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DRILLING FOR POLAR CONTINENTAL ICE-CORES BETWEEN NUNATAKS VETEHEIA AND TALLAKSENVARDEN IN EAST ANTARCTICA

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Abstract

The palaeoclimatic record of past several thousand years is preserved in the Antarctic ice sheet as atmospheric air, gases, pollen, dust, volcanic emissions, pollutants. The $^{18}0$ content of ice shows a general linear relationship with prevalent surface air temperature, thus it is possible to establish a palaeotemperature vs isotope curve. It is necessary to recover continuous ice cores from deeper levels to unravel this palaeoclimatic information..Ice core drilling was done in the 15th Indian Antarctic Expedition in 1996. The effort was successful in touching the bedrock of the glacier at 76 m depth, drilling through its entire thickness. Brittle core was encountered near the bedrock. In the same polar season, a second borehole was drilled at a higher elevation in the continental interior, which generated continuous ice cores upto a depth of 84 m. Core from both the boreholes has been logged for physical parameters. The average density of the core from the first borehole is 0.89 gm/em^3, while the overall density of the column from the second borehole is 0.89 gm/cm^3.

Introduction

About 98% of the continent of Antarctica is covered by ice. Within the ice, in the form of air bubbles, inclusions and isotopes is preserved the palaeoclimatic record of past several thousand years as atmospheric air, gases, pollen, dust, volcanic emissions, pollutants etc. The $^{18}0$ content of snow shows a general linear relationship with surface air temperature, making it possible to establish a temperature-isotope equation. Again, since the temperatures in polar regions reflect the pronounced changes in seasonal patterns, it is possible to find out if the snow fell in summer or winter. Thus, by counting the thermal layers, it becomes possible to date the ice from depths. To unravel all this palaeoclimatic information, it is necessary to raise ice core samples from deeper levels of the glaciers or ice sheet. A small capacity, cable suspended, dry-electromechanical, Japanese drilling machine was used during the 15th expedition in 1996. Two boreholes were drilled in polar continental ice.

Equipment and Methodology

Many ice coring systems have been developed in the past 30 years. These systems produce core by cutting, shaving, or melting ice. Various factors have to be weighed for deciding the choice of the drill to be used. These include weight, cost, required depth capability, core-size needed, power requirement, pattern of fuel consumption and expected associated logistic requirements. Mainly, there are two classes of drills, thermal and mechanical. Thermal ones can be subdivided into electrical and hot water types. Thermal drilling is very fast but it is a non-coring method. Mechanical drills are classified into conventional rock drill systems having metallic barrels and the cable suspended drills. Cable suspended drills can be further divided into electrical or hydraulic. Again, at depths greater than 200 m ice becomes brittle due to high internal pressure of air bubbles and requires to be balanced by some drilling fluid. Thus, dry-electromechanical drilling is limited to a depth of 200 m and beyond that fluid-filled electromechanical drilling is undertaken. The drilling machine used in the 15th expedition was such a cable-suspended, dry-electromechanical, rotary drill; having a maximum capacity of around 200 m.

The machine had a 3.7 m high drilling mast with a 0.3 m diameter pulley on top. A winch operated insulated electrical cable passed through this pulley. Its breaking strength was 2050 kg. A 700 W motor was attached to the winch for powering the upward and downward movement. The main drilling unit comprised a two metre long barrel connected at the end of the winch wire. It had an outer jacket of aluminium, which housed the drilling motor and the torque-mechanism. The inner barrel was made of indurated polyethylene and it harboured core-cutters and core-catchers at its mouth. Helical spirals were built on the inner barrel to facilitate the removal of waste ice chips. A control panel was attached to the system to monitor the movement of winch wire and also the rotation-speed of the drill-head. Since the drill required a 110 V power supply, a step-down transformer along with a portable generator completed the system.

After each run of about 60 cm, the barrels were taken out, cleaned, ice-scrapings removed, cutters and catchers were checked for sharpness. Finally, a new coating of antifreeze was applied to the inner barrel and the next run started. The generated core was physically logged in the field itself and cut into 20 cm long segments. These core-segments were packed in air tight plastic jars. Normally, ice core drilling is carried out within some sort,of shelter to avoid the interference of weather and wind. But since no such shelter was available, the entire task was performed in open field conditions **(Fig.1),** whenever the weather permitted it. An electrical bulb was installed near the drill mast to facilitate the work during the dark hours (Fig.2).

Fig. 1: Drilling machine in field-conditions

Fig.2 : Drilling operations continue during polar night under an electric bulb

Observations

The first borehole was drilled on continental blue ice sheet about 3 km south of Maitri station. Its location was 70° 46' 51.9" south latitude and 11 ° 43' 05.3" east longitude. The work was carried out between March and May, 1996. The air temperatures at the drilling site varied between -10° C to -25° C. The total core recovered from this borehole, before encountering the bedrock, was 76.23 *m.* A brittle zone was encountered between 69 m to 71 m depth, where all the. cores spontaneously exploded (Fig.3), a few minutes after reaching the surface. The first borehole displayed a uniform blue ice column from top to bottom, though the bubble size did become smaller with depth (Figs 4&5).

The second borehole site was also on continental blue ice sheet, about 15 km south-west of Maitri station. The altitude of the site-was 600 m above the msl. Its location was 70° 48' 56.6" south latitude and 11° 33' 35.9" east longitude. The work was done during June-July, 1996. This period coincided with the peak polar-night-conditions and the temperatures at the drilling site ranged from -30°C to -45°C. This borehole generated ice cores upto a depth of 83.86 m. Thus in the 15 expedition, a total of 160 m of ice core was recovered from two boreholes. The second borehole showed a lot of interlayering of firn and ice (Fig.6), especially in the top 8 m. The contrasting sections of uppermost, upper and deeper levels are represented in Figs7,8&9.

The entire core has been logged in great physical detail, recording depth-scale, core-quality, bulk-density, grains size variation and visual stratigraphy. There is hardly any density variation in the first borehole, as blue ice is encountered at the surface itself. However, in the second borehole, there is a lot of variation and this log is displayed in Table-1. The core has also been extensively photographed. The 160 m of total core has been cut into samples averaging 20 cm each and have been packed in 800 air-tight plastic jars (Fig. 10). All these jars are kept in plastic baskets (5 jars per basket) for ease of : transportation. To keep the core in frozen condition, the entire lot has been lowered (Fig.1l) in Dakshin Gangotri hanger building, 40 feet below the surface of the shelf.

Discussion and Conclusions

1. For ice core drilling, colder temperatures are more conducive to drilling speed; the rate of core output was highest during the peak polar winter. The present machine with a 3-cutter, 30 degree cutter-angle-system , worked more efficiently than the 4-cutter, 45 degree cutter-angle-systems of previous machines.

Fig.3 : Core from bottom of first borehole that exploded spontaneously

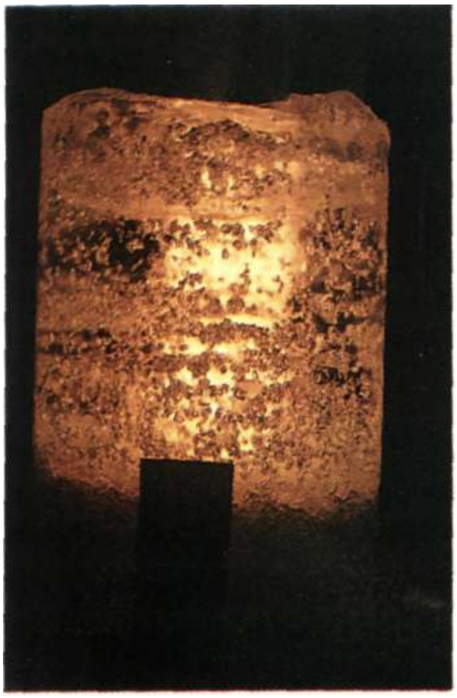

Fig.4 : Upper levels of ice showing large and irregular air bubbles

Fig. 5 : Lower levels of ice showing smaller and regularly spaced bubbles

Fig.6: Core showing inter-layering of firn and ice in upper parts of second borehole

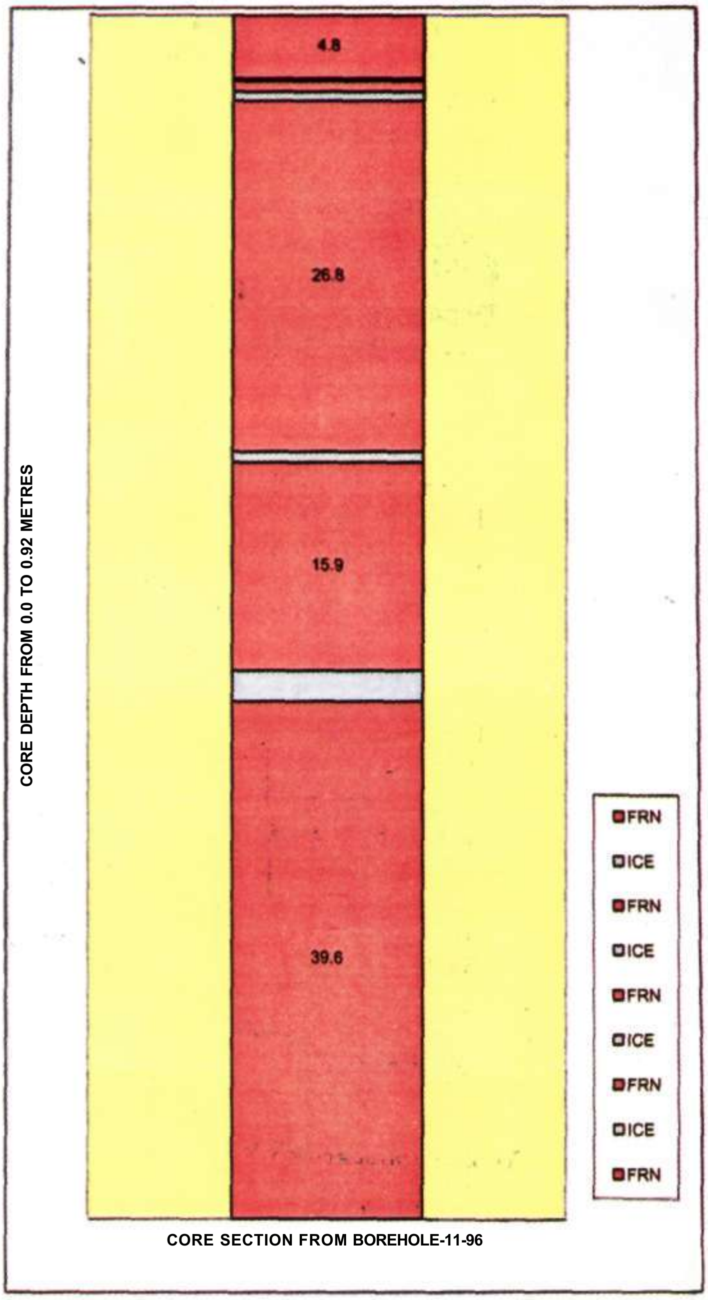

Fig.7: A representative section of top most part of second borehole

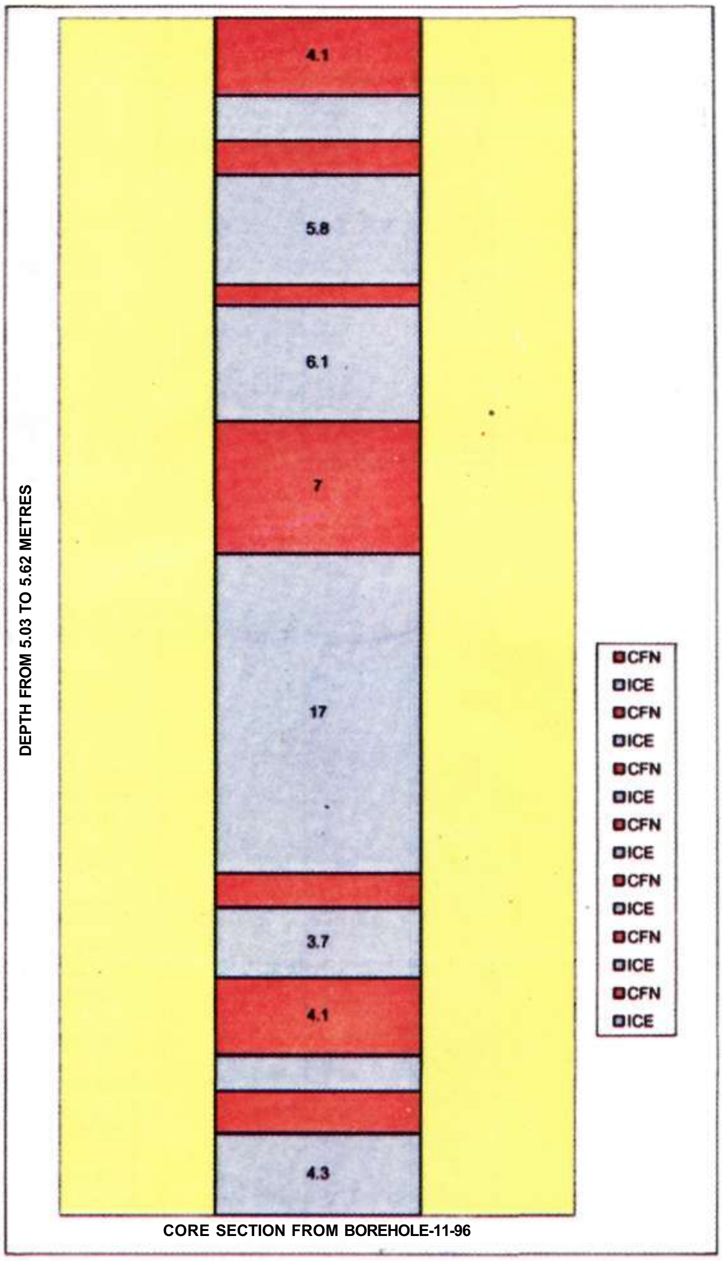

Fig.8 : A representative section of middle part of second borehole

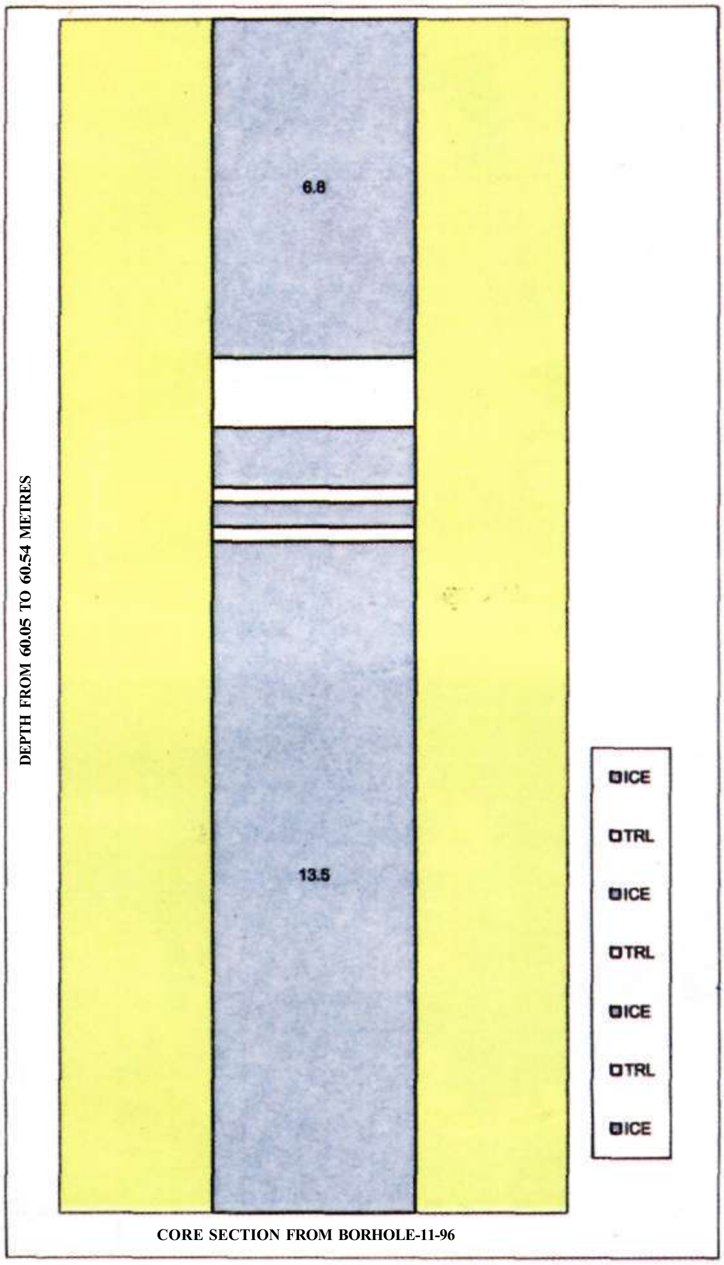

Fig.9 : A representative section of bottom part of second borehole

Fig. 10 : Core cut and packed in plastic jars

Fig. 11 : Core being lowered in Dakshin Gangotri hanger building below the surface

Table 1: Density Data for Second Borehole

Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length inm	Jar no.	Core length in cm	Core density gm/cm	Cummulative length inm
381	19.9	0.42	0.20	413	18.6	0.91	6.27
382	19.6	0.36	0.40	414	20.5	0.87	6.48
383	22.8	0.40	0.62	415	20.0	0.70	6.68
384	19.5	0.42	0.82	416	20.4	0.86	6.88
385	19.7	0.43	1.02	417	17.5	0.86	7.06
386	21.0	0.45	1.23	418	16.9	0.89	7.23
387	20.2	0.47	1.43	419	19.6	0.90	7.42
388	22.1	0.46	1.65	420	19.5	0.89	7.62
389	19.2	0.48	1.84	421	18.1	0.90	7.80
390	20.5	0.47	2.05	422	18.0	0.90	7.98
391	19.8	0.47	2.24	423	20.6	0.87	8.19
392	20.6	0.49	2.45	424	20.0	0.88	8.39
393	20.0	0.47	2.65	425	20.0	0.88	8.59
394	17.9	0.48	2.83	426	20.7	0.90	8.79
395	20.0	0.50	3.03	427	20.9	0.87	9.00
396	17.6	0.50	3.20	428	20.9	0.90	9.21
397	18.1	0.40	3.39	429	19.8	0.87	9.41
398	19.2	0.55	3.58	430	18.0	6.87	9.59
399	14.8	0.51	3.73	431	19.5	0.90	9.78
400	14.3	0.52	3.87 .	432	19.9	0.88	9.98
401	19.8	0.52	4.07	433	20.3	0.88	10.19
402	19.8	0.52	4.26	434	20.5	0.86	10.39
403	20.1	0.54	4.47	435	18.2	0.88	10.57
404	20.2	0.53	4.67	436	24.8	0.89	10.82
405	18.0	0.53	4.85	437	20.2	0.87	11.02
406	19.9	0.61	5.05	438	20.6	0.87	11.23
407	19.6	0.69.	5.24	439	20.0	0.86	11.43
408	16.9	0.62	5.41	440	20.0	0.86	11.63
409	17.8	0.61	5.59	441	20.2	0.86	11.83
410	14.8	0.49	5.74	442	18.3	0.90	12.01
411	15.0	0.48	5.89	443	18.7	0.91	12.20
412	20.1	0.86	6.09	444	20.0	0.90	12.40

Contd.

Table 1: Cond.

Jar no.	Core length in cm	Core density. gm/cm^3	Cummulative length in m	Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m
445	20.1	0:86	12.60	477	20.6	0.86	18.94
446	20.0	0.88	12.80	478	19.2	0.83	19.13
447	19.0	0.85	12.99	479	22.8	0.83	19.36
448	19.3	0.89	13.18	480	19.7	0.87	19.55
449	19.4	0.88	13.38	481	20.5	0.88	19.76
450	16.0	0.88	13.54	482	19.8	0.85	19.96
451	20.0	0.88	13.74	483	19.5	0.84	20.15
452	20.0	0.88	13.94	484	19.0	0.84	20.34
453	19.5	0.87	14.13	485	20.0	0.85	20.54
454	20.6	0.86	14.34	486	19.9	0.85	20.74
455	19.7	0.86	14.54	487	19.7	0.86	20.94
456	19.8	0.85	14.73	488	19.8	0.85	21.13
457	19.4	0.87	14.93	489	19.7	0.87	21.33
458	20.8	0.87	15.14	490	19.7	0.84	21.53
459	20.4	0.86	15.34	491	19.4	0.85	21.72
460	20.1	0.86	15.54	492	24.6	0.88	21.97
461	17.3	0.86	15.71	493	19.2	0.89	22.16
462	18.1	0.86	15.90	494	21.7	0.89	22.38
463	19.3	0.86	16.09	495	19.8	0.85	22.58
464	20.5	0.86	16.29	496	19.4	0.89	22.77
465	26.0	0.87	16.55	497	19.6	0.88	22.97
466	17.9	0.85	16.73	498	19.9	0.87	23.16
467	18.8	0.86	16.92	499	19.4	0.86	23.36
468	17.4	0.85	17.09	500	19.9	0.83	23.56
469	19.2	0.84	17.29	501	19.3	0.88	23.75
470	20.2	0.84	17.49	502	19.4	0.87	23.94
471	25.3	0.89	17.74	503	18.6	0.87	24.13
472	20.4	0.89	17.95	504	19.7	0.89	24.33
473	19.6	0.88	18.14	505	18.3	89	24.51
474	19.4	0.87	18.34	506	17.8	0.88	24.69
475	19.2	0.88	18.53	507	19.1	0.88	24.88
476	20.2	0.85	18.73	508	19.4	0.89	25.07

Contd.

Table 1: Cond.

Jar no.	Core length in cm	Core density gm/cm^3	Cumrnulative length in m	Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m
509	20.4	0.86	25.28	541	19.9	0.89	31.29
510	19.4	0.88	25.47	542	19.7	0.89	31.49
511	20.5	0.91	25.68	543	19.5	0.88	31.68
512	15.6	0.91	25.83	544	19.9	0.89	31.88
513	19.1	0.91	26.02	545	21.5	0.89	32.10
514	19.6	0.91	26.22	546	19.5	0.85	32.29
515	16.8	0.88	26.39	547	19.5	0.87	32.49
516	16.6	0.90	26.55	548	20.0	0.87	32.69
517	18.3	0.90	26.74	549	19.8	0.89	32.89
518	20.6	0.90	26.94	550	19.6	0.91	33.08
519	19.8	0.88	27.14	551	16.2	0.90	33.24
520	19.6	0.90	27.34	552	16.8	0.86	33.41
521	19.2	0.90	27.53	553	20.0	0.91	33.61
522	15.6	0.90	27.68	554	19.5	0.90	33.81
523	19.7	0.89	27.88	555	16.8	0.89	33.97
524	19.4	0.89	28.08	556	16.9	0.90	34.14
525	19.2	0.90	28.27	557	19.4	0.89	34.34
526	19.4	0.91	28.46	558	20.0	0.88	34.54
527	19.3	0.89	28.65	559	19.6	0.90	34.73
528	19.5	0.88	28.85	560	19.6	0.88	34.93
529	25.4	0.90	29.10	561	19.3	0.88	35.12
530	18.4	0.90	29.29	562	19.8	0.89	35.32
531	19.6	0.90	29.48	563	19.1	0.90	35.51
532	17.1	0.90	29.65	564	19.5	0.89	35.71
533	16.7	0.87	29.82	565	19.8	0.89	35.90
534	17.8	0.87	30.00	566	17.4	0.88	36.08
535	17.2	0.90	30.17	567	18.1	0.91	36.26
536	18.0	0.90	30.35	568	25.4	0.90	**36.51**
537	17.6	0.90	30.53	569	20.6	0.90	36.72
538	**17.4**	**0.89**	30.70	570	19.2	0.90	**36.91**
539	**19.4**	0.88	30.90	571	19.5	0.88	**37.11**
540	19.7	0.90	31.09	572	19.5	0.90	**37.30**

Contd.

Table 1: Contd.

Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m	Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m
573	19.9	0.88	37.50	605	19.3	0.91	43.90
574	19.5	0.88	37.70	606	18.6	0.91	44.08
575	19.4	0.89	37.89	607	19.7	0.91	44.28
576	19.5	0.91	38.08	608	19.4	0.89	44.47
577	16.5	0.90	38.25	609	19.7	0.88	44.67
578	17.5	0.91	38.42	610	19.7	0.88	44.87
579	19.1	0.90	38.62	611	20.0	0.89	45.07
580	19.0	0.91	38.81	612	26.2	0.90	45.33
581	19.6	0.90	39.00	613	19.3	0.89	45.52
582	19.4	0.91	39.20	614	19.6	0.90	45.72
583	20.6	0.91	39.40	615	20.0	0.90	45.92
584	19.2	0.90	39.59	616	19.4	0.89	46.11
585	19.1	0.92	39.78	617	19.9	0.92	46.31
586	20.4	0.89	39.99	618	19.5	0.91	46.51
587	19.6	0.91	40.18	619	19.3	0.91	46.70
588	19.4	0.92	40.38	620	20.8	0.91	46.91
589	19.7	0.89	40.58	621	24.7	0.91	47.15
590	19.7	0.89	40.77	622	15.6	0.91	47.31
591	21.6	0.88	40.99	623	14.7	0.91	47.46
592	26.2	0.90	41.25	624	20.6	0.91	47.66
593	16.5	0.92	41.42	625	80.0	0.91	48.46
594	17.4	0.92	41.59	626	80.0	0.91	49.26
595	22.6	0.92	41.82	627	19.8	0.90	49.46
596	21.3	0.92	42.03	628	19.4	0.91	49.65
597	19.4	0.91	42.22	629	23.1	0.89	49.89
598	26.0	0.88	42.48	630	19.3	0.91	50.08
599	19.4	0.88	42.68	631	19.1	0.90	50.27
600	23.2	**0.92**	42.91	632	20.5	0.92	50.47
601	20.0	0.91	43.11	633	19.6	0.91	50.67
602	**19.4**	**0.89**	43.30	634	19.5	0.91	50.87
603	**19.9**	**0.90**	43.50	635	20.4	0.91	51.07
604	**20.1**	**0.91**	43.70	636	19.6	0.90	51.27

Contd.

Table 1: Contd.

Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m	jar no.	Core length in cm	Core density gm/cm^3	Cummuiative length mm
637	18.5	0.91	51.45	669	19.9	0.89	57.83
638	20.6	0.90	51.66	670	15.4	0.89	57.99
639	19.4	0.91	51.85	671	20.6	0.89	58.19
640	17.8	0.91	52.03	672	19.8	0.91	58.39
641	26.2	0.91	52.29	673	20.1	0.91	58.59
642	18.7	0.91	52.48	674	22.3	0.91	58.82
643	17.5	0.91	52.65	675	19.3	0.91	59.01
644	20.3	0.91	52.86	676	25.9	0.91	59.27
645	20.1	0.91	53.06	677	20.5	0.88	59.47
646	19.5	0.92	53.25	678	19.9	0.88	59.67
647	20.8	0.92	53.46	679	19.9	0.90	59.87
648	18.4	0.92	53.64	680	19.9	0.91	60.07
649	18.0	0.92	53.82	681	20.4	0.88	60.27
650	20.8	0.91	54.03	682	23.5	0.91	60.51
651	19.5	0.90	54.23	683	24.2	0.88	60.75
652	26.8	0.89	54.49	684	19.3	0.90	60.94
653	19.5	0.91	54.69	685	20.2	0.87	61.15
654	19.7	0.91	54.89	686	19.4	0.91	61.34
655	20.5	0.91	55.09	687	25.6	0.91	61.60
656	19.8	0.89	55.29	688	19.6	0.91	61.79
657	20.6	0.91	55.50	689	19.9	0.91	61.99
658	20.6	0.90	55.70	690	16.9	0.88	62.16
659	19.5	0.90	55.90	691	16.7	0.90	62.33
660	18.5	0.91	56.08	692	16.5	0.90	62.49
661	19.3	0.88	56.27	693	18.7	0.92	62.68
662	19.5	0.91	56.47	694	17.9	0.86	62.86
663	19.2	0.91	56.66	695	17.8	0.90	63.04
664	19.2	0.90	56.85	696	15.4	0.90	63.19
665	19.3	0.91	57.05	697	14.4	0.89	63.33
666	19.2	0.90	57.24	698	19.4	0.89	63.53
667	20.1	0.91	57.44	699	20.1	0.91	63.73
668	19.5	0.92	57.63	700	15.3	0.91	63.88

Contd.

Table 1: Contd.

Jar no.	Core length in cm	Core density gm/cm	Cummulative length in m.	Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m
701	19.4	0.91	64.08	733	19.6	0.91	70.11
702	19.8	0.88	64.27	734	19.8	0.89	70.31
703	20.7	0.88	64.48	735	19.5	0.88	70.50
704	19.3	0.90	64.67	736	19.8	0.89	70.70
705	17.1	0.91	64.84	737	19.8	0.90	70.90
706	16.5	0.89	65.01	738	19.9	0.91	71.10
707	18.4	0.90	65.19	739	22.3	0.91	71.32
708	18.8	0.91	65.38	740	18.1	0.91	71.50
709	20.4	0.91	65.59	741	19.6	0.92	71.70
710	23.8	0.92	65.82	742	19.7	0.90	71.90
711	20.2	0.91	66.03	743	18.6	0.90	72.08
712	19.4	0.92	66.22	744	20.4	0.90	72.29
713	24.7	0.91	66.47	745	19.4	0.91	72.48
714	15.6	0.91	66.62	746	19.6	0.90	72.68
715	16.2	0.91	66.78	747	19.8	0.90	72.87
716	19.8	0.89	66.98	748	22.3	0.91	73.10
717	18.4	0.89	67.17	749	19.4	0.91	73.29
718	19.2	0.91	67.36	750	20.7	0.91	73.50
719	20.7	0.88	67.57	751	19.8	0.91	73.70
720	16.3	0.88	67.73	752	19.5	0.92	73.89
721	18.5	0.91	67.91	753	25.1	0.92	74.14
722	19.4	0.89	68.11	754	20.6	0.92	74.35
723	18.5	0.89	68.29	755	19.4	0.91	74.54
724	16.4	0.89	68.46	756	20.4	0.89	74.75
725	17.9	0.91	68.64	757	20.4	0.89	74.95
726	20.3	0.91	68.84	758	19.7	0.91	75.15
727	17.8	0.91	69.02	759	19.8	0.92	75.34
728	18.5	0.91	69.20	760	19.3	0.91	75.54
729	16.4	0.91	69.37	761	20.5	0.89	75.74
730	19.6	0.92	69.56	762	19.4	0.91	75.94
731	19.7	0.89	69.76	763	20.6	0.91	76.14
732	15.6	0.89	69.91	764	19.2	0.90	76.33

Contd.

Table 1: Contd.

Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m	Jar no.	Core length in cm	Core density gm/cm^3	Cummulative length in m
765	20.3	0.87	76.54	785	19.4	0.91	80.55
766	19.5	0.90	76.73	786	19.9	0.91	80.75
767	20.5	0.90	76.94	787	19.8	0.92	80.95
768	19.4	0.92	77.13	788	22.9	0.91	81.18
769	20.0	0.92	77.33	789	19.6	0.92	81.38
770	18.6	0.92	77.52	790	19.8	0.90	81.57
771	19.6	0.91	77.71	791	20.5	0.90	81.78
772	20.2	0.91	77.92	792	18.2	0.91	81.96
773	19.4	0.91	78.11	793	18.6	0.91	82.15
774	20.5	0.91	78.31	794	20.4	0.91	82.35
775	19.6	0.90	78.51	795	19.9	0.92	82.55
776	25.1	0.90	78.76	796	23.2	0.92	82.78
777	19.4	0.91	78.96	797	19.4	0.91	82.98
778	21.3	0.91	79.17	798	19.8	0.90	83.17
779	20.6	0.91	79.37	799	20.1	0.92	83.37
780	19.6	0.90	79.57	800	15.8	0.91	83.53
781	19.6	0.88	79.77	801	18.1	0.90	83.71
782	19.9	0.92	79.97	802	20.2	0.92	83.92
783	19.8	0.89	80.16	803	18.9	0.91	84.10
784	19.6	0.90	80.36				

2. The present lot of 160 m of core from two boreholes has been kept in a frozen condition in Dakshin Gangotri hanger building, about 40 feet below the surface. In future drilling operations, the arrangements for core-analyses should be fixed up well in advance, so that the working team can bring back the core and avoid the delay in getting isotope and dating results.
3. While drilling at an altitude of 600 m above the msl, a lot of firn and ice interlayering was observed in the lop few metres. But similar drilling at 200-300 m above the msl displayed only uniform blue ice of deeper levels. Therefore, it is concluded that the lower reaches of the ice-sheet undergo seasonal-melting and the topmost layers are washed away.
4. The overall density of the first borehole is 0.89 gm/cm^3 and it is almost uniform throughout the column. In the second borehole, the density of topmost layers of firn is around 0.4 g/cm^3 . The first appearance of blue ice shows a density of 0.86 g/cm$^{3.}$ while the deeper levels of blue ice have an average density value of 0.91 g/cm^3. So the overall variation of density in the column ranges between 0.4 g/cm^3 to 0.9 g/cm^3 and it is displayed in **Fig.12.**
5. The spontaneously exploding core at the bottom of the first borehole could be a compressed zone under severe strain at that depth, which disintegrated after surfacing. It was also found that the temperature at the bottom of the borehole was around -8°C, while the glacier surface temperature was -22°C on that day, i.e., 26.4.96. So alternatively, this could be a case of comparatively "warm" ice core from the depth receiving a colder thermal shock on the surface, which caused its disintegration.
6. There was only one barrel provided to the team and it got stuck at 84 m depth in the second borehole. We succeeded in hooking the barrel by improvised fishing tools and pulled it up by a vehicle **(Fig.13),** but even the double mountaineering ropes could not take the load and were shattered **(Fig.14).** So, the work had to be abandoned. Since sticking of drill barrels is quite a common occurrence; in future drilling operations, additional drilling barrels should be provided to the team beforehand.

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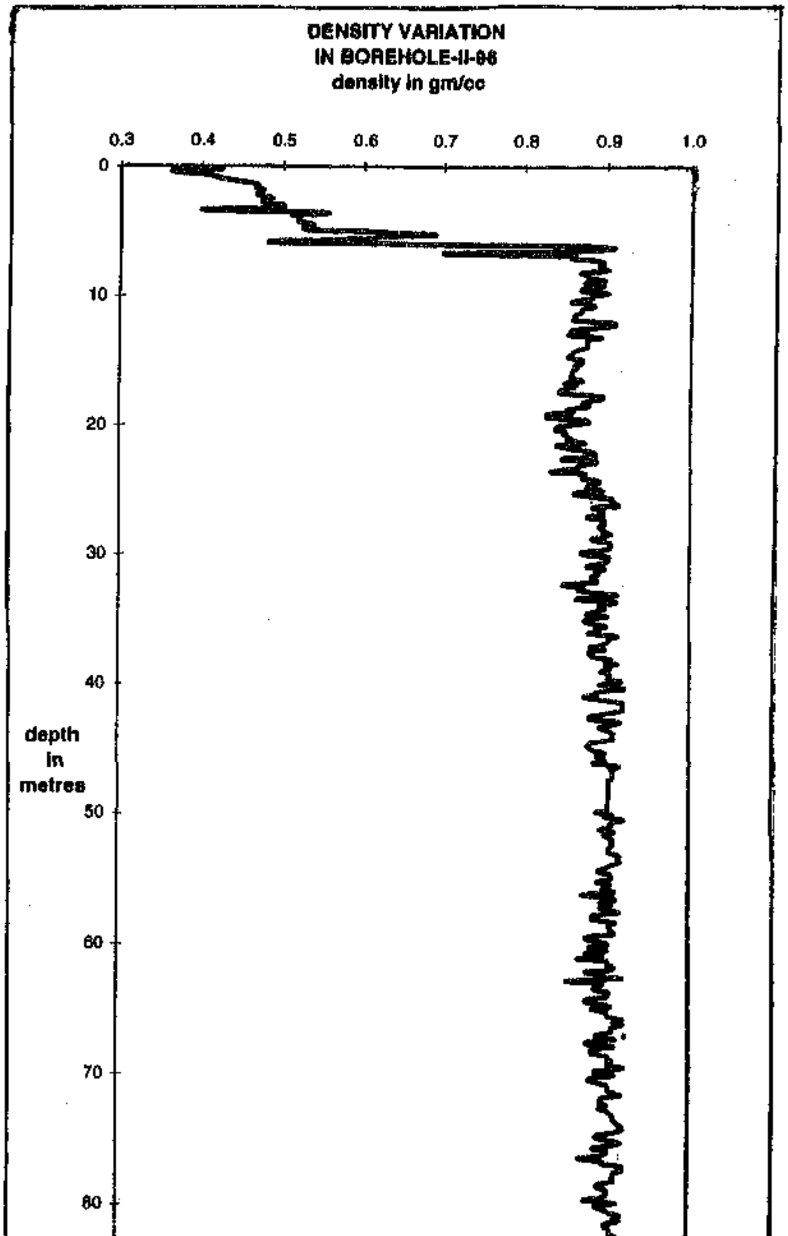

Fig. 12 : Density plot for the column of first borehole.

Fig. 13 : Attempt to retrieve the stuck drill barrel by pulling with a vehicle

Fig. 14 : Even the 3000 kg load-capacity mountaineering ropes are smashed

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References

Bhandari N., Bhattacharya S.K., Nijampurkar V.N., Sengupta D., Shah V.G., Singh vi A.K., Shukla P.N., Suthar K.M. and Vohra C.P. (1984): Isotopic and related studies in Antarctic Ice Samples. Proc. Indian Acad. Sci. (EPS), 93, No. 2, pp 135-140.

Chaturvedi A. and Asthana R. (1996): An Attempt at Shallow Ice-core Drilling in Polar Continental Ice, Central Dronning Maud Land, Antarctica. Tech. Pub. No. 10. DOD, New Delhi, pp 77-99.

Kaul M.K., Chakraborty S.K. and Raina V.K. (1985): Stratigraphic studies of Antarctic ice. Tech. Pub. No. 2, DOD, New Delhi, pp 99-102.

Nijampurkar V.N., Bhandari N., Bhattacharya S.K., Rao D.K., Sengupta D., Raina V.K. and Kaul M.K. (1985) : Isotopic and TL Studies of Antarctic Ice Samples. Tech. Pub. No. 2, DOD, New Delhi, ppl03-106.

Nijampurkar V.N., Bhattacharya S.K., Mukerji S,, Singh R.N., Srivastava D. (1988) : Oxygen Isotope Studies in Antarctica. Tech. Pub. No. 5, DOD, New Delhi, pp 171-179.

Nijampurkar V.N, Rao D.K., Kaul M.K., Mukerji S., Singh R.K. and Srivastava D. (1988) : Radioactiyity Studies in Antarctica. Tech. Pub. No. 5, DOD, New Delhi, pp 225-233.

Vohra C.P. (1983) : Glaciological studies during First Indian Antarctic Expedition. Tech. Pub. No. 1. DOD, New Delhi, pp 138-148.