SECTION-II

GLACIOLOGY

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Oxygen Isotope Studies in Antarctica

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Abstract

$8^{18}O$ measurements on fresh snow, surface ice, shallow ice cores, old ice from Maitree glacier and fresh water lakes from Schirmacher and Wohlthat ranges in Antarctica have been carried out. The mean $8^{18}0$ values in fresh snow and surface ice centre around — 19‰ whereas the old glacier ice and mean value of eighteen lakewater samples were observed to be —42‰ and —26‰ respectively. The mean annual surface air temperature (MASAT), calculated by the empirical formula given by Dansgaard (1964), at the site of precipitation of fresh snow and surface ice samples is calculated to be — 7°C.

The mean values of — 19‰ in fresh snow/ice, —26‰ in Schirmacher hills and —42‰ in old ice of Maitree glacier suggest that the Schirmacher lakes receive 70% contributions from fresh snow/ice melt waters and about 30% from Maitree glacier old ice melt waters.

No systematic cyclic variations have been observed in the three shallow ice cores collected from the shelf ice and iceberg.

Introduction

The isotopic composition of oxygen (and hydrogen) of snow deposited in the polar regions of the earth and high elevations in mountains depends on the surface air temperature, circulation pattern and source composition of moisture. The isotopic composition of oxygen is expressed as permil differences relative to standard mean ocean water (SMOW)

$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 10^{3}‰$$

The $8^{18}O$ values of snow are strongly negative (which implies the depletion of ^{18}O in the sample compared to the standard) and display variations due to

temperature fluctuations and seasonal variations related to altitude and geographical latitude. Systematic measurements of $8^{18}0$ (and 8D) have therefore been used to study flow patterns of glaciers, snow accumulation rates, past climatic variations and provide valuable information on firnification and homogenisation processes in the upper layers of the glacier ice. Oxygen isotopes therefore serve as potential tool for dating ice horizons and are known to be very good climatic indicators.

During last three decades, it has been established on a world wide scale that Oxygen-18 content of precipitation generally decreases with the mean annual surface air temperature (MASAT) and exhibits in general a linear relation at the sampling site as a result of fractionation process occurring at each, phase of the atmospheric water cycle (Dansgaard, 1964). All measurements reveal that it is possible to establish a temperature-isotope relationship in the regions with relatively uniform meteorological conditions.

The determination of $8^{I8}0$ in precipitation has been commonly used to reveal climate information. This method is particularly suitable for polar regions where the snow deposited over icy continent can be dated due to insignificant melting in this region (Dansgaard et al., 1964, 1973). Moreover, $8^{l8}O$ in precipitation exhibits seasonal pattern. This feature also offers dating of snow layer by layer where the seasonal variations are preserved during the firnification process (Hammer *et* al., 1978: Gow, 1965). Due to availability of the meteorological data of past few decades in Antarctica at different locations, the information obtained by $8^{18}0$ studies on past climatic variations can therefore be studied and compared with the present climatic conditions.

Recently some work on $S^{18}O$ in glaciers of Himalayas, Andes and Alps has been reported, particularly from the accumulation zones of the glaciers, which indicates that measurements in temperate glaciers can also be used for estimation of accumulation rates of snow and study of climatic variations (Grabczak *et al.*, 1983: Nijampurkar and Bhandari, 1984; Nijampurkar, et *al.*, 1986)

As a first step, we have collected as many as 73 samples of fresh snow, surface and old glaciers ice, three shallow ice cores, from shelf ice and iceberg, coastal sea water samples and fresh waters from lakes of Schirmacher and Wohlthat mountains at different locations in Antarctica (Fig. 1). Analyses of these samples for $8^{18}0$ should identify their inherent level of isotope composition and their relation, if any, with surface temperatures at the sampling site. To start with the data is expected to give only relative climatic information of different locations and should help in selecting the sites for deep drilling to monitor past climate. We assume that the sampling site has more or less uniform meteorological conditions.

Sample Collection and Experimental Procedure

During the Fifth Indian Scientific Expedition to Antarctica (1985-86), we have collected a series of snow, ice and lake water samples at different locations near

the permanent Indian Station Dakshin Gangotri (DG) located at 7O°S, 12°E in Antarctica.

About 30 ml of each sample, wherever necessary after melting, were collected upto the brim without leaving any air into the specially selected plastic bottles for $8^{18}O$ studies.

Fresh snow and surface ice samples

Fresh snow samples: Two fresh snow samples A and B were collected (Table I) directly into the plastic buckets during the snowfall that occurred along with the blizzards near the Indian Bay on 1st January, 1986 and the other on 4th January, 1986 near DG station.

Table I. $8^{18}0$ in Antarctic Snow, Ice, Lakes and Sea Water Samples

Code No.	Nature of sample	Location	$8^{1s}O$ (%o)
A	Fresh Snow	Indian Bay	-17.2
B	Windborne Snow	D.G. Station	-19.4
C	Shelf Ice (Surface)	—do-	-21.7
D	—do—	Indian Bay	- 18.1
E	Iceberg (Surface Ice)	—do-	-17.0
Q	Deep Snout Ice (10 m depth)	West Maitree Hills	-42.4
p	Lakewater	Maitree Hills	-24.0
R	Lake D.G, Glacier Ice, meltwater	East of Maitree Hills	-29.0
W	Frozen Lakewater	Wohlthat mountains	-23.9
T	Fast Ice	Indian Bay near Shelf	-12.7
S	Seawater	—do—	-9.2
M	Seawater	Indian Bay 65°S	-2.9

Surface j'ce *samples:* After removing the top few inches of surface ice we have collected three samples, C, D, E (Table I) from shelf ice near Indian Bay, DG station and iceberg floating near Indian Bay. At regular distance intervals of 2 km, we have collected 15 surface ice samples upto the distance of 34 km away from the coast to study the variation of $8^{18}0$ with distance from the coast.

Ice core samples

Twenty-seven samples from two shallow ice cores from shelf ice near the Indian Bay (9 m) and the other near DG station of 5 m depth were collected. The samples from 9 m ice wall (section) exposed above the water surface were

collected using crane and trolley system, available on board the Swedish ship *Thuleland*. The trolley was gradually lowered from surface of the shelf ice and samples at every 0.5 m interval were collected after removing the exposed contaminated surface ice using stainless steel hammer.

Eight samples from the shallow ice core of 5 m depth at different depth intervals were collected using a SIPRE ice corer. The surface ice was too dry to get a solid core in the form of cylinder and loose snow upto two metres was collected. From 2-5 metres, the continuous ice core was recovered in the cylinder form and sampled as per the requirement.

The shallow ice core samples upto 2 m depth were collected from an iceberg floating in the Indian Bay near the ship, to compare mainly the $\delta^{18}O$ measurements with that derived from two shallow ice cores. We landed on the surface of the iceberg with the help of two helicopters and drilled shallow ice cores using SIPRE ice corer.

Based on our knowledge of accumulation rate of ice in this coastal region and from our radiometric studies using 210 pb and total β activity, (~ 0.3 m/yr) we expect to get information about climatic variation for a period of 2-3 decades.

Fresh lake water samples

Schirmacher hill popularly known as Maitree which is situated about 100 km away from DG station (Fig. 1) has large number of fresh water lakes and ponds which are frozen in winter months. In summer, the fresh snow as well

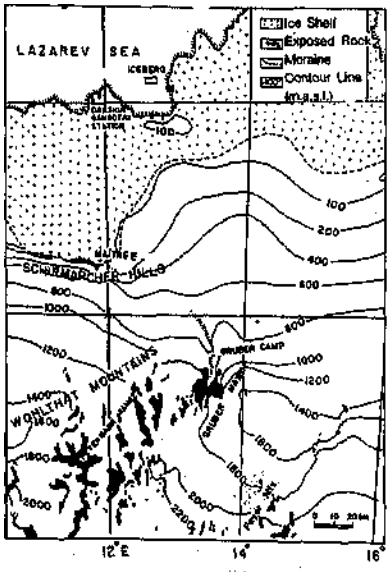

Fig. 1. Map showing major sampling locations.

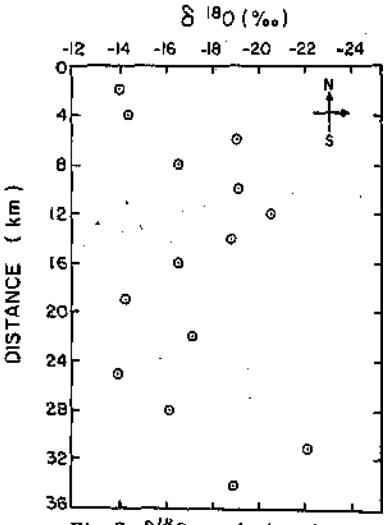

Fig. 2. $\delta^{18}O$ variation in surface ice samples collected at every two km upto 34 km inside the coast.

as glacier ice-melt waters feed the lakes. With a view to study the contributions of melt waters from snow and old ice in these lakes, we have collected samples from different lakes, from Schirmacher hills extended over 20 km in east-west direction (Fig. 4). Only one lake water sample 'W' was collected from Gruber mountains of Wohlthat range, 100 km south of Schirmacher hills for comparison with the lakes from Schirmacher hills.

Miscellaneous samples

One sample of very old ice (Q) from the deep snout ice of Maitree hills was collected to see the $8^{18}0$ variations with respect to younger snow and ice samples collected near the DG Station. Two seawater samples from Indian Bay (M&S) and one fast ice sample (T) were collected for comparison. These samples are enlisted in Table I.

All these samples were analysed at the Stable Isotope laboratory of Physical Research Laboratory using standard procedures described elsewhere (S.K. Bhattacharya et *ah,* 1985)

Results and Discussion

The $8^{18}0$ of different Antarctic samples obtained in comparison with that of SMOW are given in Table I and shown in Figs. 2, 3 and 4.

$8^{18}O$ in fresh snow and surface ice samples

The mean $8^{18}O$ value of fresh snow samples A and B collected during the summer month in Antarctica (January, 1986) has been observed to be —18.3%o. This value calculated using empirical relation given by Dansgaard (1964) corresponds to — 7°C as the mean surface air temperature for January, 1986 which agrees well with that actually observed (—6.8°C) during the month of January, 1986 as a part of the meteorological monitoring programme in Antarctica.

The mean $8^{18}O$ value of three surface ice samples C, D, and E (Table I) is observed to be -18%o. The $8^{18}O$ values of 15 surface samples (Y_1 to Y_{15}) sampled at every 2 km away from the coast upto 34 km vary from —13.9%o to —22.1%o with a mean value of -18%o. These samples do not show a systematic trend of $8^{18}O$ variation with distance from the coast (Fig. 2). The large variation perhaps could be explained by admixture of local precipitation with varying components of blizzard borne snow brought from the colder regions at higher latitudes.

$8^{18}O$ in Shallow ice cores

The $8^{18}0$ values of a shallow ice section near Indian Bay sampled upto 9 m depth show a cyclic variation (Fig. 3) and fluctuates from —18.2 to — 21.3%o with a mean value of —19.4%o. The seasonal cyclic variations generally observed

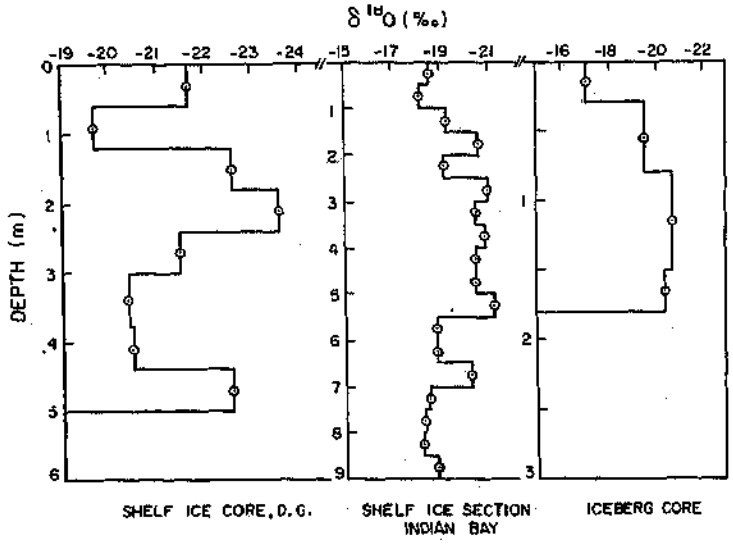

Fig. 3. The shallow ice profiles of $8^{18}O$ *in the shelf ice and iceberg.*

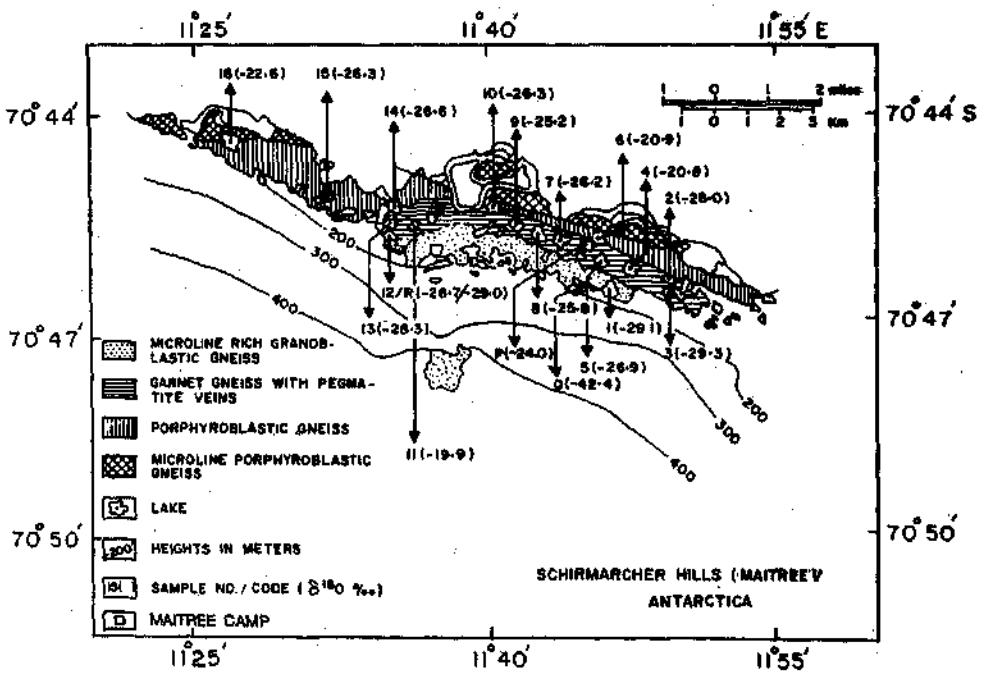

Fig. 4. $8^{18}O$ *studies in fresh lake waters of Schirmacher hills. The values given in the bracket are the* $8^{/5}O$ *numbers expressed per mil. (Geology after the Second Indian Expedition to Antarctica.)*

in the polar ice cores could not be seen here due to poor resolution in sampling at every 0.5 m depth interval. One needs to sample at every 5 to 10 cm depth to observe good seasonal variations. Based on the total β activity depth profile (Nijampurkar *et al.,* this volume) and general knowledge of ice deposition at this location the ice core (~ 10 m) represents a time span of 30-35 years.

Another shallow ice core of 5 m depth raised using a SIPRE ice corer shows a cyclic variation and fluctuates from -19.7 to —23.6‰ with an average of -21.3‰ which represents an average deposition over a period of about 10 years.

The third shallow ice core samples collected, upto a depth of only 2 metres, using a SIPRE ice corer from the Iceberg show an $8^{18}0$ variation of -19.5 to -21.8‰ with an average of -20.6‰ which does not show any significant change in $8^{18}O$ concentrations from those observed in any other ice core.

The mean $5^{18}0$ value of all these samples of the three ice cores has been calculated to be -20.4‰ which represents a $8^{18}0$ mean value precipitation of 5 to 20 vears and shows a MASAT value of -10°C at this location.

This work demands raising of shallow ice cores at least upto 50 m if any meaningful information is to be obtained about the past climatic variations at DG station.

$8^{18}0$ in coastal sea waters and old glacier ice

The $8^{18}0$ values, of fast ice (T) and sea water sample (S) collected near the shelf ice in Indian Bay, have been observed to be -12.5‰ and -9.2‰ which can be explained by mixing of sea water with shelf ice melt water. The sea water sample 'M' collected away from the shelf ice at 65°S in the open ocean shows a $8^{18}O$ value of -2.5‰ which is expected to be closer to zero and more positive w.r.t. sea water in contact with shelf ice.

The deep ice sample 'Q' collected from the 10 m depth or tne snout or the glacier in the western part of Maitree hills near Indian Camp is expected to be very old. This sample has a very low $8^{18}0$ value of -42.4‰ which suggests that either at the time of deposition of this ice, the MASAT value was around -40°C, or this ice may have been deposited at higher latitudes in past and then moved to its present position. Unfortunately we could not date this sample by any other technique and it is not possible at this stage to explain as to how back in time this ice was formed. In any case it is desirable to date this ice mass using suitable dating techniques based on ^{32}Si and ^{14}C radioisotopes and extend such studies to different locations towards the Wohlthat mountains.

$8^{18}O$ in fresh lake waters in Antarctica

$S^{18}O$ measurements were carried out on eighteen fresh lakewater samples collected from Schirmacher hills and one sample from frozen lake of Gruber mountains of Wohlthat range. The locations of Schirmacher and Wohlthat hills and the sampling locations are shown in Fig. 1 and 4.

$8^{18}O$ values of different lakes vary from —19.9 to -29.3‰ with a mean value of -26.2‰. The mean $S^{18}O$ values of surface ice (~20‰) and that of old glacier ice (—42‰) clearly suggest that these lakes are fed by 70% of fresh snow/young ice meltwaters and 30% of melt water from old glacier ice.

It is interesting to note that the lakes (L_1, L_2 and L_3) situated on the western most part of the Maitree hill and lake formed near the snout of DG glacier (sample R) are fed by 60% of fresh snow melt water and 40% of the old glacier ice melt water.

To summarise, $8^{18}O$ measurements in old glacier ice and lakewaters can be used to study the past climate variations and identification of the contributions made by the different sources to the lakes in Maitree hill.

Suggestions

(i) It is desirable to raise 30-50 m ice cores in shelf ice and inland polar ice in future expeditions as a priority programme of shallow ice drilling programme (SIDP) to estimate accumulation rates of ice and to study past climatic variations near the permanent Indian Station in Antarctica.

(ii) ^{32}Si and ^{14}C techniques should be employed for dating old glacier ice from Antarctic ice sheet at different locations.

Acknowledgements

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