Oxygen Isotope Studies In an Ice Wall Near Maitri, Indian Antarctic Station

N. SHARMA[1], R.A. JANI[2] and R. RAMESH[2]
'Department of Geology, Faculty of Science, M.S. University of Baroda, Vadodara 390 002
[2] Physical Research Laboratory, Ahmedabad 380 009
E-mail: rajani@prl.ernet.in

Abstract

Stable oxygen isotope(^{18}O) data from the continental ice wall near Maitri station has revealed the transported nature of the ice. The ^{18}O profile for the ice wall shows three distinct short duration warmer events. Earlier reported (Nijampurkar *et. al.* 2002) stable isotope data from a shallow ice core in the area when compared with the present data, suggests *insitu* ice accumulation over the older ice surface represented by the ice wall Two ice units are identified; namely, the older basal unit of an unknown age and the upper unit of recent times respectively. A wide hiatus in the ice record has been observed, which probably represents larger scale melting of ice during a warmer climatic phase in the past.

Introduction

Indian expeditions to Antarctica were undertaken to carry out a variety of scientific researches including investigation of past climate using diverse proxy indicators. With this aim, the first Indian station Dakshin Gangotri was constructed on an ice shelf on the Lazarev sea in 1983-84; subsequently this station was abandoned as it got buried in accumulating snow on the shelf and a new station, Maitri was constructed near the Schirmacher Range in a relatively ice-free rocky region. Maitri station is located at lat 70° 46'S and long. 11° 49'E at an elevation of 87 m and a distance of about 80 km from the Dakshin Gangotri (DG) station.

Long ice cores from Antarctica and Greenland have provided excellent record of variations in past climate, atmospheric trace gases composition, ice temperature etc. and geographical events like volcanic expeditions, storm activity etc. (Grootes and Stuiver, 1997; Bluimer et al. 1998). However, the selection of sites for drilling long ice covers is to be done carefully after taking into account the local meteorological, geomorphological and geochemical factors. The Indian scientific expedition to Antarctica has yet to initiate a systematic ice core-drilling programme. A shallow ice core was drilled in the year 1992 (Chaturvedi and Asthana, 1996) on the continental ice sheet near Maitri. Nijampurkar et al (2002) have reported records of recent volcanic events, accumulation rates of ice and ^{18}O data from this core. Bhattacharya and Nijampurkar (1998) have dealt with the oxygen isotopic studies of ice, snow and lake water around the Indian station. Oxygen isotopic composition of surface and near surface water, snow and ice samples provide an important input. It is known that ^{18}O value in falling snow is influenced by source composition, circulation pattern and the thermodynamic history of the precipitating air mass. As a consequence, the mean ^{18}O of precipitation at a given place is linearly related its mean temperature and can this be used as a proxy temperature indicator (Dansguard 1964; Robin 1983a). Systematic measurements of ^{18}O in ice cores have been used to study flow patterns of glaciers, snow accumulation and homogenisation processes in the upper layers of the glacier ice and most importantly past climatic variations. With the objective of establishing an isotopic database which will be useful in selecting a site for deep ice core drilling at this location, the present study was undertaken. In this study, we undertook during the 21^{st} expedition in 2002, a systematic sampling of the ice-wall located south of Maitri station to study the ^{18}O variation. The study was undertaken primarily to evaluate the importance of exposed cliffs of continental ice sheet for the purpose of paleoclimatic studies. The sampling is relatively simpler and has potential of complementing ice core data, in the places where ice coring is still to be done. Analysis of these samples for ^{18}O should identify their inherent isotopic composition variations and their relation, if any, with surface temperature at the sampling site.

Location and Sample Collection

The continental ice sheet near Maitri station 70° 46'S, long. 11° 49'E is a part of the East Antarctic ice sheet. The margin of the sheet runs E-W parallel to the Schirmacher Oasis and stands as a wall of variable 20 m to 30 m height. To ensure collection of unaltered samples free from human activity, the location about 500 south east of Maitri was selected for sampling. Before the collection of the actual sample, about 10 cm of the wall surface was scrapped off to obtain fresh samples. Samples were taken in polythene bags and sealed at the site at regular intervals of 20 m from the top to downwards as far as possible. These samples were allowed to melt. For storing and transportation, melted samples were put in polythene plastic bottles, ensuring that no gap was left in the bottles for air.

The water samples from Priyadarshini lake near the Maitri station were collected from a location near the water pump. The average surface temperature recorded during the summer of 2002 was -6°C. The surface locations were limited within an area of about 70 sq. km due to limited mobility and the preliminary nature of the study.

Analytical Procedure

Oxygen isotopic analysis was done using a Stable Isotope Ratio Mass Spectrometer (Geo 20 20 PDZ Europa, UK) fitted with an automatic water equilibration system. Pure carbon dioxide gas is equilibrated with 1 ml of water sample at 35°C in a thermal bath for nearly overnight (~ 12 hrs.). The analytical reproducibility is better than + 0.1%. The values are reported relative to the international V-SMOW standard. Narmada River water, a laboratory water standard, was run with even 10 samples to monitor the process and the precision.

Results and Discussion

The ice sheet margin is about 20 m to 30 m high and exhibits layering and mild folding features. The layering may be a depositional feature or a foliation layering developed during the course of ice movement (Alley, 1988; Hudleston and Hooke, 1980). There is a strong possibility of layers representing basal foliation planes, developing as a result of progressive accumulation increasing at the source and movement of ice mass due to deeper burial along the available basement slope. Remote sensing studies suggest a general NW movement direction for the continental sheet glacier in the Schirmacher Oasis (Nath, 1990). According to him, the continental ice sheet cuts through the Petermen and Gruber massifs in N-S direction and then takes NW direction. The likely accumulation for the ice is about 300 km away from the present location beyond Gruber and Petermen Massifs (Fig. 2, after Bently, 1964). The ablation zone is confined 4 to 5 km on the ice sheet surface from the margin and wind worked surfaces, melt water channels, etc., are seen in the ablation area. There is a break in the slope of ice sheet surface. The accumulation of recent ice mass over the transported older ice is indicated by this slope break line (Fig. 1).

^{18}O data on the ice wajl samples range of from -50%$_0$ to - 38%$_O$ (Fig. 3; also Annexture -1). Such depleted values are indicative of precipitation and accumulation at higher altitudes above 3000 m (Lorius, 1983). The relatively enriched values at the depths of 5 m, 18 m and 19.0 m, suggest short duration warmer events. Similar short-term climatic changes have been reported by

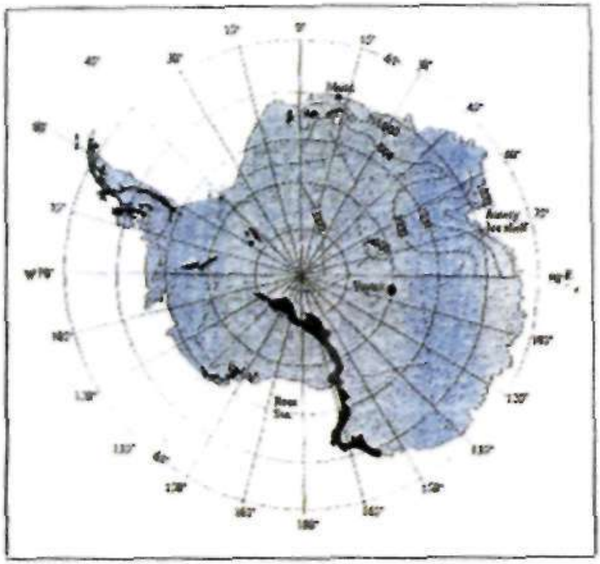

Fig. 1. *Location shown by open circle indicates the assumed accumulation source for the ice wall sampled at Maitri (after Bentley, 1964).*

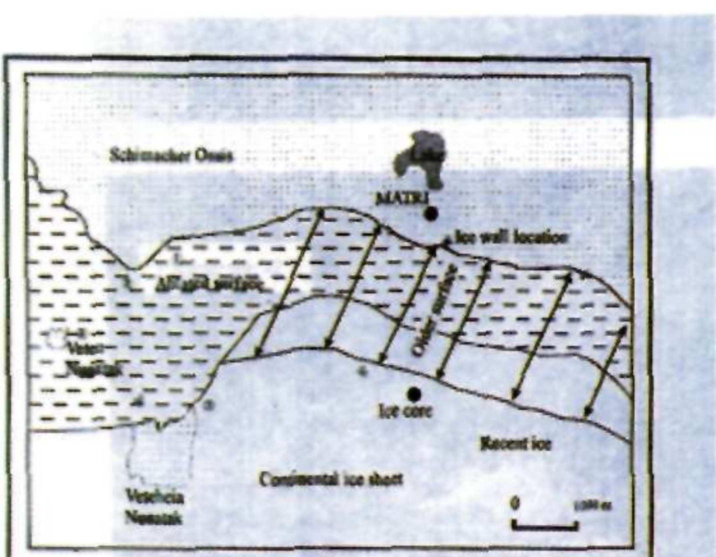

Fig.2. *Map showing ice wall location.*

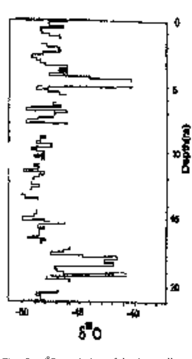

Fig .3. *δ[18]O variation of the ice wall*

Dansgaard et al (1984) The δ[18]O value of the DG glacier snout, a relatively fast moving glacier further west of the present location, is also similar to the value obtained in the present study (Bhattacharya and Nijampurkar, 1998). The published δ[18]O data (Nijampurkar et al 2002) on the shallow ice core about 5 km south of the Maitn Station are in the range -21 ‰ to -26‰ for the top 30 m of the core This big difference in the δ[18]O values of the shallow core and the ice wall implies that the core location has likely *insitu* ice accumulation. .The average accumulation rate of 20 cm/yr as published implies that this core represents about last 300 years of accumulation .These isotope records, seen collectively, suggest a wide hiatus in the ice record at Maitn, the gap must have been created by the removal of continental ice after the Last Glacial Maximum (LGM) or later glacial retreat events.

A computed age of more than 10,000 years for the ice wall profile assuming the average Antarctic Ice sheet movement as 30 m/yr (Embleton and King, 1969) and a distance of about 300 kms beyond Gruber and Peterman massifs appears reasonable, in the absence of a proper date for the ice sheet in the region The δ[18]O values are higher than in the Vostok core (Jouzel *et al*

1987). In the Holocene segment of the Vostok core the average ^{18}O (Dansgaard et al. 1993) is about *-56%₀* .whereas the present average is -48%₀, the difference expected as the Vostok core is located at a much higher elevation and latitude. The approximate rate of ice accumulation for the Vostok core during the Holocene is about 2.5 cm per year; assuming the same rate for the ice data under study it appears that the ice would have accumulated in approximately 1000 years.

The ^{18}O values of the Priyadarshini Lake agree well with the data published earlier (Bhattacharya and Nijampurkar, 1998; Sinha et al- 2000) (Table 1). The lakes in the Schirmacher Oasis, including the Priyadrashini, are continental ice sheet-denved melt water lakes; the ^{18}O of published and the present studies suggest isotopic equilibrium between melt water and the ice sheet.

Summary and Conclusion

The basal continental ice sheet stands as a cliff parallel to Schirmacher Oasis range, with varying heights between 20 to 30 m. The ^{18}O values are highly negative for the entire wall sampled at 20 cm interval from the top to the base, Such depleted values are indicative of a non-local high altitude source of more than 3000 m altitude. Its probable location is about 300 km from the present one; based on the average rate of ice sheet movement for the Antarctic ice sheet, and the probable focus of ice accumulation, the ice wall is about 10,000 years old. The Vostok ice core location has registered an accumulation rate of ice as 2.5 cm/yr; if the same rate of ice accumulation is assumed then the ice wall preserves a record of 1000 years of ice accumulation and transportation history.

The recently published ^{18}0 data of Nijampurkar et al. (2002)on a shallow ice core suggests the ice core is of *insitu* accumulation and there is a big hiatus in the ice records between the recent ice represented by the shallow ice core and the ice wall. This must have resulted due to the melting of continental ice after LGM or later.

The ice wall displays layering and mid folding, as suggested by the ^{18}O data. The ice wall represents transported ice sheet could be post depositional foliation feature resulting due to long distance transport of ice. The mild folding is due to terminal obstructions or due to differential movements of younger ice at the site of accumulation and older ice at the fringes of the sheet ice.

The study is to be regarded as preliminary, as many parameters, such as movement rates of the ice sheet and accumulation rates of ice in the interior site beyond Wholthat Mountains need to be ascertained and more detailed sampling of ice wall is needed

Annexure I

Table 1: ^{18}O Data of Ice wall samples near Maitri Station

Sr No	Sample No	Depth (M)	0 18 (‰)
I	E1- 1	0 2	46 03
2	2	2 44	47 62
3	3	4 6	46 30
4	4	6 8	48 52
5	5	8 1	48 23
6	6	1 12	47 57
7	7	12 14	46 62
8	8	14 16	
9	9	16 18	48 25
10	10	1 8 2	47 88
11	E_2 11	2 2 2	46 92
12	12	2224	46 87
n	13	2426	48 19
14	14	2628	49 13
15	15	283	48 86
16	16	3 32	48 47
17	$E_3$1	3234	48 00
18	2	3436	46 15
19	3	3638	46 86
20	4	384	46 04
21	5	442	47 64
22	6	4244	43 98
23	7	4446	40 18
24	8	4648	
25	9	485	39 93
26	E_4 10	5 52	48 93
27	11	5254	47 71
28	12	5456	46 78
29	13	5658	46 09
30	14	586	
31	15	6 62	47 12
32	16	6264	47 27
33	17	6466	46 65
34	18	66 68	49 78
35	19	687	46 14
36	20	7 72	47 22
37	21	7274	47 27
38	E_S22	7476	48 74
39	23	7678	49 79
40	24	78 8	45 90

Sr No	Sample No	Depth (M)	δO_{18} (‰)
41	25	8-8 2	-
42	26	8 2-8 4	-46 99
43	27	8 4-8 6	-
44	28	8 6-8 8	-48 66
45	29	8 8-9	-48 07
46	30	9 9 2	-48-56
47	31	9 2 9 4	-48 70
48	E_6-32	9 4 9 6	-47 36
49	33	9 6 9 8	-49-33
50	34	9 8-10	-48 52
51	35	10-10 2	-48 13
52	36	10 2-10 4	-49 00
53	37	10 4-10 6	-47 93
54	38	10 6-10 8	-48 55
55	E_7-39	10 8-11	-48 95
56	40	11-11 2	-48 68
57	41	11 2-11 4	-49 55
58	42	11 4-11 6	-47 94
59	43	11 6-11 8	-48 56
60	44	11 8-12	-49 23
61	45	12-12 2	-
62	46	12 2-12 4	-49 27
63	E_8-47	12 4-12 6	-48 52
64	48	12 6-12 8	-49 33
65	49	12 8-13	
66	50	13-13 2	-50 06
67	51	13 2-13 4	-49 84
68	52	13 4-13 6	-48 79
69	53	13 6-13 8	-
70	54	13 8-14	-
71	55	14-14 2	-
72	56	14 2-14 4	48 84
73	E_9-55	14 4-14 6	-48 80
74	56	14 6-14 8	-49 28
75	57	14 8-15	-50 12
76	58	15-15 2	-48 13
77	59	15 2-15 4	-46 27
78	60	15 4 15 6	-48 73
79	61	15 6 15 8	-48 20
80	62	15 8 16	-48 76
81	63	16-16 2	-48 77
82	E_{10}-64	16 2-16 4	-49 45
83	65	16 4-16 6	-47 97

Sr No	Sample No.	Depth (M)	δO_{18} (‰)
84	66	16 6-16 8	-45-36
85	67	16 8-17	-
86	B_{II}-68	17-17 2	-45 72
87	69	17 2-17.4	-46 53
88	70	17 4-17 6	-47 36
89	71	17 6-17 8	-44 68
90	F_{4}+-72	17.8-18	-41 58
91	73	18-18.2	-42.76
92	74	18 2-18 4	-41 81
93	75	18 4-18 6	-47.15
94	76	18.6-18 8	-46 91
95	77	18.8-19	-46-37
96	78	19-19 2	-40 70
97	79	19 2-19 4	-47-80
98	80	19 4-19 6	-45-86
99	81	19 6-19 8	-
100	82	19.8-20	-
101	83	20-20 2	-
102	84	20 2-20 4	-46 91
103	85	20 4-20 6	-48 78
104	86	20 6-10 8	-48 46

The lake water samples have not shown any deviation from the data published earlier by Bhattacharya and Nijampurkar (1998) and Sinha et al. (2000). Therefore, it appears that the lake systems in the Schirmacher Oasis are in equilibrium with the melt water supply, and outflow and ice sheet melting are also in 'temporal' isotopic equilibrium as the parameters controlling the ice melting perhaps have not changed drastically in the recent times.

Acknowledgement

N. Sharma is grateful to Vice Chancellor and Head, Department of Geology, M.S. University of Baroda for granting leave to join the Antarctic expedition. Acknowledgements are also due to the authorities of DOD, New Delhi and Director, NCAOR, Goa for extending logistic and other field help during the 21st Indian Antarctic Expedition. Director, PRL, Ahmedabad is also gratefully during the 21st' expedition in acknowledged for granting a visiting Associateship to carry out isotopic work in the stable isotope lab. of PRL.

References

ALLEY, RB (1988) Fabrics in the polar ice sheets, development and prediction Science, v 240, pp 493-495.

BENTLY, CR (1964) The land beneath the ice, New Zeal and Antarctic-Society.

BHATTACHARYA, S. K and NIJAMPURKAR, V. N (1998) Oxygen isotopic studies of ice, snow and water samplers near the Indian Stations in Antaictica Jour Geol. Soc. Ind , v. 51, PP 399- 404

BLUNIER, T. SCHWANDER, J, STAUFFBR, B , STOCKER. F. DALLENBACH, A, INDERMUHLE, A, TSCH UMI H, CHAPPELLEZ, J RAYNAUD, D , BARNOLA, J-M , JOUZEL, J, CLAUSSEN, HB, HAMMER CU and JOHNSEN, SJ (1997) Timing of temperature variations during the last deglaciation in Antarctica and the atmospheric CO_2 increase with respect to the Younger Dryas event Geophysical Research Letters, v 24, pp 2683 -2686

CHATURVEDI, A and ASTHANA, R (1996) An attempt at shallow ice core drilling in polar continental ice, Central Droning Maud Land, 12th Indian Expedition to Antarctica DOD Tec. Publ. No. 10, pp. 77-99

DANSGAARD, W (1964) Stable isotopes in precipitation Tellus XVI 4, pp 436-468

DANSGAARD, W, JOGNSEN, S .J CLAUSEN, H. B , DAHL-JENSEN, D , GUNDESTRUP, N.S. and HAMMER, CU (1984) North Atlantic climatic oscillations revealed by deep Greenland ice cores, (In) Climate Processes and Climate sensitivity Geophys Monogr, V 29. pp 288-298

DANSGAARD, W, JOHNSEN, SJ, CLAUSEN, H B , DAHL-JENSEN, D , GUNDESTRUP, NS HAMMER, CU, HVIDBERG, CS, STEFFESEN, JP, SVEINBJORNSDOTTIR, AE, JOUZEL, J and BOND, G (1993) Evidence of general instability of past climate from a 250 kyr ice-core record Nature, v 364, pp 218-220.

DELMAS, R (1997) Ice core tecords of global climate and environment changes Isotopes in solar system.

EMBLETON, C and KING, CAA (1969) Glacial and penglacial Geomorphology Edward Arnold (Pub) Ltd.

GROOTES, P.M and STUIVER, M (1997) Oxygen 18/16 variability in Greenland snow and ice with 133 to 105-year resolution Journal of Geophysical Research, v 102, pp 26455-26 470

HUDLESTON, P.J and HOOKE (1980) Cumulative deformation in the Barnes Ice Cap and implications for the development of foliation Tectonophysics v 66, pp 127- 146

JOUZEL, C, LORIUS, JR , GENTHON, C , BARKOV, N I, KOTLIYAKOV, M and PETROV VM (1987) Vostok ice core 200 ma continuous isotope temperature record over the last climate cycle (160,000 years), Nature, v 329(l),pp 404-408

LORIUS, C (1983) Antarctica Survey of near surface mean isotopic values, (In) G. O Robib (Ed), The climate record in polar ice sheets, Cambridge Univ Press, pp 52-56

NATH, A. N (1990) Glacial morphology and geology ot Dakshin Gangotri and Eastern Wohlthats, through remote sensed data Proc Workshop on Antarctic Studies DOD and CSIR, New Delhi, pp 171-178

NIJAMPURKAR, N. V, RAO, D. K, CLAUSEN, H. B., KAUL, M. K and CHATURVEDI, A (2002) Records of climatic changes and volcanic events in an ice core from Central Droning Maud Land (East Antarctica) during the past century Proc. Indian Acad. Sci. CEarth Planet Sci), v 111(1), pp 39- 49

SINHA, R, NAVADA, S.V, ASIM CHATTERJEE, SARAVANA KUMAR , MITRA, A AND A.R NAIR (2000) Hydrogen and oxygen isotopic analysis of Antarctic lake waters, Curr. Sci. v. 78(8), pp 992-995