obtain information about paleoclimatic records from $\delta^{18}O$ in the cores.

2. Climatic Conditions at the Drilling Site

2.1. Geographical situation

Mizuho Station (formerly Mizuho Camp; officially renamed Mizuho Station in March 1978) was established by the 11th Japanese Antarctic Research Expedition (JARE-11) in July 1970 as an intended site of a core drilling operation. The inland station is located at 70°41′53″S and 44°19′54″E, and lies at an altitude 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. Meteorological conditions

From the data of meteorological observation since 1971 (YAMADA *et al.*, 1974; KAWAGUCHI, 1975, 1979; WADA *et al.*, 1980; NISHIO and KAWAGUCHI, 1977; FUJII and KAWAGUCHI, 1978), meteorological conditions are as follows: The annual air temperature ranges from −57.7°C to −4.3°C with a mean of −32°C. The direction of prevailing wind is around E-ESE with an annual mean velocity of 10 m/s. The snow temperature at a depth of 10 m at this station was −33°C (SATOW, 1977, 1978).

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

From measurements of snow accumulation with snow stakes, the mean annual accumulation in 1972–1975 is estimated to be about 4.5 g/cm^2 (OKUHIRA and NARITA, 1978). However, a glazed surface with interruptions in the annual layer(s) overspread the stake farm. Therefore, the conditions of snow accumulation are considered to be more complicated. From stratigraphic interpretation of the Mizuho Station core, about 10.6 g/cm^2 is estimated to be the mean annual accumulation, when the periods of interruptions in the annual layer(s) are excluded (WATANABE *et al.*, 1978). Comparison of the oxygen isotope profile in the Mizuho Station core with that in the Camp Century core indicates that the period of interruptions in the annual layer(s) 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 in the past 300 years (KATO *et al.*, 1979).

2.3. Surface conditions

Observations of surface features in the region of the drilling site and Mizuho

Plateau have been made by WATANABE and YOSHIMURA (1972), WATANABE (1978a) and OKUHIRA and NARITA (1978).

In the region of the drilling site, dunes representing a typical depositional form are brought about by cyclonic disturbances and occur predominantly in the direction deviating by 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 deviating by 30 degrees to the left from the direction of the maximum slope.

Frequent occurrences of glazed surfaces 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 interruptions in the annual layer(s). Most of the surface around the station is usually glazed.

WATANABE (1978a) showed from observations of surface features in Mizuho Plateau that a glazed surface occurs in the region between 1800 and 3200 m in altitude, and a highly developed glazed surface occurs in the region between 2500 and 3100 m in altitude. The occurrence of a highly developed glazed surface near the station may be due to the temporal local topography of the ice sheet.

3. Oxygen Isotope Determination

3.1. *Core samples*

The adjacent cores used in this study are a 75 m core and a 145 m core, which were obtained in 1971 by JARE-12 and in 1974–1975 by JARE-15 and JARE-16, respectively. The drilling site for the 75 m core was constructed in 1971 by JARE-12. That for the 145 m core is about 50 m from that for the 75 m core and was constructed in 1974 by JARE-15, as summarized by SUZUKI and TAKIZAWA (1978).

The JARE-12 cores (75 m) were wrapped with aluminum foil and put in polyethylene bags. Then they were packed in cartons lined with polystyrenefoam boards. The JARE-16 cores (145 m) were put in polyethylene bags and placed in ordinary cartons with snow as insulator and spacer. The cores packed in the containers were transported to Japan under refrigeration. The JARE-12 cores were sampled in the cold room of the Institute of Low Temperature Science, Hokkaido University, Sapporo. The JARE-16 cores were sampled in the cold room of the Department of Glaciology, National Institute of Polar Research, Tokyo. The sampled cores were put in polyethylene bottles and melted. Core melt was poured into 30 m*l* glass bottles and transported to Water Research Institute, Nagoya University.

3.2. *Experimental procedures*

The experimental procedures for the oxygen isotope determination of water samples are essentially the same as those described by EPSTEIN and MAYEDA (1953). After equilibrating 4 cm^3 (STP) of CO_2 isotopically with 2 m*l* of a water sample at

25°C, the $^{18}O/^{16}O$ ratio of CO_2 was measured with a double collector mass spectrometer (Varian MAT CH-7) at Department of Earth Sciences, Nagoya University for the JARE-12 core samples, and with a triple collector mass spectrometer (Varian MAT 250) at Water Research Institute, Nagoya University for JARE-16 core samples.

Analytical results are given in $\delta^{18}O$ notation (CRAIG, 1961) as follows,

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

SMOW: Standard Mean Ocean Water

and the analytical error is $\pm 0.2‰$.

4. Oxygen Isotope Profile in Surface Snow Cover

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. The snow stratigraphy was also determined in the pit (WATANABE *et al.,* 1978).

Figure 1 shows the $\delta^{18}O$ profile in the surface snow cover together with the range of $\delta^{18}O$ of drifting snow (broken line) at Mizuho Station. Annual layer boundaries (summer surface of every year) after 1970 were determined by artificial marks. The annual accumulation in 1972 was much larger than those in the other years.

Seasonal variations and regional characteristics of $\delta^{18}O$ of drifting snow collected at Mizuho Station were studied by KATO (1977) and KATO *et al.* (1977, 1978). According to these studies, the range of $\delta^{18}O$ of drifting snow from January 1974 to February 1975 is between -28.4 and $-44.1‰$, whereas that of fallen snow at Syowa

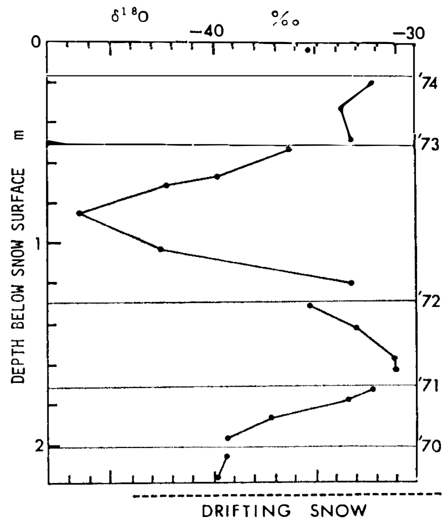

Fig. 1. Oxygen isotope profile in the pit dug at Mizuho Station. A broken line shows the annual range of $\delta^{18}O$ of drifting snow sampled at Mizuho Station in January 1974–February 1975.

Station is between -11.3 and $-36.8‰$ (KATO, 1977, 1978a; KATO *et al.*, 1977, 1978).

Firn for oxygen isotope determination was sampled from each unit layer. From Fig. 1 it is seen that every annual layer contains only a few unit layers, and there is no obvious seasonal variation of $\delta^{18}O$, except for 1972. These facts show that the mode of snow accumulation depends largely on the surface condition.

On the other hand, the seasonal variation of $\delta^{18}O$ was found in the firn accumulated in 1972. Its amplitude is almost the same as that of drifting snow from January 1974 to February 1975, though the annual range of $\delta^{18}O$ in the firn in 1972 differs, to some extent, from that of drifting snow. These facts show that snow can accumulate in every season under the surface condition favorable to snow accumulation. Since snow accumulation occurred in every season of 1972, the annual accumulation in 1972 was extremely larger than those in the other years.

Many cores from Greenland and Antarctic ice sheets show an obvious seasonal variation of $\delta^{18}O$ (JOHNSEN *et al.*, 1972; KATO and WATANABE, 1977; HAMMER *et al.*, 1978). In the Camp Century core it was found that the obvious seasonal cycles of $\delta^{18}O$ are preserved to a depth of 1000 m (JOHNSEN *et al.*, 1972).

In these cores, the annual layers were determined from the seasonal cycles of $\delta^{18}O$. Furthermore, counting of annual layers in these cores is rarely missed, because the annual layers are extremely thick and have many unit layers showing various $\delta^{18}O$ values. Therefore, from $\delta^{18}O$ in these cores important information was obtained about accumulation and date as well as temperature in the past (JOHNSEN *et al.*, 1972; DANSGAARD *et al.*, 1973; HAMMER *et al.*, 1978).

As shown in Fig. 1, no obvious seasonal cycles of $\delta^{18}O$ were found in the surface snow cover at Mizuho Station. The annual layers cannot be determined from the cycles of $\delta^{18}O$. Therefore, information about the variation of annual accumulation and the date of snow accumulation cannot be known from $\delta^{18}O$. Furthermore, it is difficult to obtain information about the variation of air temperature in the past from $\delta^{18}O$.

5. Oxygen Isotope Profiles in the Cores

5.1. *Oxygen isotope profile in the JARE-12 cores*

According to the stratigraphic observation of the cores (NARITA *et al.*, 1978; WATANABE *et al.*, 1978), appropriate samples for the oxygen isotope study were collected. The $\delta^{18}O$ values determined were reported by KATO (1978b).

The $\delta^{18}O$ profile at the depths of 20.62–23.00 m is shown in Fig. 2, together with the stratigraphic diagrams (NARITA *et al.*, 1978; WATANABE *et al.*, 1978).

No obvious seasonal cycles of $\delta^{18}O$ are seen in this figure, as KATO and WATANABE (1977) pointed out in the core drilled in the katabatic wind region. As previously mentioned, this is because snow accumulation in the katabatic wind region hardly occurs in every season.

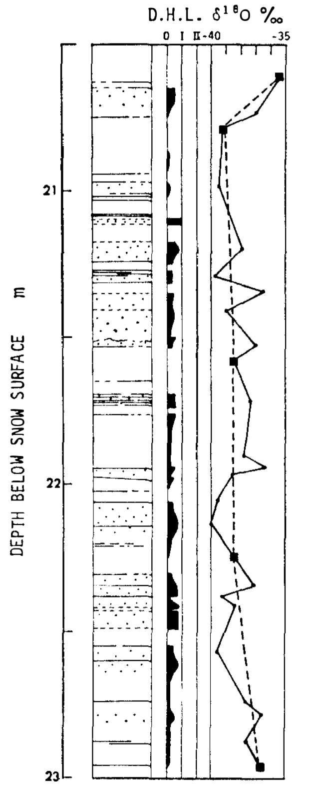

Fig. 2. Oxygen isotope profile and stratigraphic diagrams in the depth range 20.50–23.00 m of the JARE-12 cores from Mizuho Station. Stratigraphic diagrams are after NARITA et al. (1978) and WATANABE et al. (1978). A descriptive legend of stratigraphy and depth hoar level, abbreviated as D.H.L., is shown in WATANABE (1978b) and WATANABE et al. (1978). ■: Thick and fine-grained layer with little-developed depth hoar.

Furthermore, KATO and WATANABE (1977) pointed out that a change of $\delta^{18}O$ in firn is caused by movement of water vapor in firn during depth hoar formation. A glazed surface is occasionally exposed over one year, resulting in interruption in the annual layer(s). Subsequent movement of water vapor in firn occurs during depth hoar formation under a large temperature gradient. Movement of water vapor contributes to mass exchange. Accordingly, depth hoar formation causes some change of the original $\delta^{18}O$ of the accumulated snow.

Thus, the interpretation of $\delta^{18}O$ in the Mizuho Station cores becomes more complicated. How to obtain information about paleo-temperature records from $\delta^{18}O$ in the cores must be carefully examined, taking into consideration the above mentioned factors controlling $\delta^{18}O$ in the cores.

According to the stratigraphic study of surface layers in the katabatic wind region of Mizuho Plateau by WATANABE (1978b), surface leveling occurs generally in summer and a relatively thin layer with loose texture is formed in the warmer season. A thick ice crust develops occasionally during the summer and depth hoar develops to a high degree in the layer deposited in late summer or autumn. On the other hand, a large deposition with homogeneous or wind-packed texture occurs in the winter season.

Since snow does not always accumulate in every season in the katabatic wind region, $\delta^{18}O$ of the layers formed in the same season should be used to obtain information about paleo-temperature records from $\delta^{18}O$ in the cores. Moreover, it is necessary that the original $\delta^{18}O$ of the accumulated snow is well preserved in the cores without significant change of the original $\delta^{18}O$ caused by depth hoar formation.

Taking these factors into consideration, $\delta^{18}O$ of the thick and fine-grained layers with little-developed depth hoar in the cores was considered to provide the best information about paleo-temperature records. The thick and fine-grained layers were formed by large deposition with homogeneous or wind-packed texture in the winter season. As seen from Fig. 2, depth hoar in these layers developed in the lowest degree in the cores. Thus, this selection of $\delta^{18}O$ of the thick and fine-grained layers with little-developed depth hoar, which provides the best information about paleo-temperature records in the cores, satisfies the above two necessary conditions. Moreover, this selection is also supported by the fact that the variation in annual air temperature is best shown by that in the air temperature in winter.

The vertical variation of $\delta^{18}O$ of such layers in the JARE-12 cores is shown in Fig. 3. Fairly large fluctuations of $\delta^{18}O$ are seen in this figure. These fluctuations may indicate a paleo-temperature change. The colder the climate, the smaller the $\delta^{18}O$ and *vice versa.*

5.2. *Oxygen isotope profile in the JARE-16 cores*

About one-third of the drilled JARE-16 cores was lost. Then, these cores were not used for the studies, which were published in "Ice-coring project at Mizuho Station, East Antarctica, 1970–1975" edited by KUSUNOKI and SUZUKI (1978).

No stratigraphic observations were made on these cores. So, $\delta^{18}O$ of long depth interval of core was determined to check the trend of paleo-temperature change shown in the $\delta^{18}O$ profile of the thick and fine-grained layer with little-developed depth hoar in the JARE-12 cores. The $\delta^{18}O$ profile of the long depth interval of core is considered to also provide information about the trend of variation of mean air temperature in the long term. This is because the $\delta^{18}O$ of long depth interval of a core, though it is the mean $\delta^{18}O$ of many unit layers in the long depth interval of the core, may be less affected than the $\delta^{18}O$ of each unit layer by movement of water vapor in firn accompanied by depth hoar formation, and is a composite $\delta^{18}O$ of many layers formed in various seasons.

The vertical variation of $\delta^{18}O$ in the JARE-16 cores is shown in Fig. 3, together with that of the thick and fine-grained layers with little-developed depth hoar in the JARE-12 cores. The former shows, as a matter of course, a smaller amplitude and a lower frequency than the latter. However, the trend of $\delta^{18}O$ variation is surprisingly similar between these two cores. $\delta^{18}O$ variation in the JARE-16 cores follows 2–3 m behind that in the JARE-12 cores. This is reasonable because the drilling site for the JARE-16 cores is about 50 m from that for the JARE-12 cores and was constructed

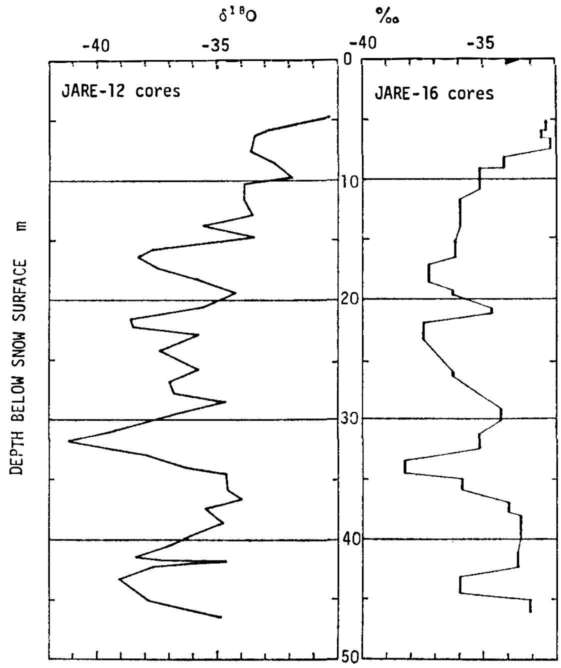

Fig. 3. Oxygen isotope profiles in the adjacent cores from Mizuho Station, JARE-12 cores and JARE-16 cores.

4 years after the construction of that for the JARE-12 cores.

This good agreement of the trend of $\delta^{18}O$ variation between these two cores shows that the trend of $\delta^{18}O$ variation indicates that of paleo-temperature change, and that the method of obtaining information about paleoclimatic records from $\delta^{18}O$ in the cores in the present study is reasonable.

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References

CRAIG, H. (1961): Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. Science, **133**, 1833–1834.

DANSGAARD, W., JOHNSEN, S. J., CLAUSEN, H. B. and GUNDERSTRUP, N. (1973): Stable isotope glaciology. Medd. Grønl., **197**(2), 53 p.

DANSGAARD, W., JOHNSEN, S. J. MØLLER, J. and LANGWAY, C. C., JR. (1968): One thousand centuries of climatic record from Camp Century on the Greenland ice sheet. Science, **166**, 377–381.

EPSTEIN, S. and MAYEDA, T. (1953): Variation of O^{18} content of water from natural sources. Geochim. Cosmochim. Acta, **4**, 213–224.

EPSTEIN, S., SHARP, R. P. and GOW, A. J. (1970): Antarctic ice sheet: Stable isotope analyses of Byrd Station cores and interhemispheric climatic implications. Science, **168**, 1570–1573.

FUJII, Y. and KAWAGUCHI, S. (1978): Meteorological data at Mizuho Station, Antarctica in 1977–1978. JARE Data Rep., **47** (Meterology), 107 p.

HAMMER, C. U., CLAUSEN, H. B., DANSGAARD, W., GUNDERSTRUP, N., JOHNSEN, S. J. and REEH, N. (1978): Dating of Greenland ice cores by flow models, isotopes, volcanic debris, and continental dust. J. Glaciol., **20**, 3–26.

JOHNSEN, S. J., DANSGAARD, W., CLAUSEN, H. B. and LANGWAY, C. C., JR. (1972): Oxygen isotope profiles through the Antarctic and Greenland ice sheets. Nature, **235**, 429–434.

KATO, K. (1977): Oxygen isotopic composition and gross β-radioactivity in firn. JARE Date Rep., **36** (Glaciology), 156–167.

KATO, K. (1978a): Factors controlling oxygen isotopic composition of fallen snow in Antarctica. Nature, **272**, 46–48.

KATO, K. (1978b): Oxygen isotopic composition in the cores from Mizuho Station. Mem. Natl Inst. Polar Res., Spec. Issue, **10**, 165–166.

KATO, K. and WATANABE, O. (1977): Nankyoku Mizuho Kôgen kara eta sensô bôringu koachû no sanso dôitai no bunpu (Oxygen isotope profiles in firn cores from Mizuho Plateau, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **58**, 254–262.

KATO, K., WATANABE, O. and SATOW, K. (1977): Nankyoku Mizuho Kôgen no yuki no sanso dôitai sosei (Oxygen isotopic composition of snow on Mizuho Plateau, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **58**, 263–270.

KATO, K., WATANABE, O. and SATOW K. (1978): Oxygen isotopic composition of the surface snow in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 245–254.

KATO, K., WATANABE, O., SATOW, K. and OKUHIRA, O. (1979): Rate of snow accumulation determined from oxygen isotope and stratigraphic analyses of the core from Mizuho Station, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **14**, 88–92.

KAWAGUCHI, S. (1975): Meteorological data at Mizuho Camp, Antarctica in 1974–1975. JARE Data Rep., **30** (Meteorology), 35 p.

KAWAGUCHI, S. (1979): Meteorological data at Mizuho Station, Antarctica in 1978. JARE Data Rep., **52** (Meteorology), 91 p.

KUSUNOKI, K. and SUZUKI, Y. ed. (1978): Ice-coring project at Mizuho Station, East Antarctica, 1970–1975. Mem. Natl Inst. Polar Res., Spec. Issue, **10**, 172 p.

NISHIO, F. and KAWAGUCHI, S. (1977): Meteorological data at Mizuho Camp, Antarctica in 1976–1977. JARE Data Rep., **40** (Meteorology), 68 p.

OKUHIRA, F. and NARITA, H. (1978): A study of formation of surface snow layer. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 140–153.

PICCIOTTO, E., CAMERON, R., CROZAZ, G., DEUTSCH, S. and WILGAIN, S. (1968): Determination of the rate of snow accumulation at the pole of relative inaccessibility, Eastern Antarctica: A comparison of glaciological and isotopic methods. J. Glaciol., **7**, 273–287.

SATOW, K. (1977): Snow temperature at a depth of 10 meters. JARE Data Rep., **36** (Glaciology), 59–60.

SATOW, K. (1978): Distribution of 10 m snow temperatures in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 264–274.

WADA, M., YAMANOUCHI, T., MAE, S. and KAWAGUCHI, S. (1980): Meteorological data at Mizuho Station, Antarctica in 1979. JARE Data Rep., **57** (Meteorology), 91 p.

WATANABE, O. (1978a): Distribution of surface features of snow cover in Mizuho Plateau. Mem. Natl Instl. Polar Res., Spec. Issue, **7**, 44–62.

WATANABE, O. (1978b): Stratigraphic studies of the snow cover in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 154–181.

WATANABE, O., KATO, K., SATOW, K. and OKUHIRA, F. (1978): Stratigraphic analyses of firn and ice at Mizuho Station. Mem. Natl Inst. Polar Res., Spec. Issue, **10**, 25–47.

WATANABE, O. and YOSHIMURA, A. (1972): Mizuho Kansokukyoten fukin no seppyogaku-teki jôtai ni tsuite (Glaciological observations in the vicinity of Mizuho Camp, Enderby Land, East Antarctica, 1970). Nankyoku Shiryô (Antarct. Rec.), **45**, 20–30.

YAMADA, T., SASAKI, H. and KAWAGUCHI, S. (1974): Meteorological data at Mizuho Camp, Antarctica in 1971–1973. JARE Data Rep., **25** (Meteorology), 85 p.

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