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MICROPARTICLE CONCENTRATION AND ELECTRICAL CONDUCTIVITY OF A 700 m ICE CORE FROM MIZUHO STATION, ANTARCTICA

by

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ABSTRACT

The present paper gives the preliminary results of the analyses on microparticle concentration and electrical conductivity of a 700.56 m ice core from Mizuho Station, Antarctica. Concentration of microparticles coarser than 0.63 μm in diameter increases more than twofold at the 240–440 m depth interval compared with that below 440 m in depth. The higher particle concentration is well associated with higher electrical conductivity and lower $\delta^{18}O$. Periods of high particle concentration are estimated to be 3000–6000 years B.P. A visible volcanic dirt band was found at 500.7 m below the surface. This dirt band may be isochronous with the shallowest ash band of the Byrd Station core, found at 799 m depth. The present study indicates that large-scale environmental changes possibly occurred in the Southern Hemisphere in the middle of the Holocene.

INTRODUCTION

In August 1984, the 25th Japanese Antarctic Research Expedition (JARE-25) succeeded in drilling an ice core to a depth of 700.56 m at Mizuho Station (70°42'S, 44°20'E; 2230 m a.s.l.; Fig.1). The ice-core samples were transported from Mizuho Station to Tokyo by the icebreaker *Shirase* and were stored at about −20°C in a cold laboratory at the National Institute of Polar Research (NIPR) in April 1985.

As the first step in reconstructing past large-scale climatic and environmental changes during the Holocene as they affected this Mizuho core, we started systematic analysis of microparticle concentration, electrical conductivity and $\delta^{18}O$.

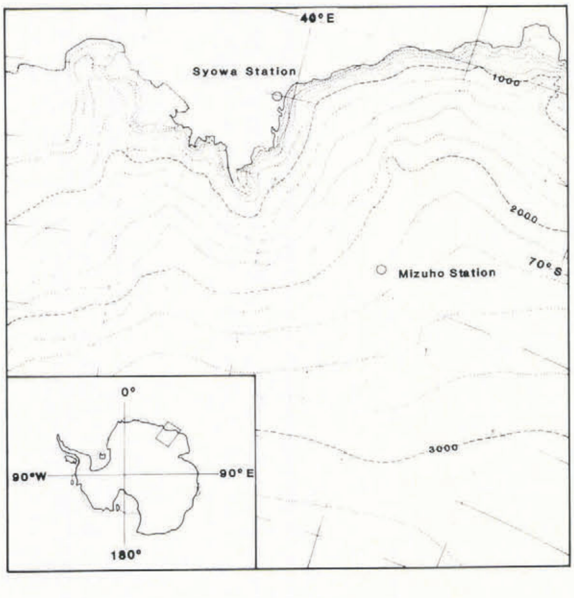

Fig.1. Location of Mizuho Station.

Insoluble microparticles contained in the Antarctic ice sheet originate primarily from arid regions in the Southern Hemisphere and from local–regional volcanic activity. So the concentration of microparticles in an Antarctic ice core possibly indicates such past environmental and climatic changes as the extent of the arid region, the strength of meridional air-mass transportation and local–regional volcanic activity. The electrical conductivity of melted samples from an ice core provides the primary information on the content of ionic impurities originating from sea salt and mineral acid.

The present paper shows the results obtained hitherto and gives preliminary interpretations of the variation in microparticle concentration, electrical conductivity and $\delta^{18}O$. The ice coring techniques and various results of ice-core analyses are outlined by Narita and others (1988, this volume) and Higashi and others (1988, this volume) respectively.

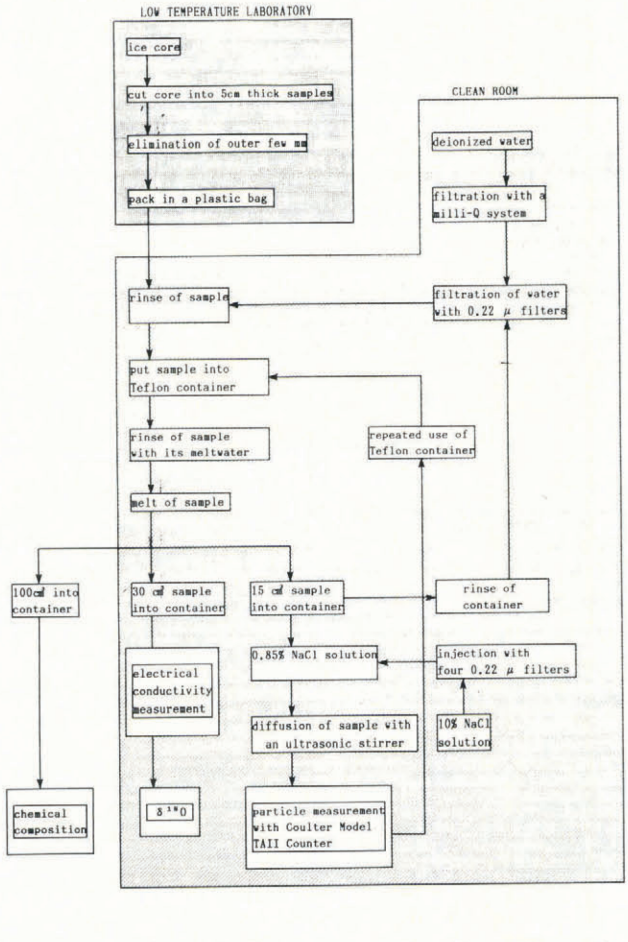

Fig.2. Processing of ice-core samples for microparticle counting and electrical conductivity measurement.

LABORATORY TECHNIQUES

Sample preparation and measurements of microparticle concentration and electrical conductivity were carried out in the NIPR and the procedure is summarized in Figure 2.

Sample preparation

Ten successive samples, approximately 5 cm thick, are cut at 5 m depth intervals from a 50 cm long core which had been cut in half vertically, and their outer few mm are then eliminated with a band saw at −20°C in a low-temperature laboratory. The latter procedure is carried out (wearing disposable polyethylene gloves) in order to remove most of the contaminated outer parts of the core.

Samples are then moved from the low-temperature laboratory to a refrigerator, where they are stored at −10°C. This is done in order to avoid fracturing when their outer few mm are melted away by pouring clean water over their outer surface. Clean water is provided by a Milli-Q system in a class 1000 clean-room. A further few mm of the surface of the sample are allowed to melt in a Teflon container and it is then rinsed with its melt water. After the self-rinsing, the melt water is abandoned and this procedure is repeated twice.

After melting, the sample is divided between three sample containers: 15 cm^3 for microparticle analysis, 30 cm^3 for measurements of electrical conductivity and stable oxygen-isotope composition, and the remainder of about 100 cm^3 for major chemical-composition analysis.

For microparticle analysis, 15 cm^3 of the sample is converted into 0.85% (concentration equivalent to Isoton-II, which is used as an electrolyte) NaCl electrolyte by injecting the appropriate amount of 10% NaCl solution, using a plastic syringe with four 0.22 μm pore-sized Millex (Millipore Corporation) filter units. The samples are analyzed on the day of preparation.

Particle counting

We use the Coulter model TAII counter in our analysis. Before analysis, suspended particles are diffused uniformly with an ultrasonic stirrer for about 10 s. 0.05 cm^3 of water sample is analyzed repeatedly to obtain the average counts.

For particle analysis with the counter, a 30 μm aperture tube is used and particles are electrically separated into 16 size ranges between 0.25 and 8.00 m in diameter; smaller particles, less than 0.63 μm in diameter, are excluded from the analysis in order to avoid inaccurate counting due to electric noise.

Particles coarser than 10 μm in diameter do not occur in the water sample for particle counting because they have already been precipitated in melt water by the time the melt water is put into three containers for analysis, less than 5 min after the melting of the ice. Stokes' law gives velocity (v) of a spherical particle with diameter d and specific gravity ρ′, moving through a fluid with specific gravity ρ and kinematic viscosity ν:

$$v = \frac{1}{18}\left(\frac{\rho'}{\rho} - 1\right)\frac{g}{\nu}d^2$$

As the depth of melt water in a Teflon container is about 3 cm, Stokes' law means that most particles larger than 10.6 μm in diameter are precipitated in 5 min.

Electrical conductivity measurement

Electrical conductivity of the melt-water sample is measured at 20°C in less than 5 min after melting the ice with an AOC-10 meter manufactured by the Denki Kagaku Keiki Co. Ltd. The measurement is made in a class 1000 clean-room. (No correction of ambient CO_2 is made.)

Stable oxygen isotope $\delta^{18}O$

The stable oxygen-isotope composition ($\delta^{18}O$) is measured on a mixed melt-water sample prepared by mixing ten successive samples of 3 cm^3 each, cut at 5 m depth intervals from a 50 cm long ice core. For the depth range from 5 to 150 m, however, $\delta^{18}O$ was measured for individual samples 3–5 cm thick which had been cut successively from the core.

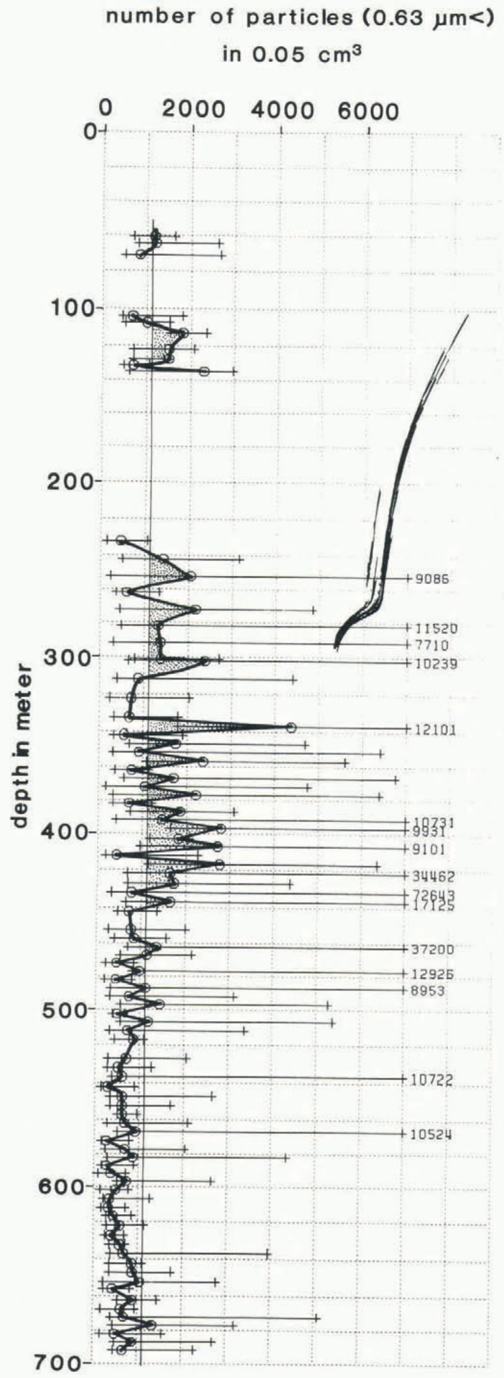

Fig.3. The maximum, minimum and median values of microparticle concentration of ten samples selected at 5 m depth intervals from a 50 cm long core. The arithmetic mean of the median values, 1070 per 0.05 cm^3, is shown as a vertical straight line.

3. RESULTS

Microparticle concentration

The maximum, minimum and median values of the ten successive samples which had been selected at 5 m depth intervals from a 50 cm long core are illustrated in Figure 3. The maximum value exceeds 7000 per 0.05 cm^3 at several depths between 250 and 570 m below the surface, as indicated by the numbers to the right of the horizontal lines. The arithmetic mean of the median values through the total depth is 1070 per 0.05 cm^3; it is shown as a vertical straight line. The minimum value ranges from 80 to 1100 per 0.05 cm^3.

The general tendency of the variation in microparticle concentration is given by the profile of the median values. Particle concentration is higher at a depth interval from 240

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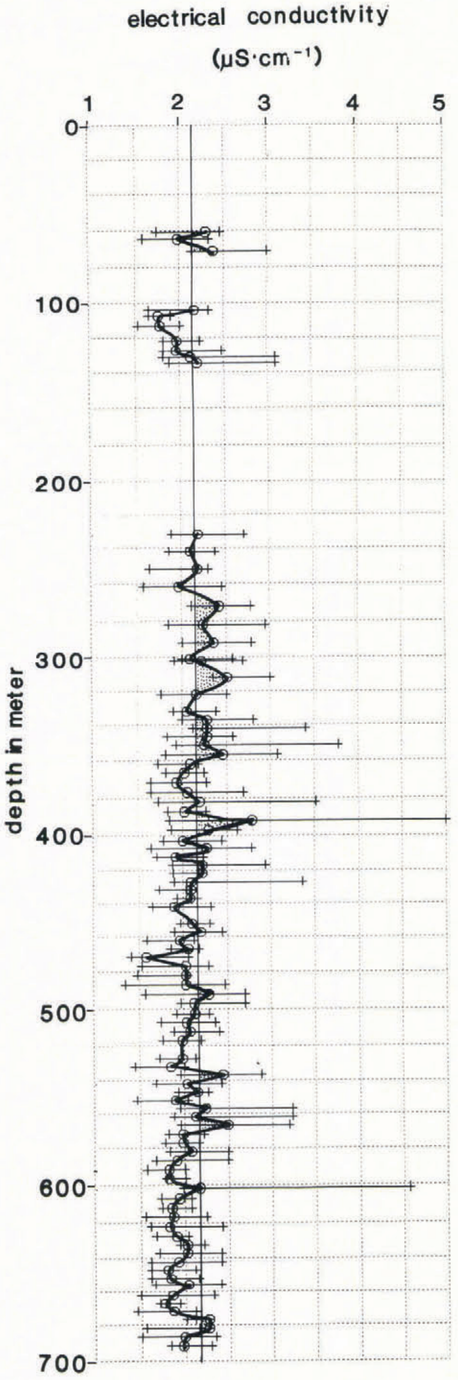

Fig.4. The maximum, minimum and median values of electrical conductivity among ten successive samples selected at 5 m depth intervals from a 50 cm long core. The arithmetic mean of the median values, 2.16 μs cm^{-2}, is shown as a vertical straight line.

to 440 m than at a depth below 440 m. The average concentration of the median values between 240 and 440 m depth is 1560 per 0.05 cm^3, i.e. more than double the 700 per 0.05 cm^3 which is found below 440 m depth.

Concentration higher than the average of 1070 per 0.05 cm^3 appears at depth intervals of 110–130, 240–300 and 340–440 m. In particular the median value exceeds 2000 per 0.05 cm^3 at depths of 250, 270, 300, 340, 360, 380, 400, 410 and 420 m, i.e. at a depth range between 250 and 420 m.

Electrical conductivity

Figure 4 shows the maximum, minimum and median values of electrical conductivity in ten successive samples cut at 5 m depth intervals from each 50 cm long core.

Electrical conductivity ranges from 1.34 to 4.99 μS cm^{-1} and takes 2.16 μS cm^{-1} as an arithmetic mean of the median values through the total depth. The median value higher than its average appears at depth intervals of 265–360, 390–400, 495–540 and 555–570 m. High minimum values, which exceed 2.0 μS cm^{-1}, appear at depths of 272, 291, 311, and 341 m, where higher median values are measured.

Stable oxygen isotope, δ^{18}O

The depth profile of δ^{18}O is shown in the paper by Higashi and others (1988, this volume).

DISCUSSION

Estimate of core age

A break in seasonal layer formation frequently occurs at Mizuho Station. According to accumulation measurements at nine snow stakes, mean monthly snow accumulation was positive in only 16 out of 55 months from June 1976 to December 1980 (Fujii and Ohata 1982). It is, therefore, clear that it is impossible to estimate the age of the 700 m Mizuho core by counting the number of such seasonal peaks as the oxygen-isotope ratio (Dansgaard and others 1973), microparticle concentration (Thompson and others 1981) or chemical composition (Herron and Langway 1979).

As the first step in estimating the age of the 700 m core from Mizuho Station, we adopt Nye's time-scale. Although the station is not located at the center of a steady-state ice sheet, Nye's time-scale is thought to give an approximate but reasonable age for the Mizuho 700 m ice core because it was recovered from the shallow part of the ice sheet at Mizuho Station and ice thickness and the snow-accumulation rate do not vary greatly up to about 100 km up-stream of Mizuho Station.

$$t = \left(\frac{H}{a}\right) \ln(1 - Z/H)$$

where t is the age of ice before present, z is the ice-equivalent depth, H is the ice equivalent thickness, and a is the annual accumulation rate (ice equivalent).

As the annual accumulation rate at Mizuho Station, we take 7 g cm^{-2} on the basis of a regional annual mean snow-depth accumulation of 16 cm (Watanabe and others 1988, this volume) and a regional mean surface-snow density of 0.44 g cm^{-3} (Ohmae 1984) respectively around Mizuho Station. On the basis of these conditions, the 700 m depth at Mizuho Station is calculated as 10 500 years old. This means that the 700 m Mizuho ice core may cover the major part of the Holocene period.

Climatic conditions during the period of high particle concentration in the Holocene

Figure 5 shows the depth profiles of microparticle concentration, electrical conductivity and δ^{18}O, on the time-scale discussed in the previous section.

The straight line for δ^{18}O in Figure 5 indicates the standard depth profile which is obtained on the assumption of unchanged ice dynamics and climatic conditions during the last 10 k/a. On the basis of present spatial distribution of the surface velocity and age–depth relationship, the straight-line profile of δ^{18}O may correspond to the present spatial distribution of δ^{18}O along the up-stream flow from Mizuho Station, which is shown by Watanabe and others (1988, this volume). Thus the standard δ^{18}O at 600 m depth, for example, can be given by the present mean of δ^{18}O at the conjunctive point, Y100, which is a glaciological observation point 100 km up-stream of Mizuho Station.

The depth interval of 240–440 m, where particle concentration is higher than the average, coincides well with the depths at which higher electrical conductivity and more negative δ^{18}O than the average values are found in the figure. This may be explained by changes in the climatic environment.

One possible explanation may be the increase in the transportation of aerosol to the Antarctic ice sheet: insoluble particles primarily originating from arid regions in the middle and low latitudes of the Southern Hemisphere, as mentioned by Shaw (1979), and soluble particles such as sea

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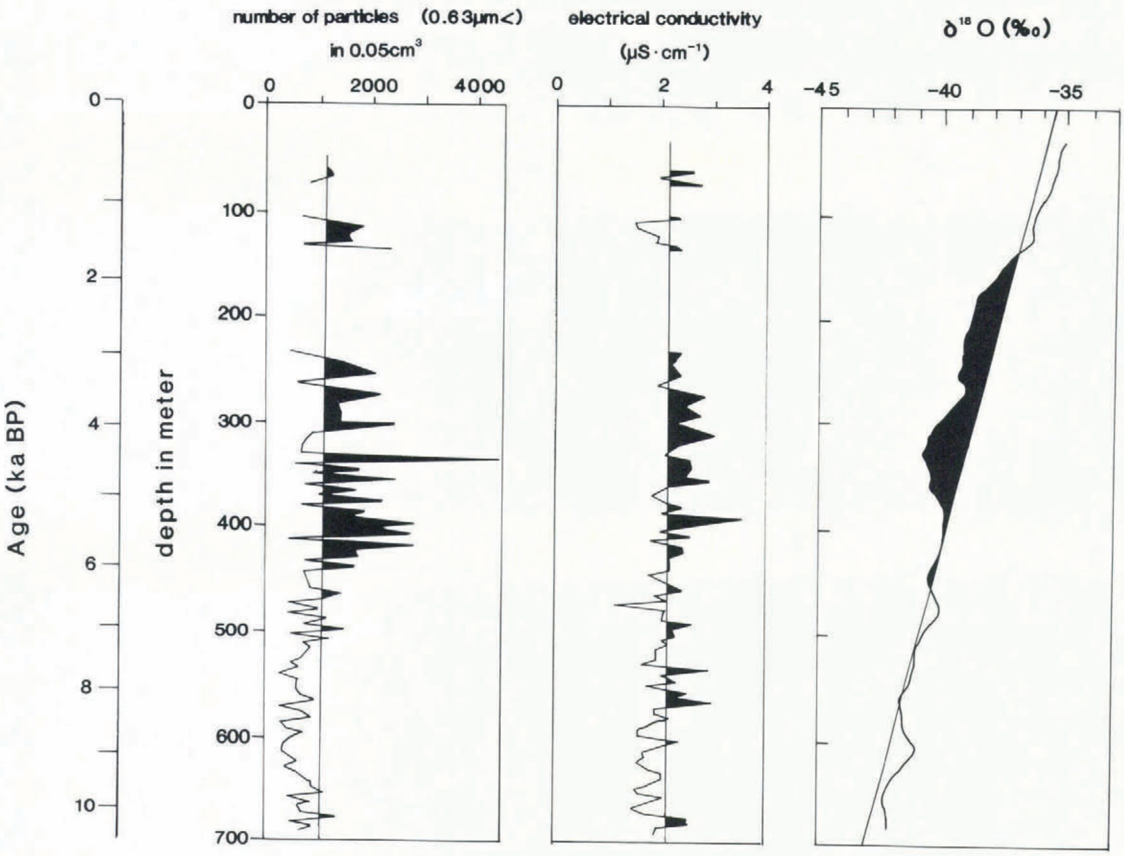

Fig.5. Depth profiles of microparticle concentration, electrical conductivity and $\delta^{18}O$ with age, according to Nye's time-scale.

salt from the Southern Ocean and gas-derived aerosol (Delmas and others 1982).

Greater negative $\delta^{18}O$ values during this period are associated with colder climatic conditions, which may have led to the development of low-pressure disturbances and then caused an increase in transportation of both sea salt from the ocean and particles from the arid regions in the Southern Hemisphere. The latter mechanism was suggested by Petit and others (1981) as an explanation of the intense increases in insoluble particles and soluble oceanic material during the ice age; however, it may not apply to Holocene conditions.

Another possible cause is the decrease or frequent break in the snow-accumulation record at the ice-sheet surface. During such conditions, particles and soluble aerosols in the surface-snow layer probably condense on the ice-sheet surface because of the sublimation of snow particles.

On the basis of the age estimate described in the previous section, the ages of high particle concentration associated with high electrical conductivity and large negative $\delta^{18}O$ are thought to be *c.* 3000–6000 years B.P.

This high particle concentration during the middle of the Holocene has not been reported for other Antarctic ice cores, except in a report on the Byrd Station ice core by Thompson and others (1975). They obtained higher particle concentration during the period from 4000 to 8000 years B.P. (600–700 m depth), but they disregarded it because of probable contamination from fractures.

These high particle concentrations in both the Mizuho Station and the Byrd Station ice cores suggest that the high particle concentration in the Byrd Station ice core is not due to contamination and may have been caused by the area of arid regions which extended widely over the Southern Hemisphere in the middle of the Holocene.

Volcanic events

Only one visible dirt band was found at 500.7 m below the surface. Its thickness is 49 mm. As shown in Figure 6, the boundary between the dirt and the clean parts is clearer at the lower end than at the upper one. Coarse particles with a diameter of about 10 μm are concentrated in the lower part of the dirt band. These characteristics are the same as those of volcanic dust bands seen in the Byrd Station ice core (Gow and Williamson 1971).

The first visible dirt band in the Mizuho Station core may be isochronous with the shallowest ash band, which appeared at 799 m below the surface at Byrd Station (Gow and Williamson 1971). The age of the shallowest ash band of the Byrd Station core is estimated to be 7500 years (Gow and Williamson 1971). On the other hand, the age of the dirt band of the Mizuho Station core is calculated as 7000 years according to Nye's time-scale, as previously mentioned.

The highest electrical conductivity, 4.99 $\mu S\ cm^{-1}$, appears at 392 m depth, as shown in Figure 4. High particle concentration is also measured at the highest electrical conductivity. Figure 7 shows the results of particle concentration, electrical conductivity and SO_4^{2-} composition

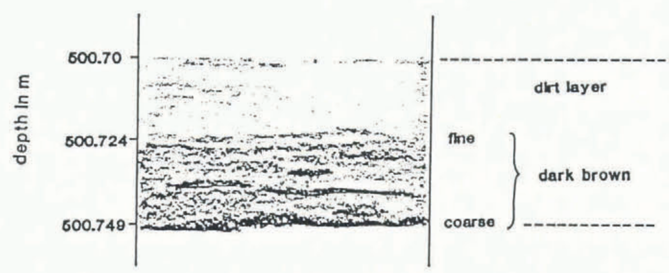

Fig.6. Sketch of a dirt band seen at 500.7 m below the surface.

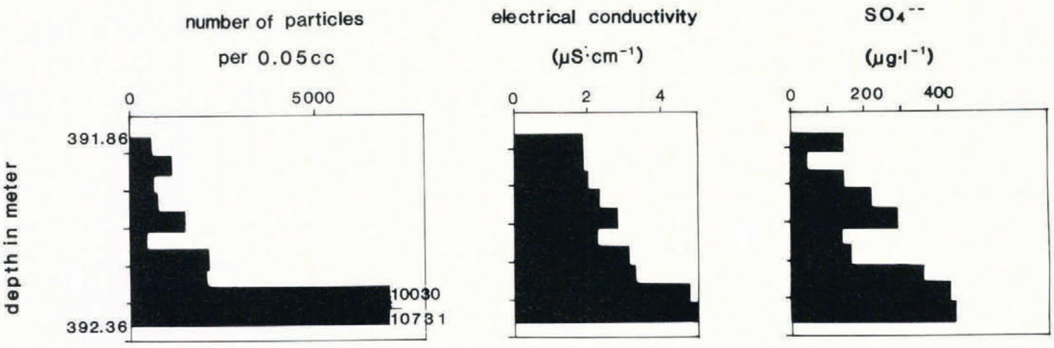

Fig.7. Microparticle concentration, electrical conductivity and SO_4^{2-} content at 391–392 m depth.

analyzed by a Dionex 2000 ion chromatograph. As the variation in SO_4^{2-} composition is well associated with the change in electrical conductivity, the contaminated layer between 392.01 and 392.36 m depth is possibly an invisible volcanic dirt band. The particle concentration shows a peak at the maximum of both electrical conductivity and SO_4^{2-} content. If we assume the particles are of volcanic origin, the volcanic eruption would have been a "local" event, such as a volcanic eruption in West Antarctica or on one of the islands in the Southern Ocean.

CONCLUSION

Analysis of the microparticle concentration of a 700 m deep ice core from Mizuho Station reveals an increase in the concentration which more than doubles at a depth interval of 240–440 m, compared with the depth below 440 m. The age of high particle concentration is estimated to be 3000–6000 years B.P.

The overall increase in microparticle concentration and electrical conductivity and a decrease in $\delta^{18}O$ can be seen from 6000 to 3000 years B.P., in the middle of the Holocene. This may be due to the increase in the transportation of aerosol to the Antarctic ice sheet during the colder period or due to the condensation of both insoluble and soluble particles in snow on the ice-sheet surface by strong sublimation of snow during the period of less or no snow accumulation in the colder period.

A first visible volcanic dirt band found at 500.7 m below the surface may be isochronous with the shallowest ash band of the Byrd Station core which was found at 799 m depth.

The present study reveals an invisible layer which may be influenced by "local" volcanic activity.

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