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BASIC ANALYSES OF DOME FUJI DEEP ICE CORE PART 1: STABLE OXYGEN AND HYDROGEN ISOTOPE RATIOS, MAJOR CHEMICAL COMPOSITIONS AND DUST CONCENTRATION

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Abstract: Basic chemical analyses of a 2503 m deep ice core obtained at Dome Fuji Station, Antarctica in 1995–1996 were carried out to determine stable oxygen and hydrogen isotope ratios, major chemical compositions and microparticle concentrations. We here describe the analytical procedure and the results as well as the determination of working time scale. The ice core covers the past 340 ka which includes three glacial-interglacial cycles clearly shown by the stable oxygen isotope profile. Major chemical compositions and microparticle concentrations larger than 0.52 μm show high concentrations in glacials and low in interglacials.

1. Introduction

The Antarctic ice sheet preserves past global scale climate and environment signals, which are indicated by stable isotope ratios of oxygen and hydrogen in water molecules, primary aerosols such as sea salt and dust, secondary aerosols such as sulfate and nitrate, and so on. To reconstruct long term paleocimate, deep ice core drillings have been carried out at Vostok (*e.g.* PETIT *et al.*, 1999), Byrd (*e.g.* PALAIS and LEGRAND, 1985), Dome-C (*e.g.* LORIUS *et al.*, 1979) and Low Dome (*e.g.* MORGAN *et al.*, 1997) in Antarctica.

To clarify past climatological and glaciological features of the Antarctic ice sheet in Dronning Maud Land, a 2503 m deep ice core was obtained at Dome Fuji Station (77° 19′01″S, 39° 42′12″E; elevation 3810 m a.s.l.), the highest point of Dronning Maud Land, Antarctica, in 1995–1996 (Dome-F Deep Ice Coring Group, 1998). *In-situ* core analyses were performed on stratigraphical features, bulk density and AC- and DC-ECM (electrical conductivity measurement; HAMMER, 1980). The core was cut in

three along the core axis in area ratios of 60% (A core), 25% (B core) and 15% (C core). Each of these core pieces was then cut into 50 cm sections for packing. The B and C cores have been used for basic analyses mainly on physical and chemical properties, respectively. The A core will be used for gas content and future analyses (DOME-F DEEP ICE CORING GROUP, 1998).

Objectives of the basic analyses of Dome Fuji deep ice core are 1) to clarify profiles of chemical and physical properties at fixed depth intervals through the whole core depth, and 2) to establish the working time scale. Elements of basic chemical analyses are stable oxygen and hydrogen isotope ratios, major chemical compositions and microparticle concentrations, for which analytical methods have been established. The preliminary results of stable oxygen and major chemical analyses of the ice core together with surface glaciological characteristics were reported by DOME-F ICE CORE RESEARCH GROUP (1998).

In the present paper entitled "Basic analyses of Dome Fuji deep ice core. Part 1: Stable oxygen and hydrogen isotope ratios, major chemical compositions and dust concentration", we describe the results of the basic analysis program of Dome Fuji Ice Core Drilling Project obtained by December 1998. Details of the indivisual data sets and discussions on the data will be given in other papers to be prepared by the proper authors.

2. Method of Basic Analyses

2.1. Ice core cutting and pre-processing for analyses

The C core was used for sample consumption type analyses such as stable oxygen and hydrogen isotope ratios, major chemical compositions and microparticle concentrations. The inner part of the C core was cut for stable oxygen and hydrogen isotope ratio analyses. The outer part was used for the analyses of major chemical compositions and microparticle concentrations.

2.2. Method of analyses

1) Stable oxygen and hydrogen isotope ratios

So-called 'bag samples' of 50 cm long were used for analyses but samples at depths deeper than 2000 m were cut into 25 and 12.5 cm length to obtain ratios averaged over less than 50 years. Outer 1 mm contaminated parts of samples were removed by using a ceramic knife. Preprocessed samples were melted at room temperature in a clean room; three 10 m*l* melted samples were obtained for oxygen and hydrogen isotope analyses, and one spare.

Analyses of stable oxygen and hydrogen isotope were carried out for the samples at 2.5 m depth intervals with a mass spectrometer (Delta E; Finigan Mat Co.) at the National Institute of Polar Research and a mass spectrometer (Mat 252; Finigan Mat Co.) at the Atmospheric and Hydrospheric Research Institute, Nagoya University, respectively. The analytical errors are ± 0.2‰ and ± 1.2‰, respectively. Total numbers of samples analyzed are 1423 for $\delta^{18}O$ and 399 for δD, respectively.

2) Major chemical compositions

Analysis of major chemical compositions was carried out using 7 cm long ice

samples cut at 1 m and 2.5 m depth intervals above and below 430 m depth, respectively. The samples, the outer contaminated part removed with a ceramic knife in a clean bench in a cold laboratory, were preserved in plastic bags, rinsed with ultra pure water to complete elimination of the outer contaminated part in a clean room, and then melted in pre-cleaned Teflon bottles in a refrigerator at $+4°C$.

Analysis was done with ionchromatographs (Dionex DX-500) for anions such as F^-, CH_3COO^-, $HCOO^-$, MSA, CL^-, NO_2^-, NO_3^-, SO_4^{2-}, $C_2O_4^{2-}$, and PO_4^-, and cations such as Na^+, NH_4^+, K^+, Mg^{2+} and Ca^{2+}. The measuring systems, working gradient conditions and detection limits were described in WATANABE *et al.* (1997). The total number of samples analyzed was 1427. The results for shallow depth to 106 m have been reported by WATANABE *et al.* (1997).

3) Microparticle concentration

The same samples as prepared for major chemical composition analysis were used for microparticle analysis with a laser particle counting system (Model No. 211, Met One Co.). The analysis was done for particles larger than 0.52 μm in diameter on their concentration and size distribution. The size distribution was carried out for ten size ranges: 0.52–0.63 μm, 0.63–0.79 μm, 0.79–1.00 μm, 1.00–1.26 μm, 1.26–1.59 μm, 1.59–2.00 μm, 2.00–2.52 μm, 2.52––3.17 μm, 3.17––4.00 μm and larger than 4.00 μm. The total number of samples analyzed is 890.

3. Results of the Analyses

3.1. Time scale

Working time scale of the Dome Fuji deep ice core was calculated using the relationship between the snow accumulation rate and $\delta^{18}O$ value of snow in the area with $\delta^{18}O \geqq -51$ per mil in east Dronning Maud Land (SATOW *et al.*, 1999), and a simple steady state ice flow model proposed by DANSGAARD and JOHNSEN (1969) (WATANABE *et al.*, 1999). The chronological accuracy for this time scale calculation is estimated to be about 20% for long term variations. The age of the ice core at the bottom, 2503 m in depth, is calculated to be 340 ka B.P.

3.2. Stable oxygen and hydrogen isotopes

The profile of the stable oxygen isotope was obtained by using bag sample data for 2.5 m depth intervals and is shown in Fig. 1, which covers the past three glacial cycles (WATANABE *et al.*, 1999). Time scale is shown at the right. The numbers in the figure indicate Marine Isotope Stages (MIS). Accumulation rate (λ_0; cm of ice equivalent/year) and temperature difference, ΔT, between the present temperature and the past value were calculated by using present relationships between $\delta^{18}O$ and accumulation rate, and $\delta^{18}O$ and the 10-m snow temperature, respectively (WATANABE *et al.*, 1999). The figure shows an overall amplitude of glacial-interglacial temperature change is about 8°C for the last glacial termination and ~10°C for the penultimate and antepenult glacial terminations. The amplitudes are close to those of Vostok ice cores (PETEIT *et al.*, 1999).

Profiles of the stable hydrogen isotope ratio (δD) and excess D are shown in Fig. 2. As a result of isotopic fractionation processes occurring in the atmospheric water cycle,

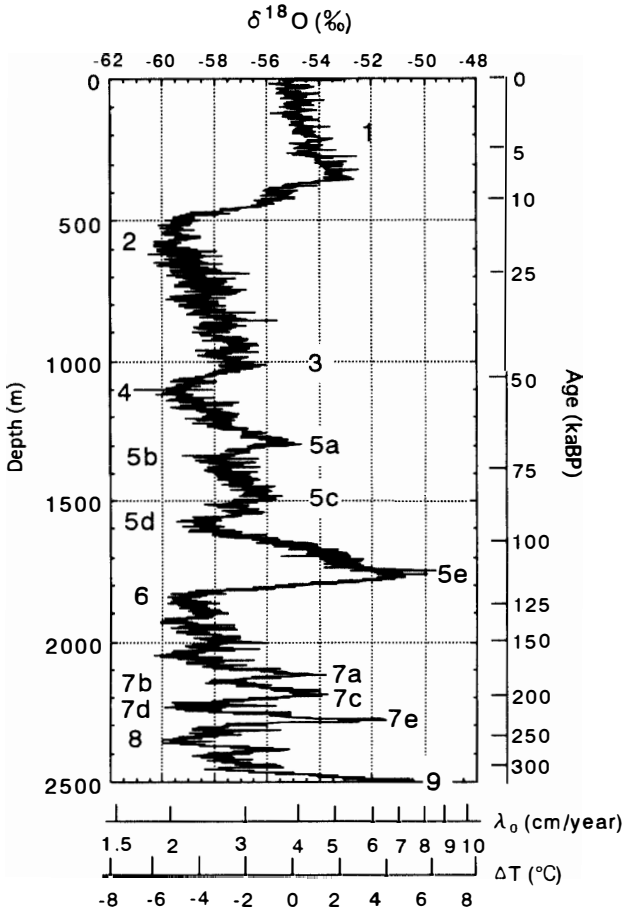

Fig. 1. *$\delta^{18}O$ profile of Dome Fuji deep ice core. Accumulation rate (λ_0) and temperature difference (ΔT) were calculated by using present relationships between $\delta^{18}O$ and accumulation rate, and $\delta^{18}O$ and mean annual air temperature, respectively. Numbers shown in the figure are Marine Isotope Stages. Working time scale is shown at the right.*

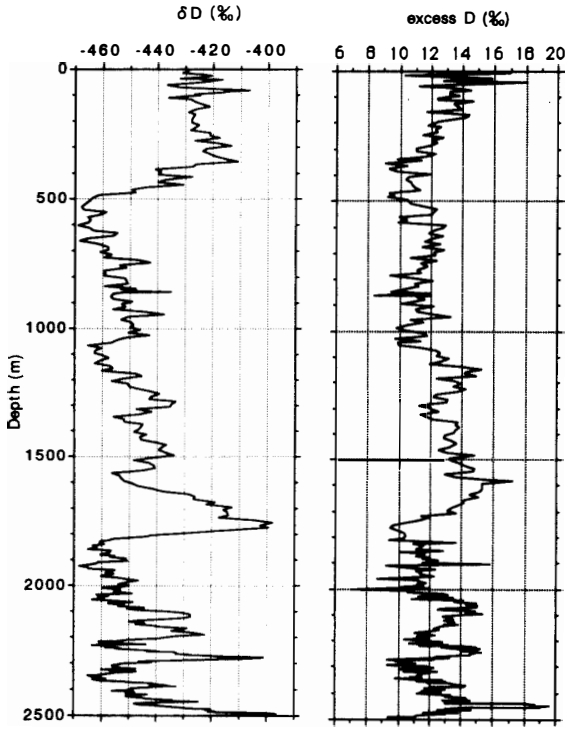

Fig. 2. *Profiles of δD (left) and excess D (right).*

there is well-known linear relationship, which is expreesed as $\delta D = 8\delta^{18}O + 10$, between $\delta^{18}O$ and δD. DANSGAARD (1964) defined the deuterium excess D as $D = \delta D - 8\delta^{18}O$ and pointed out that D can apparently be used to identify non-equilibrium fractionation processes. Figure 2 shows general negative correlation between δD and deuterium excess.

3.3. *Major chemical compositions*

Profiles of major chemical compositions are shown in Fig. 3, indicating high concentrations in glacials and low in interglacials, suggesting intense atmospheric circulation during glacials. The profile of MSA in the depth range between 1300 and 1600 m, the early stage of the last glacial, shows concentration higher than that during the LGM (last glacial maximum), suggesting changes in the oceanographic environment around Antarctica.

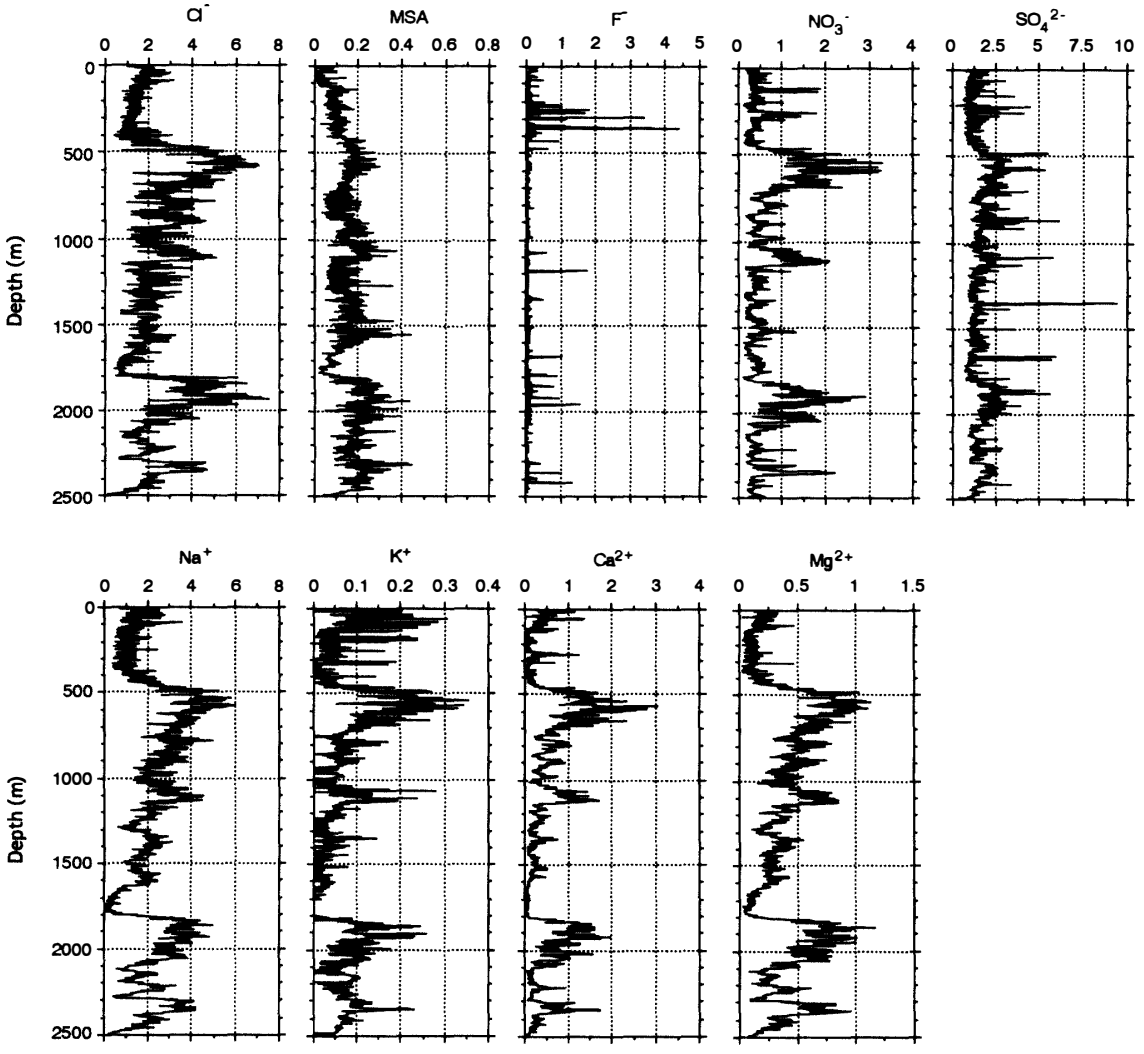

Fig. 3. Profiles of concentration of major anions and cations. Units are μ equivalent/l.

3.4. Microparticles

Figure 4 shows the volume concentration profile of microparticles larger than 0.52 μm. The concentration was high in glacials and low in interglacials, probably due to the change in area of land in the middle latitudes of the Southern Hemisphere caused by the sea level change as suggested by GROUSSET *et al.* (1992).

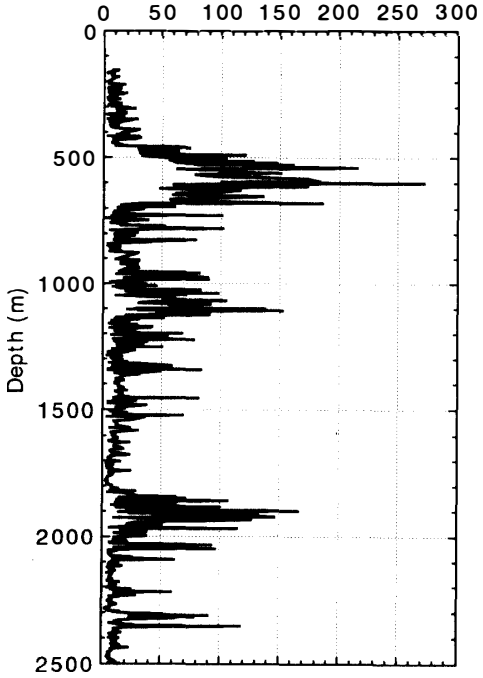

Fig. 4. Profile of volume concentration of microparticles larger than 0.52 μm (ppb).

4. Concluding Remarks

On the basis of the first stages of analyses, we have shown the profiles of stable oxygen and hydrogen isotopes, major chemical components and microparticle concentrations, and obtained the following results. Detailed description and discussion on climate and environment changes during the past 340 ka will be reported in other papers.

1) The 2503 m deep ice core obtained at Dome Fuji Station covers the past 340 ka on the basis of the present relationship between the oxygen stable isotope ratio of snow and annual snow accumulation rate obtained above 2200 m a.s.l. in east Dronning Maud Land, and a steady state ice flow model.

2) The profiles of stable oxygen isotopes show the climate change over three glacial cycles with an overall amplitude of glacial-interglacial temperature change; about 8°C for the last glacial termination and ~10°C for the penultimate and the antepenult glacial terminations. The amplitudes are close to those of Vostok ice cores.

3) The concentrations of major chemical constituents were high in the glacials and low in the interglacials. The MSA concentration in the first stage of the last glacial was relatively high, suggesting environment change in the ocean around Antarctica.

4) The volume concentration of microparticles larger than 0.52μm in diameter,

was high in the glacials and low in the interglacials, suggesting intense particle transportation from the exposed continental shelf due to sea level lowering in the glacials.

References

DANSGAARD, D. (1964): Stable isotopes in precipitation. Tellus, **16**, 436–468.

DANSGAARD, D. and JOHNSEN, S. (1969): A flow model and a time scale for the ice core from Camp Century, Greenland. J. Glaciol., **8**, 215–223.

DOME-F DEEP ICE CORING GROUP (1998): Deep ice-core drilling at Dome Fuji and glaciological studies in east Dronning Maud Land, Antarctica. Ann. Glaciol., **27**, 333–337.

DOME-F ICE CORE RESEARCH GROUP (1998): Preliminary investigation of palaeoclimate signals recorded in the ice core from Dome Fuji Station, east Dronning Maud Land, Antarctica. Ann. Glaciol., **27**, 338–342.

GROUSSET, F.E., BISCAYE, P.E., REVEL, M., PETIT, J.R., PYE, K., JOUSAUME, S. and JOUZEL, L. (1992): Antarctic (Dome C) ice-core dust at 18 k.y. B.P.: Isotopic constrains on origins. Earth Planet. Sci. Lett., **111**, 175–182.

HAMMER, C.U. (1980): Acidity of polar ice cores in relation to absolute dating, past volcanism and radio-echoes. J. Glaciol., **25**, 359–372.

LORIUS, C., MERLIVAT, L., JOUZEL, J. and POURCHET, M. (1979): A 30,000-yr isotope climatic record from Antarctic ice. Nature, **280**, 644–648.

MORGAN, V.I., WOOKEY, C.W., LI, J., VAN OMMEN, T.D., SKINNER, W. and FITZPATRICK, M.F. (1997): Site information and initial results from deep drilling on Law Dome, Antarctica. J. Glaciol., **43**, 3–10.

PALAIS, J.M. and LEGRAND, M. (1985): Soluble impurities in the Byrd Station ice core, Antarctica: Their origin and sources. J. Geophys. Res., **90**, 1143–1154.

PETIT, J.R., JOUZEL, J., RAYNAUD, D., BARKOV, N.I., BARNOLA, J.-M., BASILE, I., BENDER, M., CHAPPELLAZ, J., DAVIS, M., DELAYGUE, G., DELMOTTE, M., KOTLYAKOV, V.M., LEGRAND, M., LIPENKOV, V.Y., LORIUS, C., PEPIN, L., RITZ, C., SALTZMAN, E., and STIEVENARD, M. (1999): Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature, **399**, 429–436.

SATOW, K., WATANABE, O., SHOJI, H. and MOTOYAMA, H. (1999): The relatioship among accumulation rate, stable isotope ratio and surface temperature on the plateau of east Dronning Maud Land, Antarctica. Polar Meteorol. Glaciol., **13**, 43–52.

WATANABE, O., KAMIYAMA, K., MOTOYAMA, H., IGARASHI, M., MATOBA, S., SHIRAIWA, T., YAMADA, T., SHOJI, H., KANAMORI, S., KANAMORI, N., NAKAWO, M., AGETA, Y., KOGA, S. and SATOW, K. (1997): Preliminary report on analyses of melted Dome Fuji ice core obtained in 1993. Proc. NIPR Symp. Polar Meteorol. Glaciol., **11**, 14–23.

WATANABE, O., MOTOYAMA, H., FUJII, Y., SATOW, K. and SHOJI, H. (1999): Antarctic palaeo-temperature from the Dome Fuji ice core with field survey studies. submitted to Science.

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